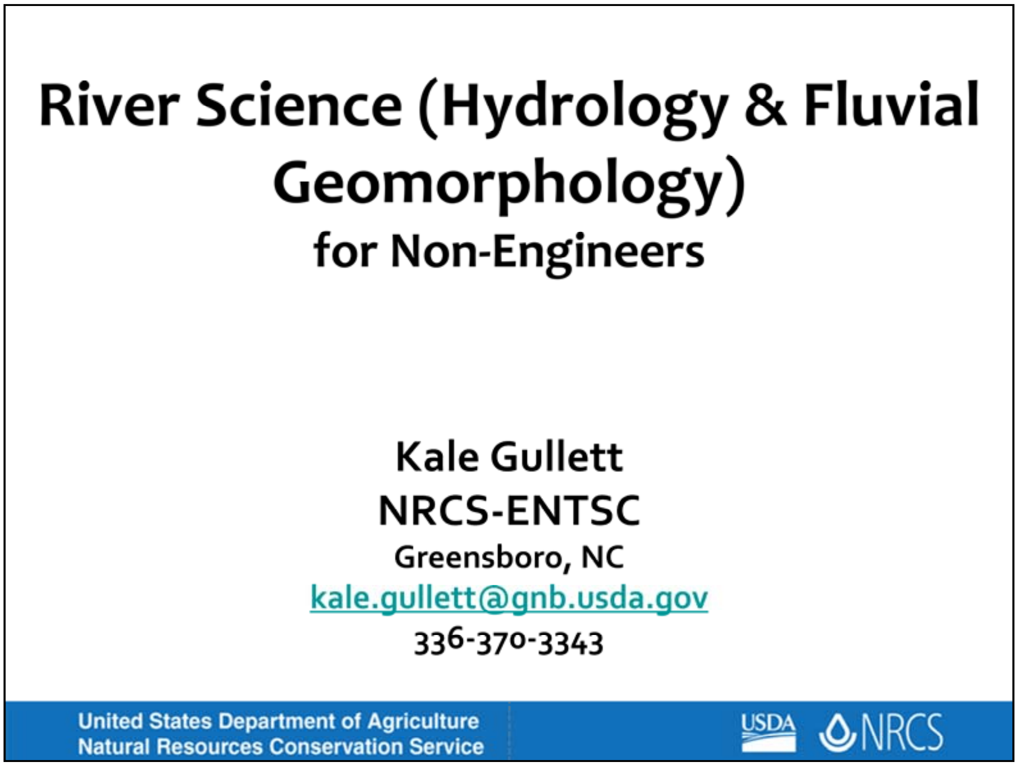

River Science (Hydrology & Fluvial Geomorphology)
for Non-Engineers

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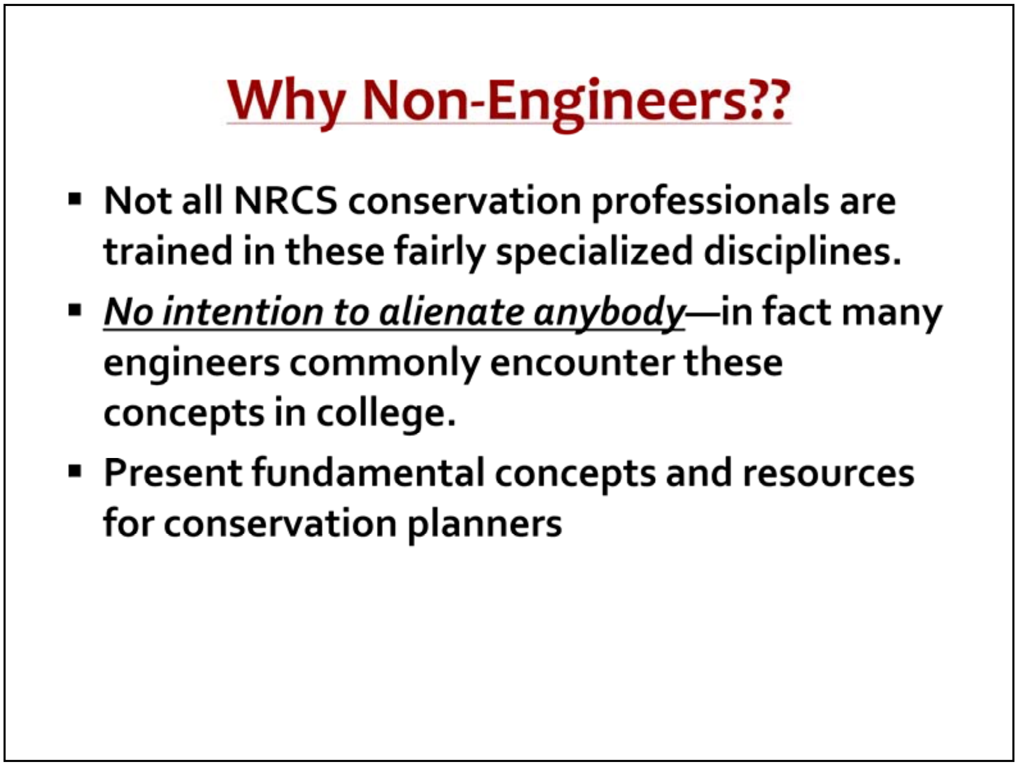
United States Department of Agriculture
Natural Resources Conservation Service

Hello, and thanks for the introduction, Holli.

Working in and around rivers and streams is often accomplished by using tools and concepts of hydrology and fluvial geomorphology—two related but specialized disciplines. Today I'll cover some of the fundamental aspects of these two sciences. I'll review the influence of land use and management actions on streamflow and river morphology using some examples from different parts of the US.

I'll suggest a few resources that may help you with river analysis, as well as short primers on river science.

Today's webinar is loaded with material, and I won't have time for details on some things that really have a lot of details. So, please feel free to contact me at any time to further discuss or get additional information on anything I talk about today.



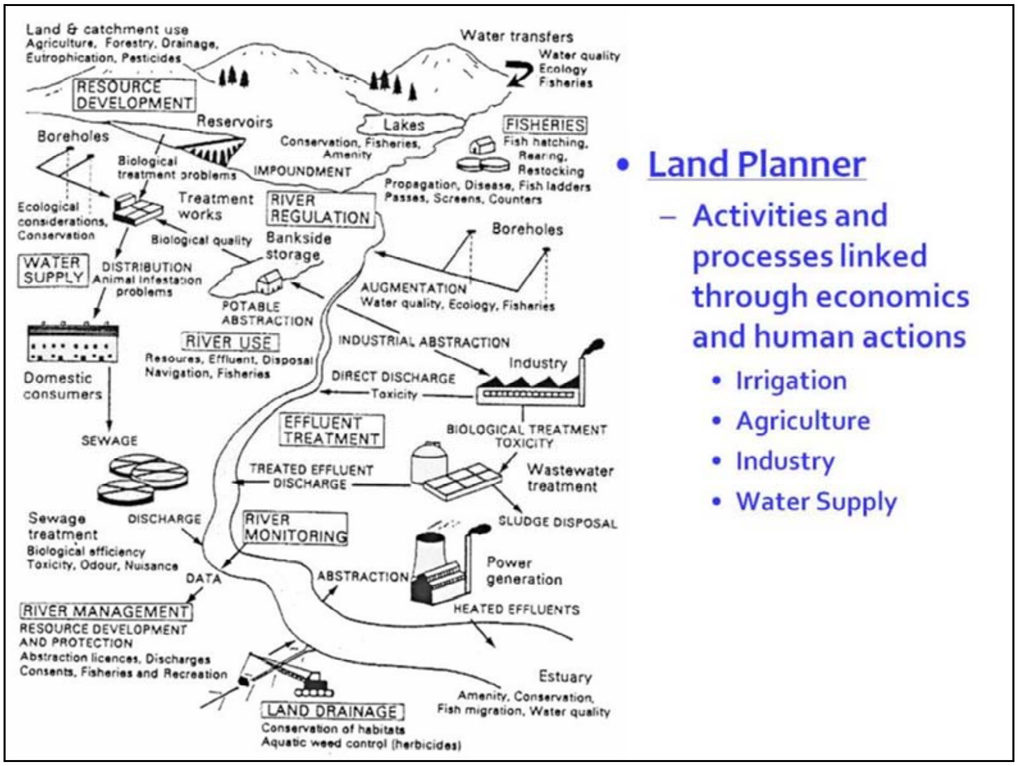
Why Non-Engineers??

- Not all NRCS conservation professionals are trained in these fairly specialized disciplines.
- *No intention to alienate anybody*—in fact many engineers commonly encounter these concepts in college.
- Present fundamental concepts and resources for conservation planners

If you are new to work in and around rivers—especially on projects with outside partners or TSPs—you might encounter a bunch of buzzwords, models, and jargon that sounds a bit foreign. Truth is, river work is fairly specialized, and not all NRCS folks are trained as hydrologists or geomorphologists. Many of these river science concepts have found their way into the mainstream only over the last 20 years or so.

I didn't intend to alienate anybody by today's webinar title. In fact, most engineers receive much of what I'll talk about today during completion of a Bachelors degree, and many NRCS engineers use tools and methods in hydrology and fluvial geomorphology in the design and construction of various conservation practices.

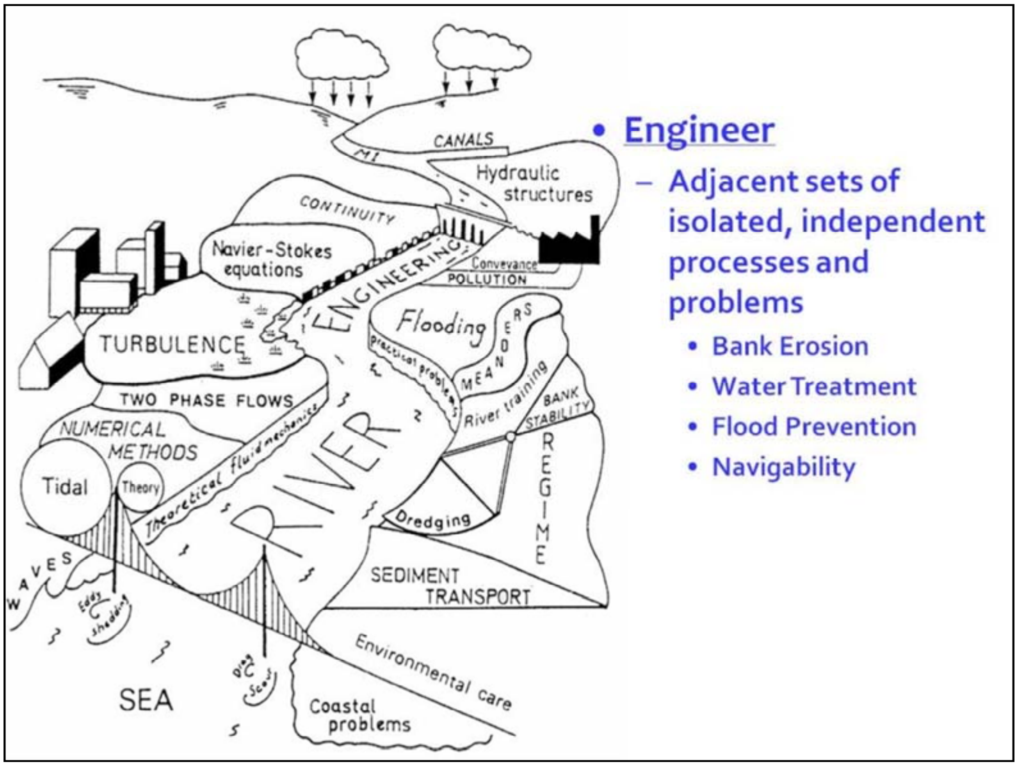
Today's webinar is aimed at conservation planners who interact with landowners and partners in the field, and is intended to provide a broad overview of the elements of river science that define rivers and may suggest why they look or act a certain way.



- Land Planner
  - Activities and processes linked through economics and human actions
    - Irrigation
    - Agriculture
    - Industry
    - Water Supply

Different professions have different views and perspectives about river corridors. Land planners often consider many aspects of land use, and may only include river corridors when their activities penetrate corridor boundaries.

For example, wastewater treatment activities often take place in confined structures far removed from a river, but the effects of releasing treated water into rivers is usually a primary consideration of water treatment planning.

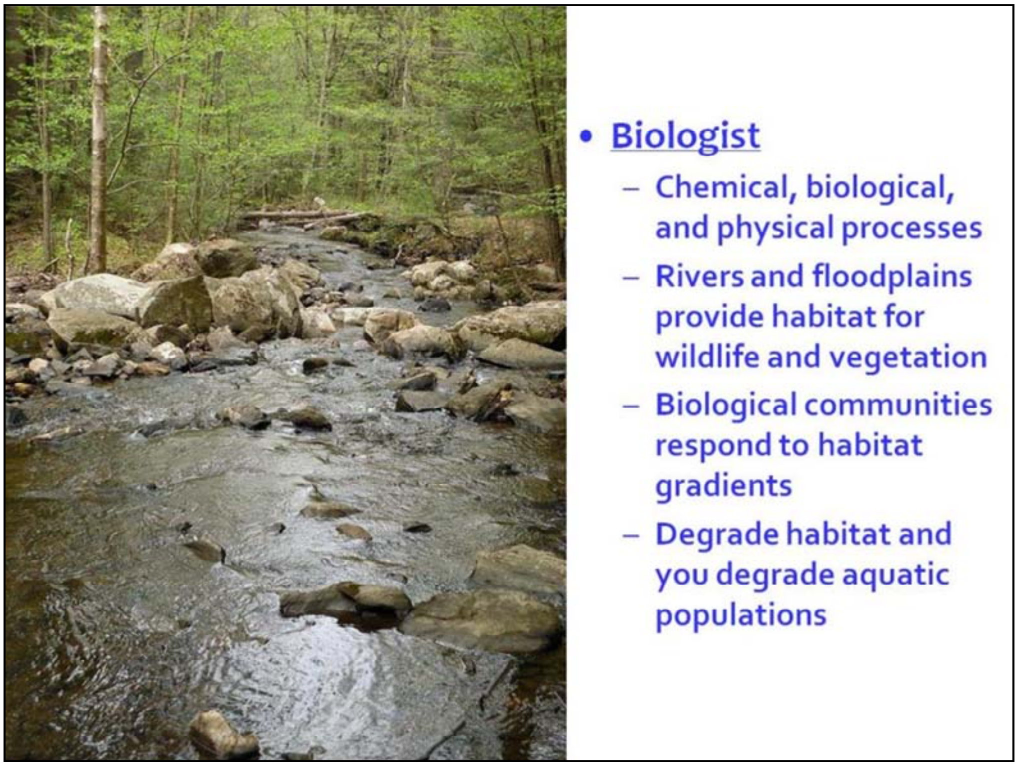


- **Engineer**
  - Adjacent sets of isolated, independent processes and problems
    - Bank Erosion
    - Water Treatment
    - Flood Prevention
    - Navigability

Engineers are often concerned with developing and implementing safe and practical solutions to human problems.

For example, cities and counties often spend hundreds of hours and millions of dollars designing, building, and maintaining civil works projects that protect infrastructure from flood damage.

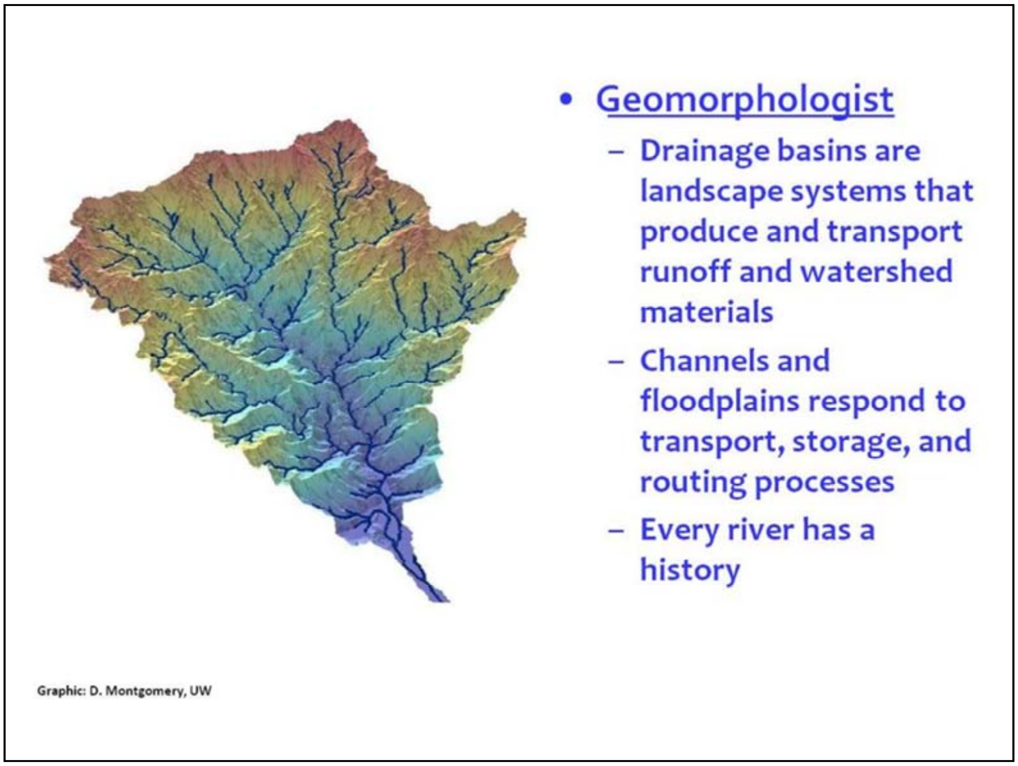
To complete these activities, engineers sometimes partition river corridors into interrelated sets of theoretical and quantitative equations to describe and predict the effects of different amounts of water in a stream channel.



- **Biologist**
  - Chemical, biological, and physical processes
  - Rivers and floodplains provide habitat for wildlife and vegetation
  - Biological communities respond to habitat gradients
  - Degrade habitat and you degrade aquatic populations

Biologists are usually charged with understanding how physical, chemical, and biological processes affect riverine species and habitat.

They commonly deal with managing habitats and populations, and are sometimes only focused on these aspects of river corridor management.



- **Geomorphologist**
  - Drainage basins are landscape systems that produce and transport runoff and watershed materials
  - Channels and floodplains respond to transport, storage, and routing processes
  - Every river has a history

Graphic: D. Montgomery, UW

Geomorphologists, on the other hand, view river corridors as a landscape system responsible for moving runoff and watershed materials from headwaters to the sea.

They’re interested in how hillslopes, channel networks, and floodplains respond to factors that change runoff and sediment production.

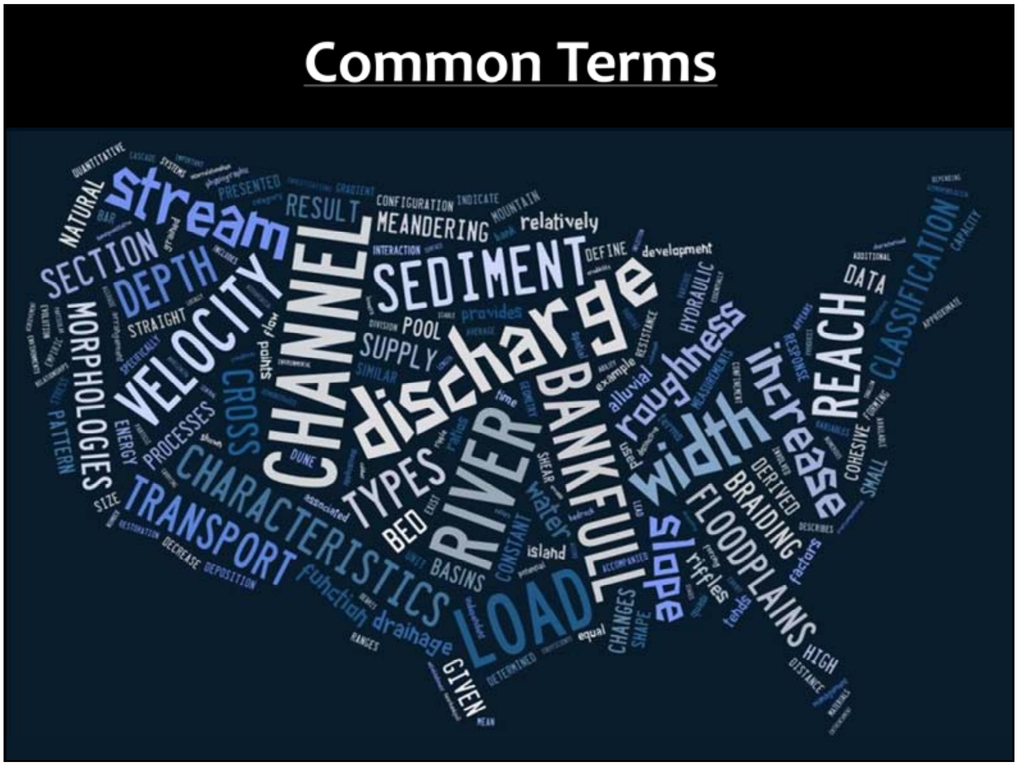
Geomorphology is a relatively “new” science, born of a marriage of physical geography of geology.

Common Goals

- Reduce erosion and conserve soil
- Improve water quality/quantity
- Increase and enhance wildlife habitat
- Preserve streambank function
- Create functional stream corridors

So, although each of the different professions I just discussed usually brings different views and responsibilities to a river project, I think they all share similar goals.

Things like reducing erosion and conserving soil, improving water quality and supply, enhancing habitat, preserving streambank function, and creating functional river corridors are common goals that all relate to river conservation.



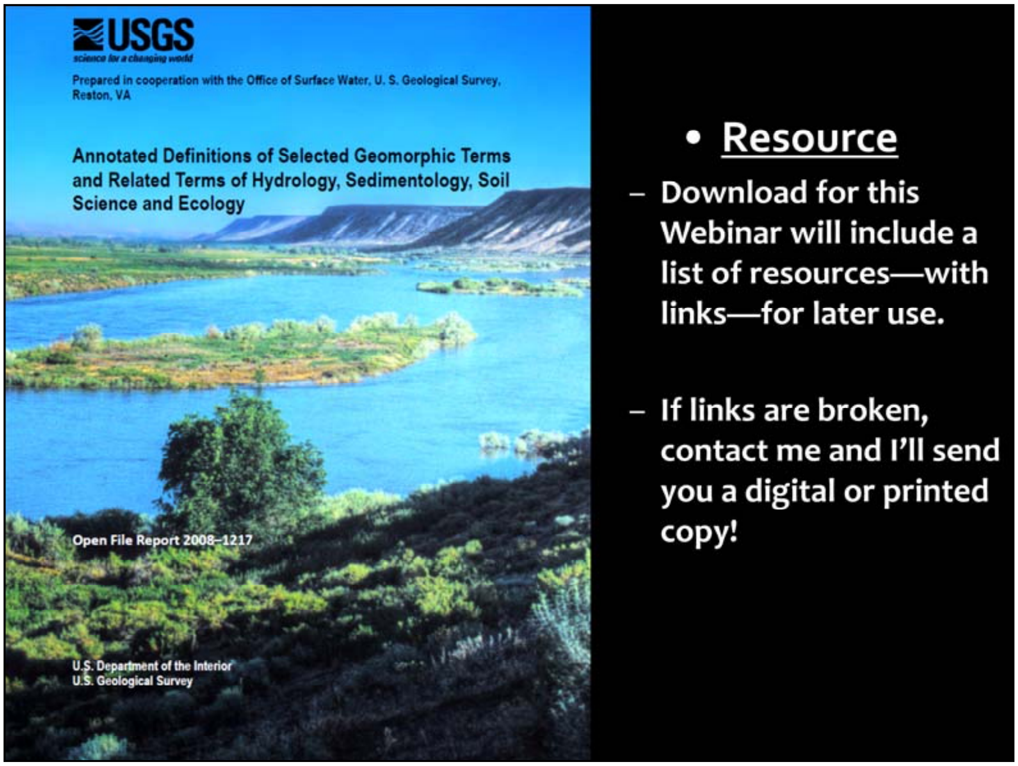
Common Terms

Another commonality of these professions is terminology—although sometimes the definitions differ a bit.

If you create a tag cloud of abstract keywords from popular published works in hydrology and fluvial geomorphology over the last 20 years in the United States, you get something that looks like this.

Some of these terms are familiar but have entirely different meaning when used in the context of river science—especially when you combine two or three of them.

Others are specific to hydrology and fluvial geomorphology. Today I’ll use many of these words and hope to explain them in a way that clears and doesn’t muddy the water.



USGS
science for a changing world

Prepared in cooperation with the Office of Surface Water, U. S. Geological Survey, Reston, VA

Annotated Definitions of Selected Geomorphic Terms and Related Terms of Hydrology, Sedimentology, Soil Science and Ecology

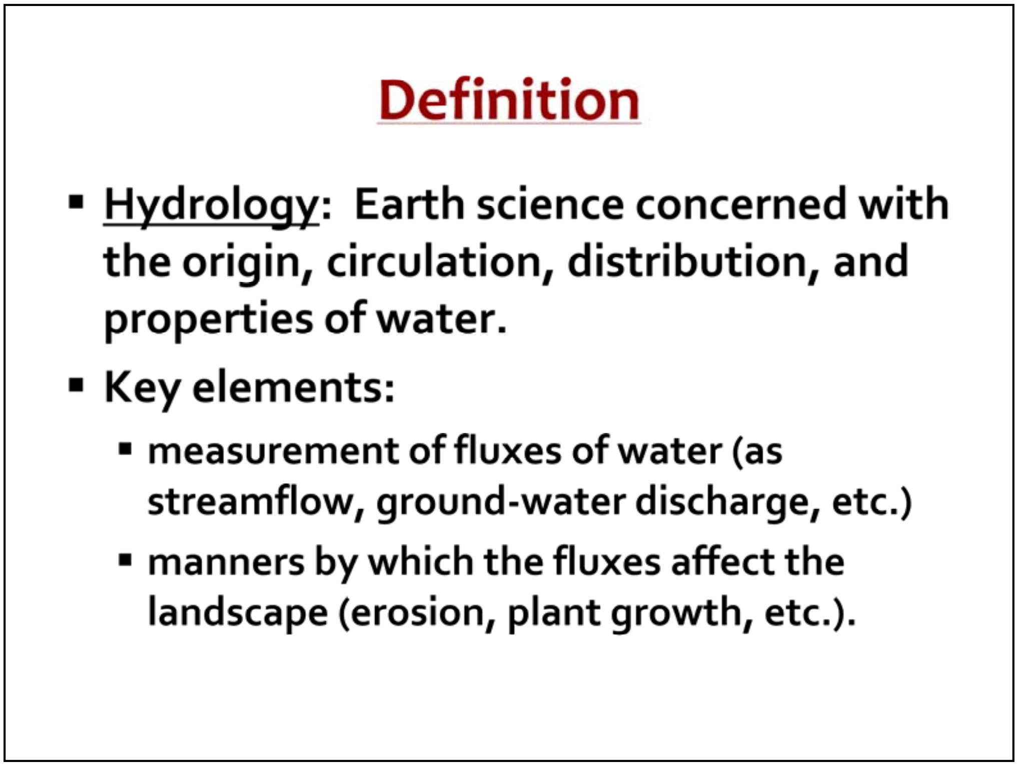
Open File Report 2008–1217

U.S. Department of the Interior
U.S. Geological Survey

- **Resource**
  - Download for this Webinar will include a list of resources—with links—for later use.
  - If links are broken, contact me and I'll send you a digital or printed copy!

I'll need a few definitions today, and here is a good resource for most of the words in the previous slide. It was developed by a well-respected hydrologist with the US Geological Survey, and is available online.

The references and resources I'll show today will be listed in a hyperlinked file included in the download package for the webinar. If any of the links are broken, just contact me and I'd be happy to send you a digital or printed copy.

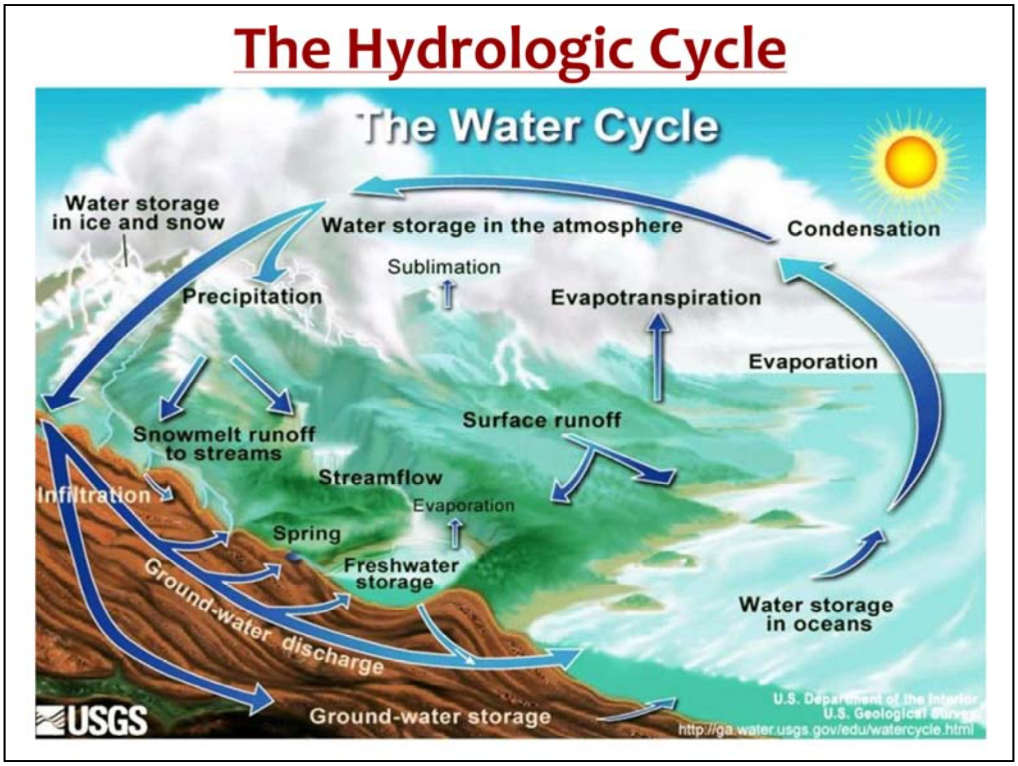


Definition

- **Hydrology: Earth science concerned with the origin, circulation, distribution, and properties of water.**
- **Key elements:**
  - **measurement of fluxes of water (as streamflow, ground-water discharge, etc.)**
  - **manners by which the fluxes affect the landscape (erosion, plant growth, etc.).**

So, lets start with a definition for hydrology. Hydrology is an earth science that deals with the flow of water across and through near surface environments.

Key elements related to today’s talk are how we measure and characterize streamflow, and how changes or fluxes in streamflow affect river channels and floodplains.

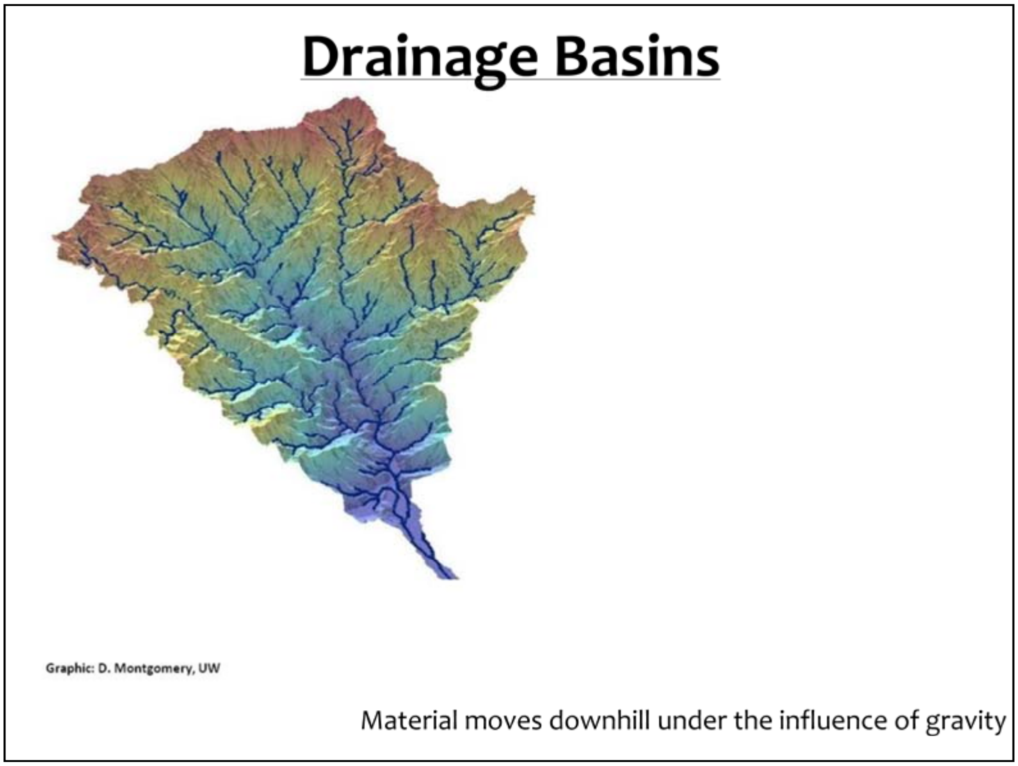


The Hydrologic Cycle

U.S. Department of the Interior
U.S. Geological Survey
http://ga.water.usgs.gov/edu/watercycle.html

Many of you will remember something similar to this graphic from a junior high science class. The water cycle is comprised of many elements, driven by precipitation and other factors, and includes both surface and subsurface pathways.

