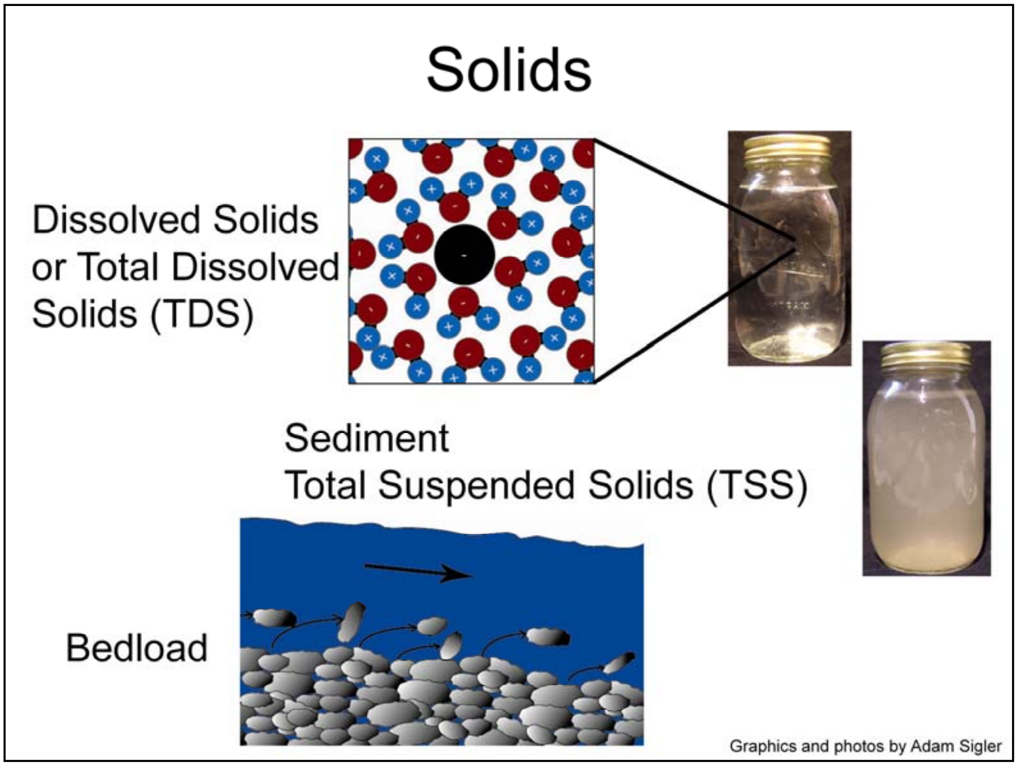
Water Quality
Physical Parameters

Solids and Sediment Transport

Demonstration Materials: Mason jar with lid, water, salt, silt, gravel



Demonstration:

Put salt, sand, and gravel in a mason jar and shake it up. Use this visual as you describe the definitions of the three categories of solids which are transported in rivers.

•**Dissolved solids** often cannot be seen. The analytical definition is the fraction of solids that pass through a 2μm glass fiber filter.

•**Total Suspended Solids (TSS)** are materials in suspension which are retained on a 2μm glass fiber filter after filtering.

•**Bedload** is the coarser portion of solids that are bounced and rolled along the stream bottom and are not in true suspension.

- •The division between bedload and suspended solids can be a little fuzzy.
- •The portion of solids moved in suspension versus along the bed, depends on the power of the water moving down the stream

Dissolved Solids

Physical or Chemical?

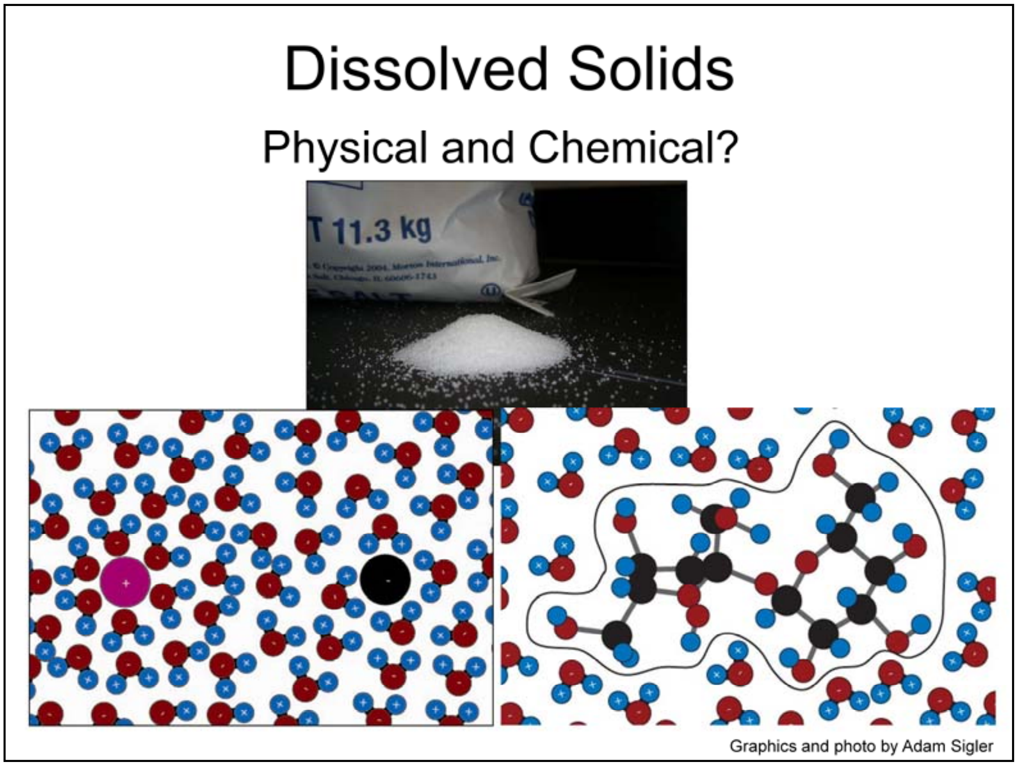
Photo by Adam Sigler

•In this section we are talking about solids. We will talk about chemical parameters in the next section.

•Do we talk about dissolved solids now or later?

•When this substance dissolves, is it a physical or a chemical process?

•What is this substance?



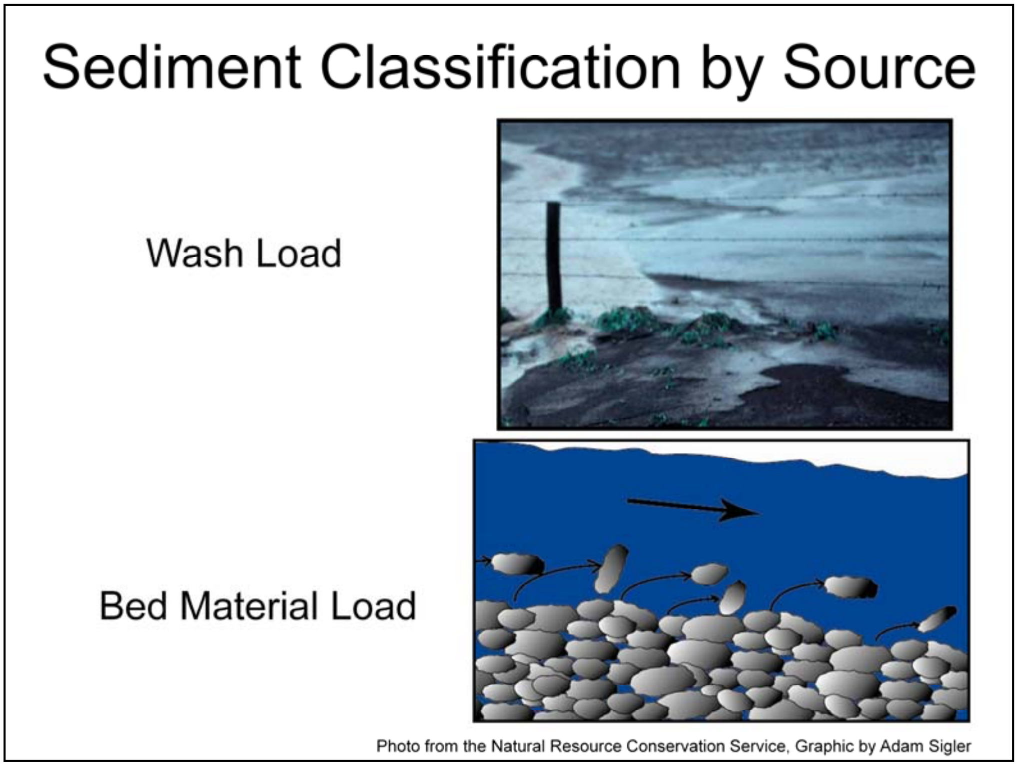
Sodium Chloride vs. Sucrose

•Salt separates into ions, undergoes a chemical change – a chemical change

•Sucrose does not separate but is suspended by attraction to separately charged portions of the molecule

> •Without the dissociation, it is a little less clear to designate this as a chemical reaction.

