Physical Properties of Watersheds

Hydrology

Fluvial Geomorphology

Water Temperature

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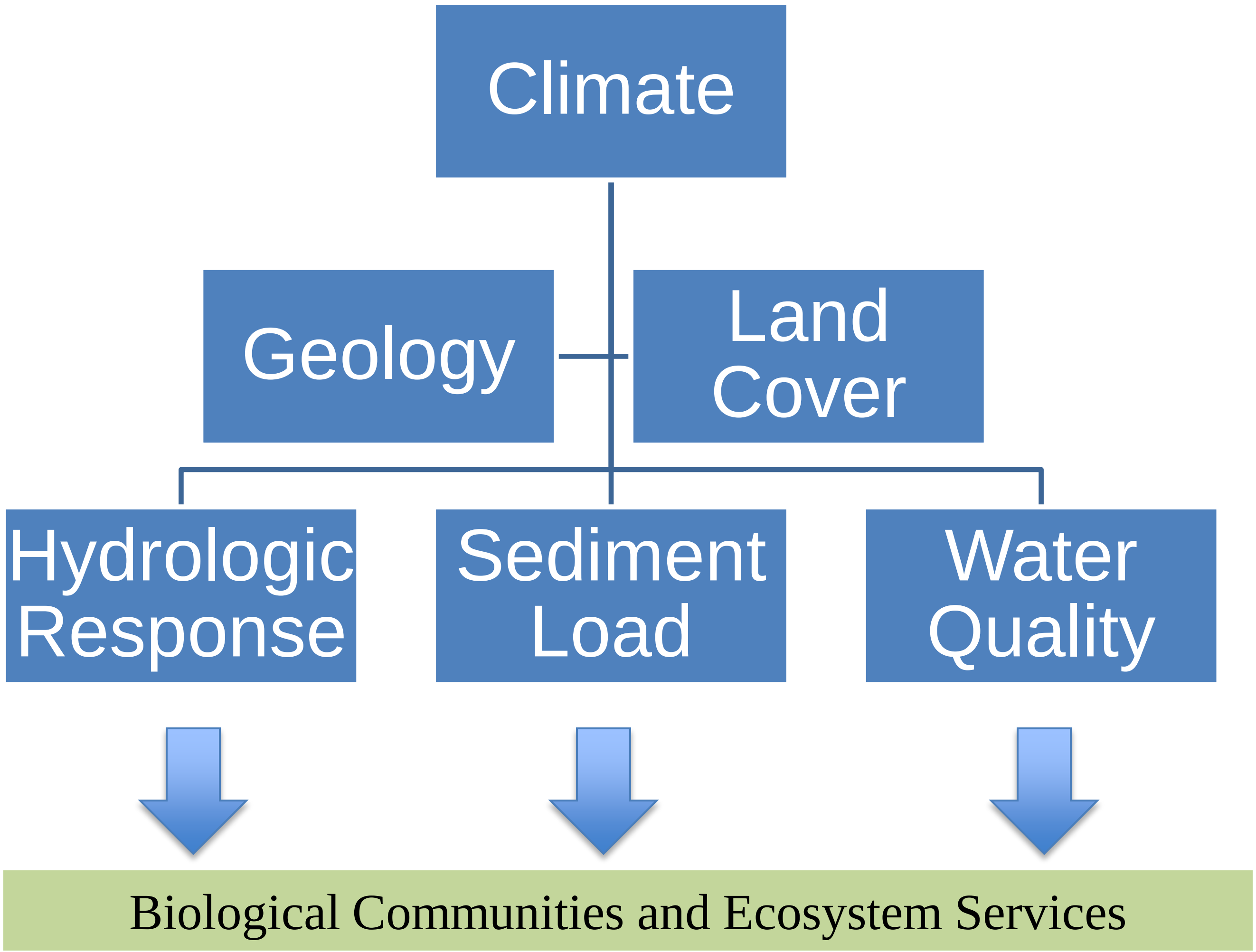
Watershed Influence on Stream Ecosystems



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Learning Objectives

- Understand what a watershed is and how water moves from watershed hillslopes into streams and rivers
- Be able to relate human and natural land use/land covers to a watershed's hydrologic response
- Understand the nature and sources of sediment loads in streams
- Understand how scientists measure stream water and sediment discharge
- Understand how restoration measures can address altered hydrologic and sediment regimes
- Understand effective means of monitoring watershed hydrology, sediment loads, and physical habitat quality

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Definitions

- Hydrology - science that encompasses the occurrence, distribution, movement and properties of the waters of the earth and their relationship with the environment
- Fluvial – processes associated with rivers and streams
- Geomorphology - the study of the physical features of the surface of the earth and their relation to its geological structures
- Fluvial Geomorphology