However, for today's purposes, we're going to focus on the part of the hydrologic cycle that concerns surface runoff, streamflow, river channels and floodplains.



Drainage Basins

Graphic: D. Montgomery, UW

Material moves downhill under the influence of gravity

Further, we'll focus mainly on drainage basins as a smaller unit of the planet where one or more rivers affects landscape appearance and function.

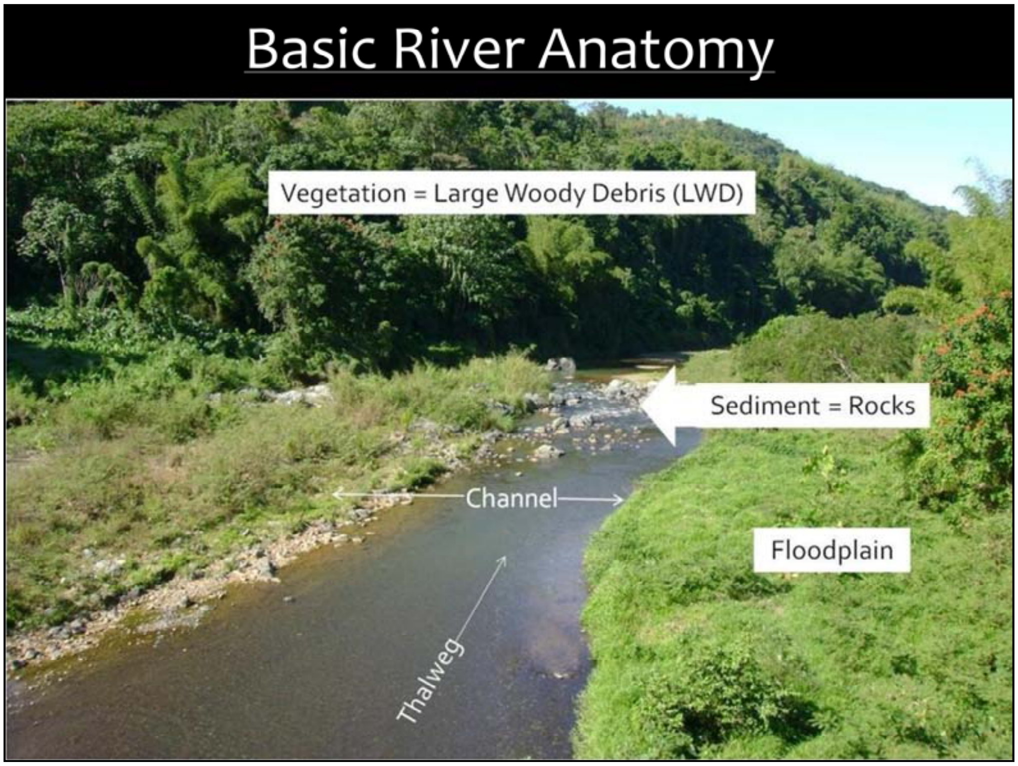
Basically, a drainage basin is a landform where watershed materials—mainly water, sediment, and wood—move downhill under the influence of gravity.

River Systems

Within a drainage basin, rivers and streams act as systems or machines that manage available resources to accomplish a task.

In this context, the primary task of a river is landscape change—collecting materials and moving them downstream.

Gravity is the basic energy source, water does most of the work, and rocks, soil, and streamside vegetation—both living and dead—provides resistance to landscape change.



Basic River Anatomy

So, we’ll need a basic stream anatomy overview before going further.

The channel is the part of a stream where water appears, and is usually bracketed by banks.

The deepest part of the stream channel is known as the thalweg, a German word meaning valley way.

Flat surfaces above and along the stream banks are called the floodplain, and its where water goes when the channel can no longer contain it.

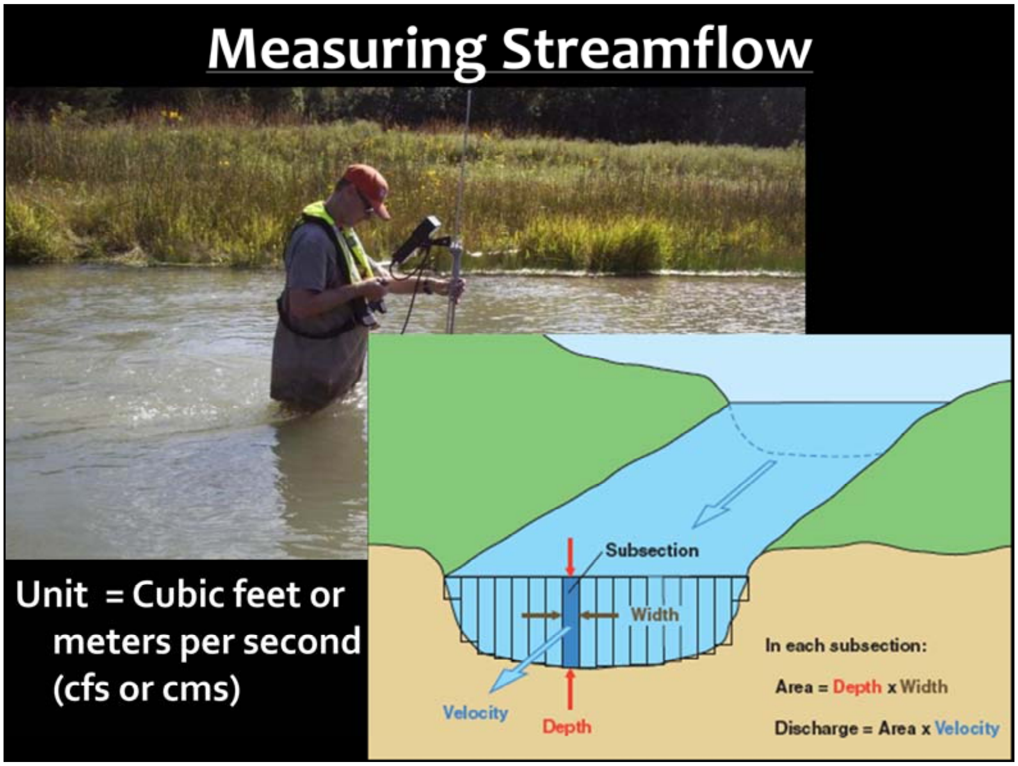
Sediment, in the broadest sense, is the sand, gravels and boulders that appear in the channel and along the river corridor.

Streamside vegetation often relies on the water table associated with the river, and once it ends up in the channel it becomes large woody debris or LWD. LWD can play a huge role as a structural element of the river channel and floodplain.

Measuring Streamflow

One of the fundamental pieces of information related to stream hydrology is streamflow, also known as discharge. Measuring the amount of water flowing down a stream channel can be done with different types of equipment, some simple and some relatively spendy like the velocity meter this gentleman is shown holding.

When streamflow is measured in a channel, it gives you a snapshot in time of how much water was there the day you visited a site.



Measuring Streamflow

Unit = Cubic feet or meters per second (cfs or cms)

In each subsection:

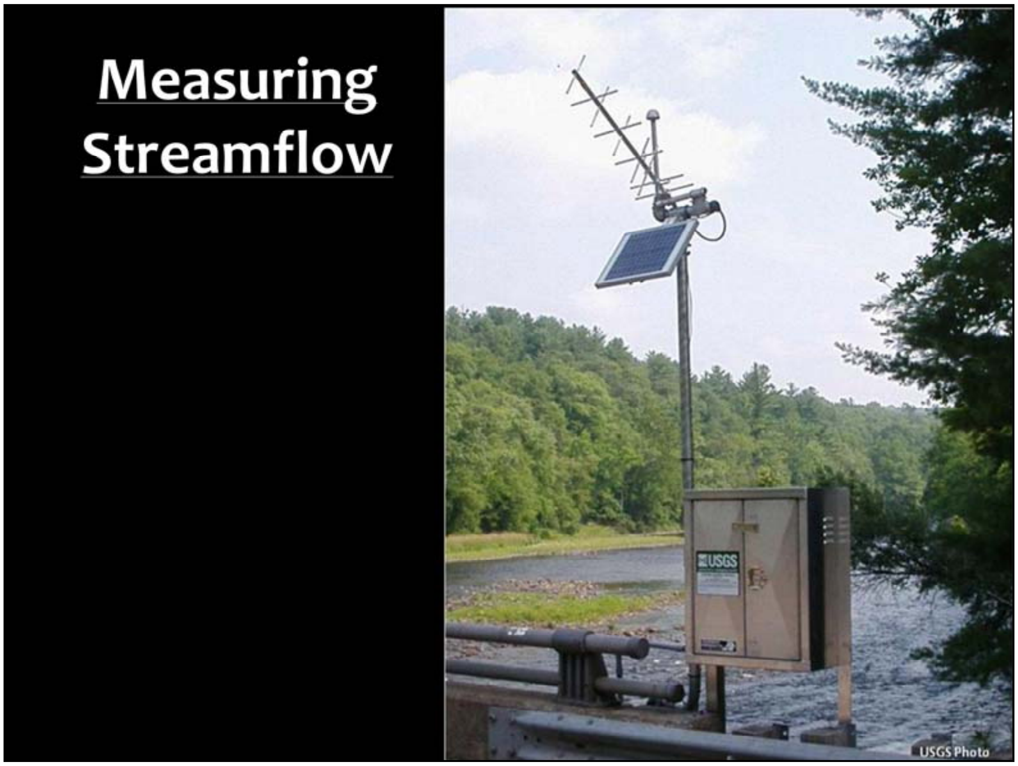
Area = Depth x Width

Discharge = Area x Velocity

Streamflow is determined by measuring the dimensions of the channel—its width and depth—and then by using meters or other means to determine the velocity of the water flowing in the channel. Once these variables are known, the streamflow can be determined by multiplying the area of the channel by the velocity of the water flowing down it.

Since velocity isn't equally distributed across a stream channel, accurate measures of streamflow are derived by subdividing the channel into equal increments, taking measurements within those increments, and then adding up the individual measurements within each of the smaller chunks.

Streamflow is a volume rate function—its a volume of water moving past a point per unit time. The basic units of streamflow are cubic feet or cubic meters per second. To put a cfs into perspective, its equal to about 450 gallons per minute. Once cubic foot per second flowing onto an acre-sized parcel for 24 hours would cover it two feet deep.

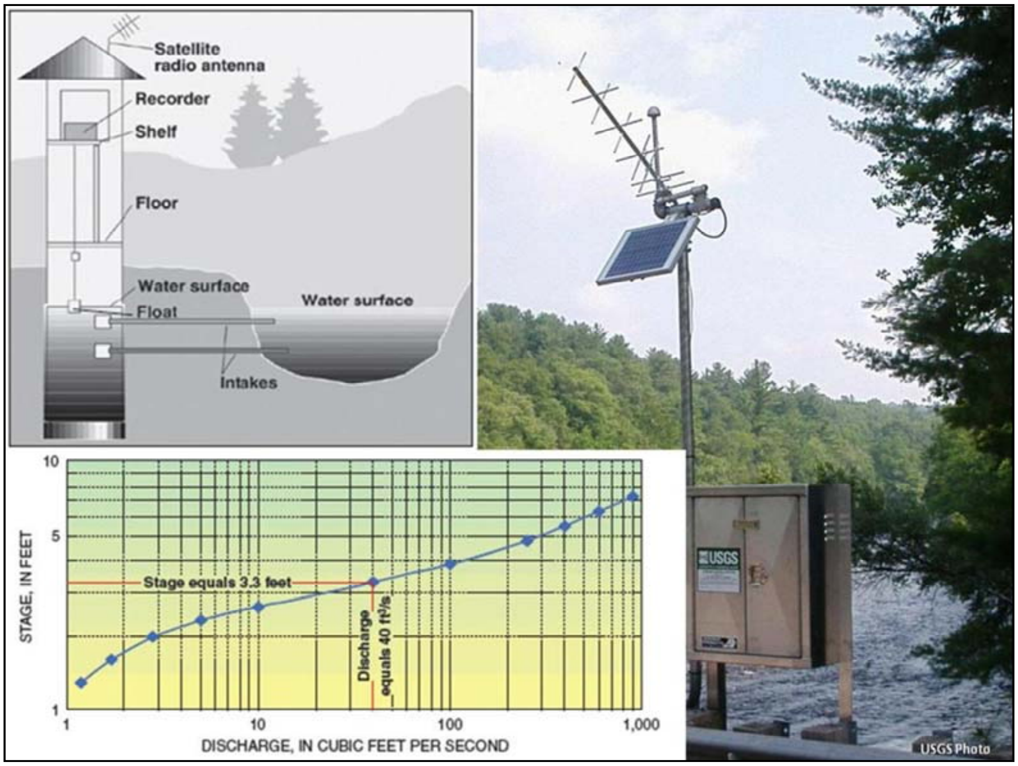


Measuring Streamflow

USGS Photo

Since a streamflow measurement only gives you a snapshot in time, we set up gaging stations to record flow over time at multiple locations.

I’m sure a few of you have seen things like this adjacent to a bridge over a river.

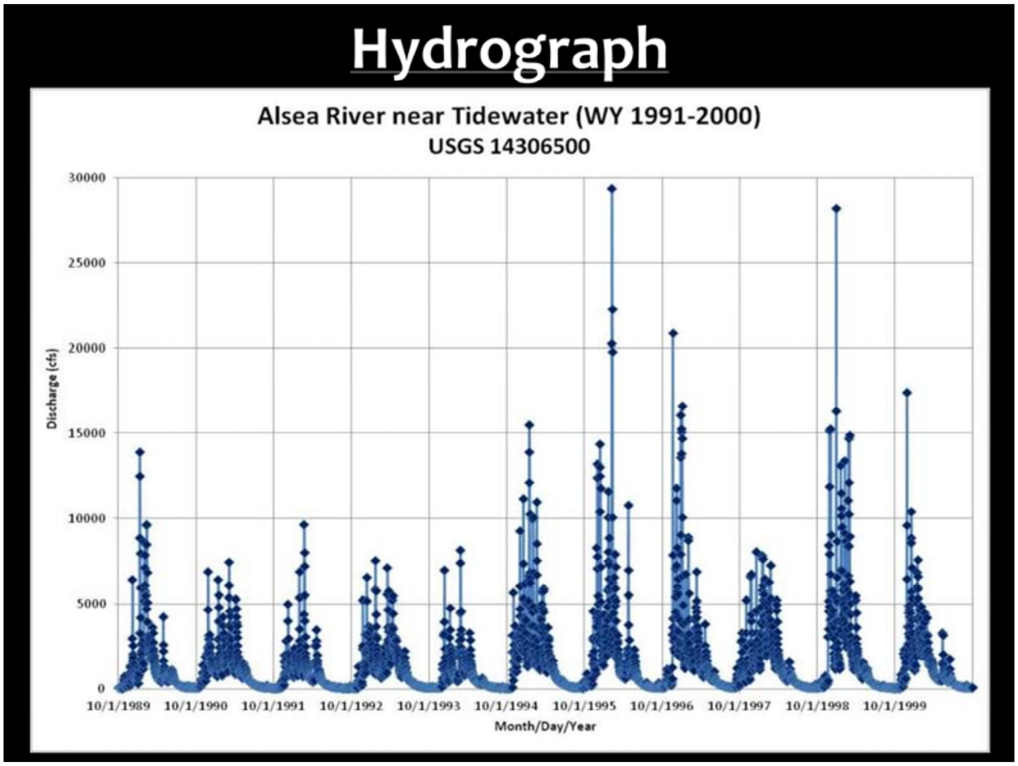


Most streamflow gages don’t record the flow velocity—it varies quite a bit with water depth and other factors.

However, the stage or level of the water in a channel can be measured with some accuracy with minimal instrumentation.

Streamgages measure the stage of the water in the channel, and a basic setup is shown here in the upper left. The stage or elevation of the water surface in the channel can be converted to streamflow by using a stage-discharge relationship, shown at the lower left. Flow data collected by folks using waders and meters as shown a couple of slides ago can be matched with river stage to develop a rating curve. As you can see on the graph, a stage of 3.3 feet equals a discharge of 40 cubic feet per second.

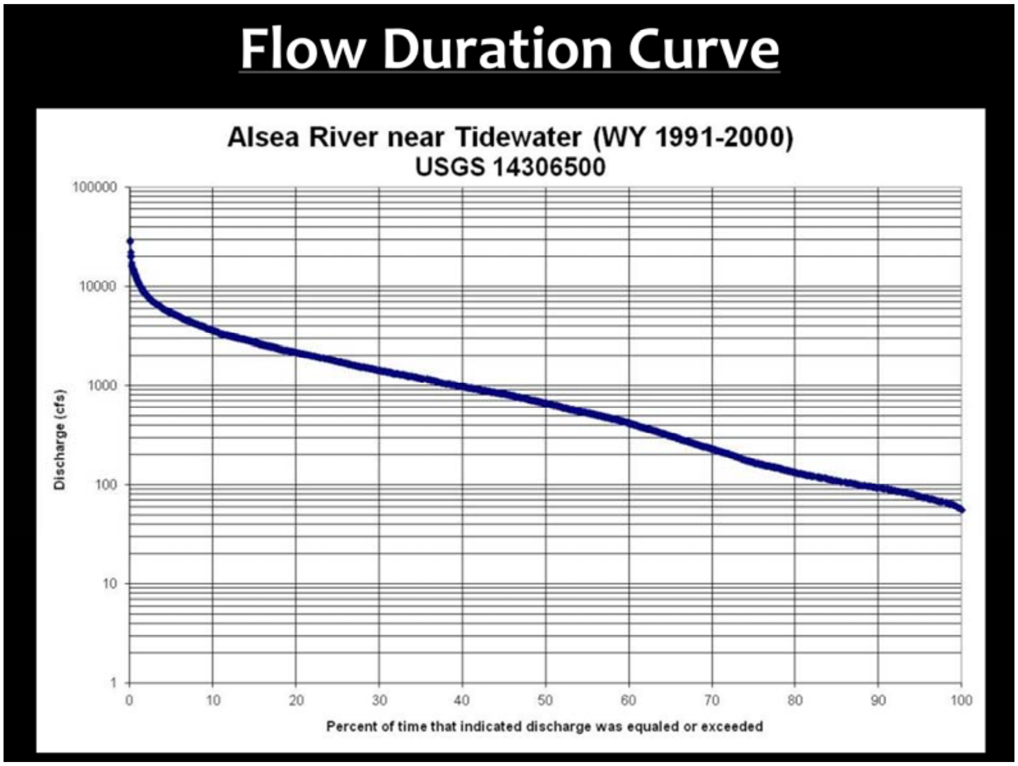
This method has been used for over a hundred years at many gage stations across the country. However, gages have to be visited regularly to maintain the accuracy of the rating curve.



Hydrograph

Stream gages can collect data at a number of different time steps—some record stage data every 15 minutes, for example. Over the long term, these data allow us to describe how much water was in a stream channel every day of the year for many years. When plotted in graphical form, the data are known as a hydrograph, which shows streamflow over time.

This hydrograph shows daily average flow in the Alsea River near Tidewater, Oregon from October 1989 through November 1999. Time is shown along the bottom or x-axis and discharge is shown along the vertical or y-axis. Every dot represents the average flow for one day, and as you can see, flow in this river ranged from very small to almost 30,000 cfs over the 10 years represented. The span of time represented by gage data is known as the period of record.

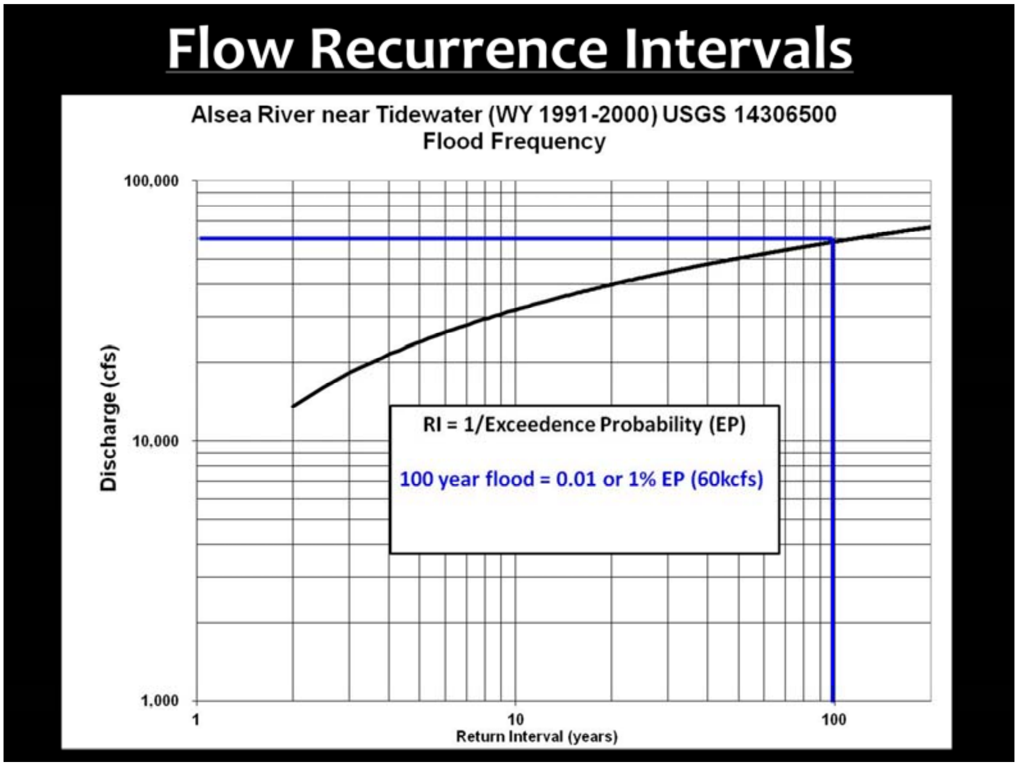


Flow Duration Curve

Here are the same data from the previous hydrograph, although this time presented as a flow duration curve. Graphs like this allow us to estimate the frequency of flows at a station, and are often the result of a cumulative frequency analysis of all available gage data for a site. On this curve, the highest flows are near the upper left, and the lowest flows are at the lower right.

Where a hydrograph shows the chronology of occurrence, flow duration curves are developed from all data—the day a certain flow occurred is not relevant.

Reading a flow duration curve is easy. For example, the flow at this station that was equaled or exceeded 50% of the time was about 650 cfs. You get this by finding 50 on the x-axis, following the grid line up to the blue curve and then moving left over to the vertical axis to read the discharge amount. The y-axis is logarithmic, so each major grouping represents an order of magnitude increase in flow.



Flow Recurrence Intervals

Alsea River near Tidewater (WY 1991-2000) USGS 14306500
Flood Frequency

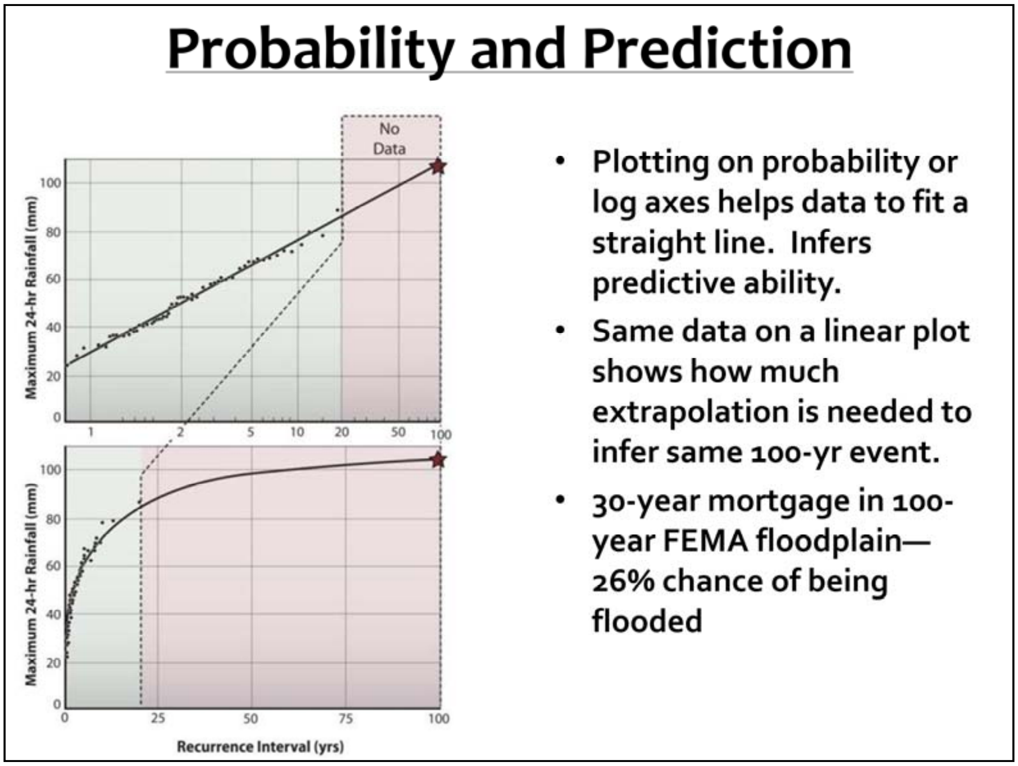
RI = 1/Exceedence Probability (EP)

100 year flood = 0.01 or 1% EP (60kcfs)

Whether you've heard of a flow duration curve or not, I would bet that you've heard of one of the ways flow frequency analyses are commonly used. Flow frequency analysis is used to determine things we hear about in the news like a 100-year flood. A new term here is recurrence interval, or the number of years it takes for a flow of some value to return. The recurrence interval of a 100-year flood is 100 years, and it has a 1% chance of occurring in any given year. Recurrence interval is found by dividing 1 by the exceedence probability.

Where duration analysis uses average daily flows, flood frequency analyses use annual peak flows from a gage.

So, if you run through the statistics, you can generate a curve that looks like this. You would read the value of the 100 year flood much the same way as we determined the 50% exceedence flow in the previous slide. So, the 100-year flood based on this record is about 60,000 cfs, shown by the blue lines connecting the x and y axis that intersect at the flood curve.



Probability and Prediction

- Plotting on probability or log axes helps data to fit a straight line. Infers predictive ability.
- Same data on a linear plot shows how much extrapolation is needed to infer same 100-yr event.
- 30-year mortgage in 100-year FEMA floodplain—26% chance of being flooded

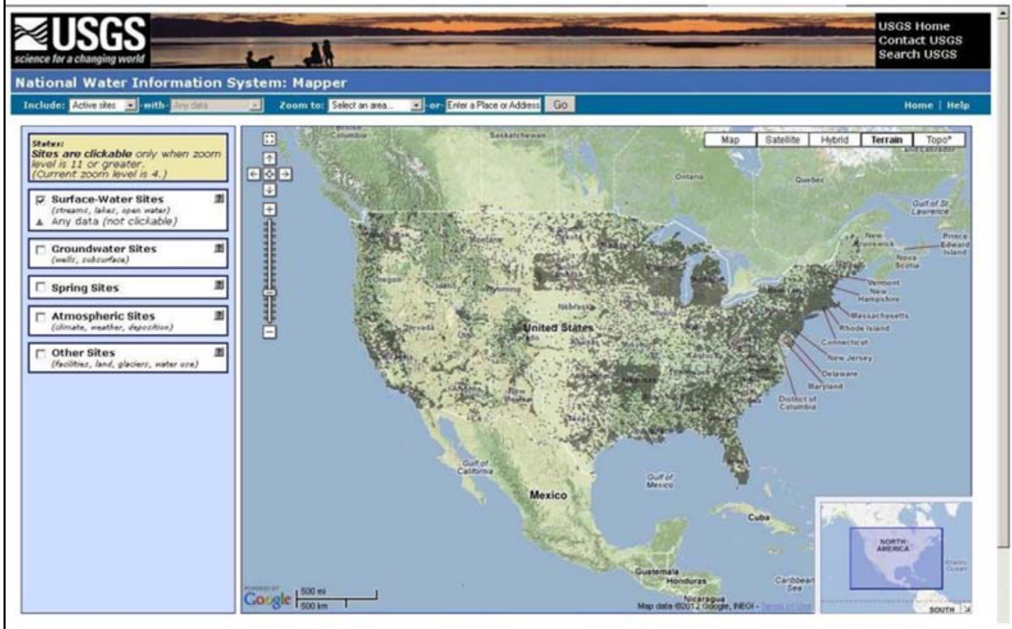
Its important to pay attention to the way data are represented to get a better idea about the accuracy of probability and prediction. The two charts on the left were developed using the exact same 20 years of data. The panel on the upper left uses log axes, which helps the data fit a straight line that appears to shoot straight as an arrow to some high value.

The panel on the lower left uses linear axes, which makes the data look quite different—curvilinear in fact. As you can see, bending the predictive line to fit the same high value out at the right takes some imagination, and could very well end up in a different place and value depending on how you fit the line.

So, there are errors and inherent ghosts when using data like this, especially when trying to predict a 100-year event based on only 20 years of data.

Also, bear in mind that this is probability theory and statistics. Recall that a 100-year flood has a 1% chance of occurring in any given year. However, the chance that a homeowner will experience a 100-year flood at least once over the term of a 30-year mortgage is 26%.

USGS National Water Information System



Include: Active sites -with- Any data Zoom to: Select an area... -or- Enter a Place or Address Go

Status:
Sites are clickable only when zoom level is 11 or greater.
(Current zoom level is 4.)

☑ **Surface-Water Sites** (streams, lakes, open water)
▲ Any data (not clickable)

☐ **Groundwater Sites** (wells, subsurface)

☐ **Spring Sites**

☐ **Atmospheric Sites** (climate, weather, deposition)

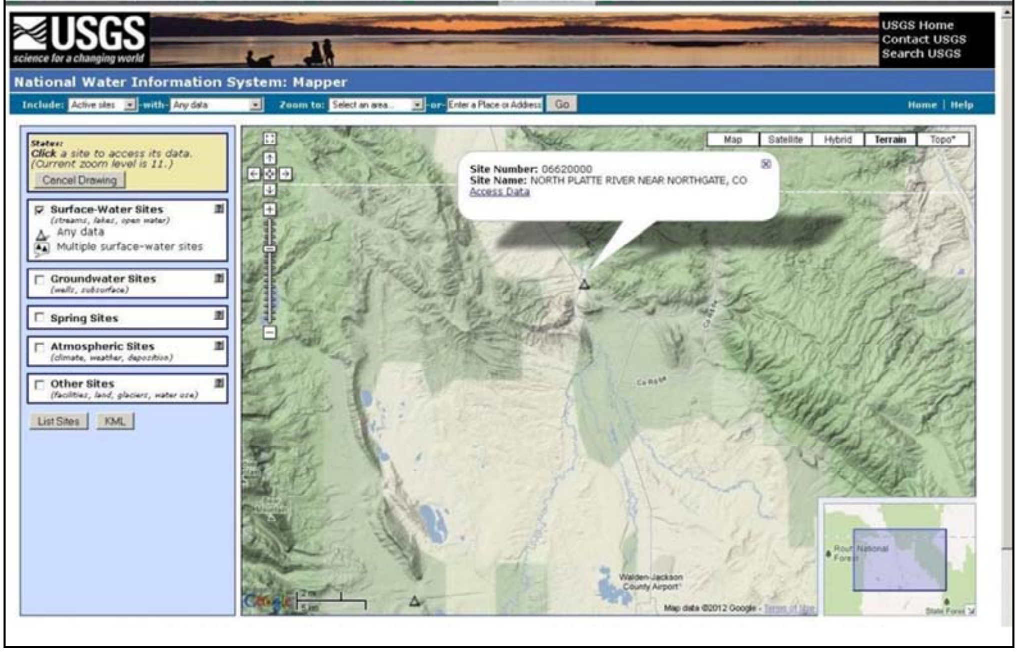
☐ **Other Sites** (facilities, land, glaciers, water use)

Alright, if you ever need to find streamflow data or are interested in the things I’ve been talking about, I’ll go over a few internet resources available out there.