•However, it is polarized reactions at the molecular scale that are at work here so we will talk about dissolved solids in the chemical section of the course.



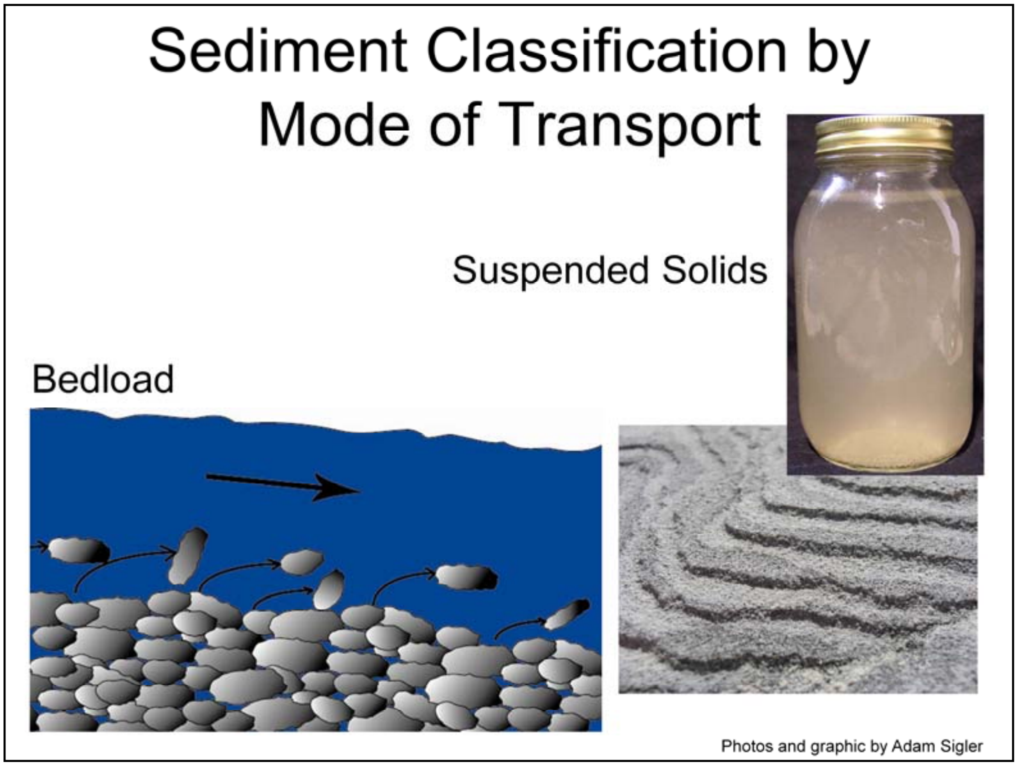
•When we talk about solids in water quality we typically mean sediment.

•Sediment refers to solids in **transport** or solids which were **previously transported**.

•One way to classify sediment is by where it came from.

<u>Sediment Classification by Source</u>: in channel vs. out of channel

- •**Bed load** originates from the river's bed and is typically more coarse (sand, gravel, cobble)
- •**Wash load** is delivered to the channel from overland flow, tributaries, or caving banks and is typically finer (clay, silt, fine sand)
  - •**Source** (Mathias Kondolf, Tools in Fluvial Geomorphology, 2003, Chapter 15 – Sediment Transport)



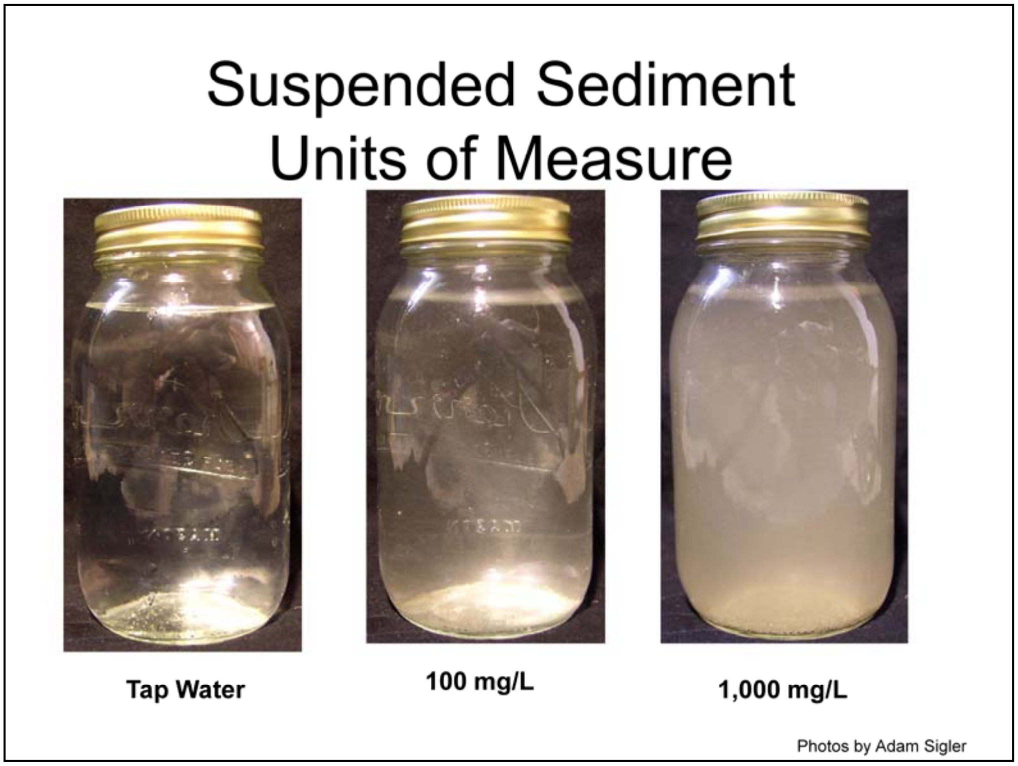
Another classification method is by the way the sediment is transported

•**Suspended Solids** - suspended for long distances and are rarely in contact with the bed. (typically clay, silt, and fine sand)

- •Refer to your jar where the cloudy materials in suspension are the suspended solids

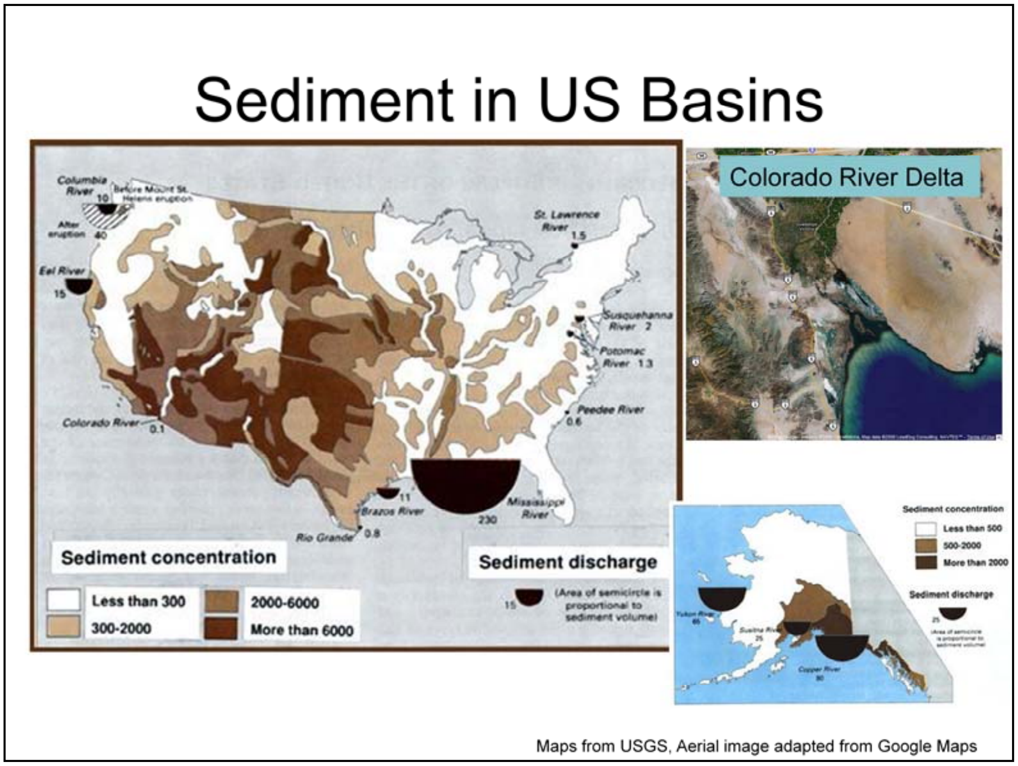
•**Bedload** - coarser material which is in regular contact with the bed as it rolls, slides, and bounces down the stream bed (typically course sand, gravel, cobbles)

- •Refer to the gravel and larger particles in the bottom of your jar, shake the jar to demonstrate bouncing down the stream bed.
- •Supplemental Source (Mathias Kondolf, Tools in Fluvial Geomorphology, 2003, Chapter 15 – Sediment Transport)



Zero mg, 100 mg, and 1000 mg of soil were weighed and added to one liter of water to take these pictures.