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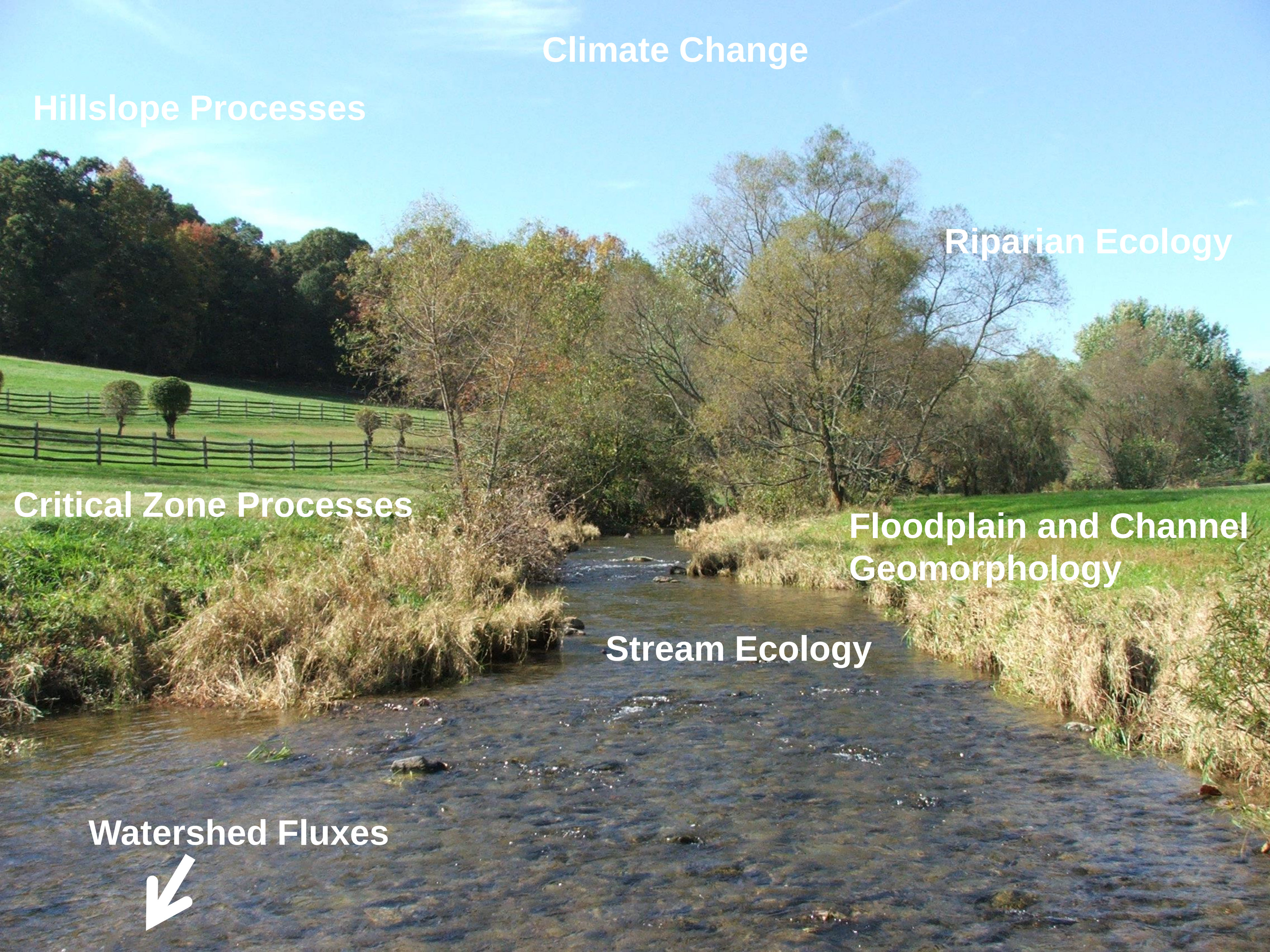
Climate Change
Hillslope Processes
Riparian Ecology
Critical Zone Processes
Floodplain and Channel Geomorphology
Stream Ecology
Watershed Fluxes

Hydrology

Learning objectives:

Understand what a watershed is and how water moves from watershed hillslopes into streams and rivers

Be able to relate human and natural land use/land covers to a watershed's hydrologic response

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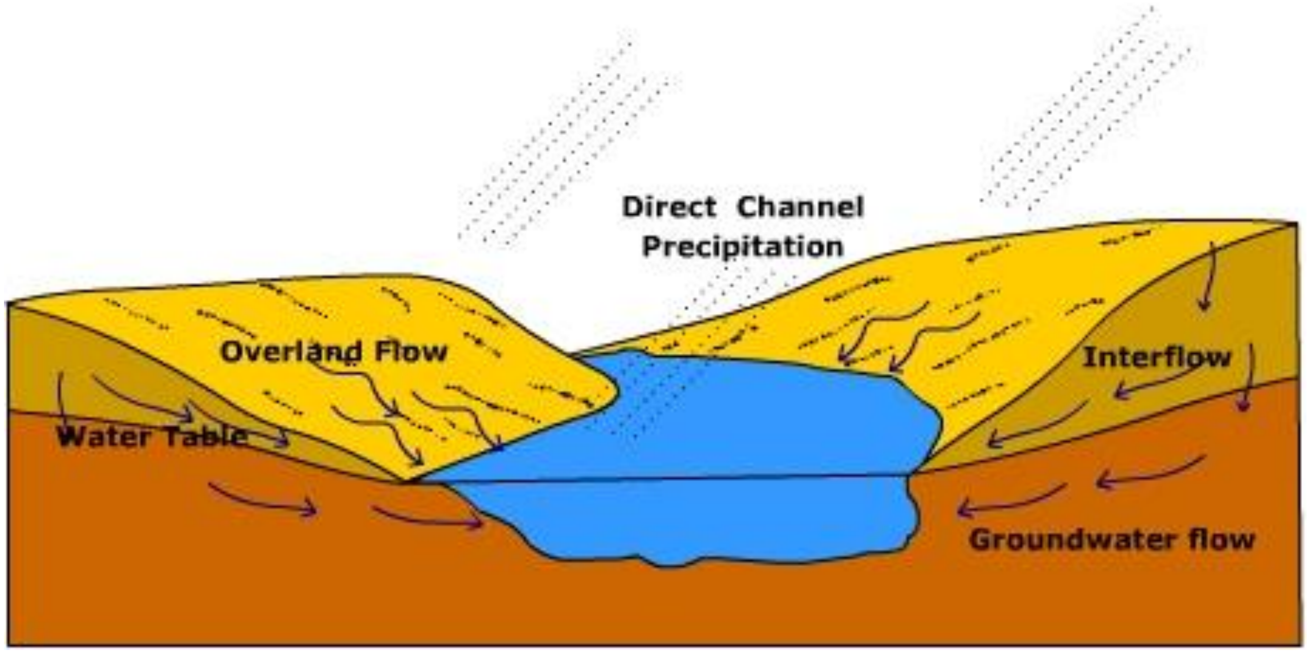
Watershed Hydrology