The first is known as the National Water Information System, or NWIS, maintained by the US Geological Survey. Information from thousands of instruments, including streamflow, groundwater, springflow, atmospheric data, and glaciers, are available at this portal.

This graphic shows the front-end for active surface water sites across the United States—each gaging station is a gray triangle.

USGS National Water Information System



Include: Active sites -with- Any data Zoom to: Select an area... -or- Enter a Place or Address Go

Status:
Click a site to access its data.
(Current zoom level is 11.)

☑ **Surface-Water Sites**
(streams, lakes, open water)
Any data
Multiple surface-water sites

☐ **Groundwater Sites**
(wells, subsurface)

☐ **Spring Sites**

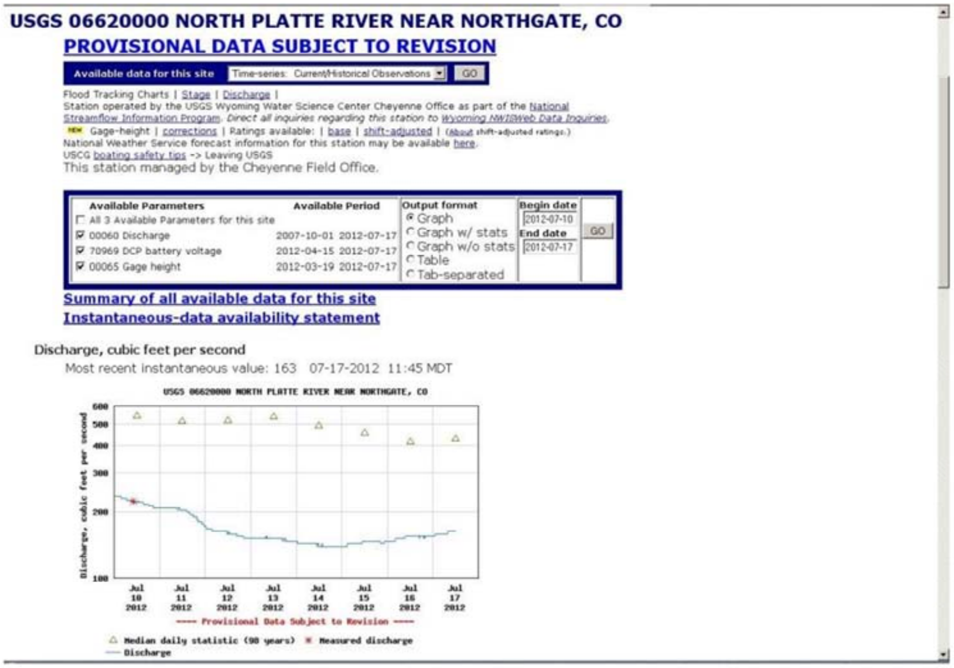
☐ **Atmospheric Sites**
(climate, weather, deposition)

☐ **Other Sites**
(facilities, land, glaciers, water use)

Site Number: 06620000
Site Name: NORTH PLATTE RIVER NEAR NORTHGATE, CO
Access Data

Zooming in on a site of interest will show you the gages in that area. Clicking on the access data link will take you to the available data for that site.

USGS National Water Information System



USGS 06620000 NORTH PLATTE RIVER NEAR NORTHGATE, CO

PROVISIONAL DATA SUBJECT TO REVISION

Available data for this site Time-series: Current/Historical Observations GO

Flood Tracking Charts | Stage | Discharge |
Station operated by the USGS Wyoming Water Science Center Cheyenne Office as part of the National Streamflow Information Program. *Direct all inquiries regarding this station to* Wyoming NWISWeb Data Inquiries.
NEW Gage-height | corrections | Ratings available: | base | shift-adjusted | (About shift-adjusted ratings.)
National Weather Service forecast information for this station may be available here.
USCG boating safety tips -> Leaving USGS
This station managed by the Cheyenne Field Office.

	Available Parameters	Available Period		Output format	Begin date	
☐	All 3 Available Parameters for this site			● Graph	2012-07-10	
☑	00060 Discharge	2007-10-01	2012-07-17	○ Graph w/ stats	End date	GO
☑	70969 DCP battery voltage	2012-04-15	2012-07-17	○ Graph w/o stats	2012-07-17	
☑	00065 Gage height	2012-03-19	2012-07-17	○ Table		
				○ Tab-separated		

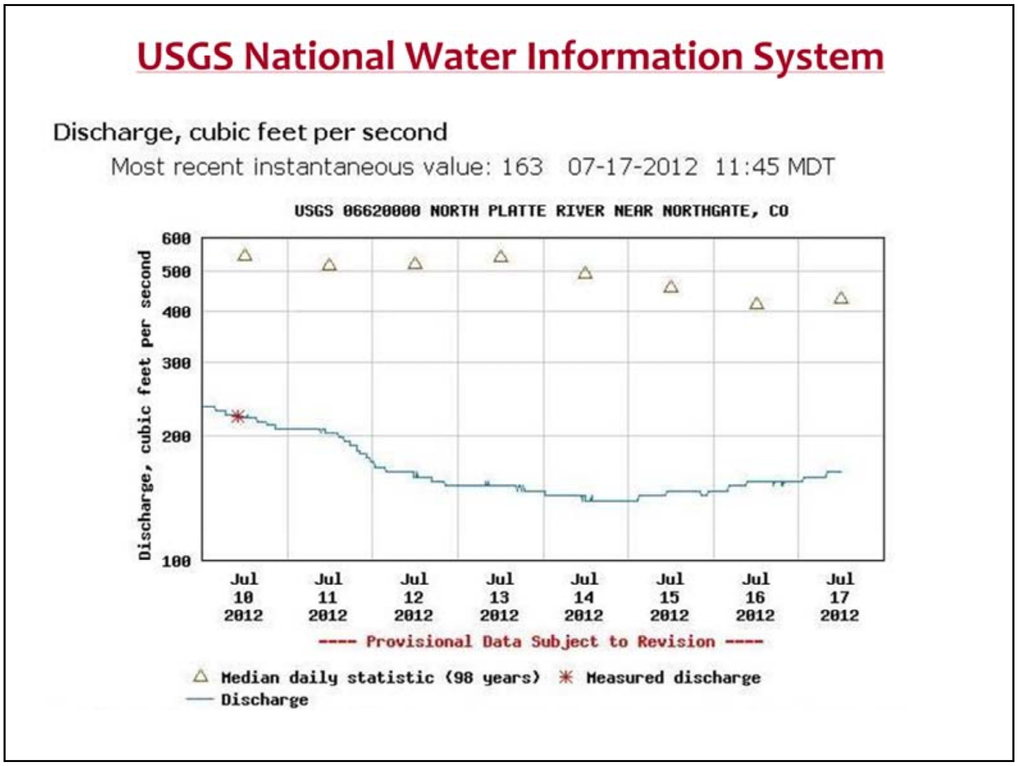
Summary of all available data for this site

Instantaneous-data availability statement

Discharge, cubic feet per second

Most recent instantaneous value: 163 07-17-2012 11:45 MDT

Here is what the site data interface looks like when you click on that access data link. A whole bunch of information can be accessed here, including streamflow, weather, water quality, and river stage. Some stations, like this one on the North Platte near Northgate, Colorado, also include real-time streamflow data.



USGS National Water Information System

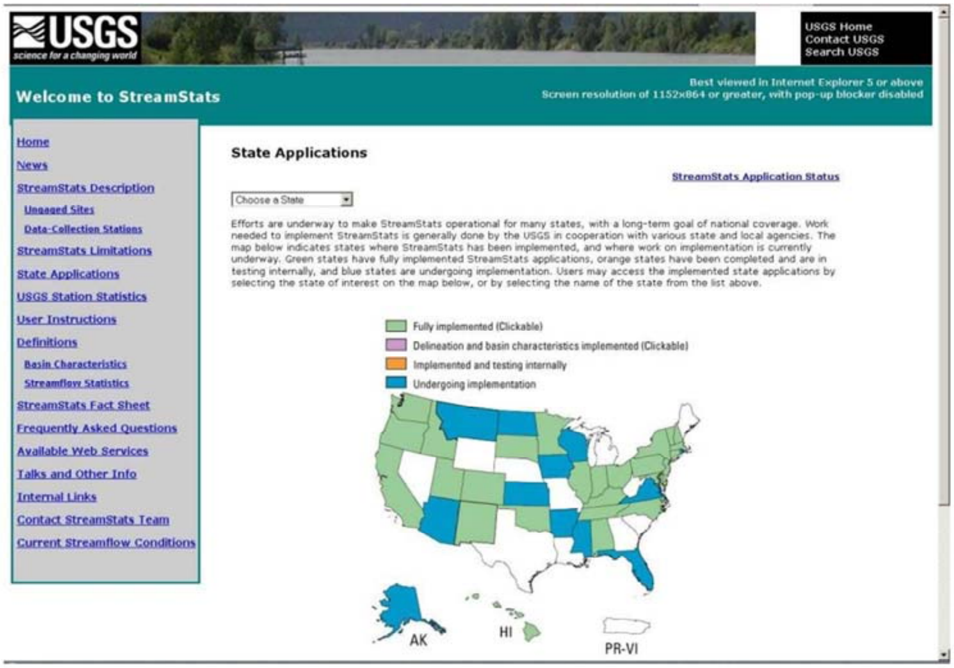
Discharge, cubic feet per second

Most recent instantaneous value: 163 07-17-2012 11:45 MDT

Real-time data are useful for a number of purposes. For example, these data, accessed last week for the same North Platte river gage, tells me whether or not I could get my driftboat down the river without dragging—probably not since daily flows are way below average based on the 98 year period of record for the gage.

Also, if I drove into the nearest town, Walden, and walked into the Elkhorn Café—in addition to being related to many of the patrons—I'd know who had irrigation water and who didn't because of the low water year in the basin. This helps you know where to sit down because some folks are going to be grumpy…

USGS StreamStats

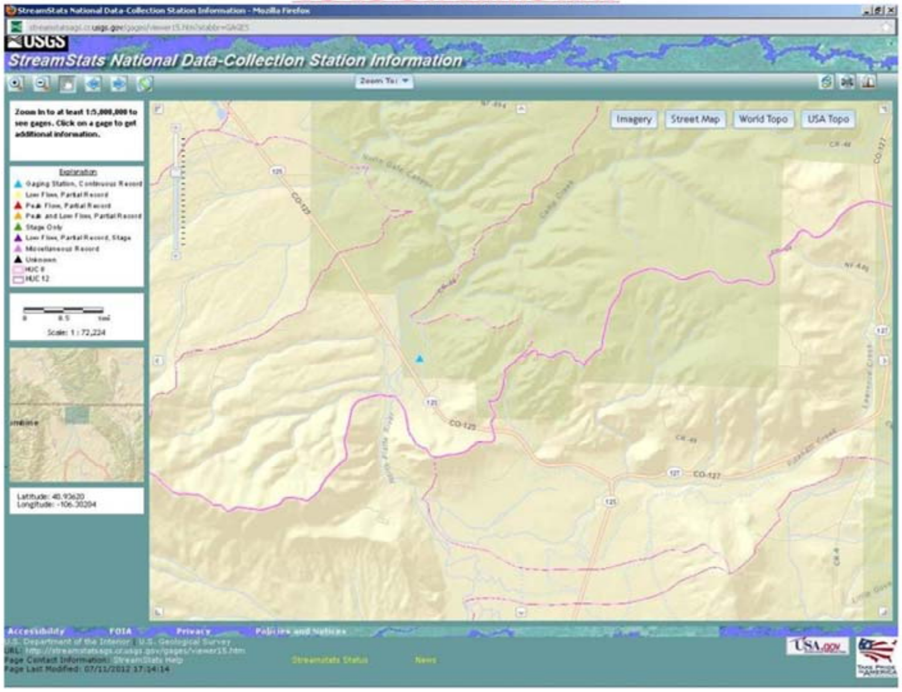


Efforts are underway to make StreamStats operational for many states, with a long-term goal of national coverage. Work needed to implement StreamStats is generally done by the USGS in cooperation with various state and local agencies. The map below indicates states where StreamStats has been implemented, and where work on implementation is currently underway. Green states have fully implemented StreamStats applications, orange states have been completed and are in testing internally, and blue states are undergoing implementation. Users may access the implemented state applications by selecting the state of interest on the map below, or by selecting the name of the state from the list above.

The NWIS makes streamflow and other hydrologic data available to anyone with an internet connection. However, it generally doesn't present data analyzed using statistical hydrology methods in the form of flow durations or flood probabilities.

Another application is known as StreamStats, and it uses a powerful set of tools to deliver statistical streamflow products. This graphic shows the front end of the tool, as well as the states—shown in green—where the tool is fully functional. Most states are functional or undergoing implementation, and the remaining 12 are slated for completion in the next few years, depending on funding.

USGS StreamStats



StreamStats National Data-Collection Station Information - Mozilla Firefox

StreamStats National Data-Collection Station Information

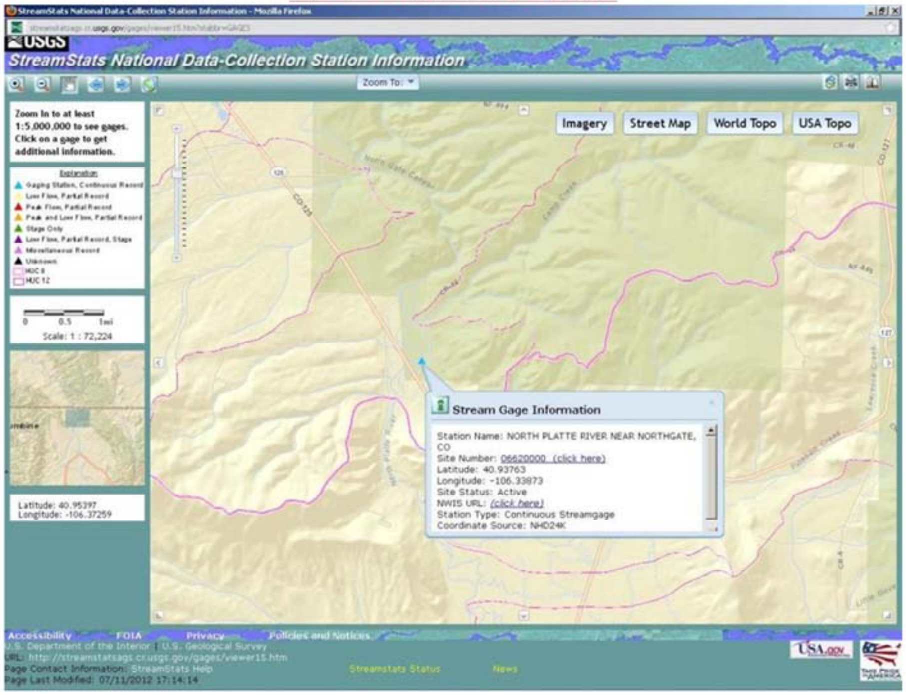
Zoom in to at least 1:5,000,000 to see gages. Click on a gage to get additional information.

Latitude: 40.93620
Longitude: -106.30204

Page Last Modified: 07/11/2012 17:14:14

Within the operational states, the interface works much the same as the previous tool. You use a map to zoom in on the area of interest until you find a gage.

USGS StreamStats

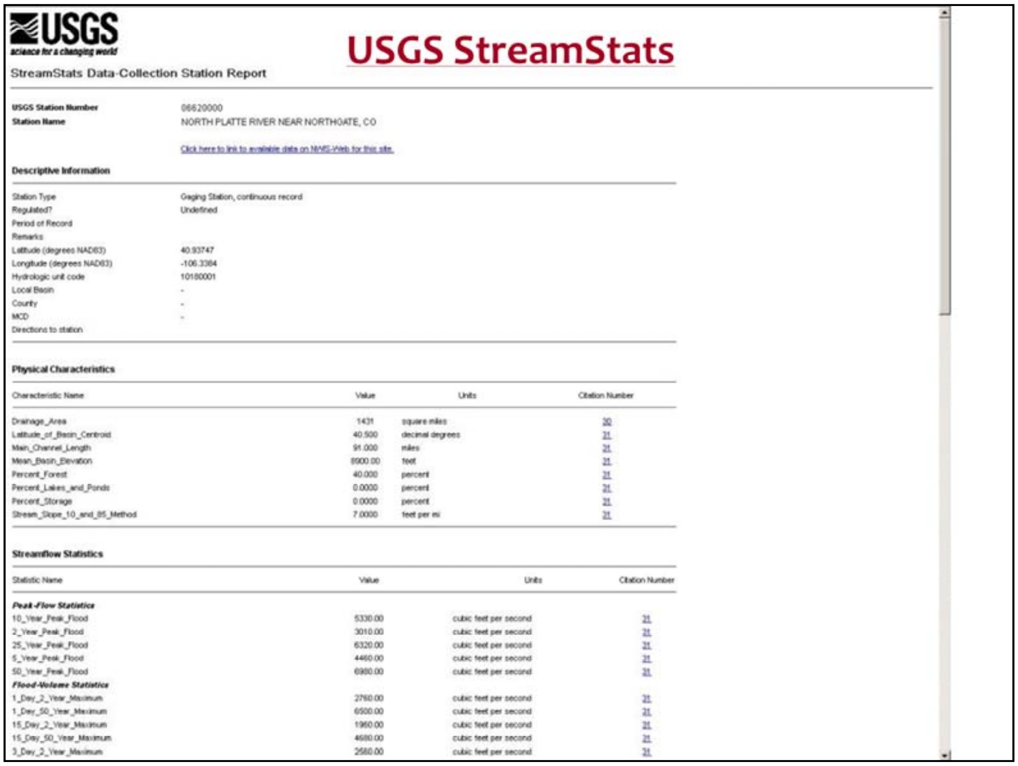


Zoom In to at least 1:5,000,000 to see gages. Click on a gage to get additional information.

Latitude: 40.95397
Longitude: -106.37259

Station Name: NORTH PLATTE RIVER NEAR NORTHGATE, CO
Site Number: 06620000 (click here)
Latitude: 40.93763
Longitude: -106.33873
Site Status: Active
NWIS URL: (click here)
Station Type: Continuous Streamgage
Coordinate Source: NHD24K

Clicking on the gage gives you access to links that take you to data.



USGS StreamStats

StreamStats Data-Collection Station Report

USGS Station Number	06620000
Station Name	NORTH PLATTE RIVER NEAR NORTHGATE, CO
	Click here to link to available data on NWIS-Web for this site.

Descriptive Information

Station Type	Gaging Station, continuous record
Regulated?	Undefined
Period of Record	
Remarks	
Latitude (degrees NAD83)	40.93747
Longitude (degrees NAD83)	-106.3384
Hydrologic unit code	10180001
Local Basin	-
County	-
MCD	-
Directions to station	

Physical Characteristics

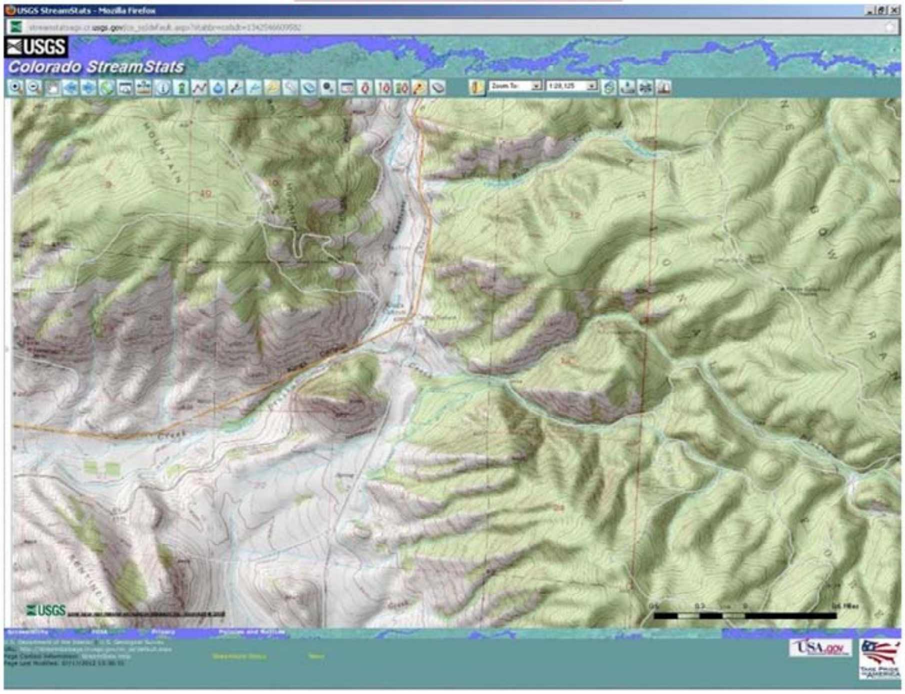
Characteristic Name	Value	Units	Citation Number
Drainage_Area	1431	square miles	30
Latitude_of_Basin_Centroid	40.500	decimal degrees	31
Main_Channel_Length	91.000	miles	31
Mean_Basin_Elevation	8900.00	feet	31
Percent_Forest	40.000	percent	31
Percent_Lakes_and_Ponds	0.0000	percent	31
Percent_Storage	0.0000	percent	31
Stream_Slope_10_and_85_Method	7.0000	feet per mi	31

Streamflow Statistics

Statistic Name	Value	Units	Citation Number
Peak-Flow Statistics			
10_Year_Peak_Flood	5330.00	cubic feet per second	31
2_Year_Peak_Flood	3010.00	cubic feet per second	31
25_Year_Peak_Flood	6320.00	cubic feet per second	31
5_Year_Peak_Flood	4460.00	cubic feet per second	31
50_Year_Peak_Flood	6980.00	cubic feet per second	31
Flood-Volume Statistics			
1_Day_2_Year_Maximum	2760.00	cubic feet per second	31
1_Day_50_Year_Maximum	6500.00	cubic feet per second	31
15_Day_2_Year_Maximum	1960.00	cubic feet per second	31
15_Day_50_Year_Maximum	4680.00	cubic feet per second	31
3_Day_2_Year_Maximum	2580.00	cubic feet per second	31

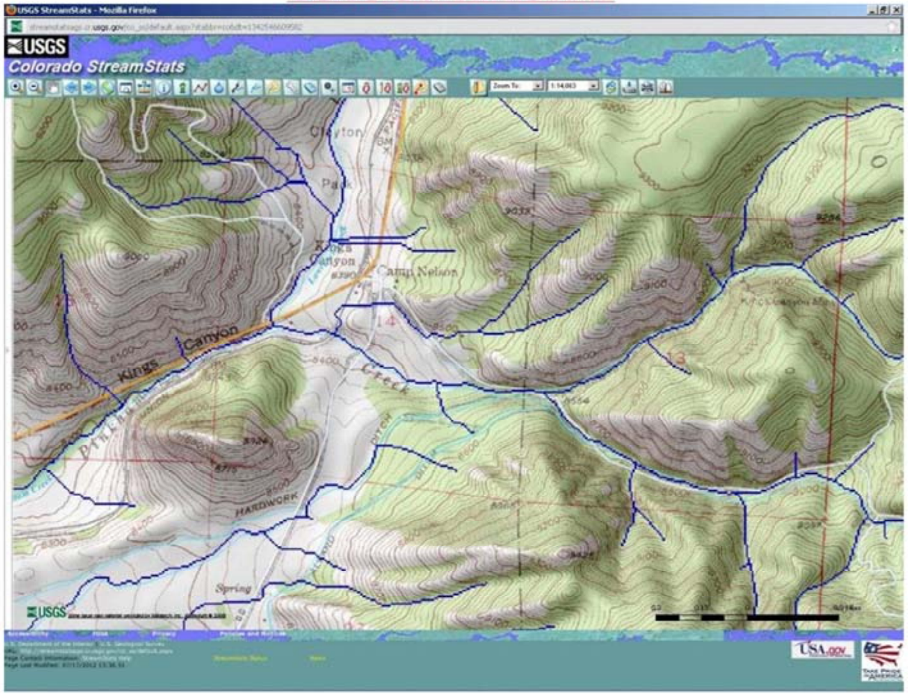
The data, however, look a little different than the NWIS interface. As you can see, this screen shot shows statistical predictors—like estimates of the 2, 5, 10, 25 and 50-year peak flows for this location.

USGS StreamStats



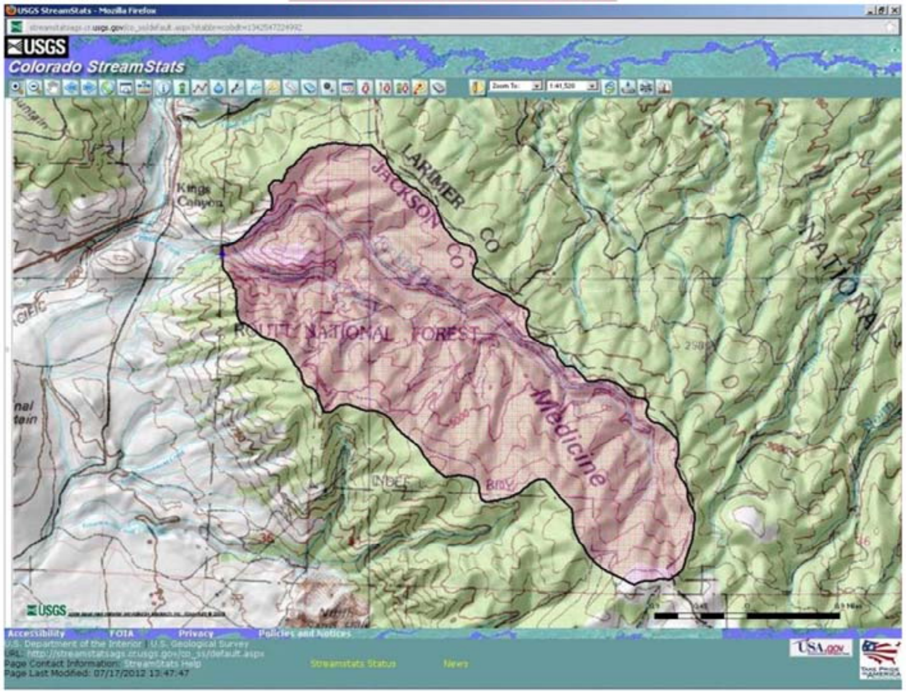
In addition to containing links to existing gages with years of streamflow data, StreamStats enables the user to select a point on an ungaged stream to generate drainage basin and streamflow information.

USGS StreamStats



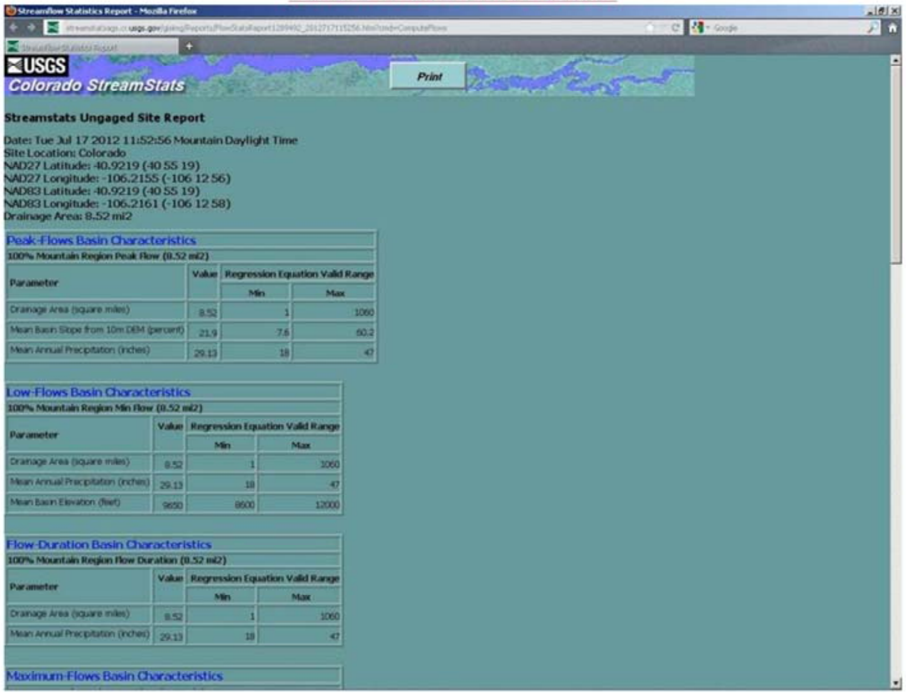
You zoom into an area of interest to the layer where blue-line coverages of stream networks from the National Hydrography Database kicks in.

USGS StreamStats



You can select a point anywhere along a stream, and StreamStats will delineate the basin and then use a number of different types of data and tools to generate streamflow estimates.

USGS StreamStats



Streamstats Ungaged Site Report

Date: Tue Jul 17 2012 11:52:56 Mountain Daylight Time
Site Location: Colorado
NAD27 Latitude: 40.9219 (40 55 19)
NAD27 Longitude: -106.2155 (-106 12 56)
NAD83 Latitude: 40.9219 (40 55 19)
NAD83 Longitude: -106.2161 (-106 12 58)
Drainage Area: 8.52 mi2

Peak-Flows Basin Characteristics

100% Mountain Region Peak Flow (8.52 mi2)

Parameter	Value	Regression Equation Valid Range	
		Min	Max
Drainage Area (square miles)	8.52	1	1060
Mean Basin Slope from 10m DEM (percent)	21.9	7.6	60.2
Mean Annual Precipitation (inches)	29.13	18	47

Low-Flows Basin Characteristics

100% Mountain Region Min Flow (8.52 mi2)

Parameter	Value	Regression Equation Valid Range	
		Min	Max
Drainage Area (square miles)	8.52	1	1060
Mean Annual Precipitation (inches)	29.13	18	47
Mean Basin Elevation (feet)	9850	8600	12000

Flow-Duration Basin Characteristics

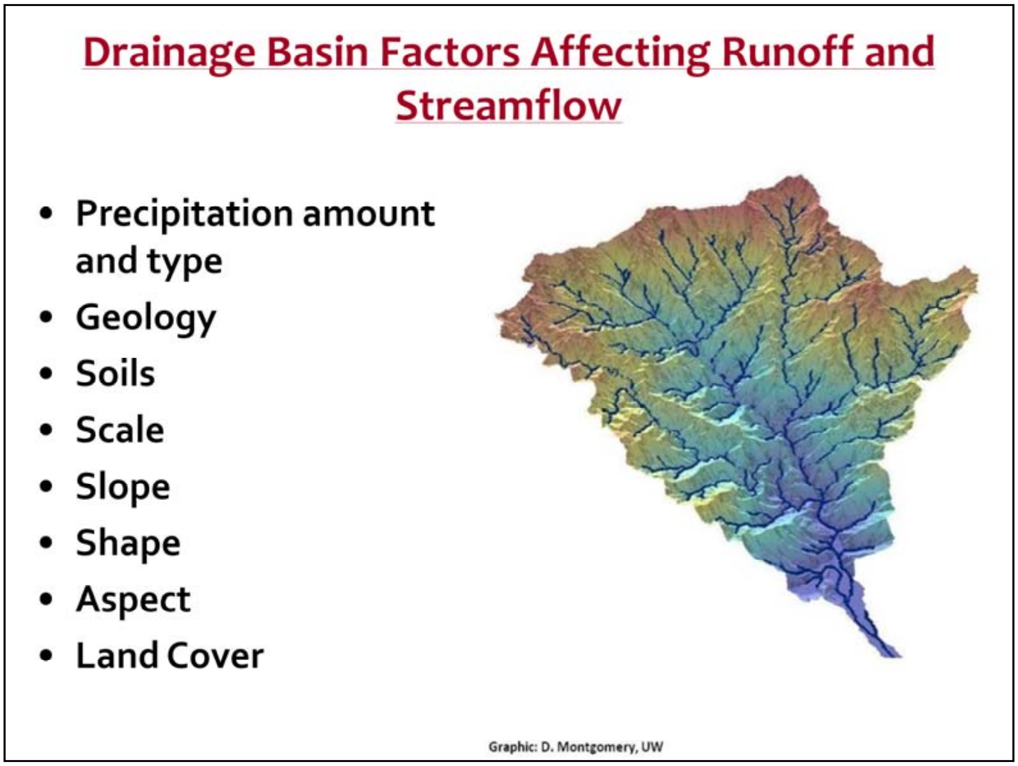
100% Mountain Region Flow Duration (8.52 mi2)

Parameter	Value	Regression Equation Valid Range	
		Min	Max
Drainage Area (square miles)	8.52	1	1060
Mean Annual Precipitation (inches)	29.13	18	47

Maximum-Flows Basin Characteristics

Here is a shot of the type of data generated from the small watershed I delineated in the previous slide. The software produces a lot of information, including drainage basin metrics, peak and low flow estimates, and flow duration data.