- A common detection limit for labs analyzing for total suspended solids is 10 mg/L, this means the method cannot accurately measure suspended sediment concentration less than 10 mg/L.
- Notice that the 100 mg/L sample is not extremely cloudy. However, if you look closely, there are solids settled out on the bottom of the jar. If this sample was taken from a stream, all of that sediment may have been in suspension when the water was moving and had energy, but after the bottle is set down on the counter, the heavier sediment begins to settle out. Now what is actually in suspension is less than 100 mg/L.



Source: USGS Suspended-Sediment Database webpage
http://co.water.usgs.gov/sediment/conc.frame.html
Visit the above website for a good overview of sediment transport patterns in the US.

•Sediment discharge to oceans.
•Semi circles = millions of tons per year
•Colors represent mg/L sediment transport in rivers

Primary Natural Influences

•Climate
•Soil Types

Ask students about the patterns they see.

•Central US (South Dakota, Colorado, Oklahoma, Texas) – highly erodible soils – enough rain to cause extensive erosion, but not enough precipitation to produce vegetation to protect the soil from transport.

•Eastern United States & Northwestern United States – low sediment concentrations – less erodible soils and sufficient precipitation to maintain vegetation to protect the soil from erosion

•Northwestern – Columbia River – extreme sediment transport occurred after Mt. St. Helens erupted and deposited ash across a wide area.

•Alaska – north is covered in Tundra where thick vegetation mats cover the land surface and protect the soil

•Alaska Southeast – glaciers forcefully erode the mountains, producing high sediment loads to the rivers.

•Mississippi, Colorado, and Rio Grande River sediment load have been notably affected by dams.

Overall amount and distribution of precipitation over a year is an important influence on erosion rates.

•**Very low precipitation rates** – not enough water to cause a lot of erosion

•**Medium precipitation rates** – enough water to cause erosion and not enough water to maintain sufficient vegetation to protect the soil surface from erosion (in the southwestern US with fall monsoon rains, the landscape is relatively dry for much of the year and lacks thick vegetation cover, when the strong monsoon rains come, erosion can be severe)

•**High precipitation rates** – enough water to maintain vegetative cover to protect soil from erosion.

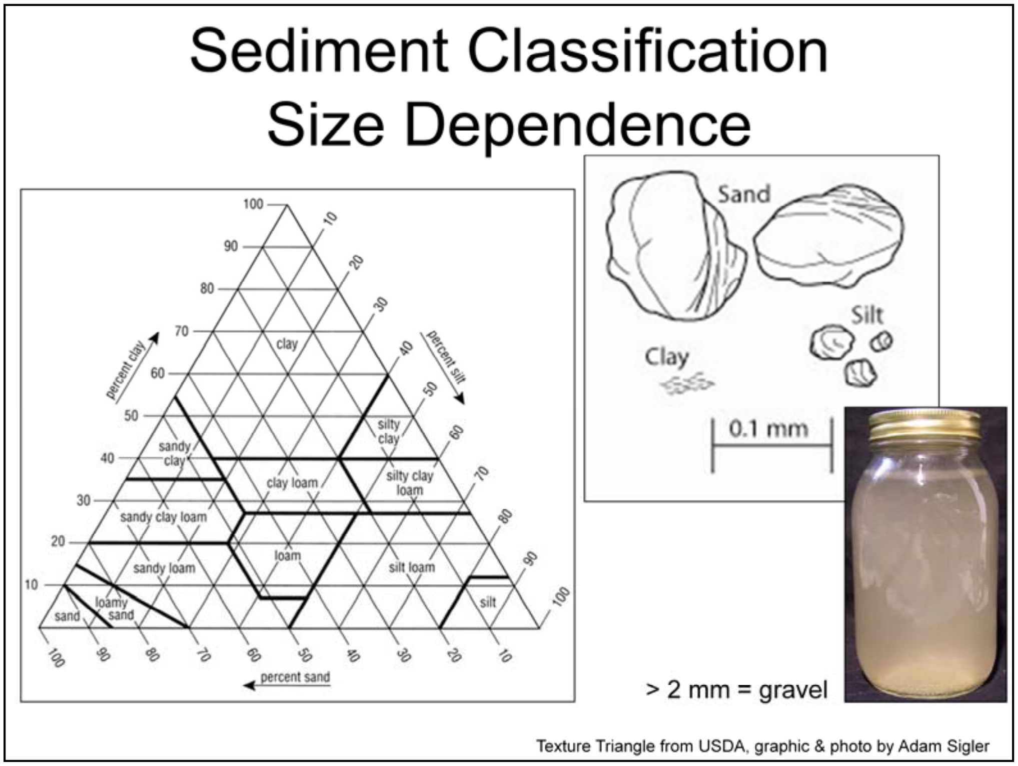
Sediment Inspires Song Lyrics

"The Mississippi delta was shining like a national guitar"

Aerial image adapted from Google Maps

Does anyone know the artist who sings this song?

Paul Simon - Grace Land



•The size of solid particles is important to the mechanisms for eroding particles from the landscape and also for transporting the sediment once it reaches the stream.

•We will talk more about particle size and erosion in the erosion lecture.

•**Top of triangle has more clay and right side has more silt**

- •Clay and silt are typically transported as suspended solids
- •Refer back to your mason jar where there are probably still some particles in suspension, these are the finer clay and silt particles from your soil.

•**Left side of triangle is more sand**

- •Sand is more likely to be transported as bedload
- •In the jar, the gravel and the courser sand are sitting on the bottom

USDA particle size delineations

- •Clay <0.001 mm
- •Silt 0.002 – 0.05 mm
- •Sand 0.05 – 2 mm
- •> 2 mm = gravel

Sediment Transport & Particle Settling
Stokes Law

$$F_g = (4/3)\pi r^3(\rho_s - \rho_f)g$$

F_g = downward force due to gravity
$\pi = 3.14$
r = radius of particle
ρ_s = density of solid
ρ_f = density of fluid
g = acceleration due to gravity

Source: Daniel Hillel, Introduction to Environmental Soil Physics, 2004, pg 46

The time it takes a particle to settle depends on:

- Size of particle
- Density of particle – simplify by assuming a standard density
- Density of fluid – simplify by assuming standard water density

$(4/3)\pi r^3$ - Volume of spherical particle

$(\rho_s - \rho_f)$ – subtracting fluid density from solid density accounts for buoyancy of particles

Sediment Transport & Particle Settling
Stokes Law Simplified

$$t = B/d^2$$

t = settling time for a given distance

B = constant

d = diameter of particle

Larger particles require less time to settle
(larger particles settle faster)
Vertical sediment concentration gradient

The take home point from this equation is recognizing the variables that are important for particle settling speed