- Study of the spatial and temporal movement of water within a watershed
  - Includes delivery of water to and movement of water through a river or stream



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Hydrologic Cycle

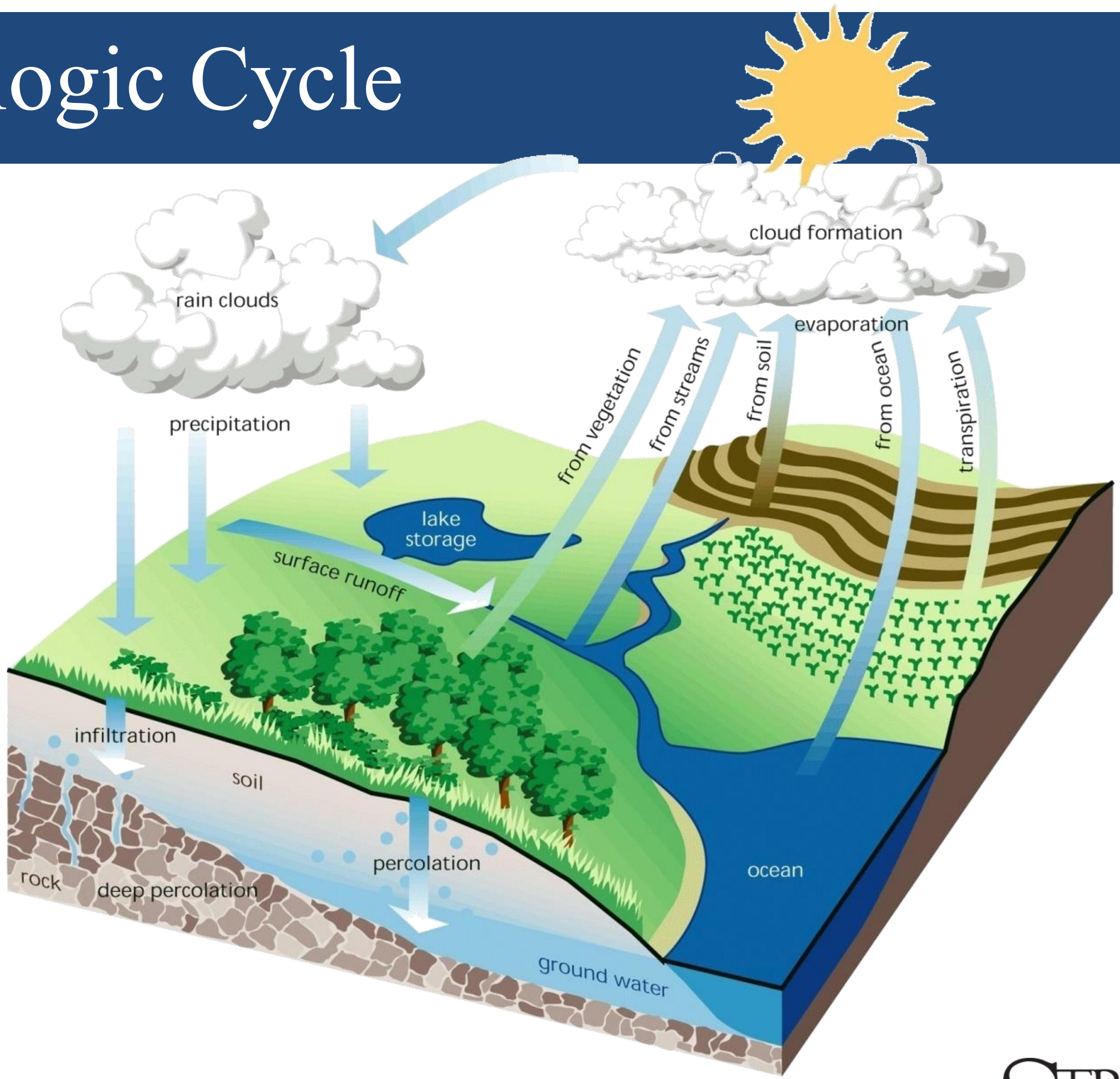

Fig. 2.2 -- The hydrologic cycle. The transfer of water from precipitation to surface water and ground water, to storage and runoff, and eventually back to the atmosphere is an ongoing cycle.
In Stream Corridor Restoration: Principles, Processes, and Practices (10/98).
Interagency Stream Restoration Working Group (15 federal agencies)(FISRWG).