However, these data—especially the streamflow—are largely estimates derived using equations, and although they give you an idea of streamflow and other facets of the hydrology of a basin, they can only get you so far. For example, they shouldn't be used for any sort of design work without calibration at a project site.



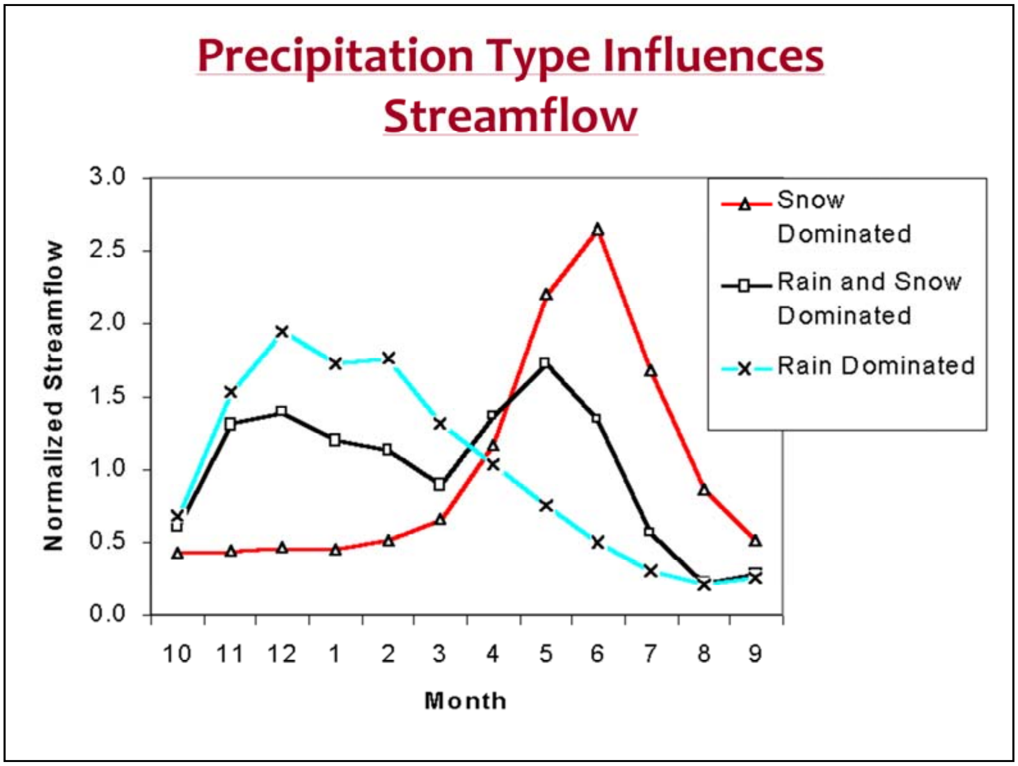
Drainage Basin Factors Affecting Runoff and Streamflow

- Precipitation amount and type
- Geology
- Soils
- Scale
- Slope
- Shape
- Aspect
- Land Cover

Graphic: D. Montgomery, UW

So, how does StreamStats generate all that data? Well, a part of the answer is related to the same factors that affect streamflow from a drainage basin.

Many things affect the way a watershed cycles precipitation and how that appears as streamflow. In addition to the type and amount of precipitation, basin geology, soils, size, slope, aspect, shape and land cover affect the timing, duration, magnitude, and intensity of streamflow at the basin outlet.

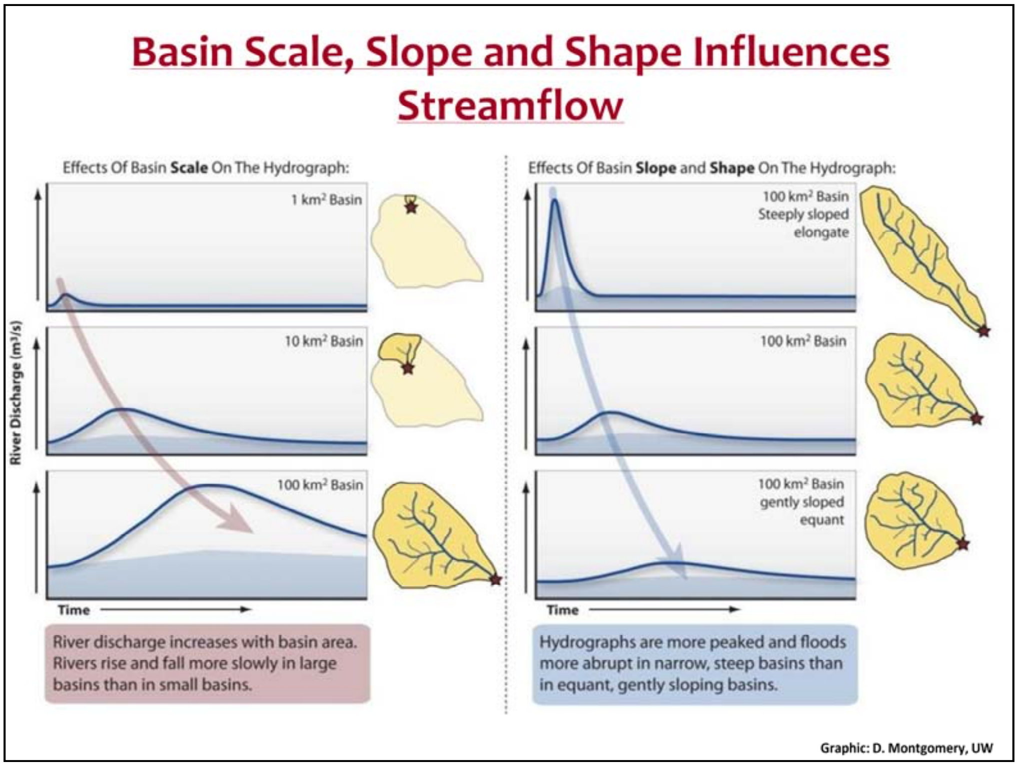


Precipitation Type Influences Streamflow

Precipitation type has a strong influence on the shape of a hydrograph from rivers in different areas. For example, snowmelt dominated rivers, shown by the red line on this graph, usually have their highest flows in the spring when snow melts and runs off, with low flows over the rest of the year when groundwater takes over. Rivers in the rocky mountain states have hydrographs like the red line.

Basins dominated by rain—shown here as the blue line—exhibit high flows for 3 to five months throughout the winter and early spring. The southeastern United States has a lot of rivers with hydrographs that look like the blue line.

Basins with both rain and snow precipitation—shown by the black line—usually have a bimodal or two-humped hydrograph which reflects two distinct periods of rainfall and snowmelt runoff. Examples of these types of rivers can be found along the west and pacific northwest coast.



Basin Scale, Slope and Shape Influences Streamflow

River discharge increases with basin area. Rivers rise and fall more slowly in large basins than in small basins.

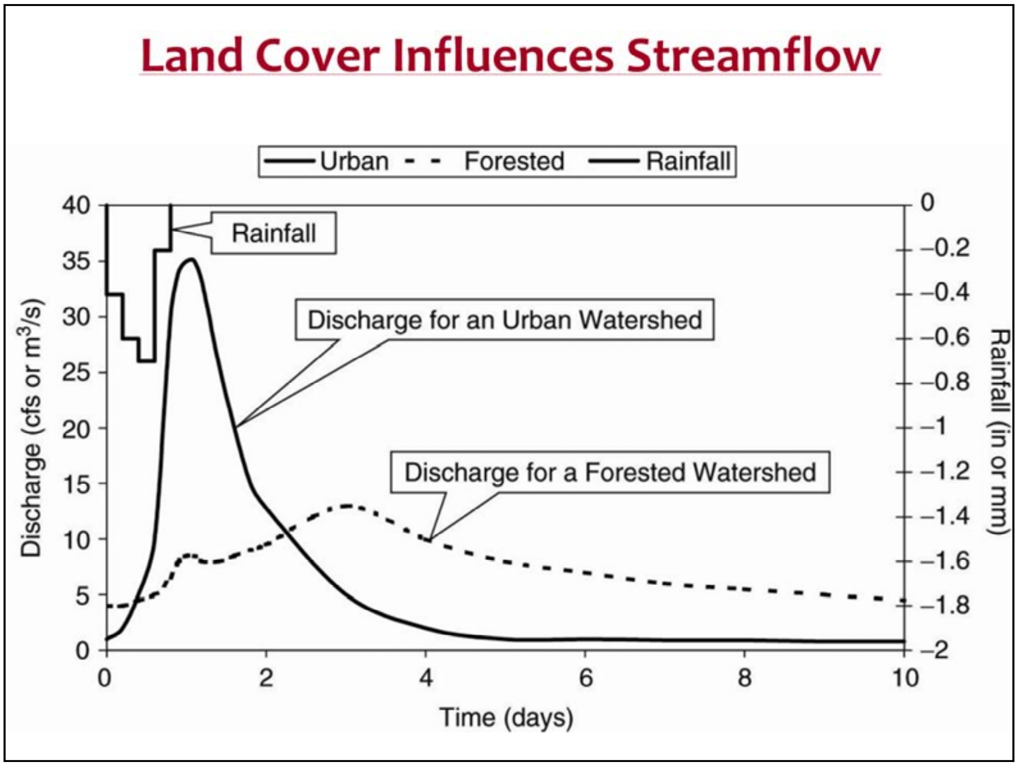
Hydrographs are more peaked and floods more abrupt in narrow, steep basins than in equant, gently sloping basins.

Graphic: D. Montgomery, UW

Basin scale, slope, and shape influence streamflow and hydrograph shape.

For example, as shown here on the left, smaller basins produce less streamflow with quicker rise and fall than a larger basin.

As shown on the right, basin slope and shape affect discharge as well. Narrow, steep basins tend to produce sharply peaked hydrographs with abrupt floods while flatter, more symmetrical basins have broader peak flows.

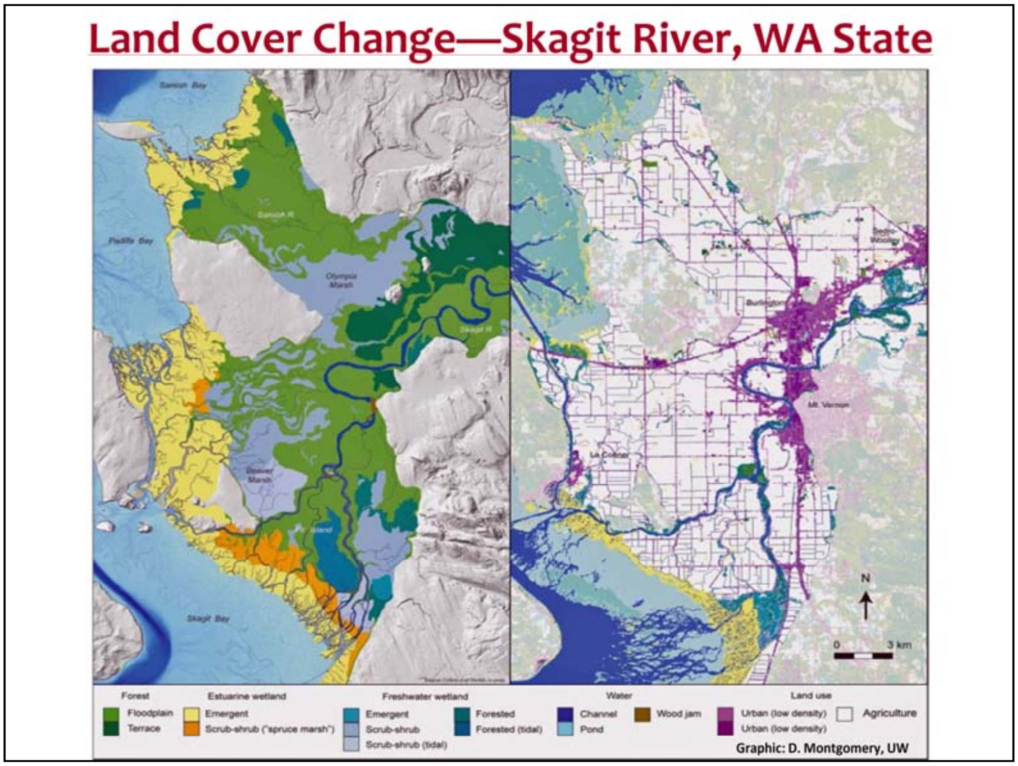


Land Cover Influences Streamflow

In addition, land cover influences the shape of a hydrograph. This figure shows the effect of the same amount of rainfall in two similar watersheds—one forested, and the other urban.

Generally, streamflow for a river draining an urban watershed is flashier—meaning it quickly spikes and recedes to very low flows—especially as compared to a forested landscape.

The forested setting processes rainfall differently, primarily due to greater vegetative cover, lack of impervious or hard surfaces like roads and parking lots, and intact shallow aquifers that act like hydrologic capacitors, releasing flow slowly back to the channel after a rain event.

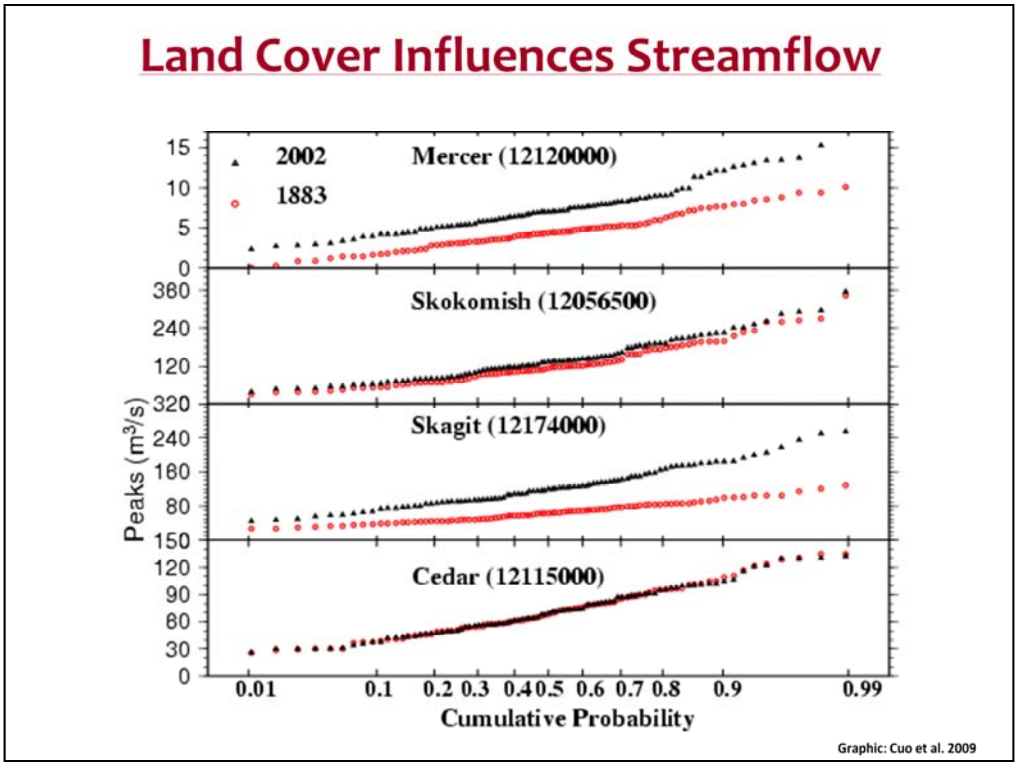


Land Cover Change—Skagit River, WA State

Graphic: D. Montgomery, UW

Here's an example of how land cover change affects streamflow, using the lower Skagit River in Washington State. This area lies along Puget Sound, north of the city of Seattle. The panel on the left shows the pre-development state of this part of the lower Skagit, and although you probably can't read the legend along the bottom, you may notice that the area around the river is composed of mostly greens, blues, yellow or orange. This means that the river was mostly surrounded by floodplains and wetlands prior to development.

The panel on the right shows the present day land cover in the same area of the basin. You'll notice mostly white and magenta, which means that land cover has shifted to mostly agriculture and urban uses. Only about 10% of the pre-development floodplain and wetland landscapes exist.

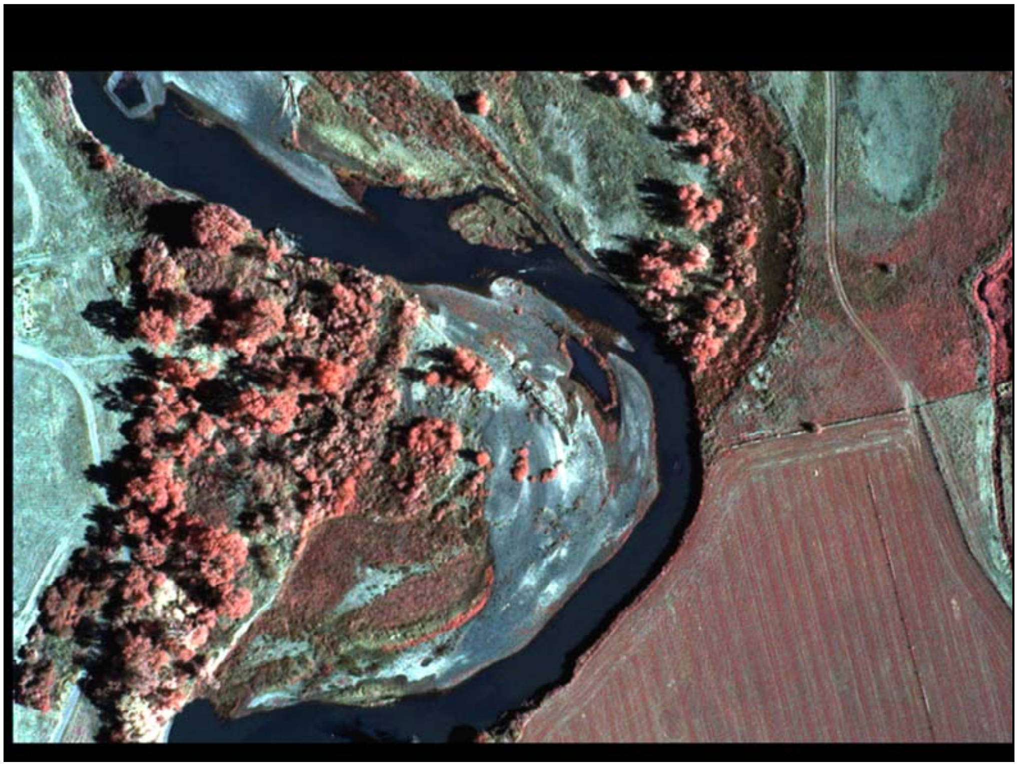


Land Cover Influences Streamflow

Graphic: Cuo et al. 2009

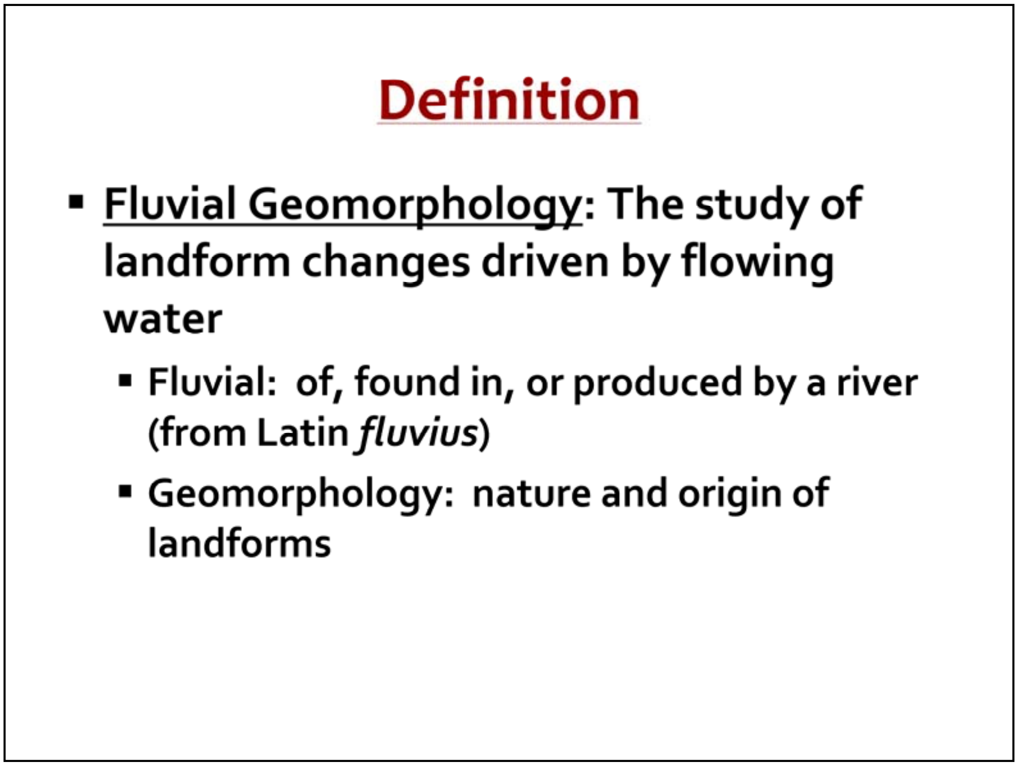
Here's the effect that change in land cover has had on streamflow in the Skagit River, and three other Puget Sound systems—two affected by urbanization and one not so much. The red markers indicate flood probabilities for 1883, while the black markers show flood probabilities for 2002.

Peak flows on the Skagit and Mercer Rivers have increased by more than 100%. By comparison, the Skokomish and Cedar Rivers have experienced much smaller changes, owing to less urbanization and greater retention of forested cover in their upper watersheds.



So, since land cover influences the frequency and magnitude of streamflow, it follows that there must be some corresponding effect on the way a stream channel looks and functions in response to hydrologic alteration.

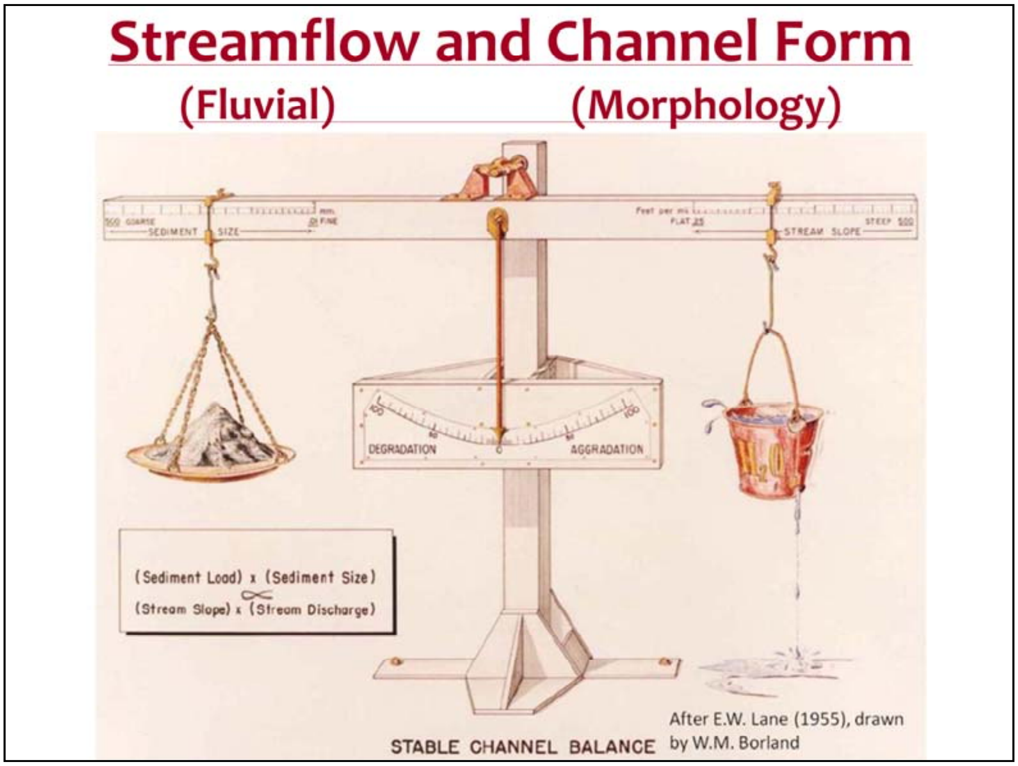
This is a decent segue into a discussion of fluvial geomorphology because over time, river systems tend to reach a balance between water and the materials it carries—mainly sediment and wood.



Definition

- <u>Fluvial Geomorphology</u>: The study of landform changes driven by flowing water
  - Fluvial: of, found in, or produced by a river (from Latin *fluvius*)
  - Geomorphology: nature and origin of landforms

So, time for another definition. Fluvial geomorphology is the study of landform changes driven by flowing water.



Streamflow and Channel Form

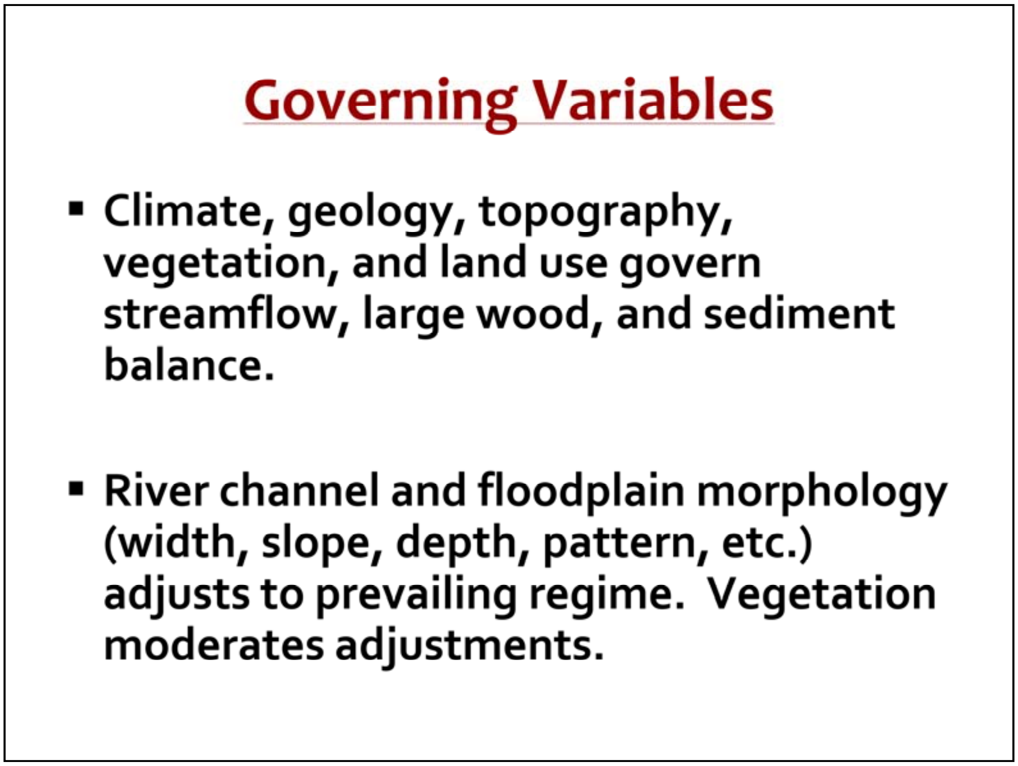
(Fluvial) (Morphology)

After E.W. Lane (1955), drawn by W.M. Borland

Many talks covering fluvial geomorphology include this graphic in some form, so we'll use it right out of the chute and refer back from time to time.

Known as Lane's Balance, the figure suggests that channel response and stability are dependent on a proportionality or balance between the load and size of sediment and the slope and streamflow of a system. Originally used by the Bureau of Reclamation in the design of stable channels, this simple tool illustrates how altering any one of the four components forces channel adjustment. For example, if you moved the bucket of water on the right side of the balance to the right, the left side will rise up, and the needle in the middle would move toward degradation. This response is commonly observed—increasing slope or adding water to a system usually results in degradation or incision, with the channel eroding downward, becoming narrower and deeper.

You could also include a vegetative component into this relationship because streamside vegetation has a strong influence on channel morphology.

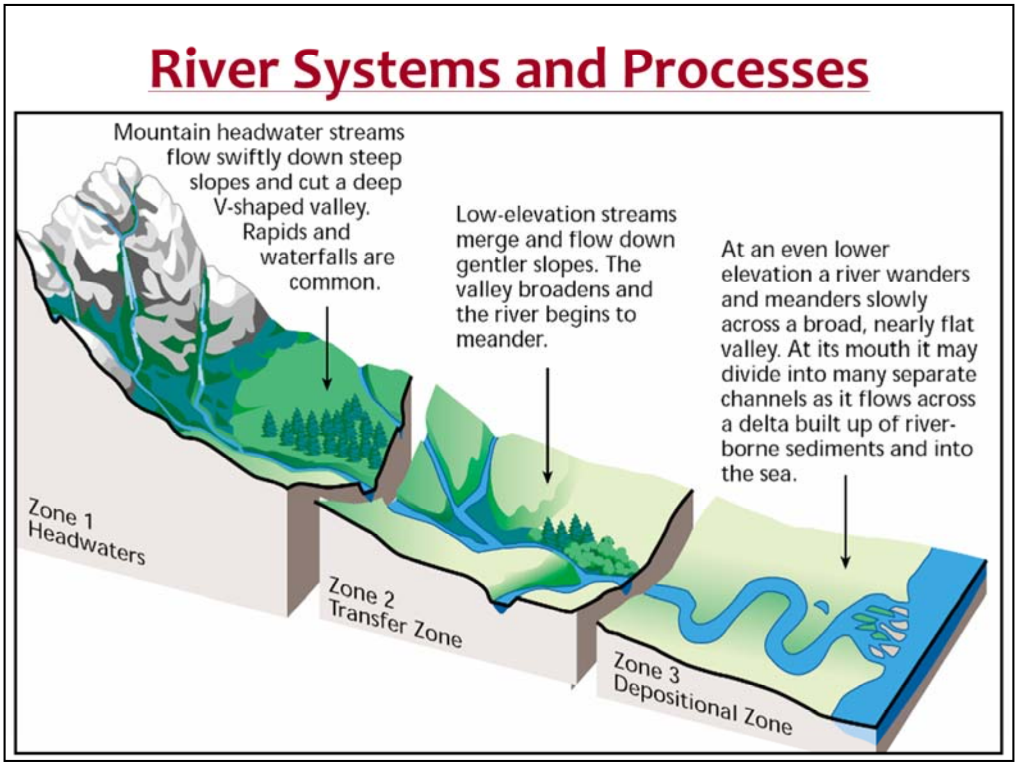


Governing Variables

- Climate, geology, topography, vegetation, and land use govern streamflow, large wood, and sediment balance.
- River channel and floodplain morphology (width, slope, depth, pattern, etc.) adjusts to prevailing regime. Vegetation moderates adjustments.

A few large-scale physical sideboards dictate the way river basins look and function. Climate, geology and the physical geography of a watershed govern the amount of water and sediment a river will process on any given day of the year.

River channel and floodplain geometry adjust themselves to the prevailing streamflow and sediment regime, and vegetation plays a big part in resisting adjustments. Again, this is the general relationship that Lane’s balance captures.



River Systems and Processes

Mountain headwater streams flow swiftly down steep slopes and cut a deep V-shaped valley. Rapids and waterfalls are common.

Low-elevation streams merge and flow down gentler slopes. The valley broadens and the river begins to meander.

At an even lower elevation a river wanders and meanders slowly across a broad, nearly flat valley. At its mouth it may divide into many separate channels as it flows across a delta built up of river-borne sediments and into the sea.