Basic structure of the equation

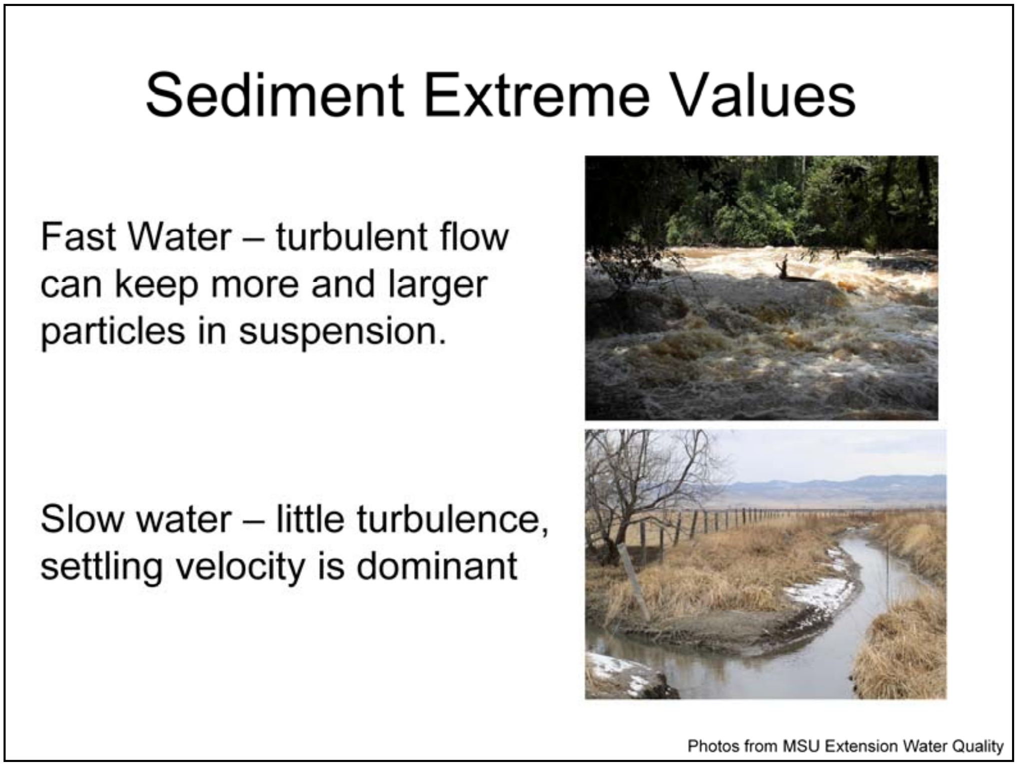
•Diameter is in the denominator - as diameter increases, settling time decreases

•Diameter term is squared – settling time decreases quickly as diameter gets just a little bit larger

•**Stokes Law** = A scientific equation to say that larger particles settle faster

•This concept can contribute to a vertical sediment concentration gradient in the water column

- •This is important for sampling. If the amount of sediment is different at different depths in the stream, that needs to be accounted for with your sampling method.
- •Depth integrated sampling means that you mix water from different depths in the stream to get a sample.



•Shake your demonstration Mason Jar

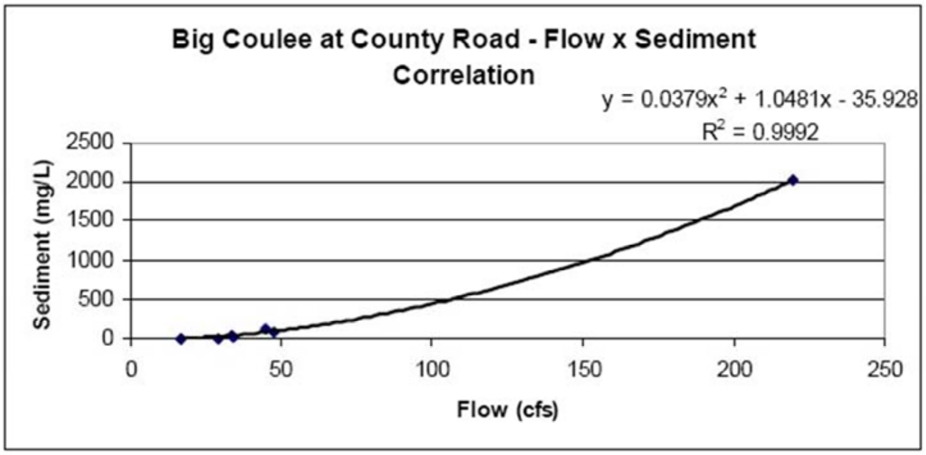
•**Fast/Turbulent water** – has more energy to keep more and larger particles in suspension

- •**Low values** – no detectable sediment – could have this in rocky headwater areas with little sediment available
- •**High Values** - Muddy Creek at Vaughn in 1981 – USGS recorded 21,100 mg/L

•**Slow water -** little turbulence to keep solids in suspension, settling velocity and stokes law is important

- •Where colloids and clay size particles are present, they can stay in suspension for a long time.
- •**Low values** – no detectable sediment – places with no source of fine sediment
- •**High values** – where clay is present, easily up to 450 mg/L, (this was a high value for suspended sediment in slow moving water with a lot of clay and fine particles present)

Sediment Behavior in Stream
Sediment Rating Curves



Graph from Kim Hershberger, MSU Extension Water Quality

A sediment rating curve is a relationship between discharge (flow) in a stream and the sediment concentration in the water.

If data is available for the discharge of a stream through a period of time, a sediment rating curve will allow you to calculate the sediment that moved through the stream in that same period.

High flows

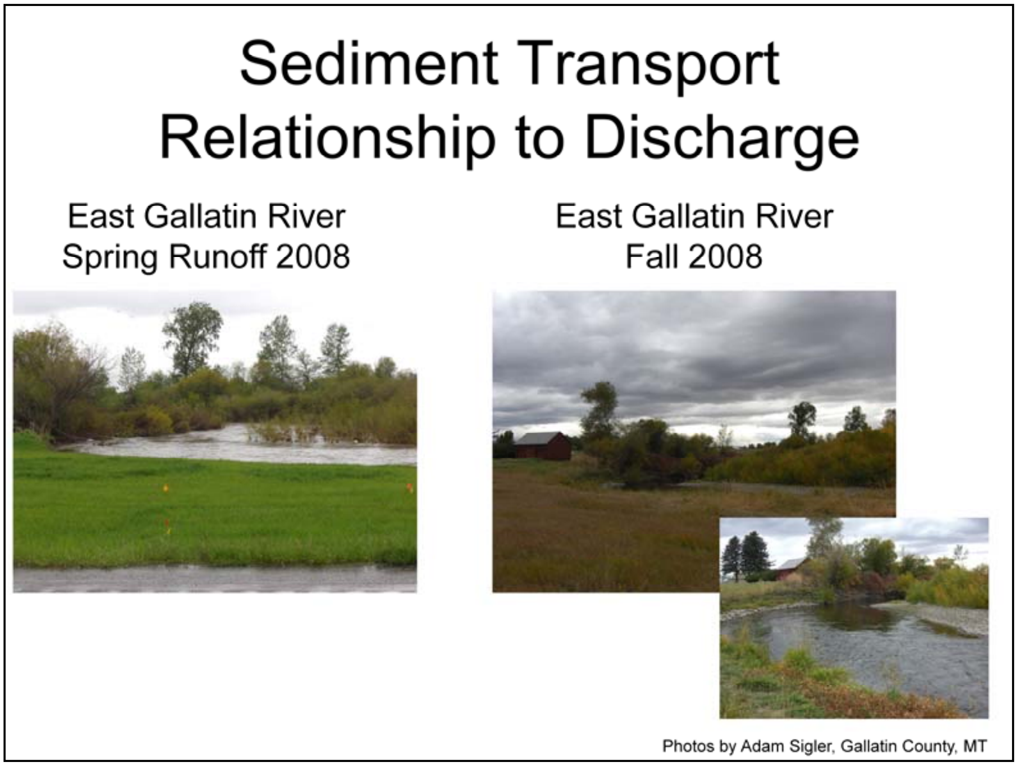
- **What is going on at high flow that leads to more sediment in the stream?**
- At high flow with fast water, a stream has more power and can transport more sediment.
- High flow often correlates with precipitation events or snow melt that causes runoff over the surface. Surface runoff often carries sediment into streams

Low Flows

- **What is going on at low flow that results in less sediment in the stream?**
- At low flow with slow water, the stream has less power to transport sediment.
- Low flow or base flow is largely fed by ground water which is low in solids because it has been filtered through the ground.

Graphing relationships between variables

- This is a common tactic in water quality and in science in general to use one variable to predict another.
- The variable on the x-axis is the independent variable used to predict the dependent variable on the y axis.
- The equation for the trend line describes the relationship between the two variables.
- The R^2 value describes how well the relationship of the two variables is predicted by the trend line.



High versus low flow

These photos were taken in the same place on the East Gallatin River

Left Picture:

In the East Gallatin River, the suspended sediment concentration is very high in the spring.

Flow is high so stream power is high and snowmelt is causing overland flow in the watershed.