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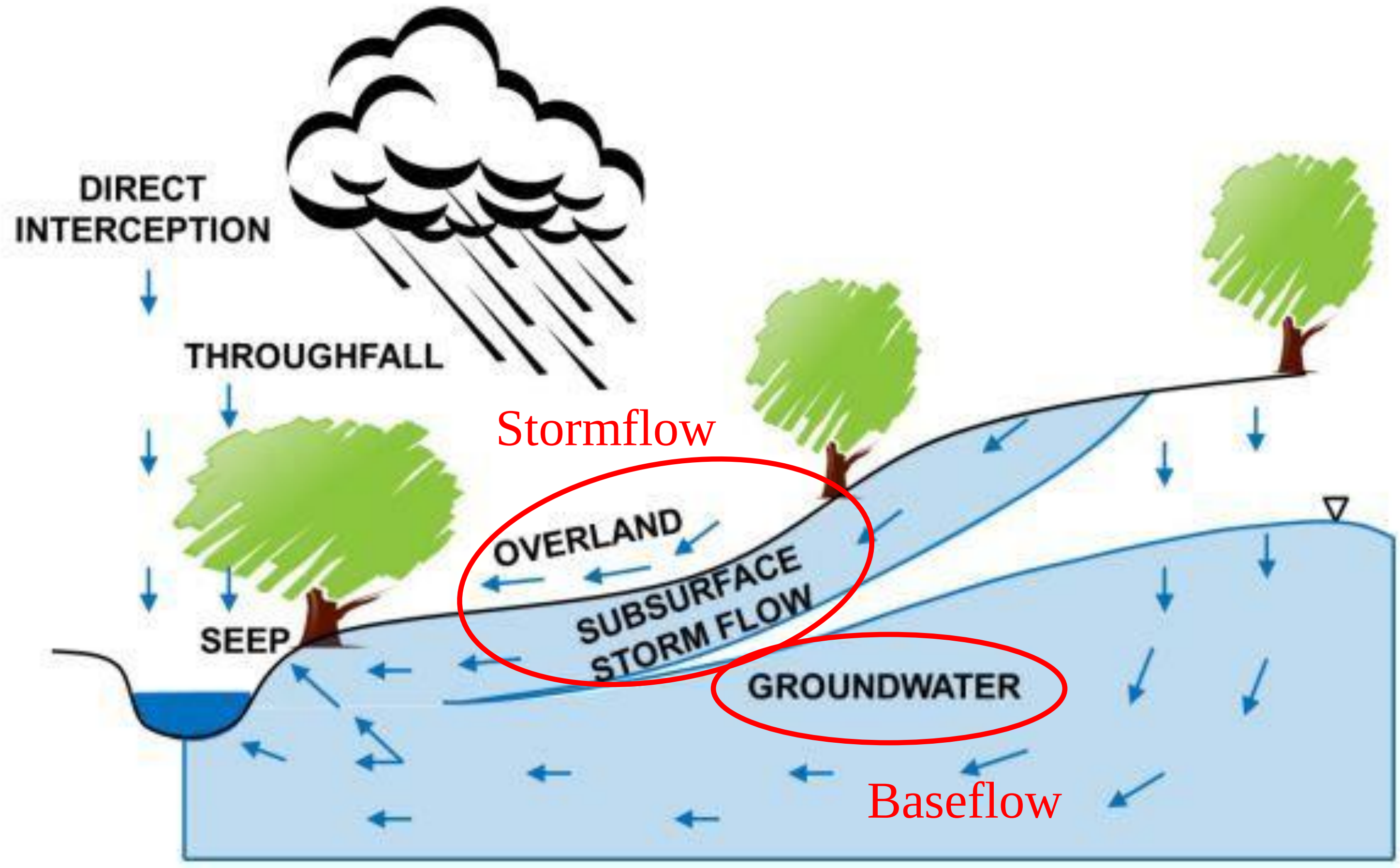
Movement of all of this water