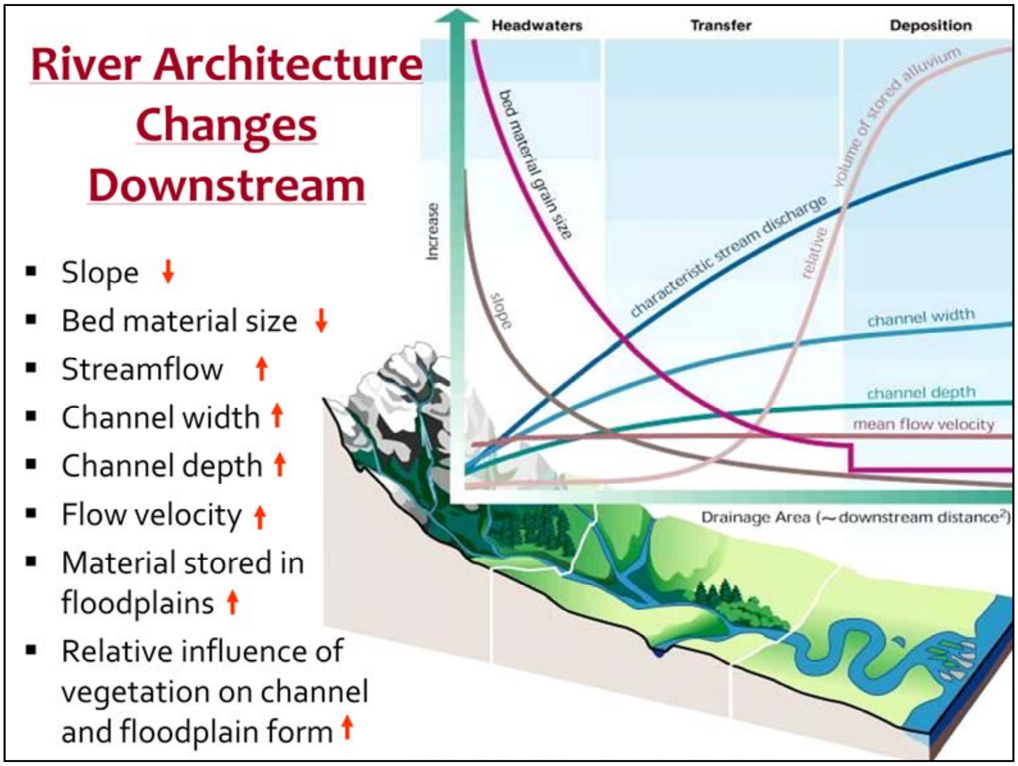
At the drainage basin scale, we tend to lump river systems into 3 parts. Gravity powers the work done, and a number of forces resist erosion along the way as rivers try to get rid of extra energy and find that balance.

So, moving from left to right, we have

Zone 1, the headwaters or uppermost reaches of a stream, serves as the supply zone. Steep slopes, bare, sometimes young landforms, and extreme climate and precipitation ranges supply sediment to a river channel.

Zone 2 – also known as the Transfer Zone – is where rivers begin to respond to materials delivered from upstream reaches. Floodplains become more extensive, channel morphology can be diverse, and streamside vegetation plays a bigger role in floodplain and channel structure and function.

Zone 3 – the Deposition Zone – is where we see the largest rivers in a given landscape, extensive floodplains, and wide, deep channels.



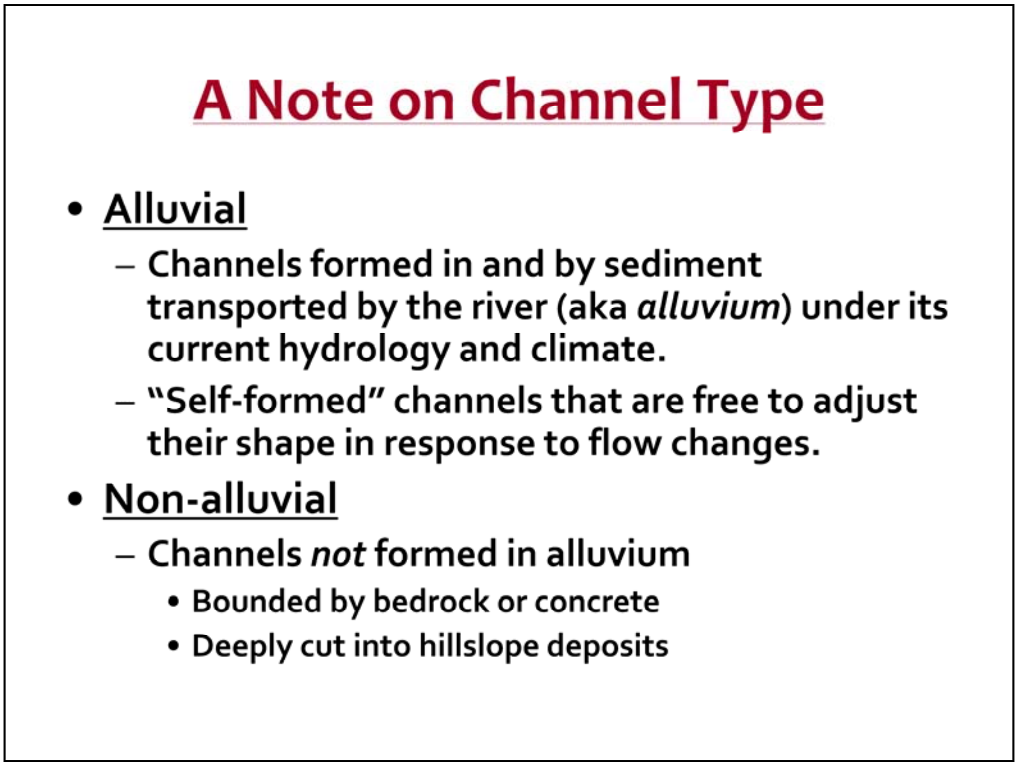
River Architecture Changes Downstream

- Slope ↓
- Bed material size ↓
- Streamflow ↑
- Channel width ↑
- Channel depth ↑
- Flow velocity ↑
- Material stored in floodplains ↑
- Relative influence of vegetation on channel and floodplain form ↑

Assuming that river systems are organized from headwaters downstream, we can make some generalizations about the basic architecture of any river from headwaters to ocean.

As you move downstream, slope and the average size of bed material decreases.

Streamflow, channel width, depth, and average velocities increase. In addition, the average amount of sediment stored in the channel and floodplain increases, as does the relative influence of vegetation on channel and floodplain form.

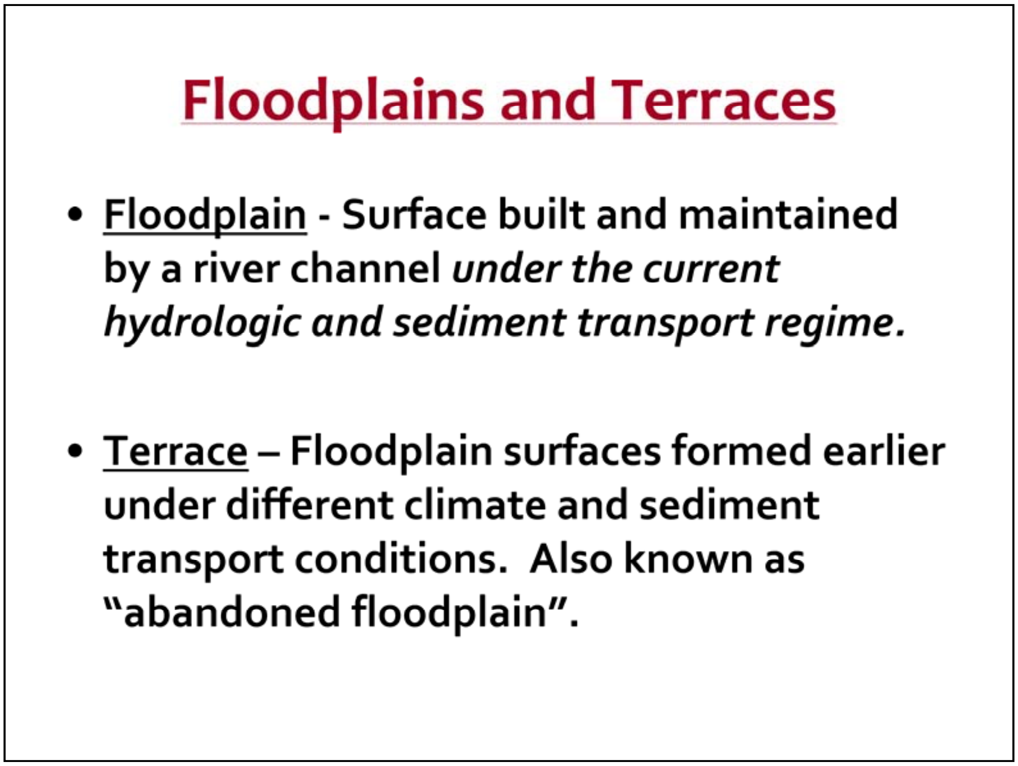


A Note on Channel Type

- **Alluvial**
  - Channels formed in and by sediment transported by the river (aka *alluvium*) under its current hydrology and climate.
  - "Self-formed" channels that are free to adjust their shape in response to flow changes.
- **Non-alluvial**
  - Channels *not* formed in alluvium
    - Bounded by bedrock or concrete
    - Deeply cut into hillslope deposits

As mentioned in the previous slide, river channels and floodplains adjust to fluxes in water and sediment over time. These are known as alluvial systems, and are often referred to as "self-formed" because of their plasticity to changes in streamflow and/or sediment regimes—think of Lane's balance.

Non-alluvial channels, on the other hand are those not formed in alluvium, and tend to remain functionally stable over long time periods—any river in a bedrock canyon is a good example.



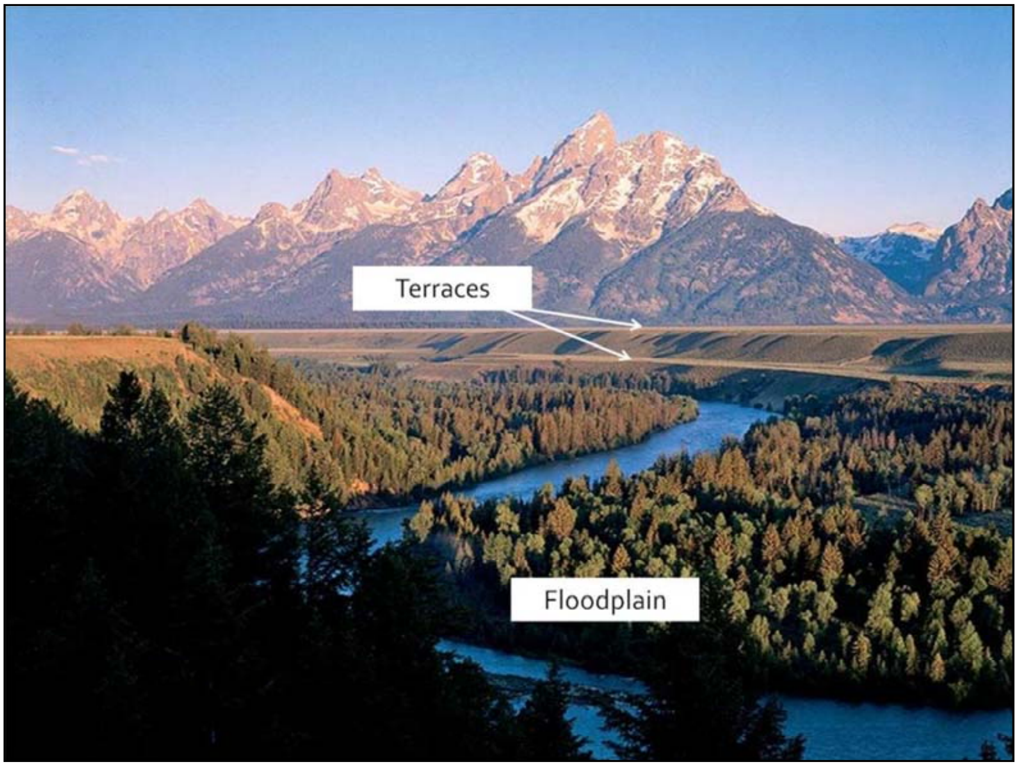
Floodplains and Terraces

- **Floodplain - Surface built and maintained by a river channel *under the current hydrologic and sediment transport regime.***
- **Terrace – Floodplain surfaces formed earlier under different climate and sediment transport conditions. Also known as "abandoned floodplain".**

I've talked about floodplains, and you may have heard of river terraces. They're related to one another, but are significantly different.

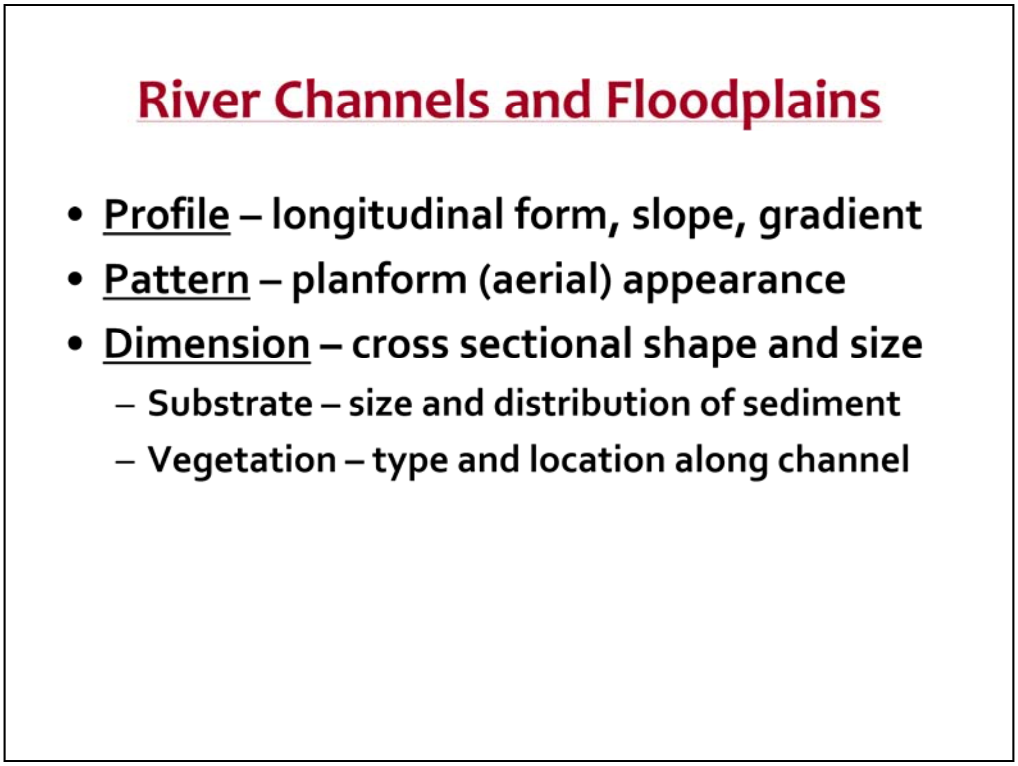
For alluvial rivers, a floodplain is the surface adjacent to the river channel built and maintained under the present streamflow and sediment transport regime. It's a geomorphic surface, and I'd like to point out that the 100-year floodplain you hear about relative to flood insurance may not always be related to the geomorphic floodplain—its an administrative boundary that often changes after a flood.

Terraces are abandoned floodplains and are usually associated with a different river than you see today.



So, here's a shot of the Snake River at the foot of the Tetons, showing the floodplain, which brackets the channel on either side.

Above there you'll find terraces, which in this setting were formed by successive periods of glacial advance down the valley and retreat back up. Again, these terraces are abandoned floodplains of a much different Snake River…



River Channels and Floodplains

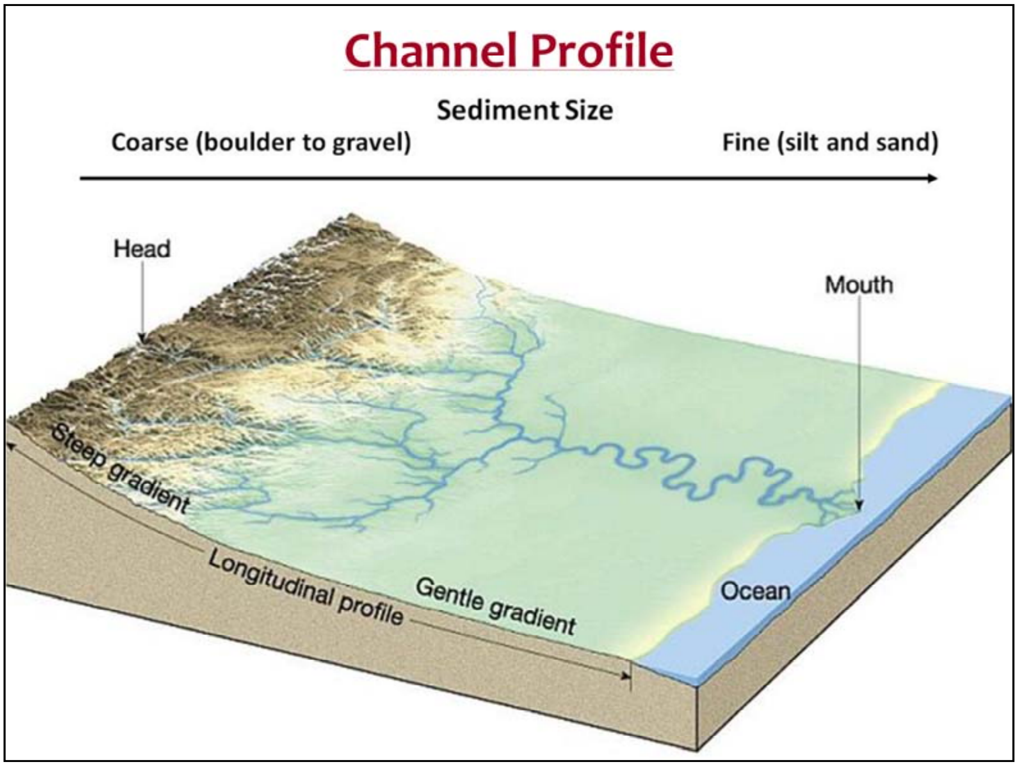
- **<u>Profile</u> – longitudinal form, slope, gradient**
- **<u>Pattern</u> – planform (aerial) appearance**
- **<u>Dimension</u> – cross sectional shape and size**
  - **Substrate – size and distribution of sediment**
  - **Vegetation – type and location along channel**

So, let's get into some of the specifics of channel form, function, and process. Specifically, we'll cover the following categories of metrics used to describe and analyze stream corridors.

Profile describes the form and shape of a river from headwaters down.

Pattern or planform is how a river looks from above

And Dimension includes elements of a river's size and shape that vary with streamflow, sediment, and the influence of vegetation.

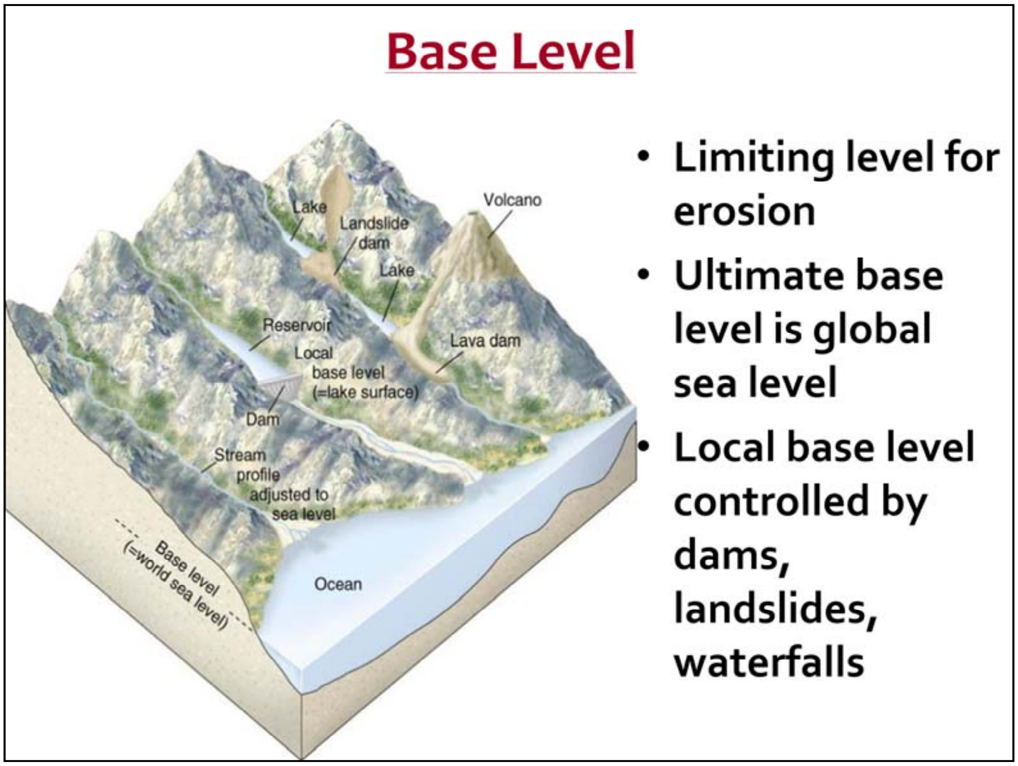


Channel Profile

Sediment Size

Coarse (boulder to gravel) **Fine (silt and sand)**

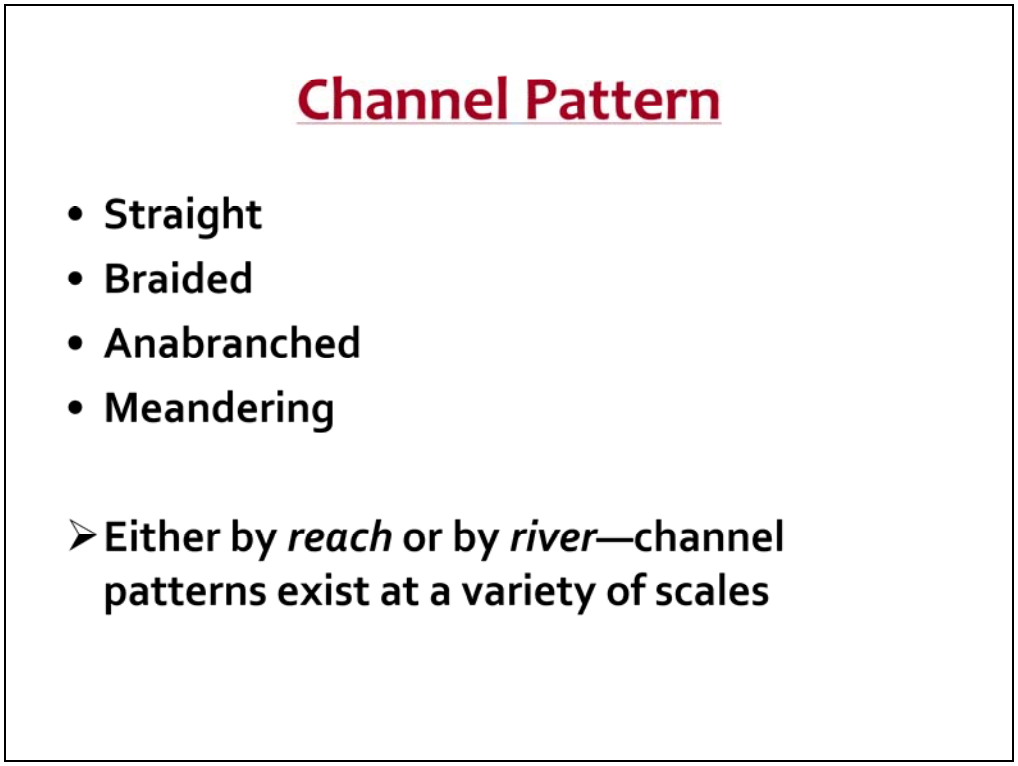
Channel profile describes the overall longitudinal shape—from headwaters to mouth—of a stream system. Fairly intuitive concept since water flows downhill—but consider also that in general terms, sediment sizes change from larger near the headwaters to fine silts and sands near a river’s mouth.



Base Level

- Limiting level for erosion
- Ultimate base level is global sea level
- Local base level controlled by dams, landslides, waterfalls

Base level is a concept that describes the factor that limits how far—in the vertical or elevation direction—a channel can erode or aggrade. For all rivers, the ultimate base level is global sea level. However, local controls on base level are afforded by dams, large landslides and geologic factors such as waterfalls.



Channel Pattern

- Straight
- Braided
- Anabranched
- Meandering

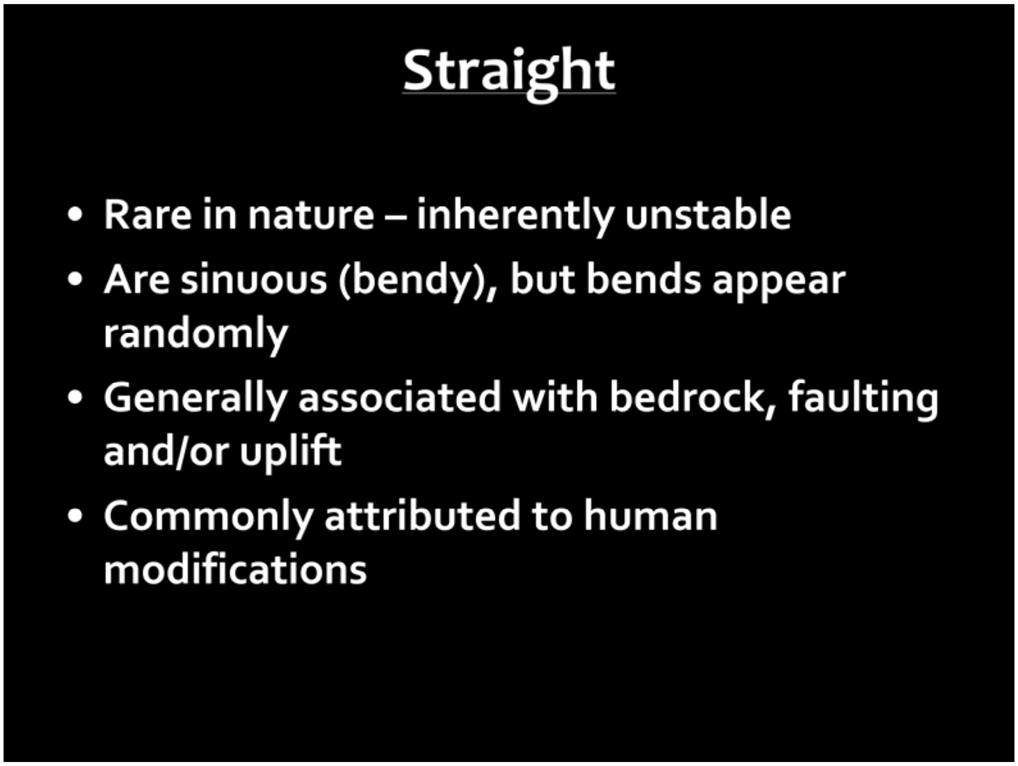
➢ Either by *reach* or by *river*—channel patterns exist at a variety of scales

Rivers are generally lumped into one of four channel pattern categories. These classifications are commonly recognized according to appearance, as well as physical variables such as slope, number of channels, vegetative characteristics, and the size of material comprising the bed and banks of the river.

The four categories are straight, braided, anabranched, and meandering. Bear in mind that each of these can exist within the same river along its entire course—channel pattern can be referenced at a variety of spatial scales.

Straight

Straight rivers or even straight reaches of rivers are relatively uncommon in nature.

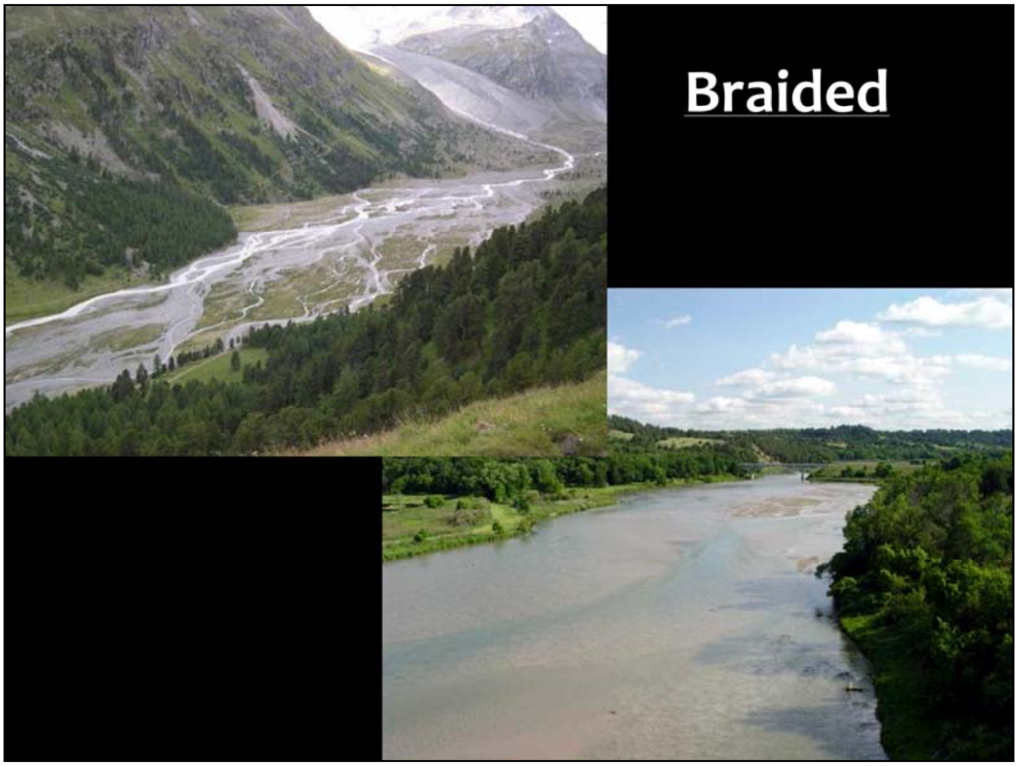


Straight

- Rare in nature – inherently unstable
- Are sinuous (bendy), but bends appear randomly
- Generally associated with bedrock, faulting and/or uplift
- Commonly attributed to human modifications

Straight rivers are relatively unstable, and while they may have a slight bend or two like a meandering river, the location and occurrence of these bends appears to be largely random. Naturally straight rivers are associated with bedrock, faulting, or other tectonic features.

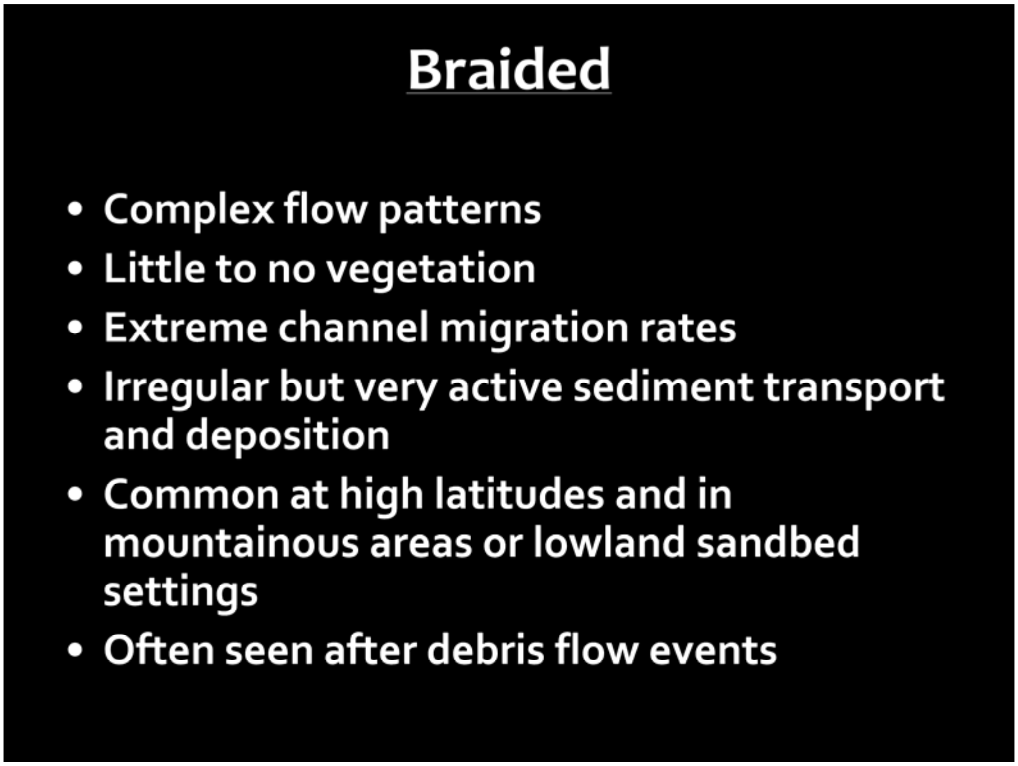
However, the most common examples of straight river reaches in the present day are associated human modification.



Braided

Braided rivers are common at high latitudes and altitudes, and likely reflect what all the rivers on the planet looked like before the advent of vascular plants, about 400 million years ago.

Today, many braided systems are associated with glaciers or in low gradient streams dominated by sands and small gravels. Braided rivers have many channels separated by high spots or areas of very shallow flow.