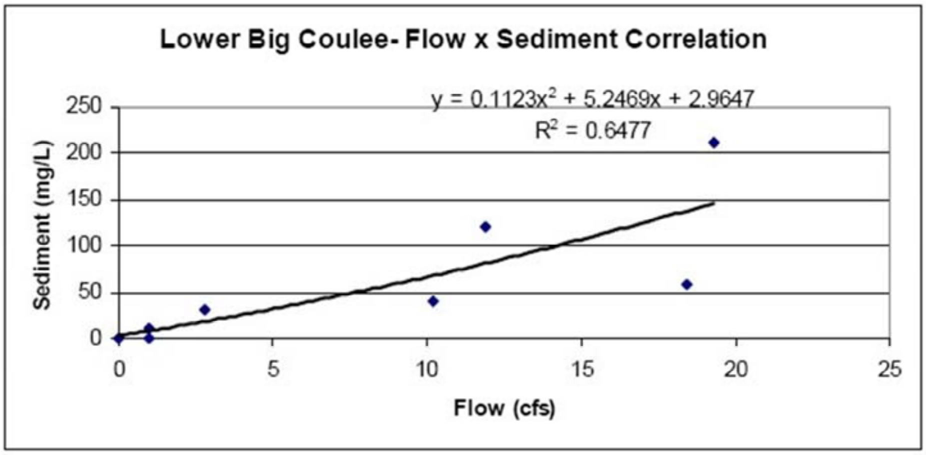
Right Pictures:

In the fall, the water is clear with a low sediment concentration.

Flow is lower so there is less power to move sediment and runoff is not occurring to move sediment into the stream.

Good time for fishing.

Sediment Behavior in Stream
Sediment Rating Curves



Graph from Kim Hershberger, MSU Extension Water Quality

Rating curves can be useful tools but data relationships are not always so straight forward.

Data points don’t always fall closely along a line.

What type of factors could cause different sediment concentrations at the same discharge?

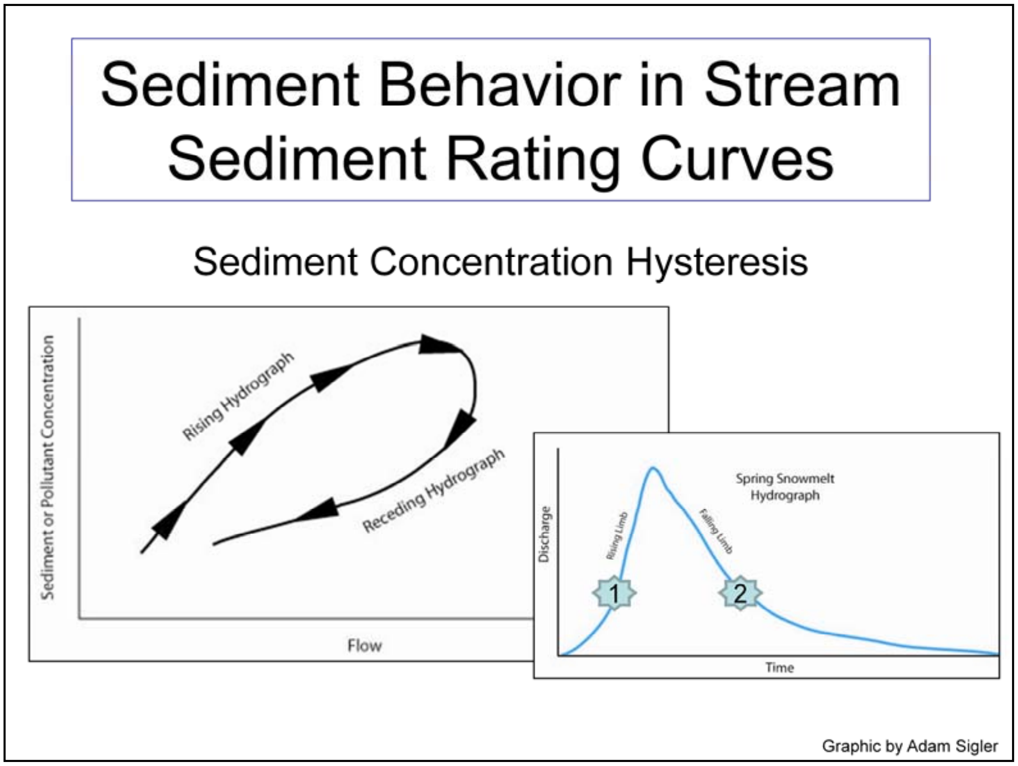
<u>Possible Causes</u>

Different landuse in the watershed during different events

Frozen soil and/or ice on the surface in the spring protecting soil from erosion during overland flow.

Hysteresis

Localized disturbance events



Hysteresis in water quality is the concept that water quality on the rising limb of a hydrograph or at the beginning of a storm is different than on the falling limb of the hydrograph or at the end of a storm.

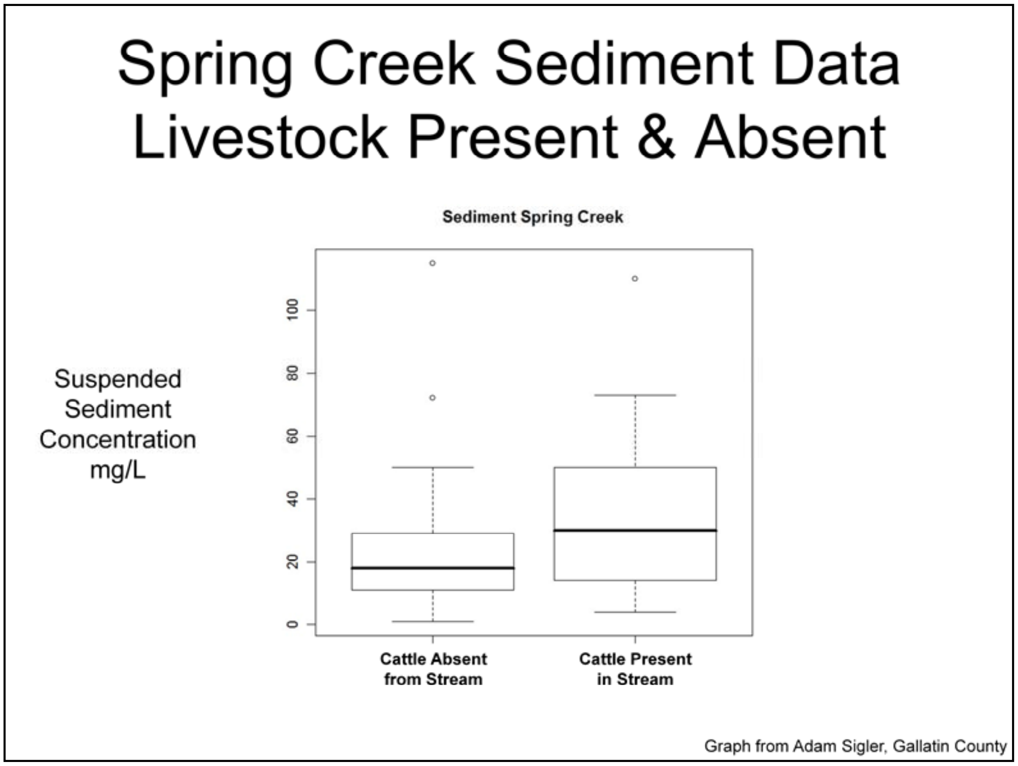
This can be thought about for the time scale of a single storm event or for a season.

Seasonal example for city streets:

- •All winter the streets are sanded for traction and this material builds up on the roads and in gutters
- •In the spring when snow starts to melt (point 1), the flow in streams starts to come up and we see the rising limb of the hydrograph.
- •This water flushes the sand that is stored on the roads into streams and there is a relatively high concentration of sediment.
- •Point 1 = high sediment

- •When snow melt is slowing down, flow in streams diminishes and we see the falling limb of the hydrograph.
- •At this point (point 2) the sand has all been washed off the roads and there is a relatively low concentration of sediment in the streams.

Point 1 and 2 on the hydrograph have the same discharge, so the rating curve would predict the same sediment concentration for both points, but hysteresis results in the concentrations being different.



Localized disturbance can also complicate correlations between discharge and sediment concentration

If there is activity in the stream above your sample site, there may be elevated sediment in your sample.