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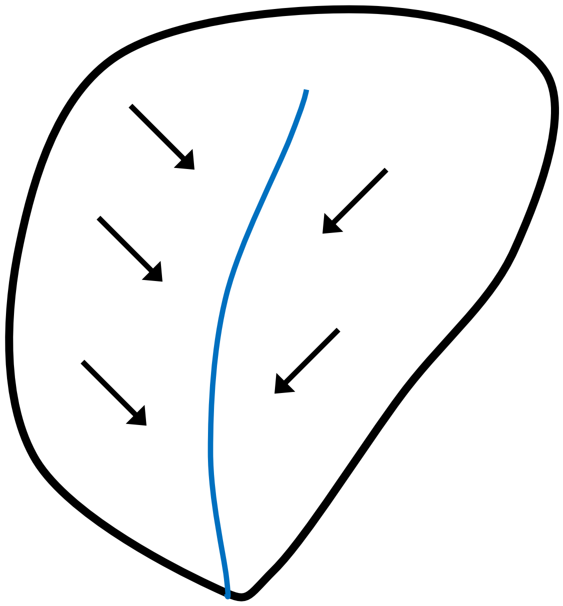
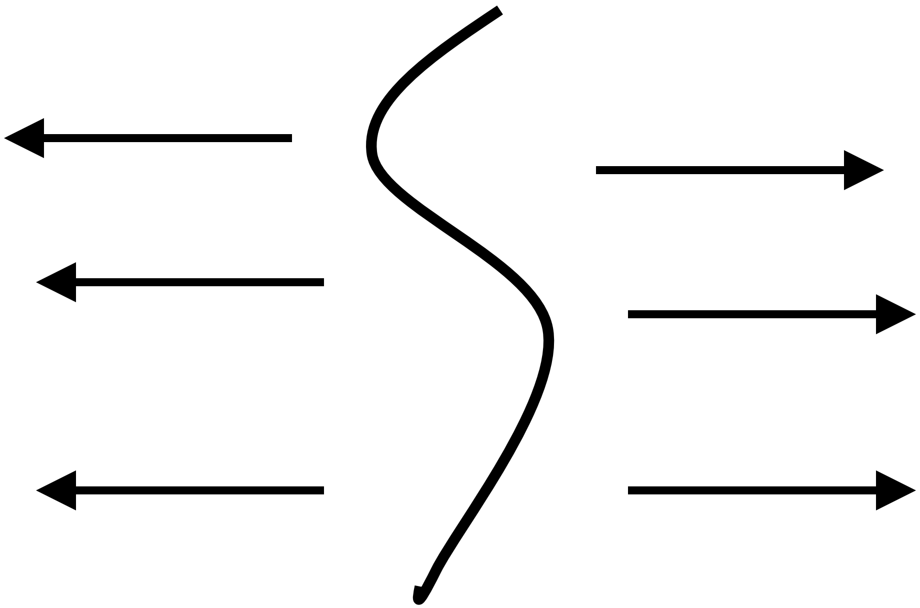
The Watershed

- Water-receiving area that drains into a stream
- All of the precipitation that falls into a watershed flows into that watershed's stream



Watershed Boundary (Drainage Divide)