Braided

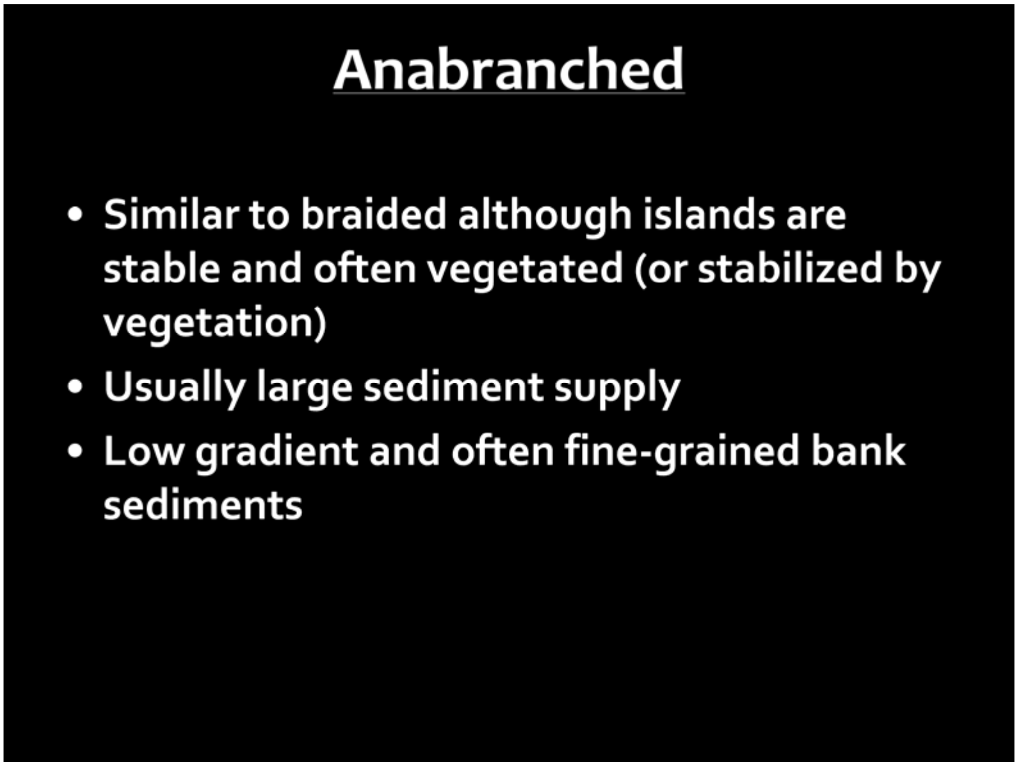
- Complex flow patterns
- Little to no vegetation
- Extreme channel migration rates
- Irregular but very active sediment transport and deposition
- Common at high latitudes and in mountainous areas or lowland sandbed settings
- Often seen after debris flow events

Braided river systems exhibit complex flow patterns that can change over short periods of time. Consequently, channel migration rates can be extreme, and the amount of material moved can be high but irregularly distributed across the channel. Braided rivers are commonly devoid of vegetation.

Braided channels are often seen after debris flows events for some period of time until the river is able to rework itself into the pattern that existed before an event.

Anabranched

Another channel pattern we'll discuss today is known as anabranched. At first glance it resembles a braided river—many channels with islands in between.



Anabranched

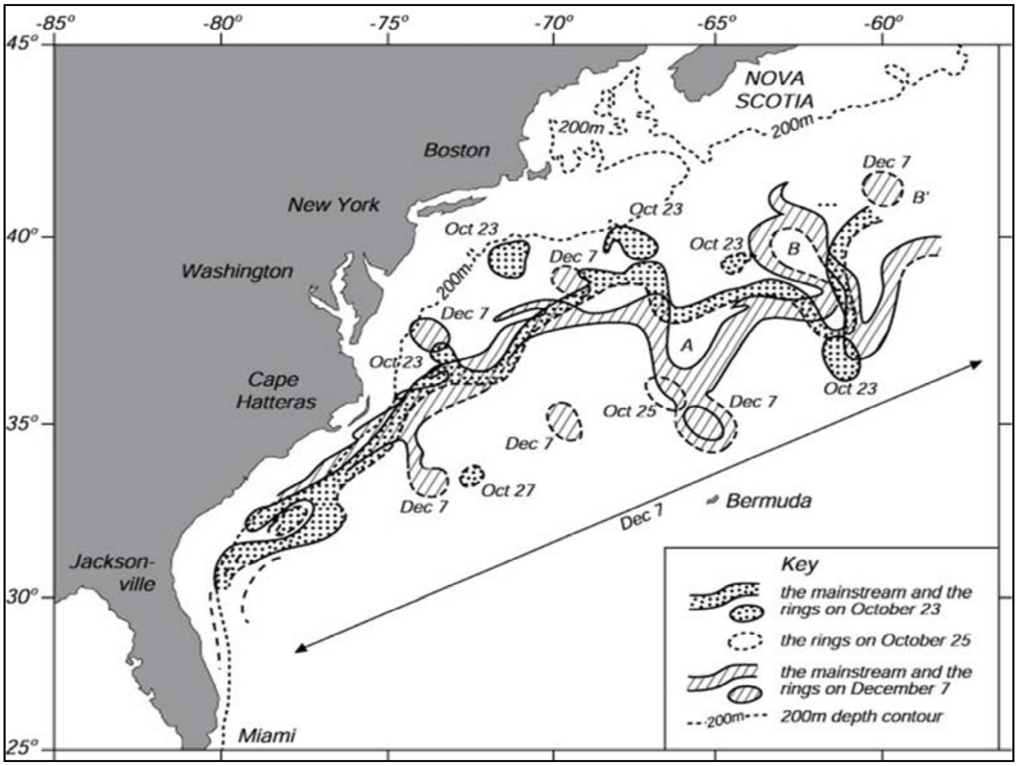
- Similar to braided although islands are stable and often vegetated (or stabilized by vegetation)
- Usually large sediment supply
- Low gradient and often fine-grained bank sediments

The main functional difference between braided and anabranched rivers is the presence of vegetated islands. Although some geomorphologists don’t recognize this as a major group of rivers, I include it here for 2 reasons—first, there is strong evidence that anabranching is an intermediate step between a braided and meandering pattern and second, anabranched rivers highlight the important role of vegetation in keeping rivers together.

In fact, there is an interesting bit of work out there that details the change in river morphology from meandering to braided after the Permian-Triassic extinction event that killed the dinosaurs. Terrestrial plants died as well, and rivers changed from meandering to braided in a relatively short period of time.

Meandering

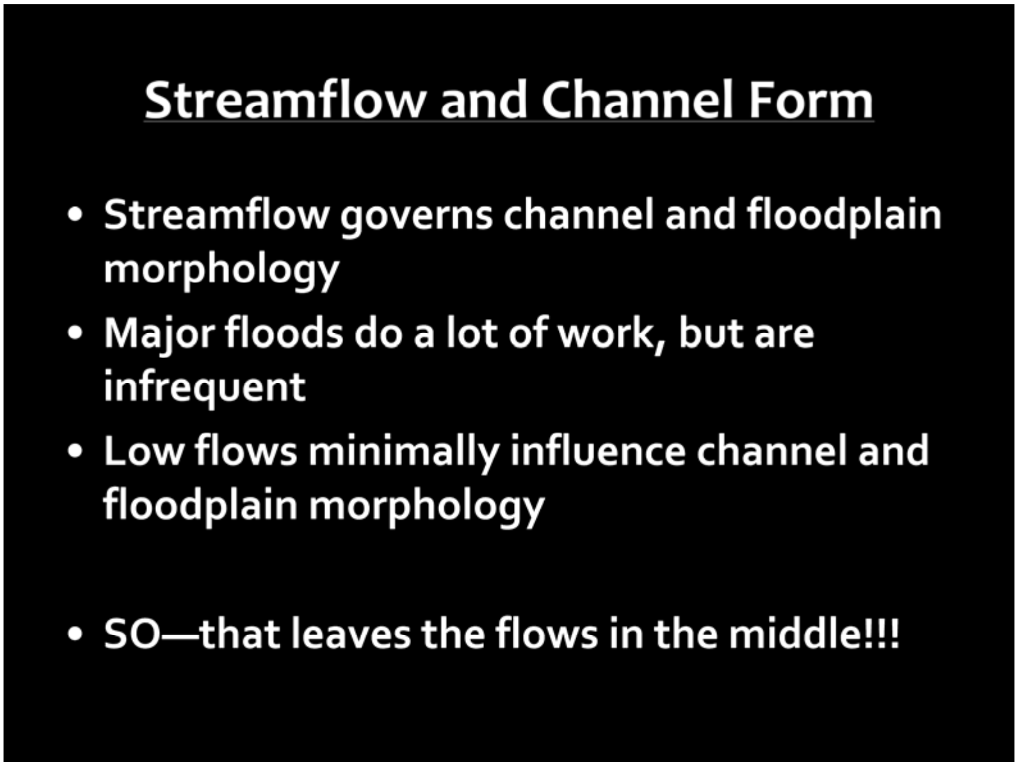
The final pattern we'll discuss is meandering. Meandering rivers wander from side to side along a floodplain in a pattern resembling a sine wave.



Meandering doesn’t have to be contained within the banks of a river—here it is purely a hydrodynamic phenomenon.

This slide shows meandering patterns observed in the Gulf Stream off the east coast of the US in the fall and winter of 1996. Hopefully you can see the meander patterns in the main current, as well as rings that have been spun off as the meanders migrated across the ocean.

Here is a large meander loop formed by meltwater running off the surface of a glacier—the meander pattern is nature’s way of minimum uniformly distributed work.



Streamflow and Channel Form

- Streamflow governs channel and floodplain morphology
- Major floods do a lot of work, but are infrequent
- Low flows minimally influence channel and floodplain morphology

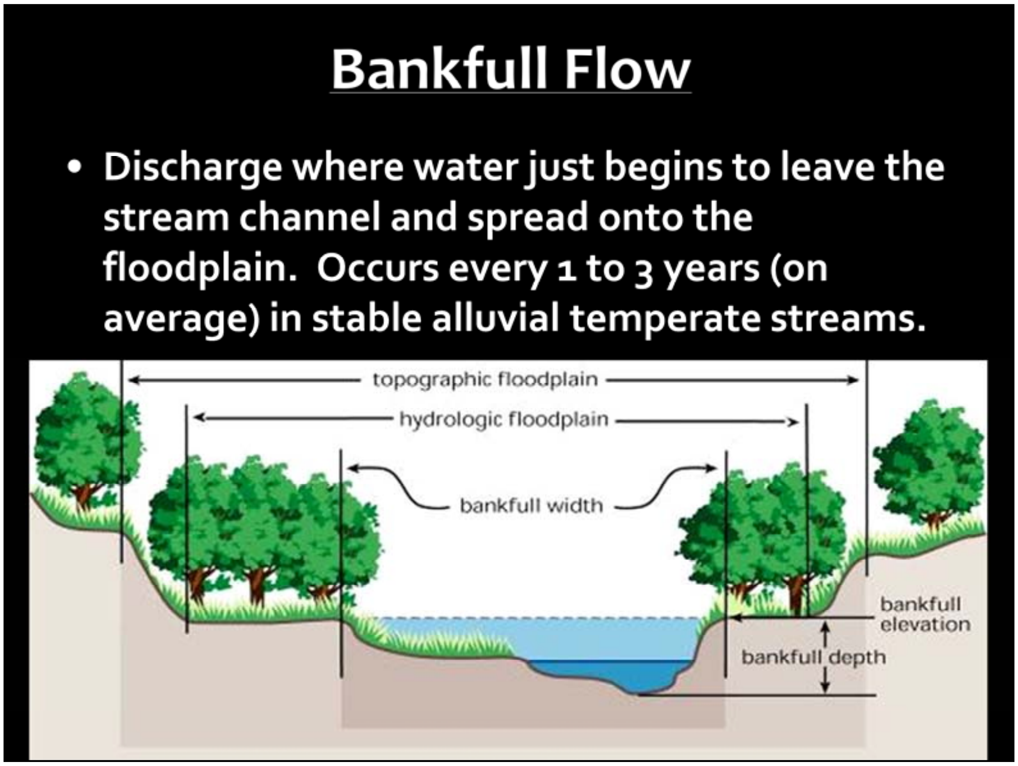
- SO—that leaves the flows in the middle!!!

Before talking more about meandering channel types, I should talk about the relationship between streamflow and channel form.

Major floods have the capacity to do a tremendous amount of work, but they occur infrequently and thus aren’t able to totally account for the morphology of rivers and floodplains over time.

On the flip side of the coin, low flows are the most frequent, but since they lack the competence to move large amounts of sediment, they don’t have much influence on channel and floodplain morphology.

So, that leaves something in the middle—medium flows that occur on a relatively frequent basis, lasting a few days or weeks every year or two.



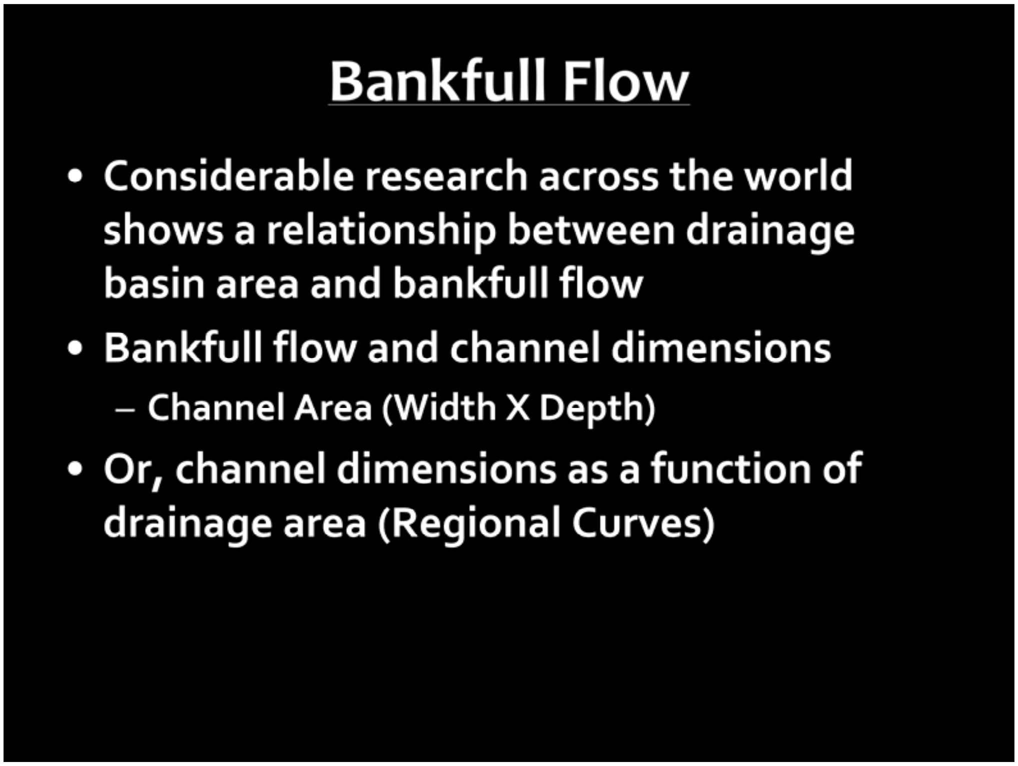
Bankfull Flow

- Discharge where water just begins to leave the stream channel and spread onto the floodplain. Occurs every 1 to 3 years (on average) in stable alluvial temperate streams.

The medium flow that has received the most attention and research in years past is known as bankfull flow—here defined as the discharge where water just begins to leave a stream channel and spread onto the floodplain.

Commonly, this discharge occurs every 1 to 3 years (on average) in stable alluvial temperate streams—however, bear in mind that variability exists with the return interval of bankfull flow.

Graphically, bankfull stage, or the level of water in the channel that coincides with a bankfull discharge, appears as the dotted line above the light blue band in the graphic shown.



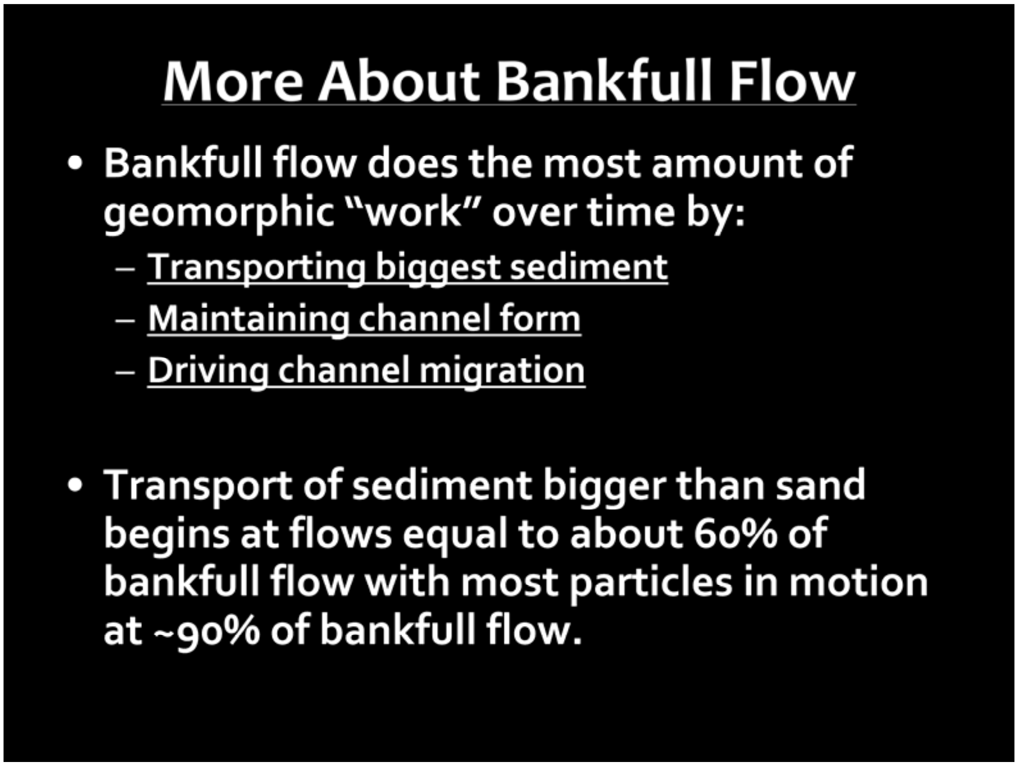
Bankfull Flow

- Considerable research across the world shows a relationship between drainage basin area and bankfull flow
- Bankfull flow and channel dimensions
  - Channel Area (Width X Depth)
- Or, channel dimensions as a function of drainage area (Regional Curves)

There’s been a bunch of research across the world in the last 50 years or so that details correlations between drainage basin area and bankfull flow.

In addition, there are numerous instances where channel dimensions, like width and depth (and thus channel area) are a function of bankfull flow.

These correlations allow folks to develop predictive relationships of channel dimension as a function of drainage area, also known as Regional Curves.



More About Bankfull Flow

- Bankfull flow does the most amount of geomorphic "work" over time by:
  - Transporting biggest sediment
  - Maintaining channel form
  - Driving channel migration

- Transport of sediment bigger than sand begins at flows equal to about 60% of bankfull flow with most particles in motion at ~90% of bankfull flow.

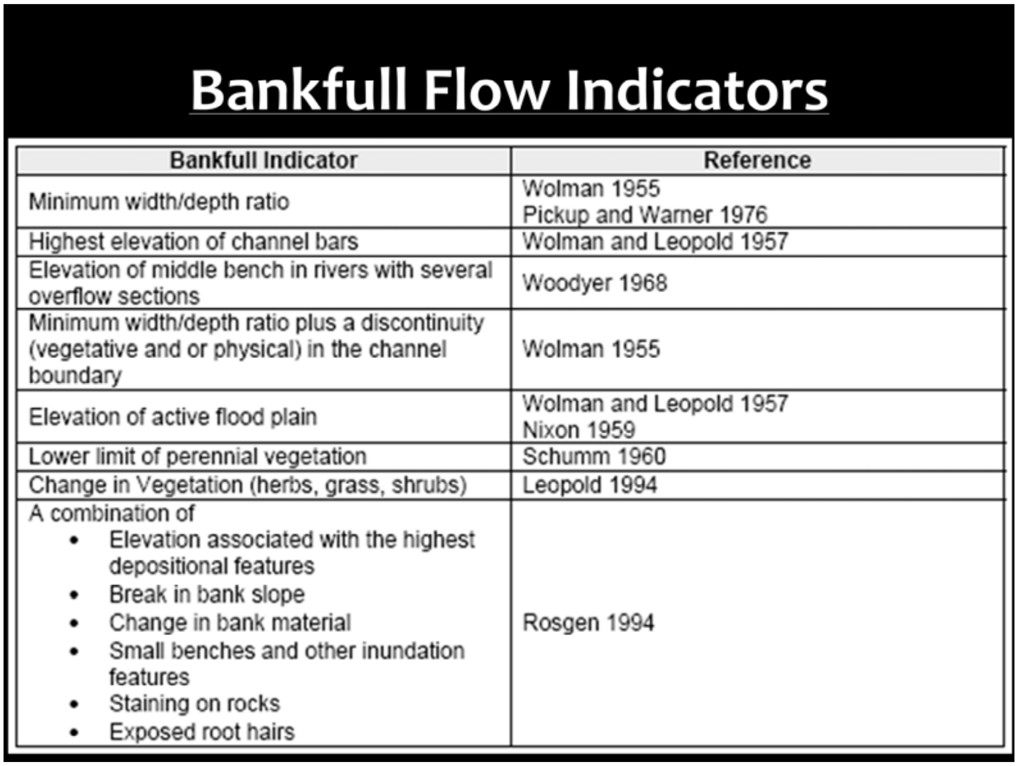
So, bankfull flow is one important driving factor behind the shape and appearance of a stream channel.

Over the long run, bankfull flow does the most geomorphic work by transporting bedload, maintaining channel form, and driving channel migration.

Bedload transport begins at flows equal to about 60% of bankfull flow with most particles in motion at ~90% of bankfull flow. If you see a channel flowing at bankfull, you can assume that most of the particles inside the channel boundary are experiencing some sort of movement.

Youngs Branch near Groveton, VA

Here’s a shot of Youngs Branch near Groveton, Virginia within a few inches of bankfull stage.



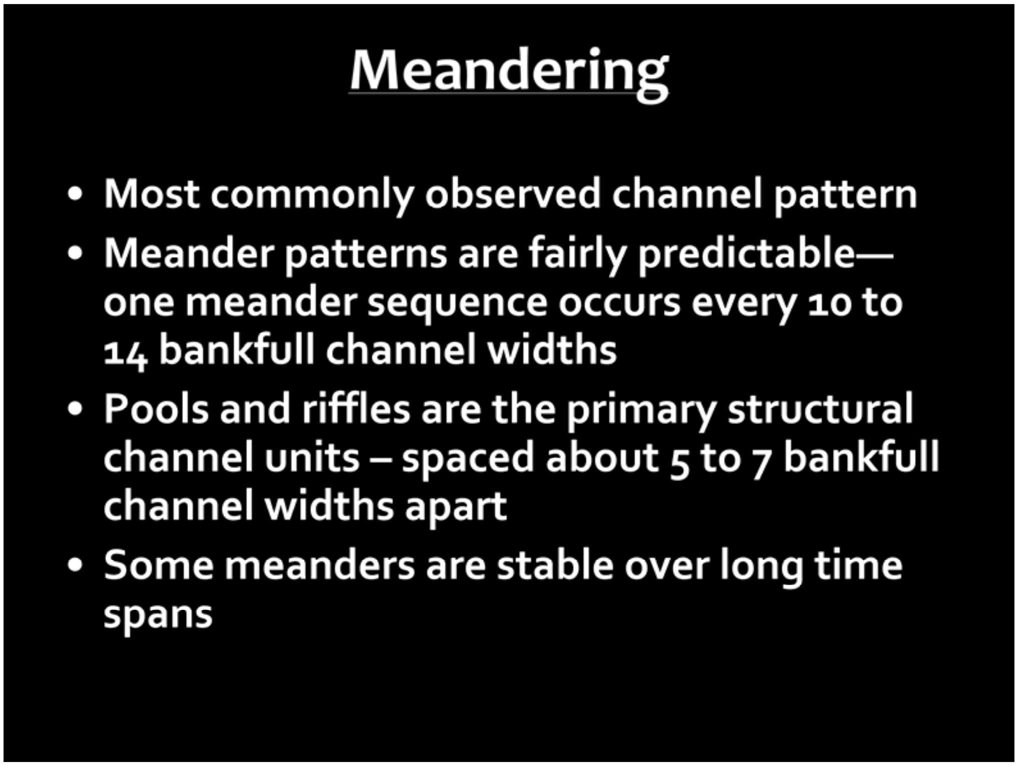
Bankfull Flow Indicators

Bankfull Indicator	Reference
Minimum width/depth ratio	Wolman 1955 Pickup and Warner 1976
Highest elevation of channel bars	Wolman and Leopold 1957
Elevation of middle bench in rivers with several overflow sections	Woodyer 1968
Minimum width/depth ratio plus a discontinuity (vegetative and or physical) in the channel boundary	Wolman 1955
Elevation of active flood plain	Wolman and Leopold 1957 Nixon 1959
Lower limit of perennial vegetation	Schumm 1960
Change in Vegetation (herbs, grass, shrubs)	Leopold 1994
A combination of • Elevation associated with the highest depositional features • Break in bank slope • Change in bank material • Small benches and other inundation features • Staining on rocks • Exposed root hairs	Rosgen 1994

Identifying bankfull in the field can be difficult, and is often the source of a fairly significant range of error. Although some river systems lend themselves to easier identification, others have been modified such that finding bankfull can be difficult. These are a few of the commonly used field indicators of bankfull flow.

Here's a cross section from a small stream in Surry County, North Carolina. The red lines indicate the channel cross section and an estimate of where bankfull stage would be found—its coincident with the top of the bar surface along the right-hand side of the picture.

But, there are quite a few streams out there where identifying bankfull stage can be difficult or entirely inappropriate given watershed condition and channel type.



Meandering

- Most commonly observed channel pattern
- Meander patterns are fairly predictable—one meander sequence occurs every 10 to 14 bankfull channel widths
- Pools and riffles are the primary structural channel units – spaced about 5 to 7 bankfull channel widths apart
- Some meanders are stable over long time spans

So, meandering rivers are the most common pattern in the world, and as I showed a few slides ago, the pattern exists in nature outside of riverine settings. In fact the pattern is so common that unless a scale is provided, the size of a river shown on an aerial photo can't really be accurately judged. Meandering rivers are most common at lower elevations where well developed soils blanket the topography and vegetative cover is dense.

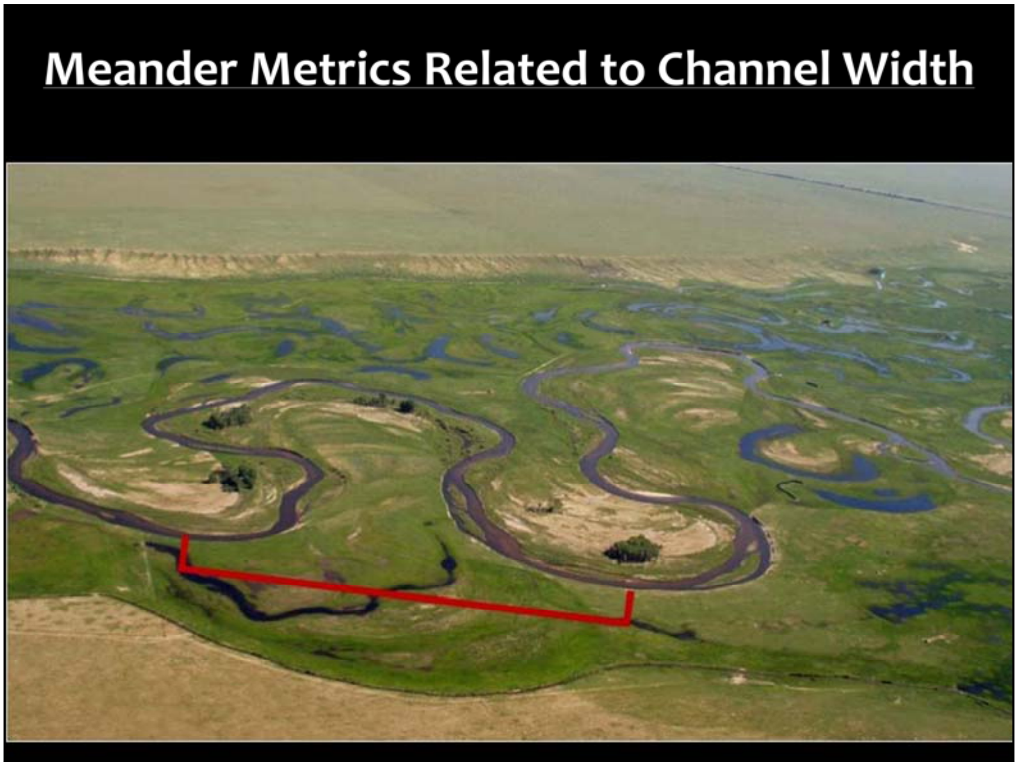
Meander patterns can be predictable—one complete sequence occurs about every 10 to 14 bankfull channel widths.

With a meander sequence, the primary structural channel units are pools and riffles, and they're spaced about every 5 to 7 bankfull channel widths.

Finally, meanders can persist over long time spans—well developed meander patterns carved into bedrock can be found all over the world.

Entrenched Meander

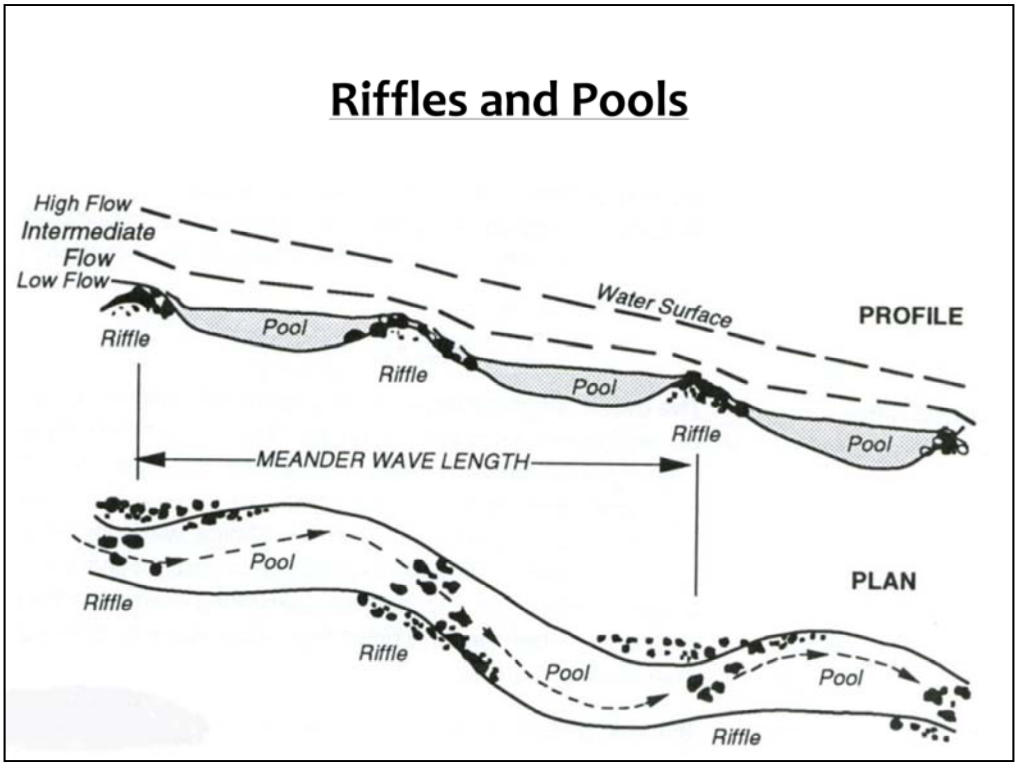
Here’s an example of a meander pattern that has remained stable over a long span of time. The meanders of the Colorado River have kept pace with the uplift of the Colorado Plateau—an ongoing process that started millions of years ago.



Meander Metrics Related to Channel Width

As I mentioned, the length of a full meander sequence or wavelength is related to bankfull channel width. This red line shows one meander wavelength, and the distance from end to end is equal to about 12 bankfull channel widths.