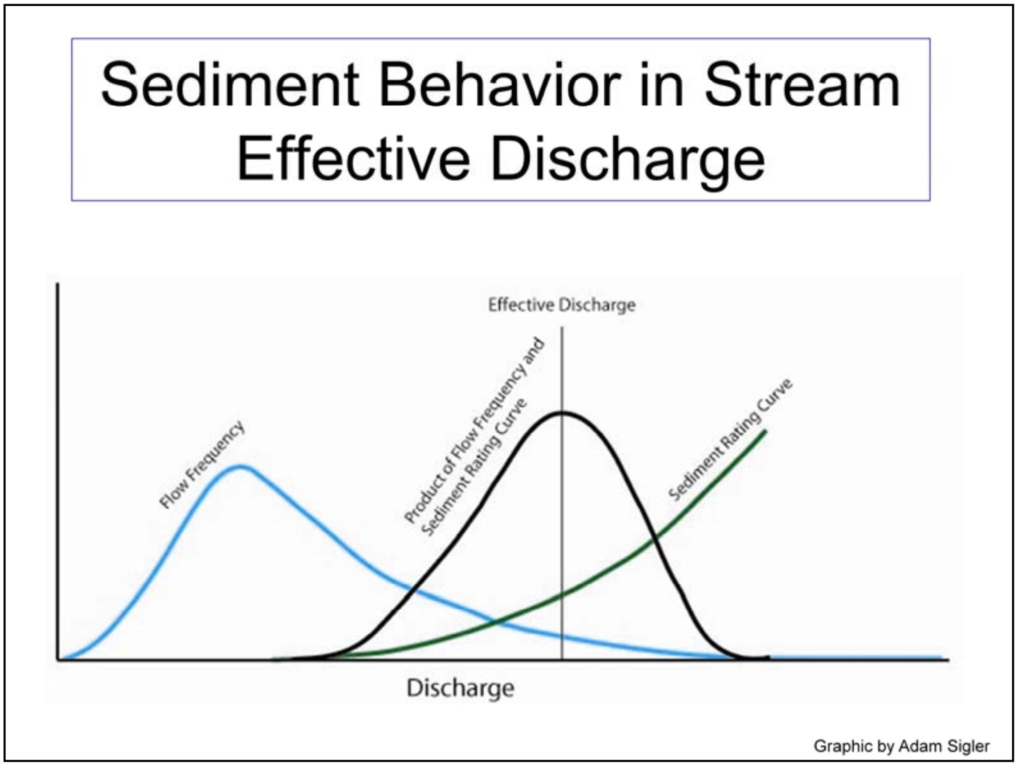
Disturbance could be discharge from a point source, irrigation return flow, recreation, livestock activity etc.

If this activity is present for some of your samples but not others, your rating curve could be messy.

Data Source: Sigler thesis research on a spring creek north of Belgrade, MT.

These samples were taken below a cattle water access point with and without animals using the stream.

- •Animals Absent ~20 mg/L sediment
- •Animals Present ~ 30 mg/L sediment



Effective Discharge Concept:

- **The blue line** shows the amount of time a stream spends at different discharge levels.
- Lower flows occur more of the time, high flows are not frequently reached

- **The brown line** is the sediment rating curve indicating how much solid material is moved down the stream at different discharge levels

- Lower flows happen often but don't move as much sediment, higher flows happen less often but move a lot of sediment.
- The flow that moves the most sediment overall is in the middle

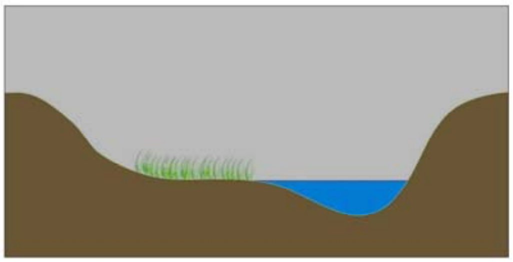
- **The black line** is the product when flow frequency and sediment rating curve are multiplied together.
- The peak of the black line is the discharge that moves the most sediment down the stream – Effective Discharge

- Because effective discharge moves the most sediment through a river system, it is closely linked to bank full discharge (the channel forming flow)

- Bank full discharge typically occurs every 1.5 years.

- We will cover this a little more under channel morphology and classification

Sediment Behavior in Stream
Bankfull Discharge



Graphic and photo by Adam Sigler

•Elevation of water level at bankfull or effective discharge can be identified on the stream bank

•Bankfull is the height on a stream bank just before it spills over into the floodplain.

•Bankfull elevation is commonly used in evaluating stream reaches and characterizing a stream.

  •We will cover this more in the next lecture.

Analyzing Samples for Suspended Sediment

What are we measuring?

What are our Units?

What do we need to know about the sample?

Photo by Adam Sigler

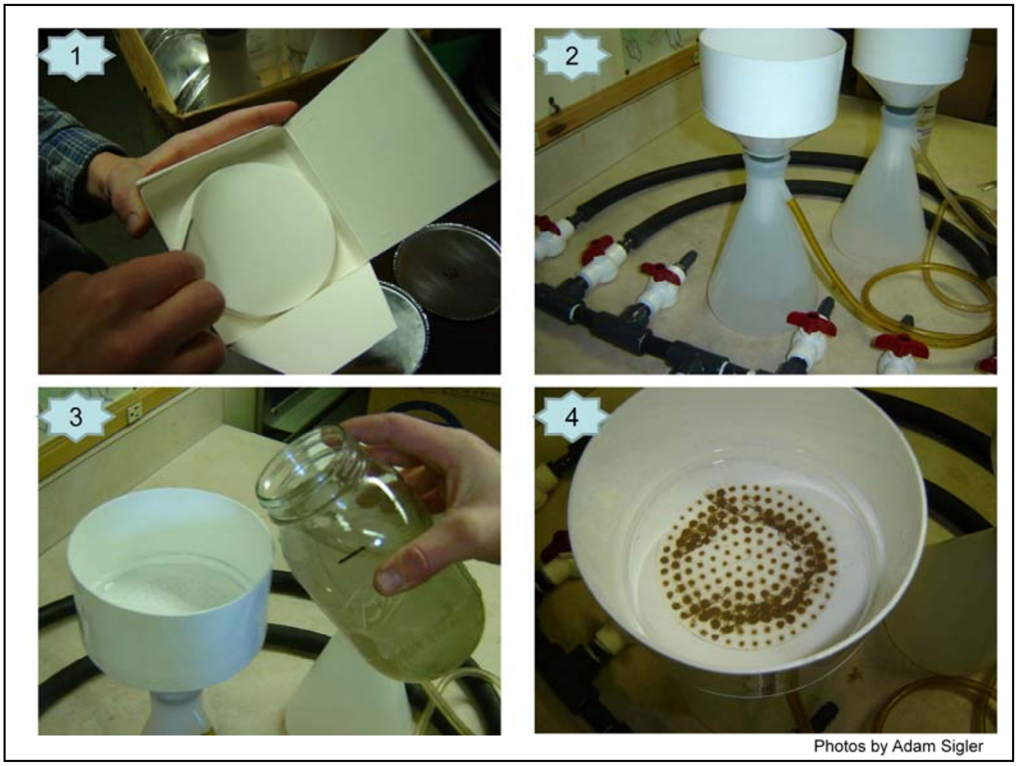
We are measuring the amount of solids in a sample that are larger than 2 micrometers (microns)

We need to know

- mass of solids
- volume of the sample

This will allow us to know both units necessary for sediment concentration

- Mass per volume (mg/L)



Example of suspended solids measurement

Photo #1: taking out a glass fiber filter to put in the Bugner Funnel

Photo #2: attaching the suction hoses to a vacuum flask to pull the water sample through the filter

Photo #3: pouring the sample into the filter

Photo #4: sediment captured on the filter after the water is vacuumed through

Note:

There is a distinction in the methods here which gives two slightly different numbers

- **Suspended Sediment Concentration**
    - Is the result if the entire sample is filtered
- **Total Suspended Solids**
    - Is the result if the sample is mixed with an automatic stirrer and a portion of the sample is pippetted out for sampling