- The line separating one watershed from another



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Watershed Boundaries

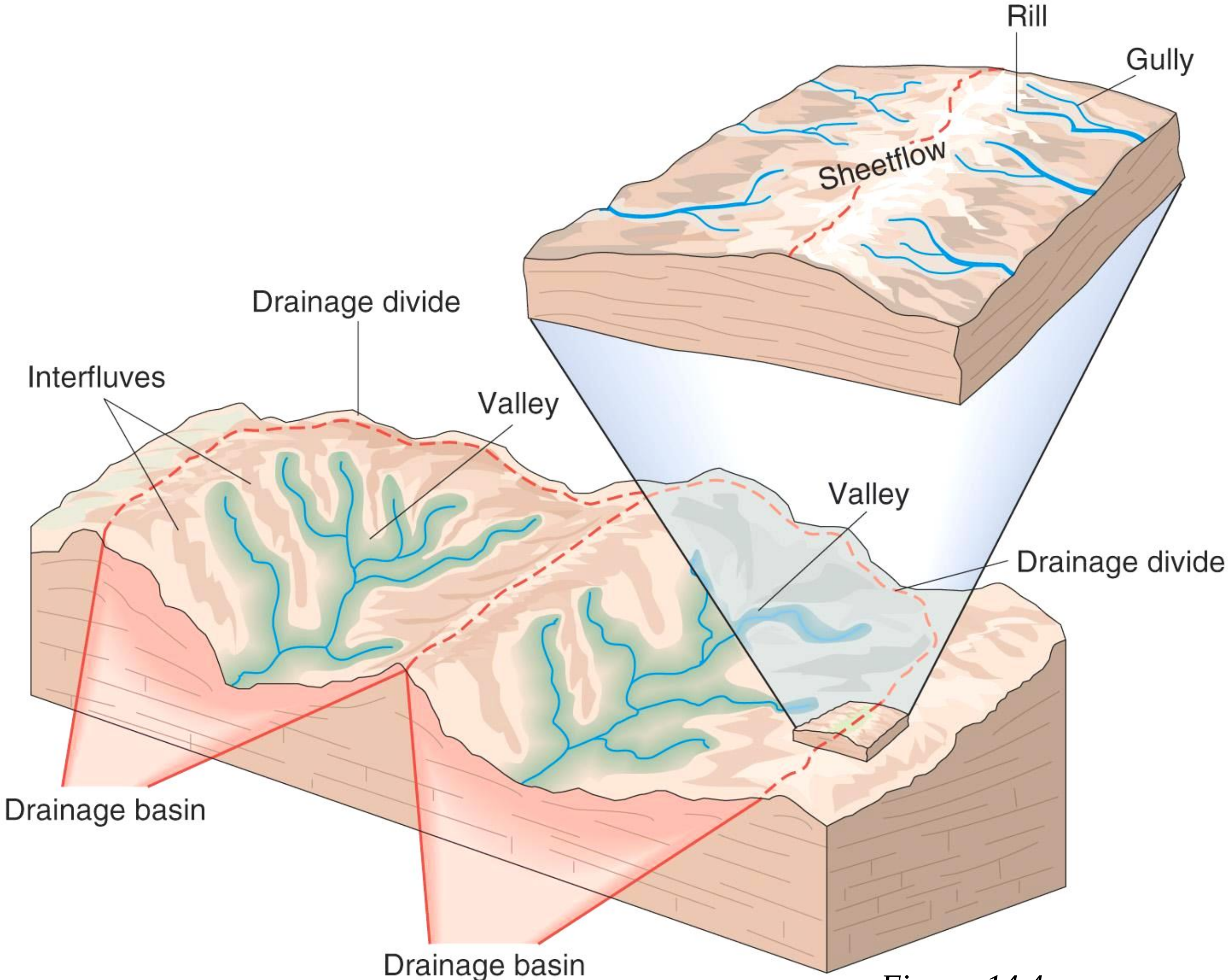

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Figure 14.4

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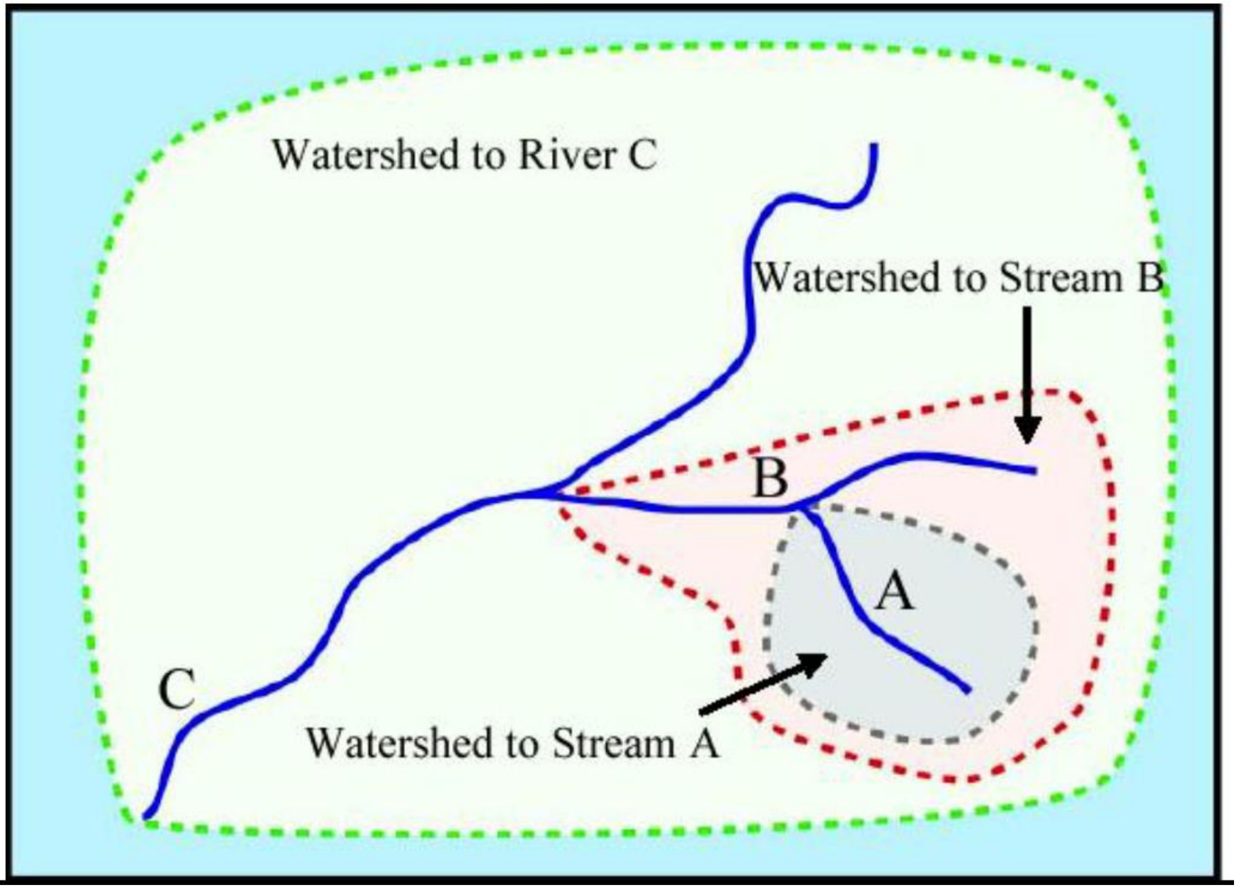
The conceptual watershed