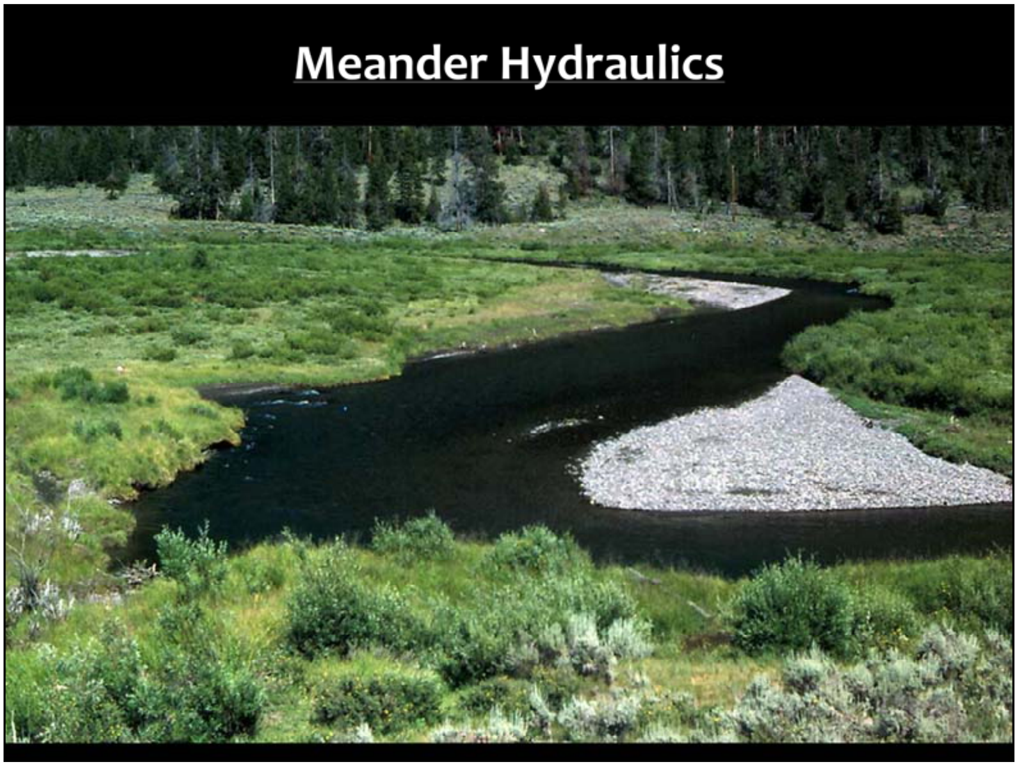
As you can see, the winding channel is longer than the straight line distance down the valley. This concept, which can be measured, describes the sinuosity or bendy-ness of the river. Higher sinuosity means the river is more bendy.



Riffles and Pools

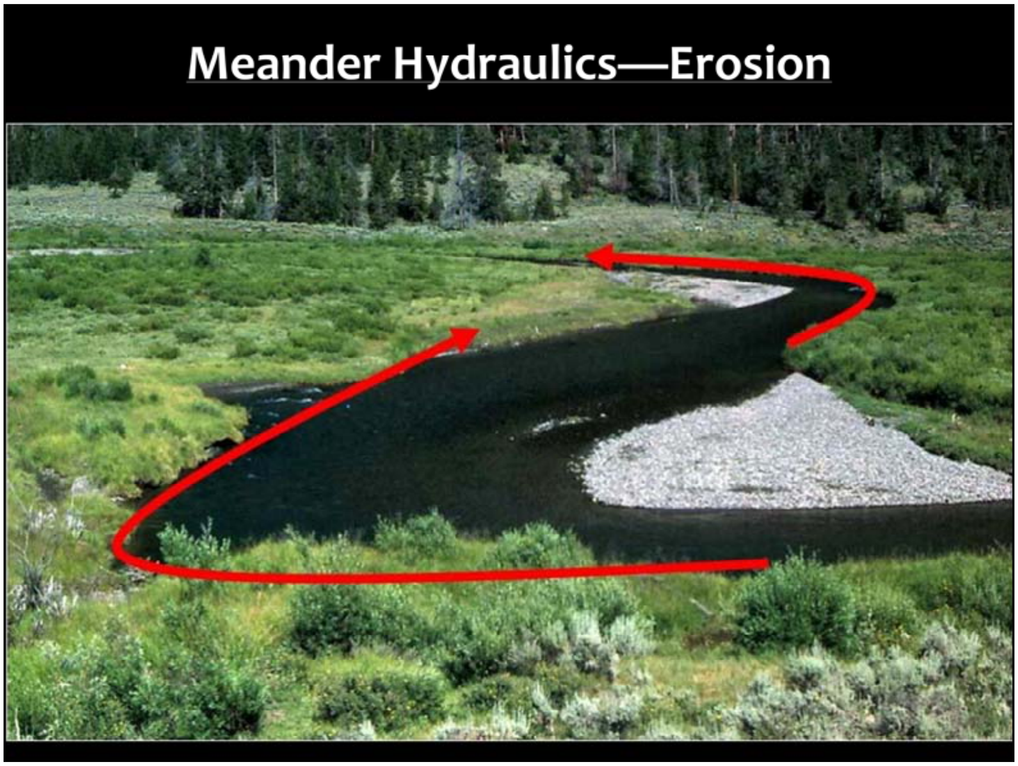
Within a meander wavelength, the primary structural elements are pools—which are low spots in the stream, and riffles, which are high spots. As I mentioned earlier, these units are often spaced from 5 to 7 bankfull channel widths apart.

So, if the bankfull width of a stream is 10 feet, the next riffle should be found between 50 and 70 feet downstream from the one you’re standing on.



Meander Hydraulics

Some interesting hydraulics operate in meanders that both maintain channel morphology and enable the channel to move across and down the floodplain over time.



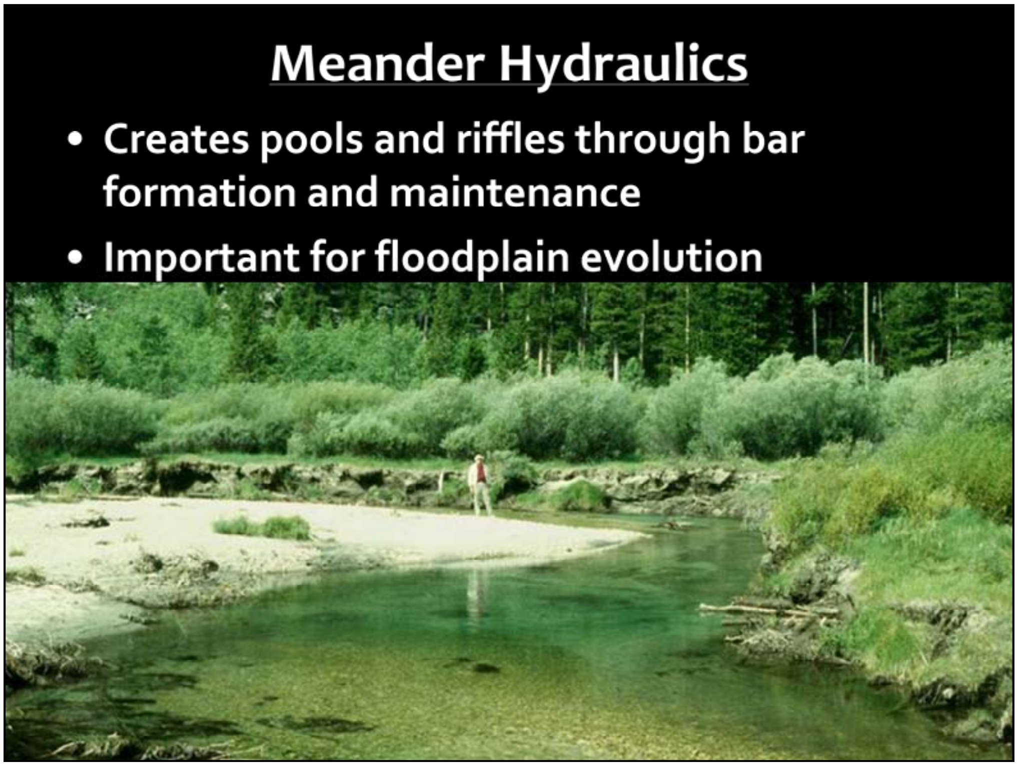
Meander Hydraulics—Erosion

Flow along the outside margin of a meander bend—shown here in red—excavates the outer bank and moves material downstream. When water flows into the bend, it generates a corkscrew-like motion known as helical flow that rotates from the channel bed upward toward the streambank. This gives the river a lot of scour or erosion ability to move the bank over time.

If you’ve ever noticed a “trash line” of foam or debris flowing away from but parallel to the bank along a meander bend, you have witnessed the effect of helical flow.

Meander Hydraulics—Deposition

Material eroded from the outside of a meander bend is dumped in a process known as deposition along the inside edge of downstream meanders. These depositional features are known as point bars.



Meander Hydraulics

- Creates pools and riffles through bar formation and maintenance
- Important for floodplain evolution

The scour and fill action of meanders creates pools and riffles as bends are scoured and bars are deposited.

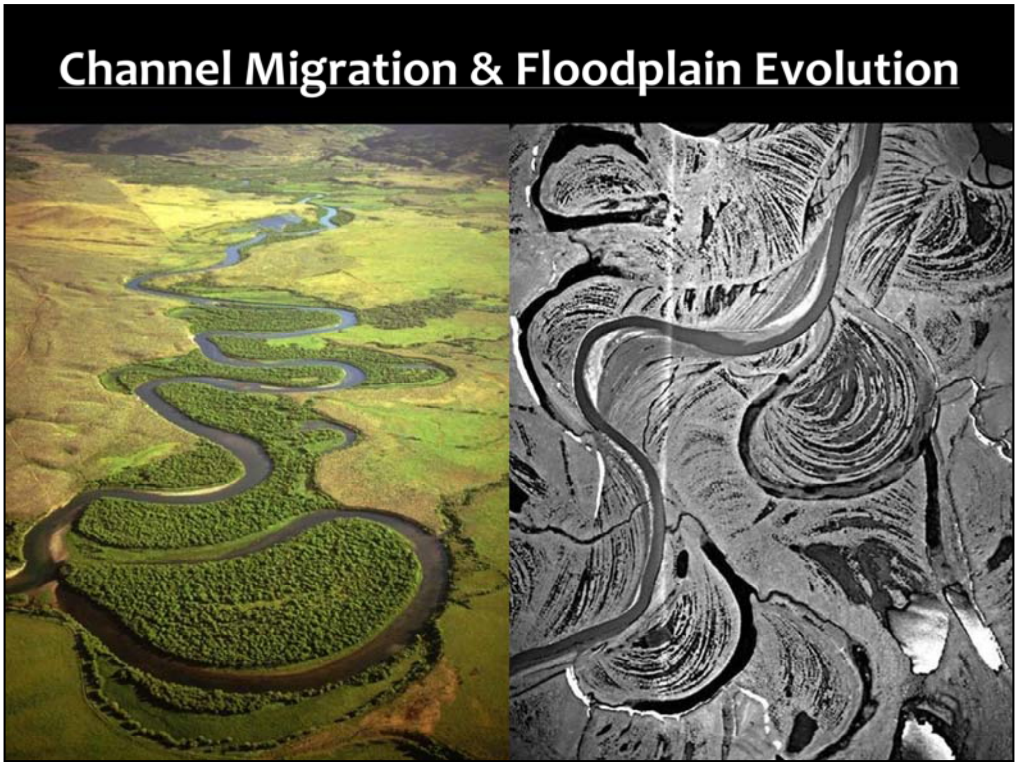
The migration of meanders by scour and fill drives floodplain evolution. Exposed bars are colonization sites for riparian vegetation.

Channel Migration & Floodplain Evolution

Here’s an example of channel migration and floodplain evolution, moving from right to left, along the Bow River in Alberta, Canada.

The tip of the point bar along the left margin of the photo is relatively barren, but as you move up onto the floodplain you begin to see at least 4 different age classes of cottonwood trees.

Aging these trees would enable you to determine the relative age of the point bar as well as channel migration rates.

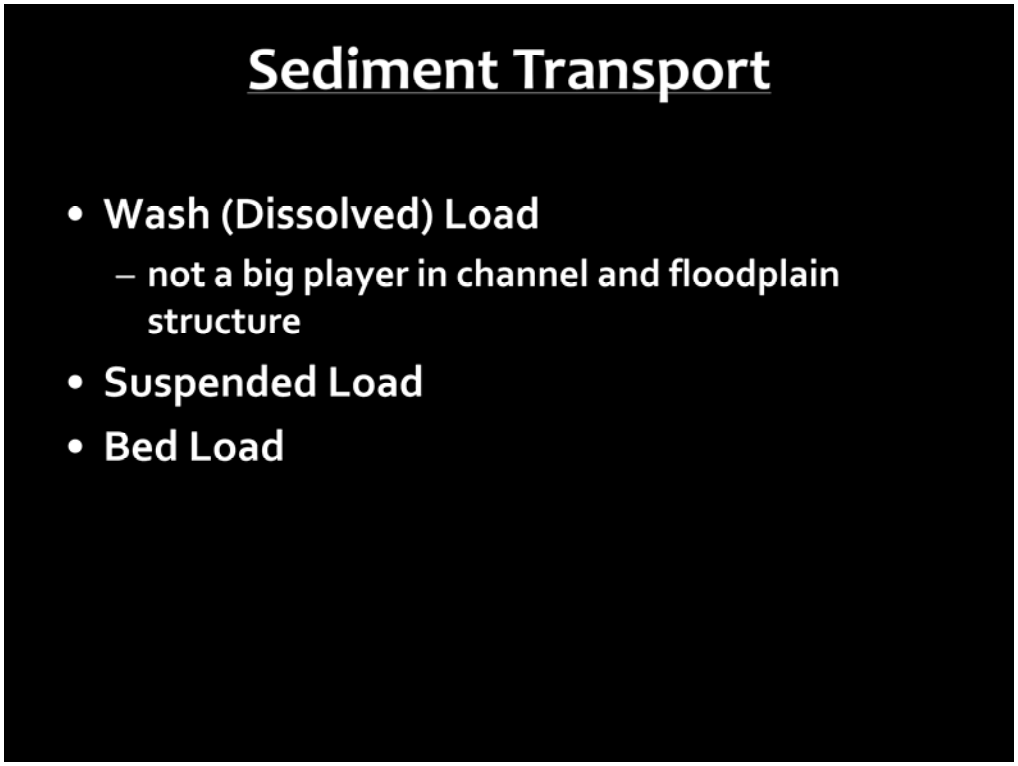


Channel Migration & Floodplain Evolution

Over time, meanders move across a floodplain, leaving scars where former main channel positions have been closed off. Floodplain features like meander scars and oxbow lakes help you identify the lateral extent of the active floodplain. A river cannot meander outside of its active floodplain without significant changes in streamflow, basin slope, or sediment supply.

Sediment Transport

Ok, now I’ll cover a few fundamental concepts of sediment transport, or how sediment moves in river channels. As I mentioned earlier, sediment generally includes a range of materials from very small to very large, like a boulder.



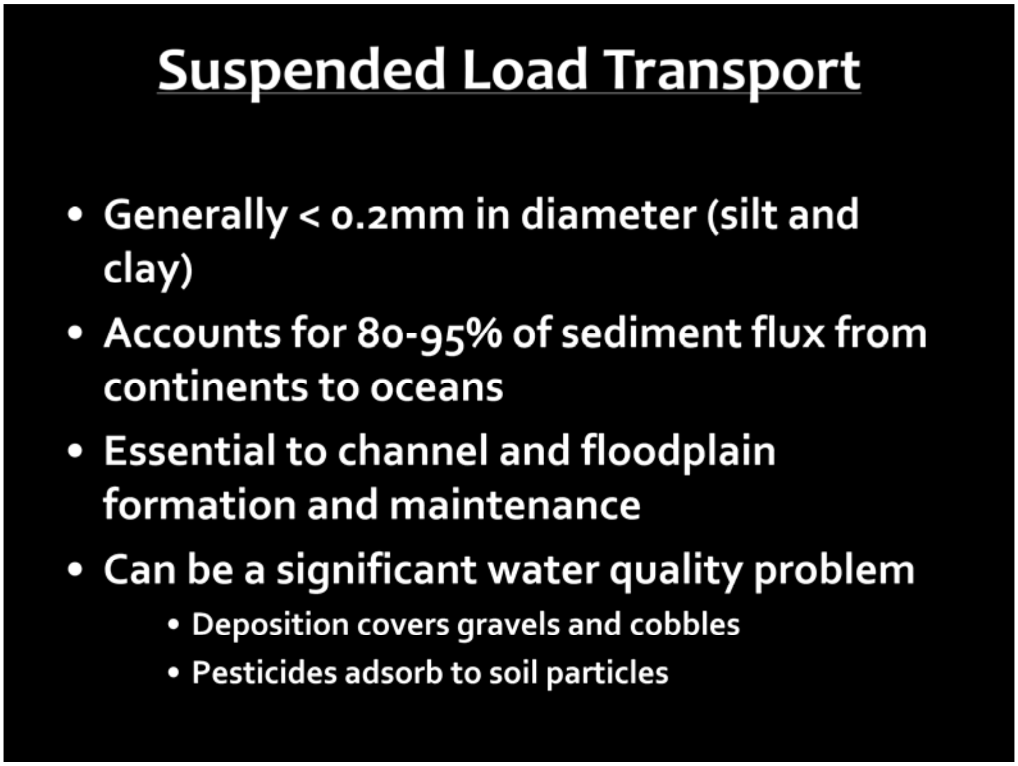
Sediment Transport

- Wash (Dissolved) Load
  - not a big player in channel and floodplain structure
- Suspended Load
- Bed Load

Sediment transport mechanisms are commonly broken into 3 categories related to the size of the material in transport—Wash, Suspended, and Bed load.

Wash load, also known as dissolved load, isn’t a big player in the morphology of channels and floodplains.

However, suspended load and bed load are building blocks in stream channels and floodplains.



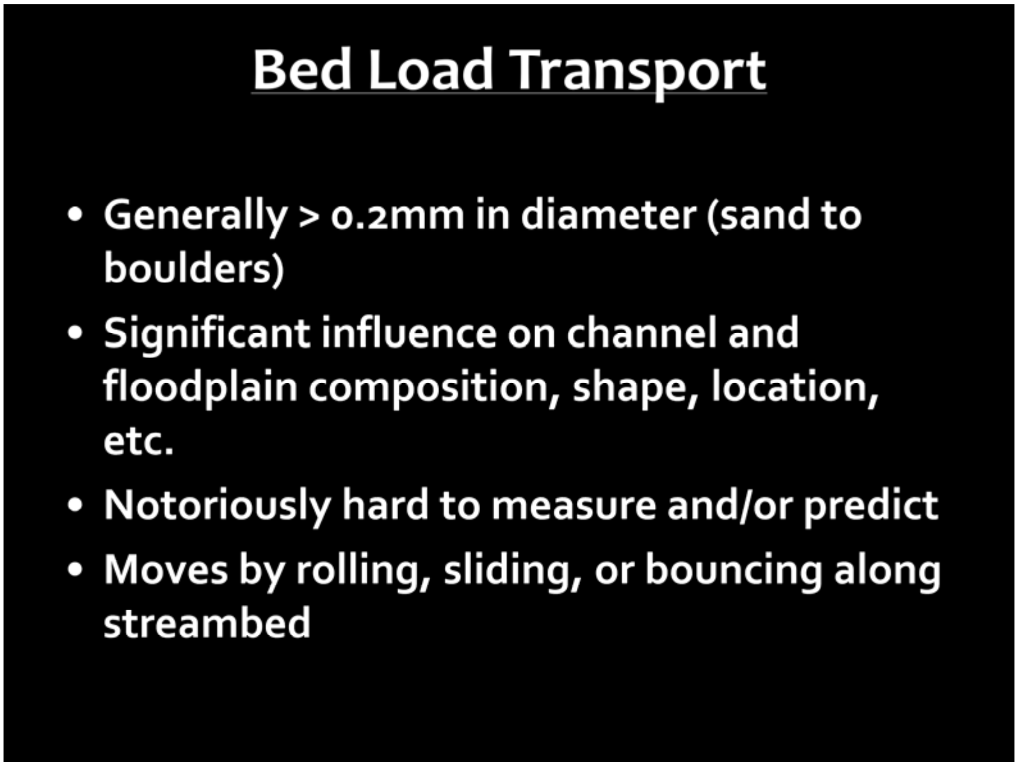
Suspended Load Transport

- Generally < 0.2mm in diameter (silt and clay)
- Accounts for 80-95% of sediment flux from continents to oceans
- Essential to channel and floodplain formation and maintenance
- Can be a significant water quality problem
  - Deposition covers gravels and cobbles
  - Pesticides adsorb to soil particles

Suspended load is mostly composed of silts and clays transported aloft in the water column by turbulence (hence the name).

It’s the largest component of the total material transported by a river or stream, and is said to be supply limited—the amount transported is limited by the supply on hand.

It plays a big part in channel and floodplain maintenance, and can be a significant water quality problem if stream is out of balance or land use introduces a bunch of fine sediment to a system.



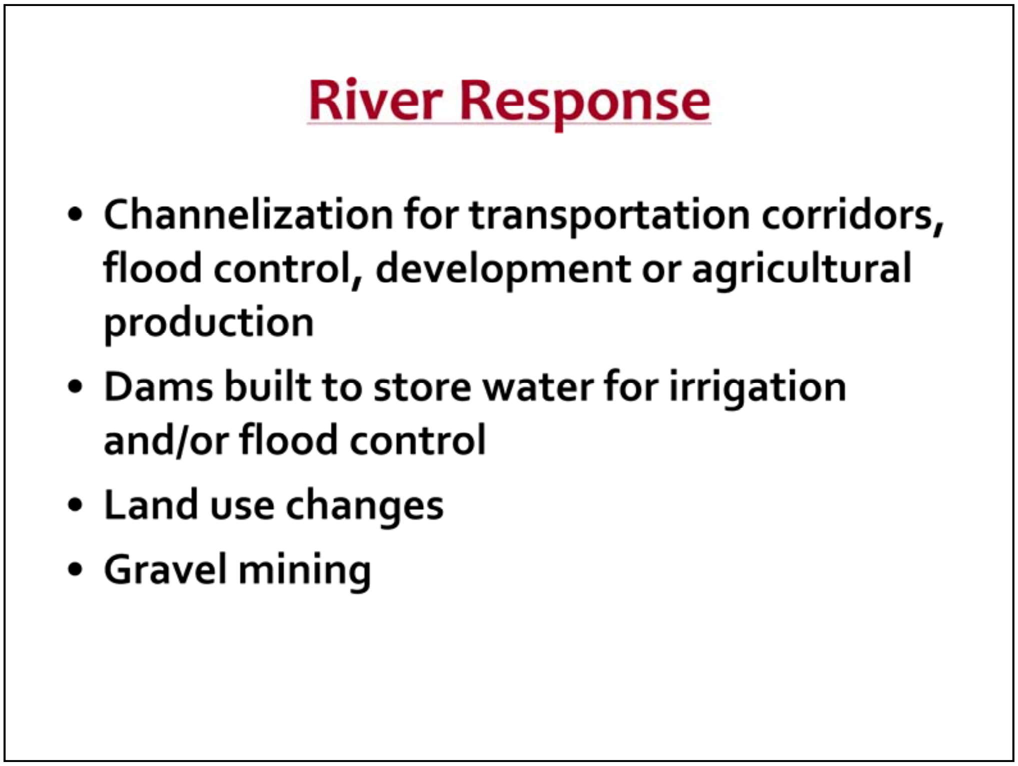
Bed Load Transport

- Generally > 0.2mm in diameter (sand to boulders)
- Significant influence on channel and floodplain composition, shape, location, etc.
- Notoriously hard to measure and/or predict
- Moves by rolling, sliding, or bouncing along streambed

Bed load, which encompasses everything from sand up to large boulders, has a strong influence on the morphology of a river.

Bed load moves in a layer immediately above the bed of a river by sliding, rolling, or bouncing along. Measuring and predicting bedload transport is notoriously hard and error-prone. One of the problems with bedload is that it moves in irregular waves or bursts that don't lend themselves easily to measurement or prediction.

Bed load is transport limited, meaning that it can only be moved when flows get high enough.



River Response

- Channelization for transportation corridors, flood control, development or agricultural production
- Dams built to store water for irrigation and/or flood control
- Land use changes
- Gravel mining

So, combining all of these concepts allows us to evaluate or describe what happens when changes are made to the water, sediment, and large wood regime of rivers. Most rivers across working lands have been modified in one way or another, and responses to these modifications is whole nother talk.

However, in the last part of our time today, I’d like to cover two of these cases—channelization and the effects of dams.

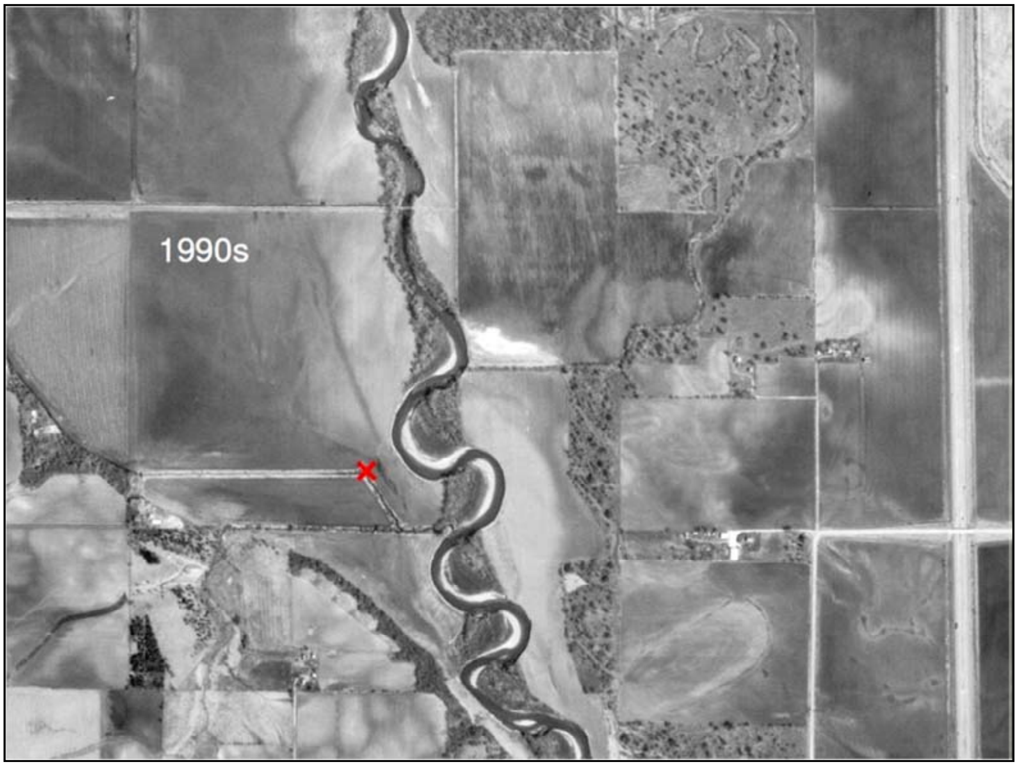
Channelization

Walla Walla River, 1964

Rivers are often realigned and placed into engineered channels in an attempt to protect adjacent land uses from flooding. Here, the Walla Walla River was placed between levees in 1963 to protect orchards and other high-value crops. However, a big flood in 1964 breached the levees, and the river assumed a fairly obvious meander pattern as it migrated beyond its constructed channel margins.

Other changes can be less dramatic, but end up looking the same over time. Many stream channels were realigned and straightened in an effort to control drainage and maximize farmable acreage. Here’s an example of a reach of stream channelized some time in the 1930s. The red X serves as a registration point to anchor your eye through the next few slides.

Some 40 years later, in the absence of continued manipulation, the channel has changed quite a bit. You can see that it has assumed a meandering pattern, the light, unvegetated bands adjacent to the meander bends are point bars, and we're starting to see some streamside vegetation.



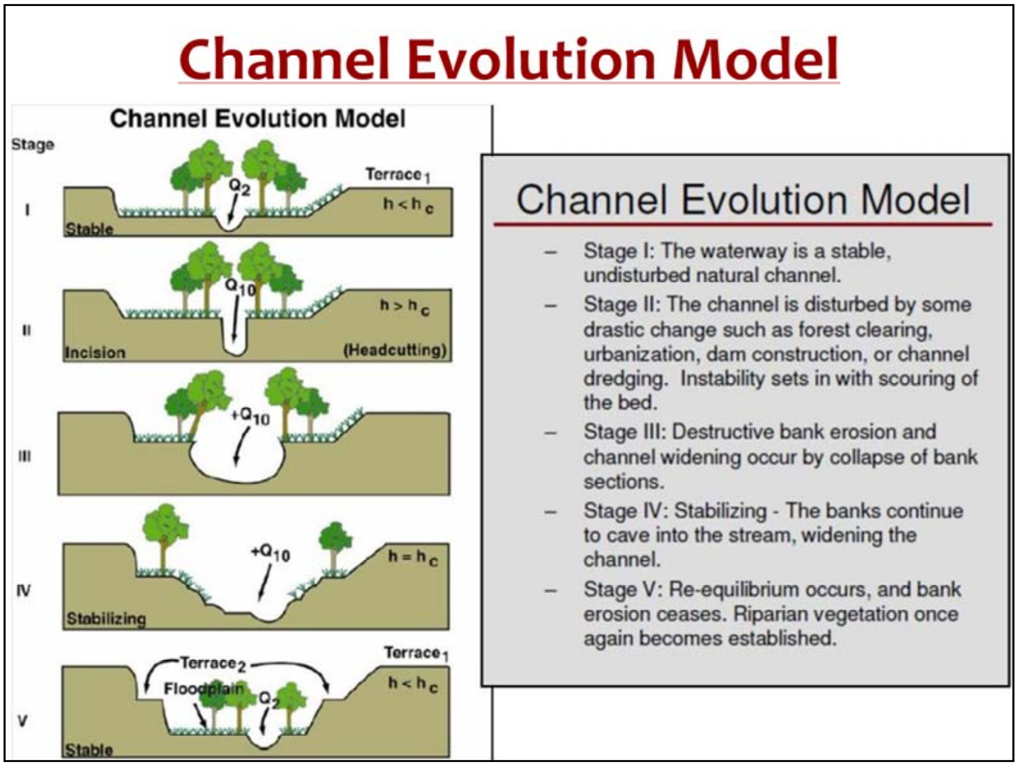
Jumping ahead another 20 years, the channel has expanded its meander pattern, point bars are more extensive, and streamside vegetation continues to increase.

By 2002, we see what appears to be a vegetated buffer, the meanders are more strongly pronounced, and streamside trees are more prevalent. There even appears to be a channel shift near the bottom of the photo on the opposite side of the floodplain from our red X.

And here is a shot from 2007, this time in color. Not a lot of difference between this and the 2002 picture, except that the meander loops have extended and moved downvalley a bit and the riparian corridor appears more continuous.

So, over the almost 80 years represented by this sequence of aerial photos, the stream has changed dramatically from its channelized condition in the thirties to the meandering system bracketed by a decent riparian corridor in 2007.

This same sequence of events can be found in hundreds—maybe thousands—of stream miles across the Eastern and Midwestern United States.



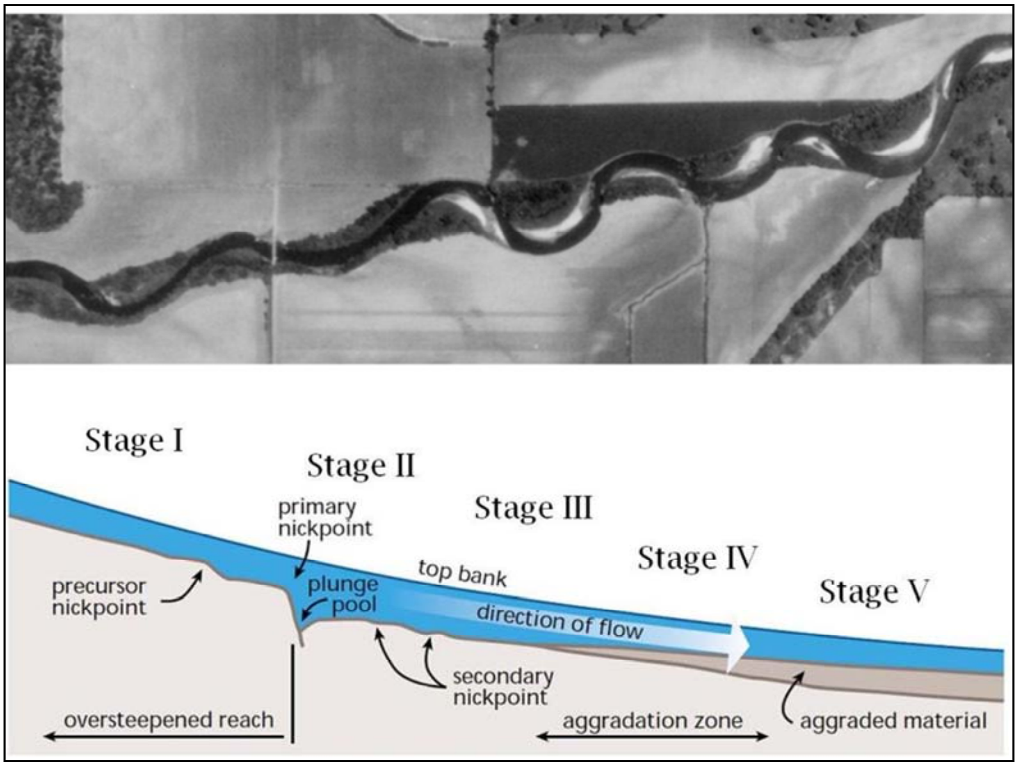
Channel Evolution Model

Channel Evolution Model

- Stage I: The waterway is a stable, undisturbed natural channel.
- Stage II: The channel is disturbed by some drastic change such as forest clearing, urbanization, dam construction, or channel dredging. Instability sets in with scouring of the bed.
- Stage III: Destructive bank erosion and channel widening occur by collapse of bank sections.
- Stage IV: Stabilizing - The banks continue to cave into the stream, widening the channel.
- Stage V: Re-equilibrium occurs, and bank erosion ceases. Riparian vegetation once again becomes established.