Photos by Adam Sigler

Photo #5: The filter and sediment are dried in the oven

Photo #6: The volume of the water from the original sample is measured

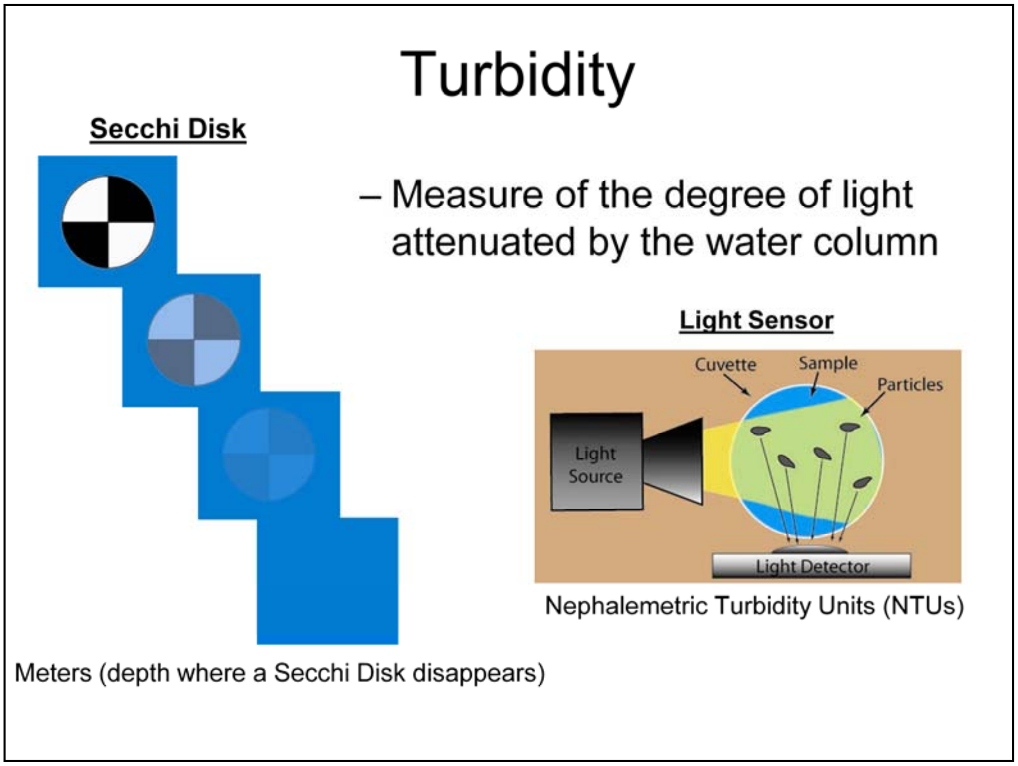
Photo #7: The dried filters are weighed

Photo #8: The values are recorded and the mass per volume is calculated

The end result is a knowledge of the volume of the water sample and the weight of the solids in the sample that were retained on a 2 micron filter.

Note:

This is an overview of the process and not all steps are included here for simplicity.

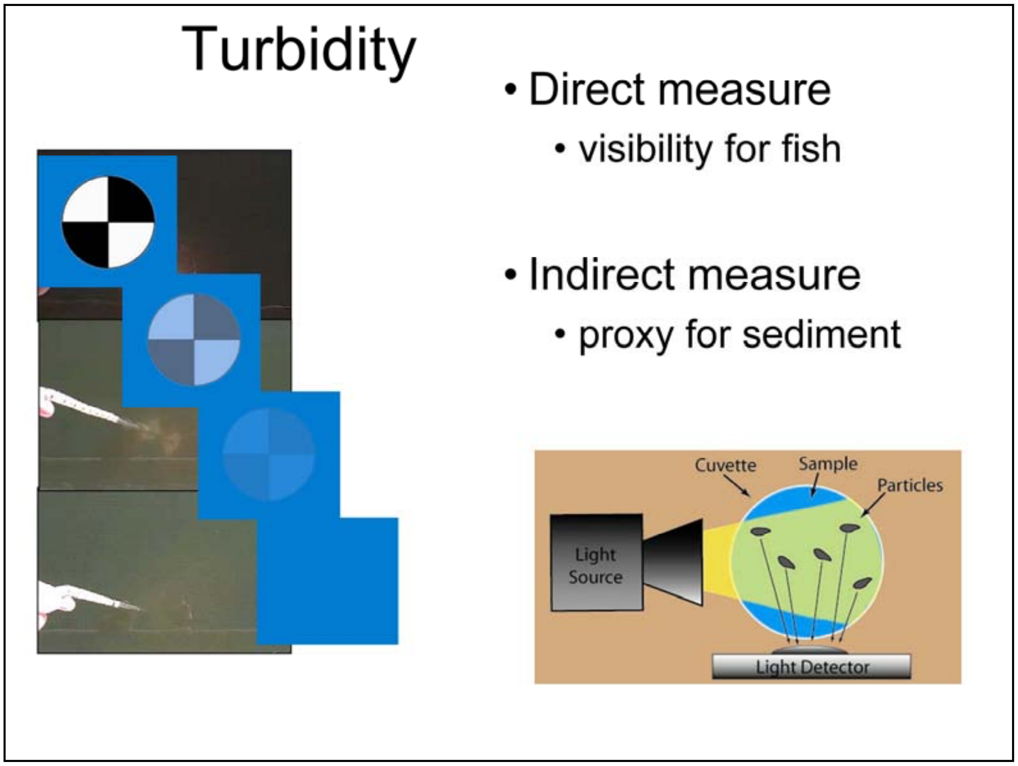


Turbidity is related to and often associated with suspended sediment.

Turbidity is a measure of the amount of light that penetrates a water sample
It can be measured in two different ways

1. **Secchi Disk Method**
    - A checkered disk is lowered into the water until it is no longer possible to see the checker pattern
    - The length of the lowering rope is marked with meters
    - The depth on the rope where the disk disappears is noted as the turbidity depth
    - The units of turbidity for this method are length (meters for example)

2. **Light Sensor Method**
    - A sample is placed in a device which sends light into the sample and measures the amount of light deflected
    - The units of turbidity for this method are nephalemetric turbidity units (NTUs)

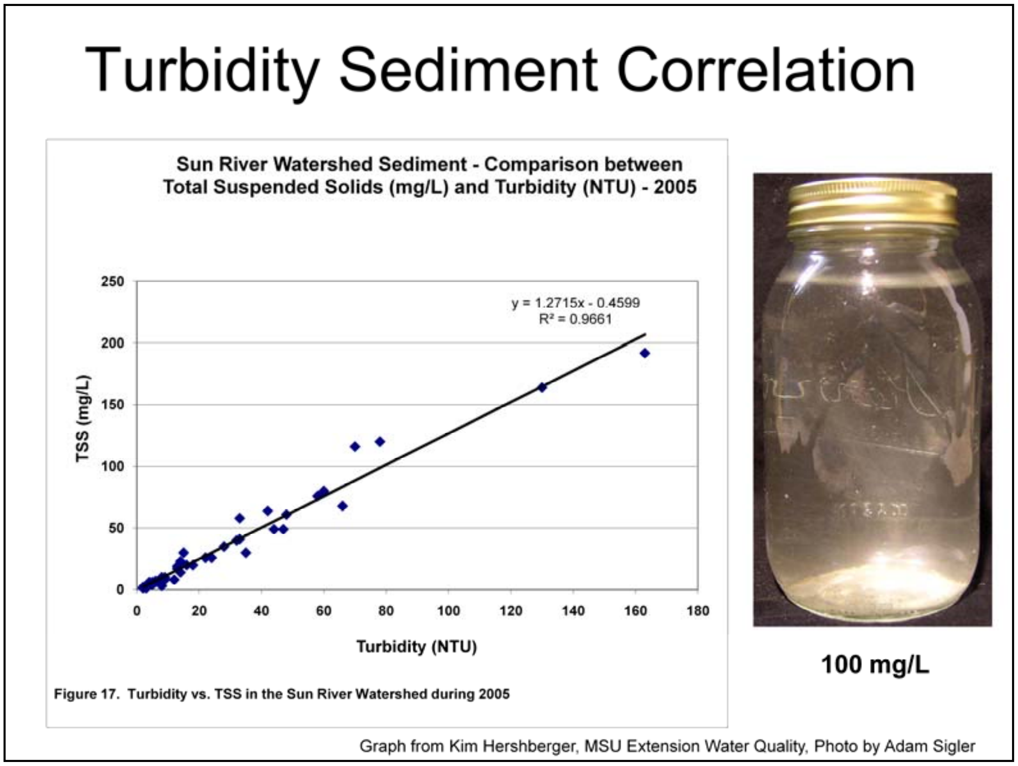


Turbidity as a direct measurement – when we are actually interested in the light penetrating the water

- •Turbidity can be of interest because it affects fishes ability to see in the water, amount of light for aquatic vegetation, etc.
- •Measuring the variable you are directly interested in is a direct measurement

•**Turbidity as an indirect measurement – to estimate suspended sediment**

- •Turbidity is also often of interest because it is related to suspended sediment concentration.
- •Turbidity is quicker, easier, and cheaper to measure than suspended sediment so if it can be correlated to suspended sediment concentration, more data may be able to be collected for the same price and effort.
- •Measuring a variable to estimate another variable is an indirect measurement.