All land is in one watershed or another



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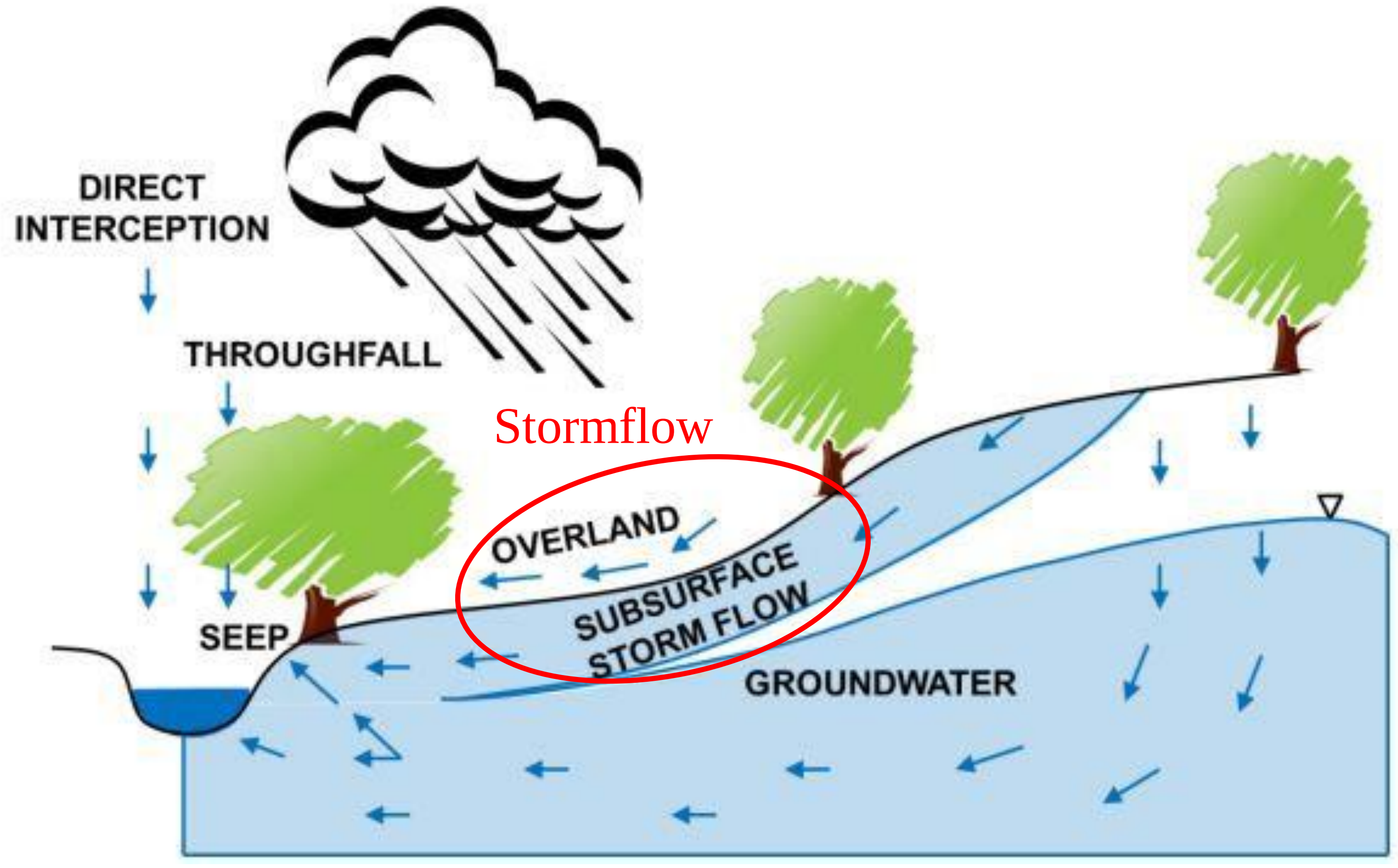
Stormflow



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Infiltration

- Infiltration
  - Movement of water into soil pores
- Infiltration rate
  - Amount soaking in over time

- Infiltration capacity
  - Maximum rate water infiltrates a soil
- Macropores (>75μm)
- Gravity
- Capillary action

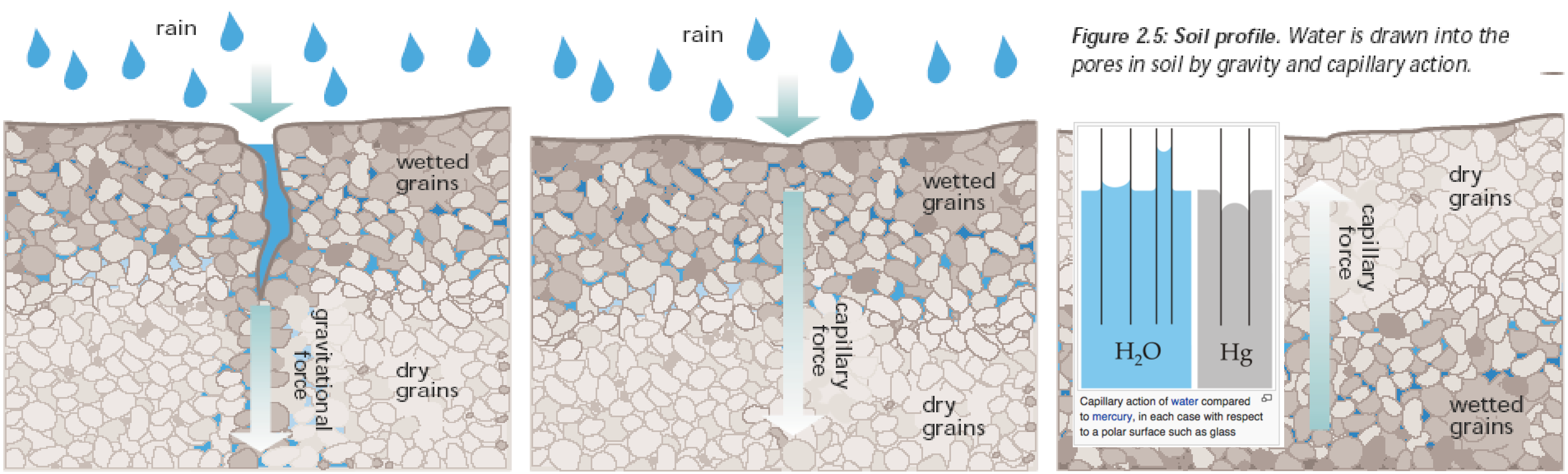

Figure 2.5: Soil profile. Water is drawn into the pores in soil by gravity and capillary action.