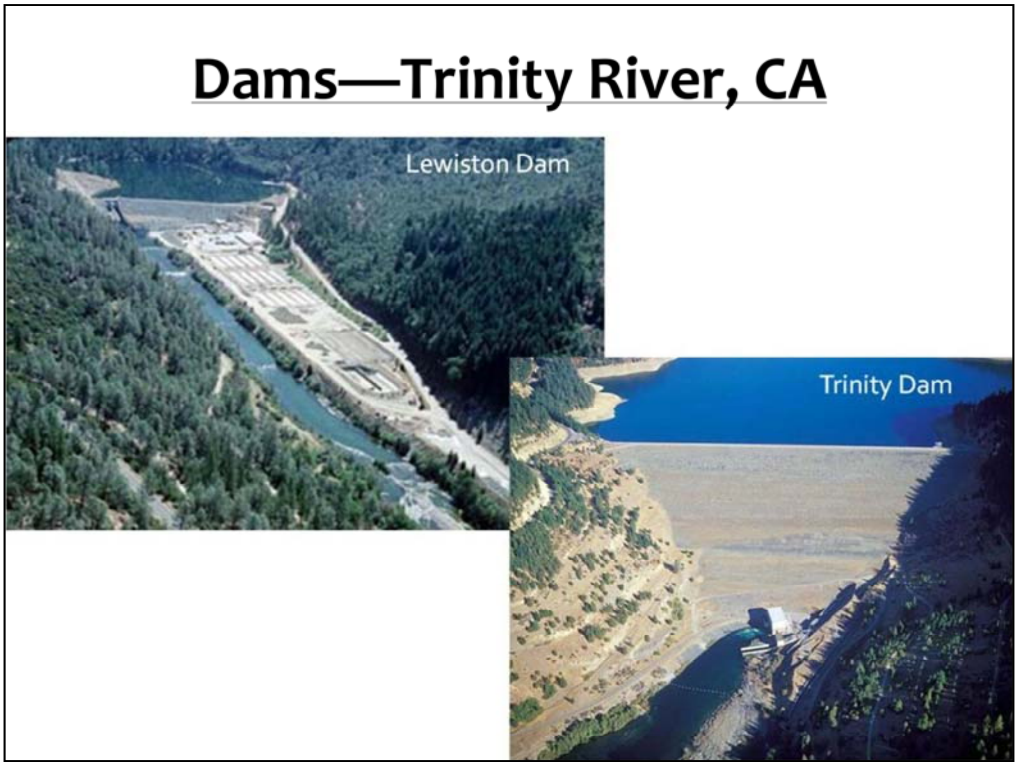
I like to use the preceding slides because they illustrate an important tool in fluvial geomorphology—the Channel Evolution Model originally developed by Schumm, Harvey, and Watson, first published in 1984.

In short, the model describes a sequence of 5 relatively predictable stages in the recovery of a channel from major disturbances like forest clearing, urbanization, dam construction, or channelization. The end stage—or point where the channel reaches equilibrium—results in a mini-me channel with a smaller floodplain that is inset into terraces comprised of the pre-disturbance floodplain.



The model accounts for many of the processes in fluvial geomorphology that I've covered today. Channel pattern and slope changes, the development of bars and structural units like pools and riffles, revegetation, and changes in sediment size and composition along the channel as it attempts to balance itself are all accounted for by the model.

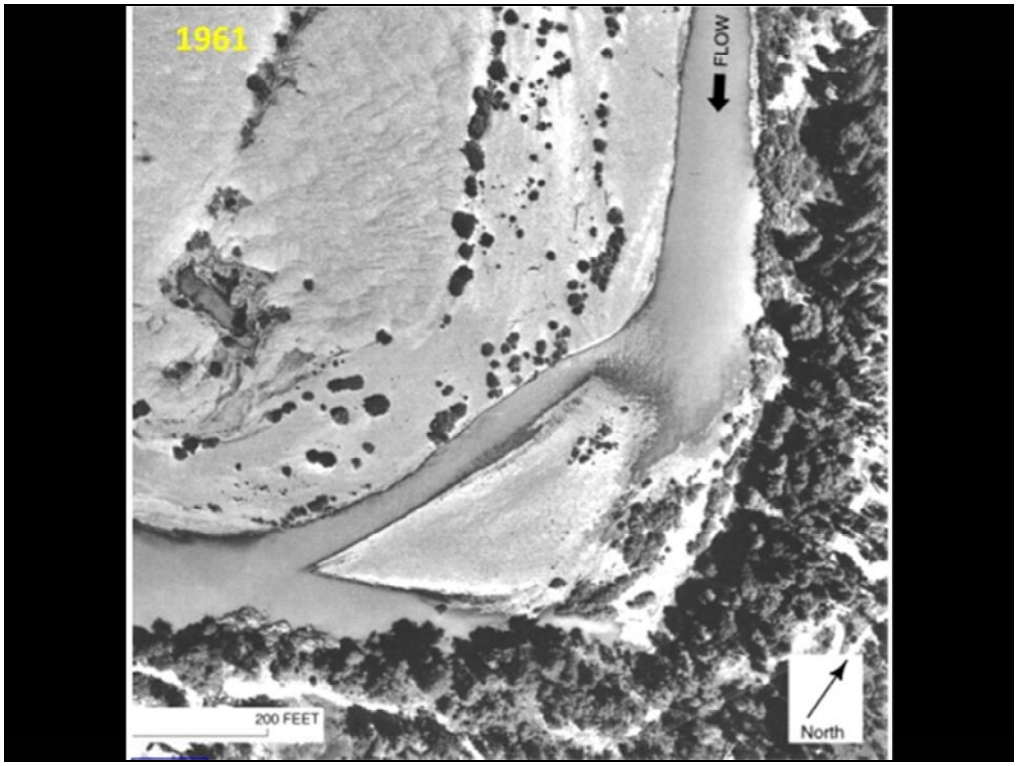
Further, when applied to a channel that hasn't reached equilibrium, the Channel Evolution Model provides a sort of road map for future changes that will likely occur over time once you've figured out what stage of recovery the channel you're looking at is in.



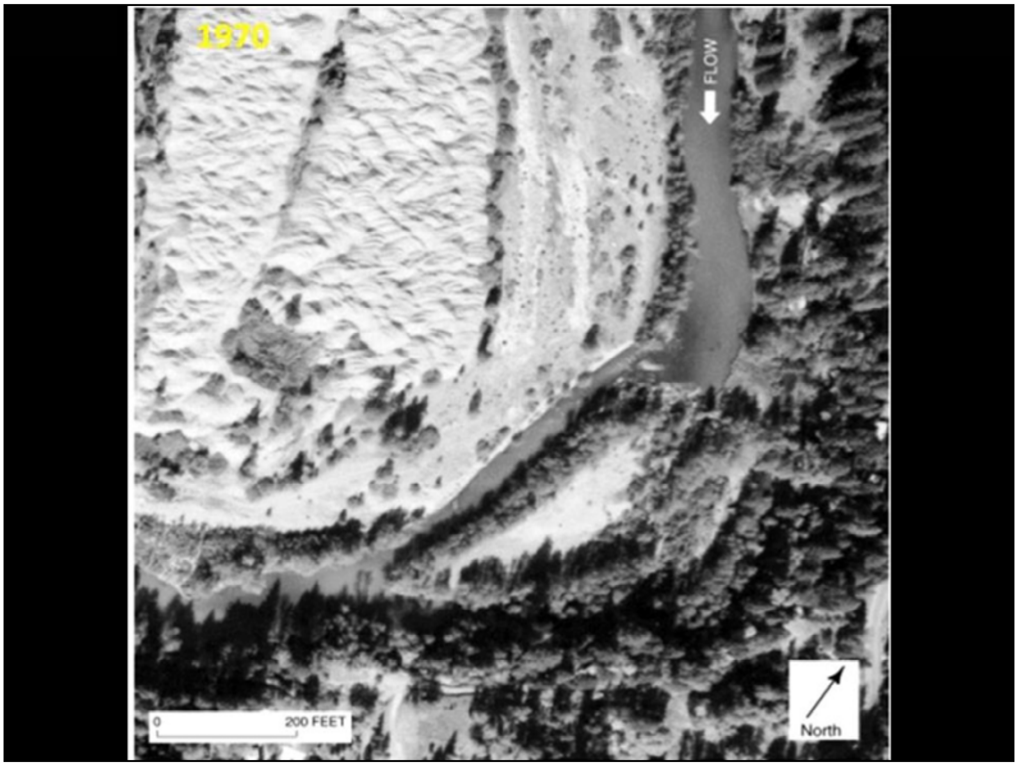
Dams—Trinity River, CA

As you might imagine, dams have a strong effect on rivers both upstream and downstream of the dam itself. Here's a well-studied example from the west coast.

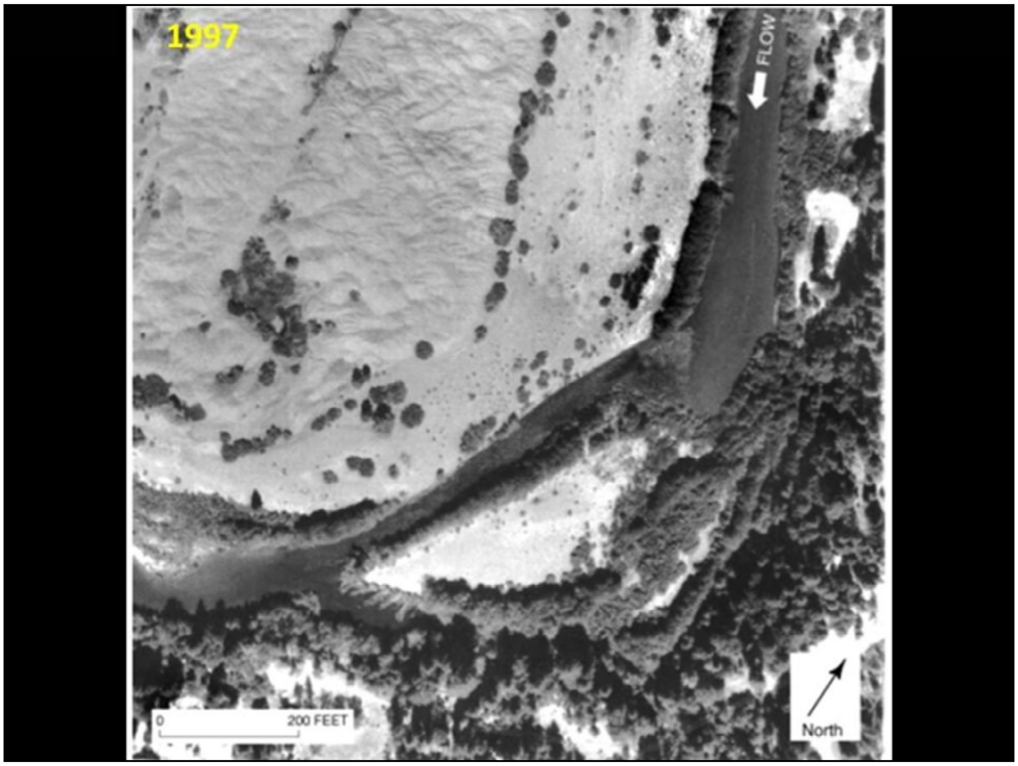
Trinity and Lewiston Dams were built on the Trinity River in California, and were finished between 1962 and 1963. Each of these two facilities provides storage for irrigated agriculture and produces hydropower.



Downstream of the two dams, the Trinity River at a place known as Gold Bar looked like this in 1961, prior to the closing of the dams. Notice the relative width of the channel, and the presence of an island in the middle of the river.

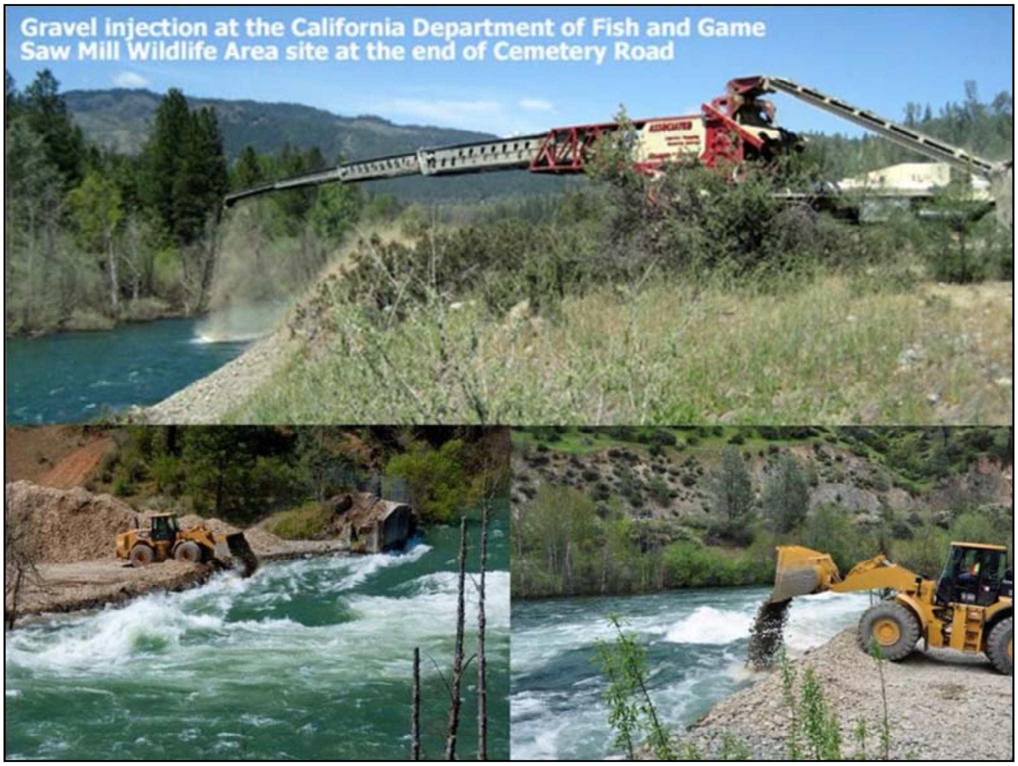


Here is the same location seen in 1970, about 7 years after the dams were closed. Since the dams both decreased streamflow to this reach and captured all the sediment that once supplied this part of the river, you can see that the channel width has decreased, and vegetation has started to encroach and narrow the channel. The margins of the island are covered by vegetation, and the channel of the river along the left side of the island—towards the lower right of the photo—is barely visible.



Here is the same location, shown in 1997. Streamside vegetation has increased in age and structure, and the channel flowing along the left side of the island has been closed off. The remaining main channel has become narrower and deeper than the pre-dam condition.

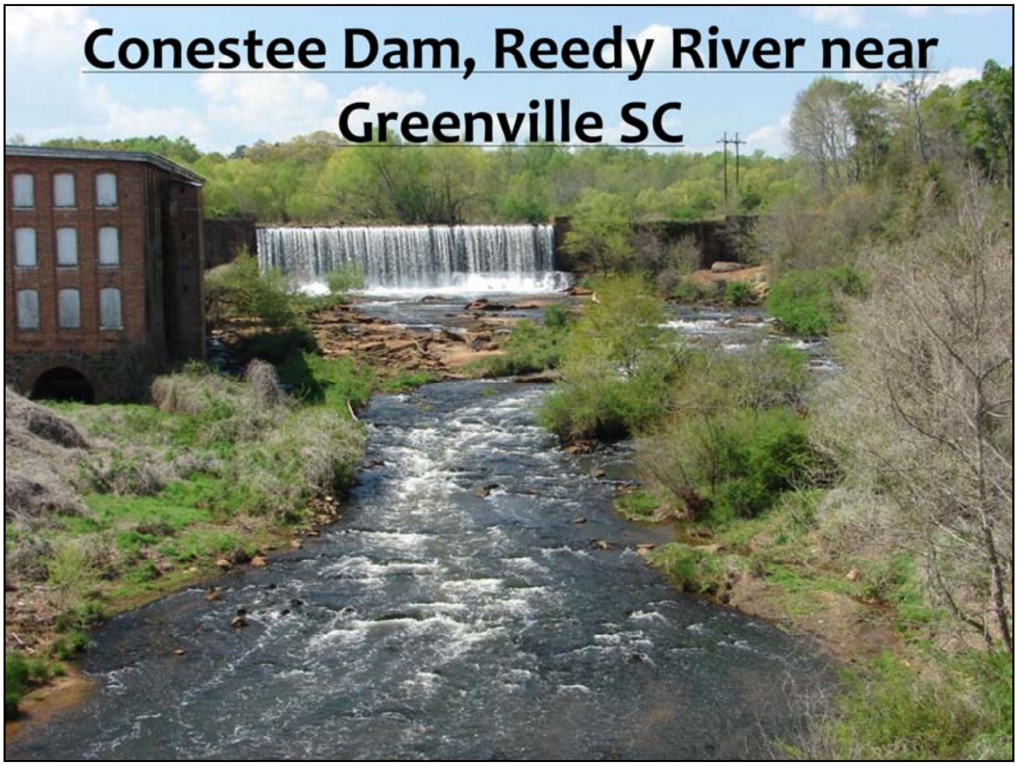
The river's response to damming shown at this specific location can also be seen for miles downstream.



Trinity and Lewiston dams trap most of the sediment that once supplied the channel, and their operations and resulting outflows generally scour smaller material from downstream channel reaches. The main channel became simplified and floored with larger sediments that no longer move frequently under the new flow regime of the river.

Although operational changes to the dams in the late ‘90s helped restore some of the geomorphic forces that maintained the channel, there is still a profound lack of diversity and habitat. So, a combined effort of state, federal and tribal entities is working to inject gravel back into the channel in an effort to replenish channel structure and provide better spawning habitat for native fish.

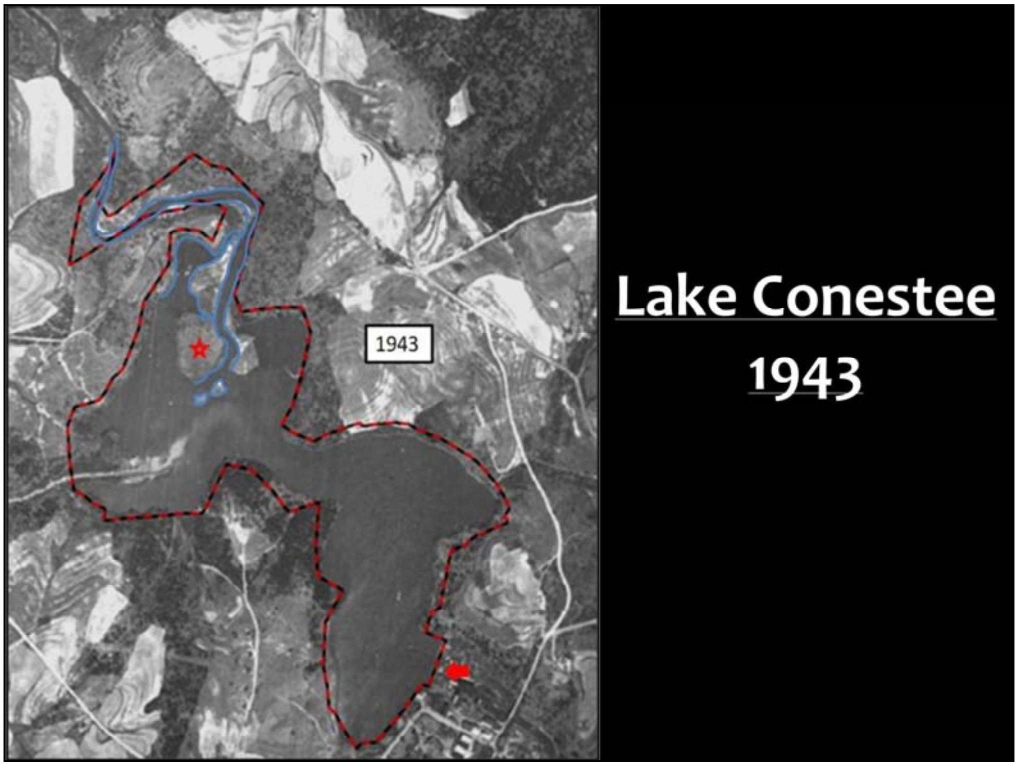
Ongoing studies are attempting to quantify the effects of gravel injection on the morphology and function of the Trinity River.



Conestee Dam, Reedy River near Greenville SC

Ok, my final example for the day looks at what can happen upstream of a dam, and incorporates the concepts of base level change, urbanization, increased sediment production, and the role of riparian vegetation in channel stabilization.

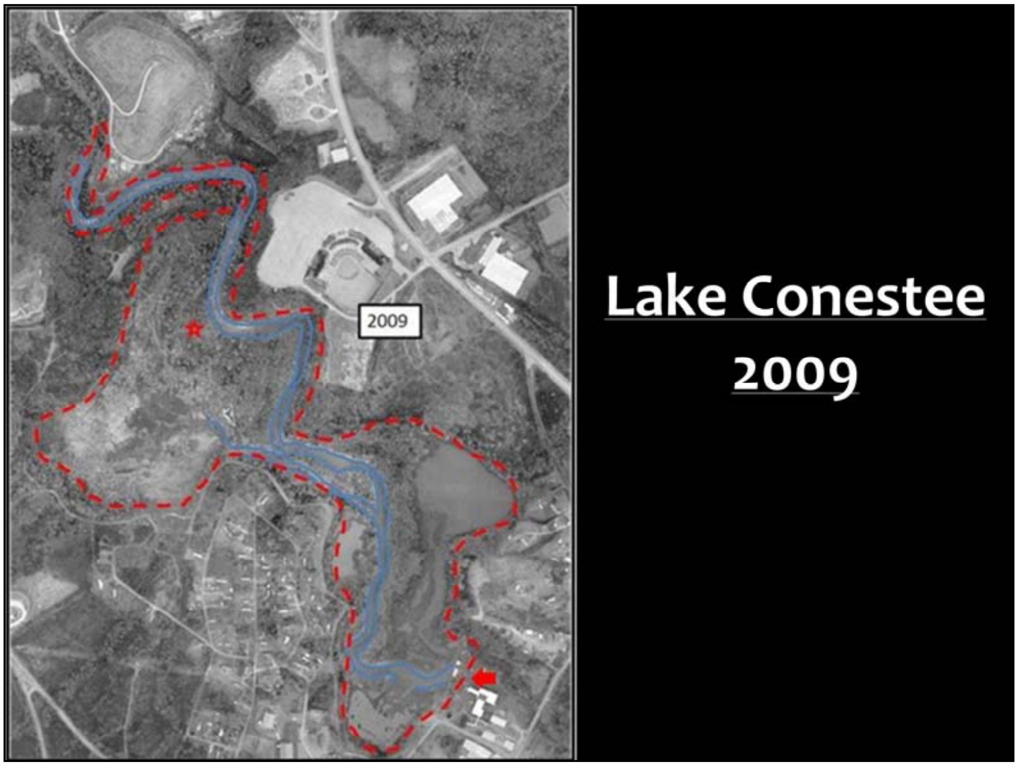
Conestee Dam on the Reedy River near Greenville South Carolina was finished to its present-day form in 1892. It was built atop a bedrock outcrop in the River, but increased the height or base level of that geological control by about 28 feet. The dam formed Lake Conestee, about 6 miles south of downtown Greenville.



Lake Conestee

1943

Here is how Lake Conestee looked in 1943. The dam is shown by the red arrow near the lower right of the photograph, and a red star indicates the location of a feature known as Taylor's Island. The red and black dashed line indicates the perimeter of the lake at the time the dam was built. As you can see, the channel of the Reedy River, indicated by the blue lines, has already started to reclaim the former lake.



Lake Conestee

2009

Here’s an aerial of the lake from 2009. The location of Taylor’s Island, perimeter of the lake, and location of the dam are noted using the red star, dashed line, and arrow, respectively.

Lake Conestee has almost completely filled with sediment, and areas of formerly open water more than 20 feet deep are occupied by a river channel and vegetated floodplain.

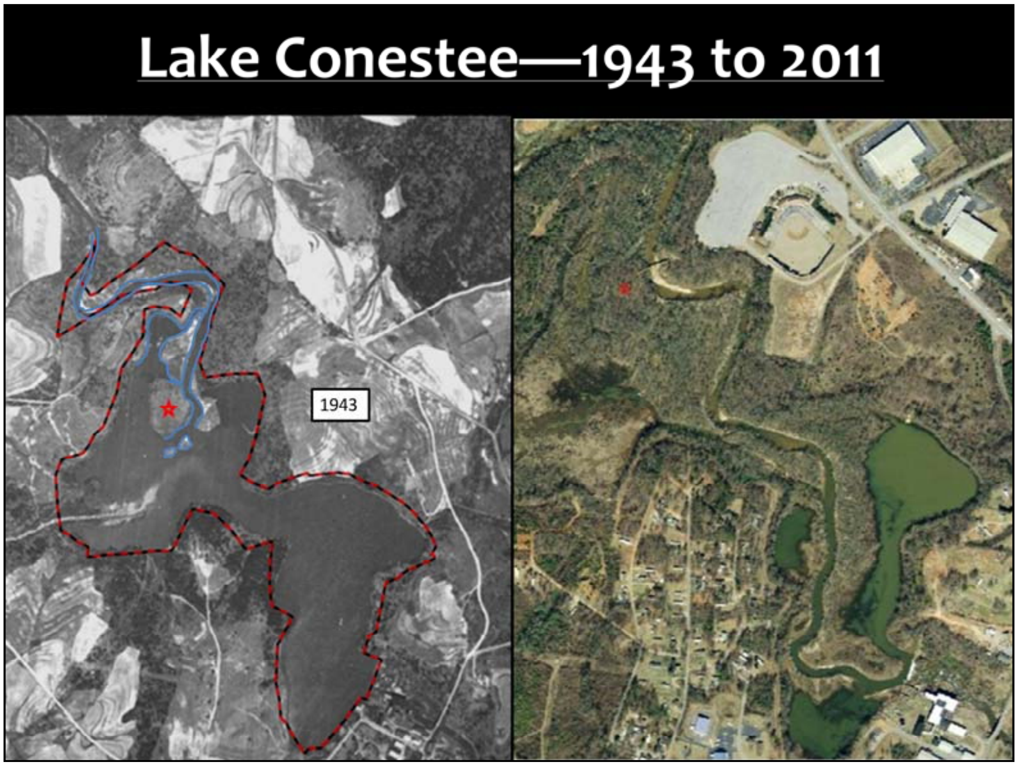
Lake Conestee

2011

And finally, a shot from 2011. The dam imparted an increase in the base level of the Reedy River in this reach of about 28 feet. As the Greenville area developed, changes in land cover contributed sediment to the river that could not be passed by the dam because of base level rise.

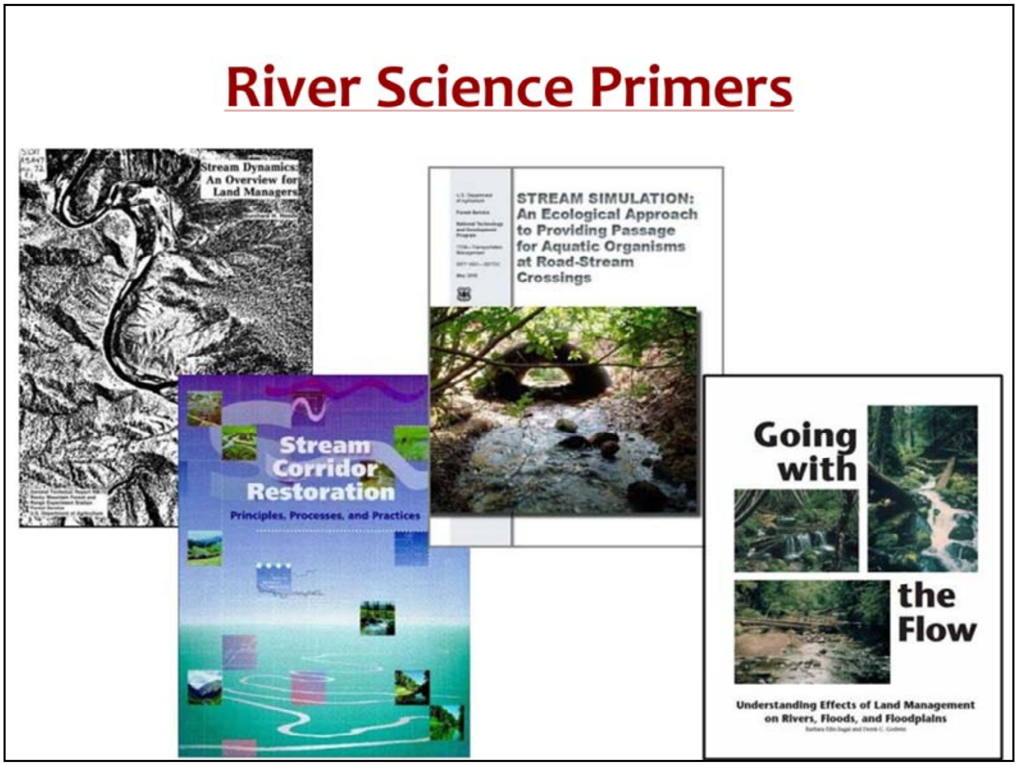
The dam created a big flat spot in the river that extended for quite a way upstream, and this slope reduction equated to a reduction in sediment transport capacity that resulted in deposition. If you look at a time series of aerial photos of the area, the site looks much like the delta of a large river emptying into the ocean. As this delta created new geomorphic surfaces, vegetation became established, defended the floodplain from erosion, and a meandering channel developed.

As you can see at the lower right of the photo, the new channel now ends only a few feet from the crest of the dam.



Lake Conestee—1943 to 2011

This is a really interesting site—the destruction of a lake and creation of a river channel in less than 100 years… Sometimes things happen fast along rivers.



River Science Primers

So, much of this information can be found all over the internet, in numerous textbooks, and thousands of journal articles.

But, I think there are a few resources out there that provide short primers on most of what I've covered today, and here are some suggestions for further reading. I think they're good because they're relatively short and written without too much technical gobbledy-gook.

The first is called "Stream Dynamics: An overview for land managers" , written by a distinguished Forest Service Hydrologist named Burchard Heede.

Next, I'd recommend Chapter 7 in the Big Blue Book—NEH-653.

I'd also recommend appendix A of the Stream Simulation culvert guide I've spoken of in other webinars. Although the guide is focused on culverts, appendix A is a great overview of stream geomorphology.

And finally, I recommend "Going with the Flow: Understanding effects of land management on rivers, floods, and floodplains". This was a cooperative effort between Oregon State University and Oregon Sea Grant written for land managers.

End

Urban and Channelized Streams: Working in highly modified environments to enhance stream function and habitat quality

January, 2013

United States Department of Agriculture
Natural Resources Conservation Service

USDA NRCS

That’s it for today. You’ve sat through a lot of material, and I really appreciate your time and attention.

Before I turn this over to Holli, I’d like to mention another webinar slated for the end of January, 2013. The working title is “Urban and Channelized Streams: Working in highly modified environments to enhance stream function and habitat quality”.

With that, I’ll now turn this back over to Holli, and would be pleased to hear any questions or comments you have regarding today’s Webinar...