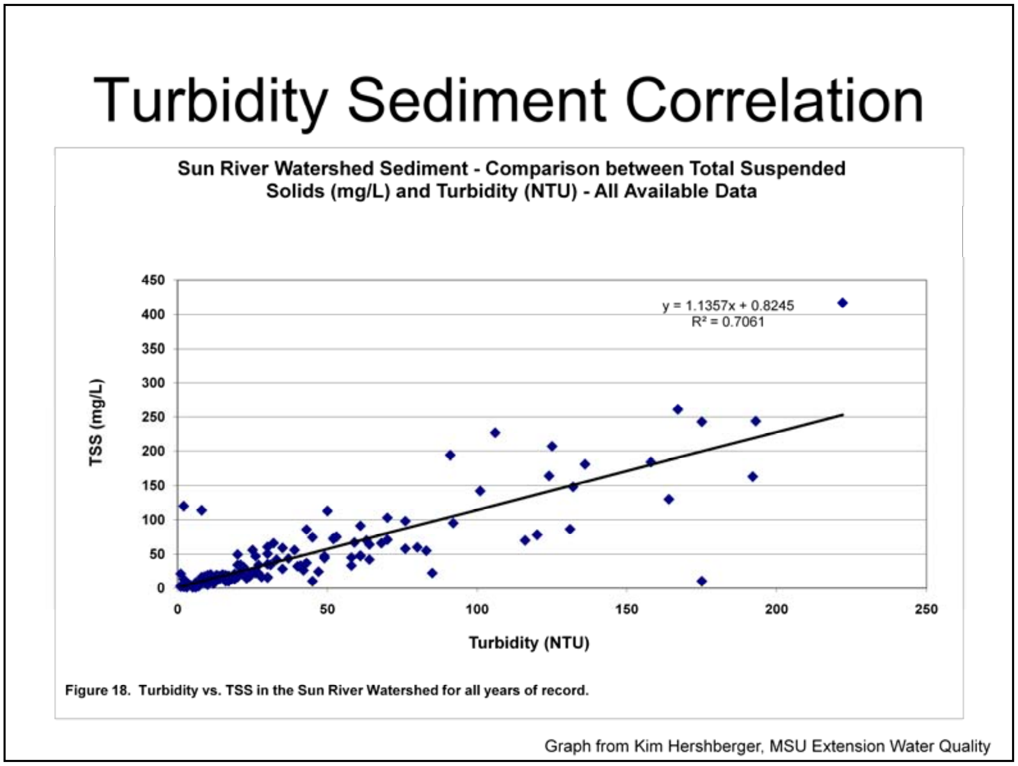


•Sometimes the correlation between sediment and turbidity is very good.

•This is very convenient because turbidity is cheaper to measure than suspended sediment.

•Turbidity can also be monitored continuously by placing a sensor in the channel with a data logger.

•The R^2 for this relationship is 0.97 which is pretty good and could give us some confidence that we could predict suspended sediment from turbidity.



•The turbidity to suspended sediment relationship is not always perfect.

•**Why?**

•Different types of sediment reflect light differently.

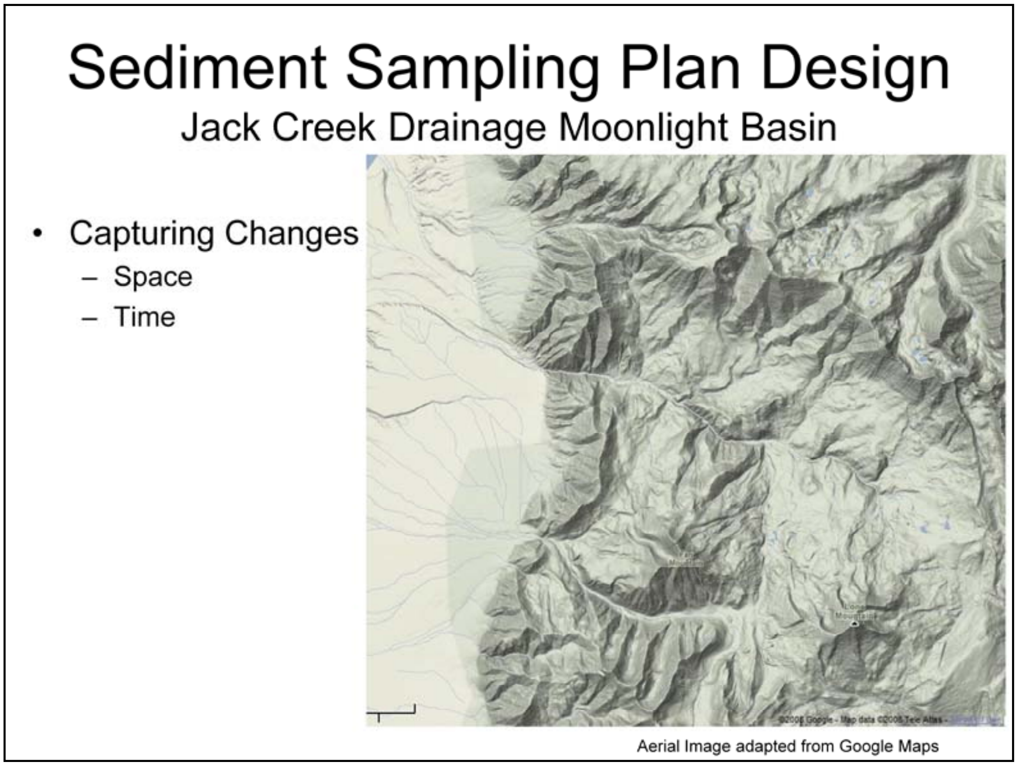
•If there are different sources of erosion in a watershed, the relationship between turbidity and sediment can change if the sediment source changes.

•For this reason, relationships between turbidity and sediment need to be assessed for the watershed of interest and measurements need to be made throughout the year. This will allow for consideration of changing sediment sources for different seasons.

- •To build these correlations, turbidity and sediment samples need to be taken at the same time and graphed.
- •If the points fall closely along a line, you can have more confidence to predict sediment concentration with turbidity.

•**The Graph Shown:**

- •The R2 for this relationship is not as good at 0.71 which might give us some concern about predicting sediment with turbidity.



Class Discussion:

Use a local watershed example and photos or this terrain map of Jack Creek watershed and the photos on the next slide to talk about locating sampling sites and determining sample scheduling for sediment.

It is important to determine why you are sampling, what questions you want to answer.

Possible Study Objective Questions:

- •Which land uses in the drainage contribute the most sediment?
- •Is development at the ski resort in the headwaters contributing sediment to the Jack Creek Drainage?
- •Do agricultural practices in the Madison Valley contribute to sediment load to Jack Creek?
- •Do different landuses contribute sediment to the stream during different seasons?

Background information:

- •New development is occurring in the headwaters as the ski resort expands. The resort is working to implement best management practices during construction to minimize erosion during spring snow melt.
- •Active and closed forest service roads are present in the canyon.
- •Irrigated agriculture is the dominant landuse around Jack Creek in the Madison Valley.

Distribution of Sampling in Time

- •Would you expect different sediment concentrations in different seasons? (yes, spring runoff)
- •Would you expect different sediment concentrations during and after precipitation events. (yes)
- •How could we design a sampling plan to capture these differences?
  - •Sample regularly over the course of spring, summer, and fall.
  - •Sample during and after precipitation events.

Distribution of Sampling in Space

- •Would we expect sediment concentrations to be different in different parts of the watershed? (probably)
- •If we are concerned about sediment pollution from different land uses, what do we need to do to study it?
  - •Options
    - •Sample above and below different landuses
    - •Sample in watersheds with and without the landuse
    - •Sample before and after a landuse takes place in a watershed
- •Locate sample sites below different land uses in a locations that will capture the effects from the landuse on the stream.

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    - •Sample above and below different landuses

Review Questions

1. What are the three categories of transport that solids are commonly categorized by?
2. What is the primary characteristic of a solid that determines if it will be transported as suspended or bed load?
3. Stoke’s Law – Settling time decreases quickly with increase in _________.
4. True/False: The sediment load in a healthy stream will be almost zero. Why?

1. Dissolved, Suspended, Bedload

2. Size

3. Diameter

4. False. Sediment transport is a natural and essential part of stream function and varies naturally between watersheds

Review Questions

5. What is the name of the graph which draws a relationship between stream discharge and sediment transport?
6. What are a few possible complications with correlating sediment concentration with flow magnitude?
7. What is the common term for the discharge which occurs approximately every 1.5 years, also known as effective discharge?

5. A Sediment Rating Curve

6.

- Hysteresis
- Changing landuses in the watershed
- Localized disturbance factors such as cows or irrigation water returning to the stream
- Frozen ground protecting the soil surface during high spring runoff

7. Bankfull discharge. The depth of water at this discharge is called bankfull stage

Review Questions

8. Suspended sediment is determined by the mass of solid retained on a filter of what pore size?
9. Turbidity is a measure of what?
10. What are a few important considerations when laying out a monitoring plan to assess sediment loading to a stream?

8. two microns

9. the amount of light attenuated by a water sample (the cloudiness of a sample)

10.

•What do you want to learn from the monitoring?

•What are the different landuses to be considered?

•Where will the effects from the different landuses show up in the stream?

•What will the timing of the sediment loading from different landuses look like?

•What effects will precipitation events have on sediment loading?

•What type of effects will season have on sediment loading?

•What is the scale of the project and the resources available for collecting and analyzing samples?