Infiltration and Runoff

- No Runoff if Rainfall Rate < Infiltration Rate
- If Rainfall Rate > Infiltration Rate
  - Water stands in small depressions
  - Travels down slope as Surface Runoff

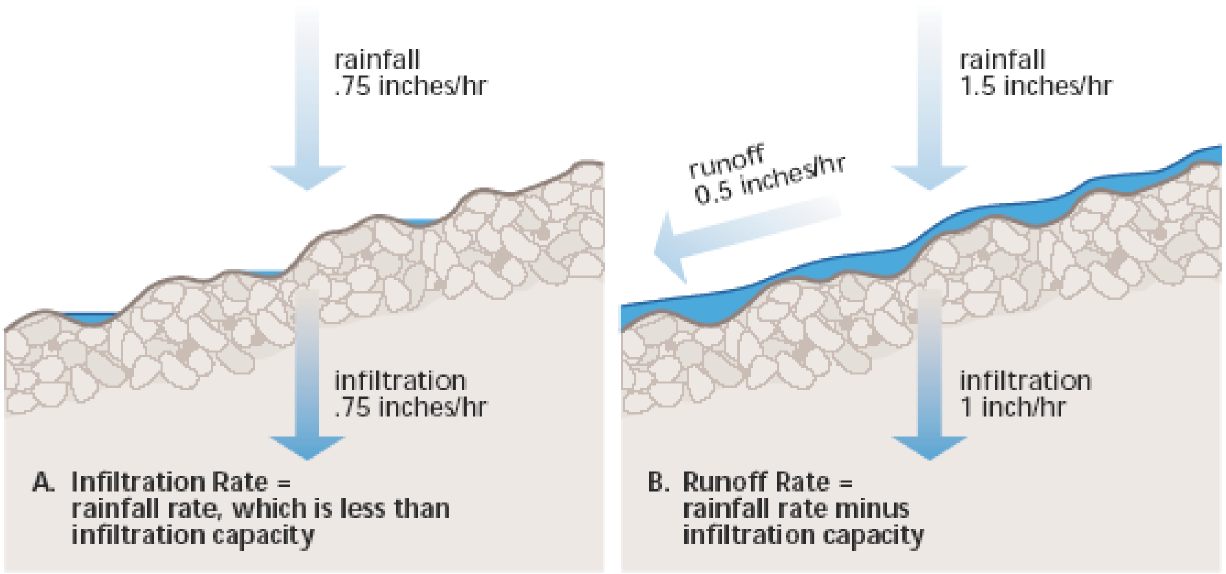

Figure 2.6: Infiltration and runoff. Surface runoff occurs when rainfall intensity exceeds infiltration capacity.

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Infiltration Rate of a Soil

- Determined by
  - Ease of entry through soil surface
  - Storage capacity of soil
  - Transmission rate through soil

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Runoff

- If Rainfall Rate > Infiltration Rate = runoff and standing depressions
- Overland flow

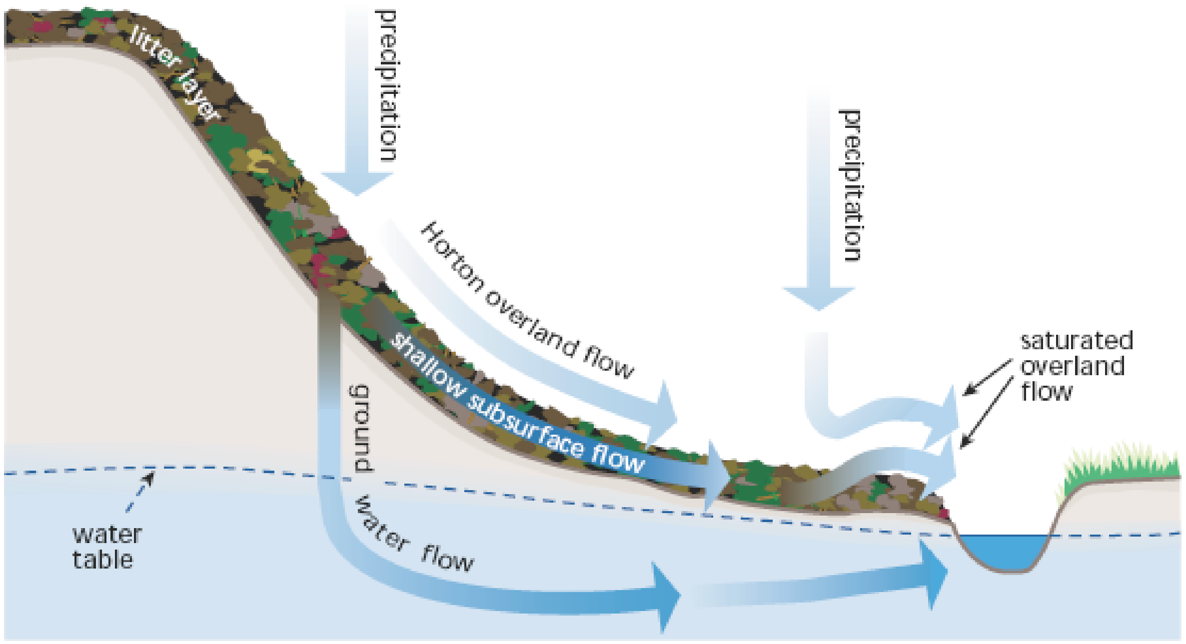

Figure 2.10: Flow paths of water over a surface. *The portion of precipitation that runs off or infiltrates to the ground water table depends on the soil's permeability rate; surface roughness; and the amount, duration, and intensity of precipitation.*

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Subsurface Flow

- *Subsurface flow* mixes with baseflow and increases ground water discharge to the channel

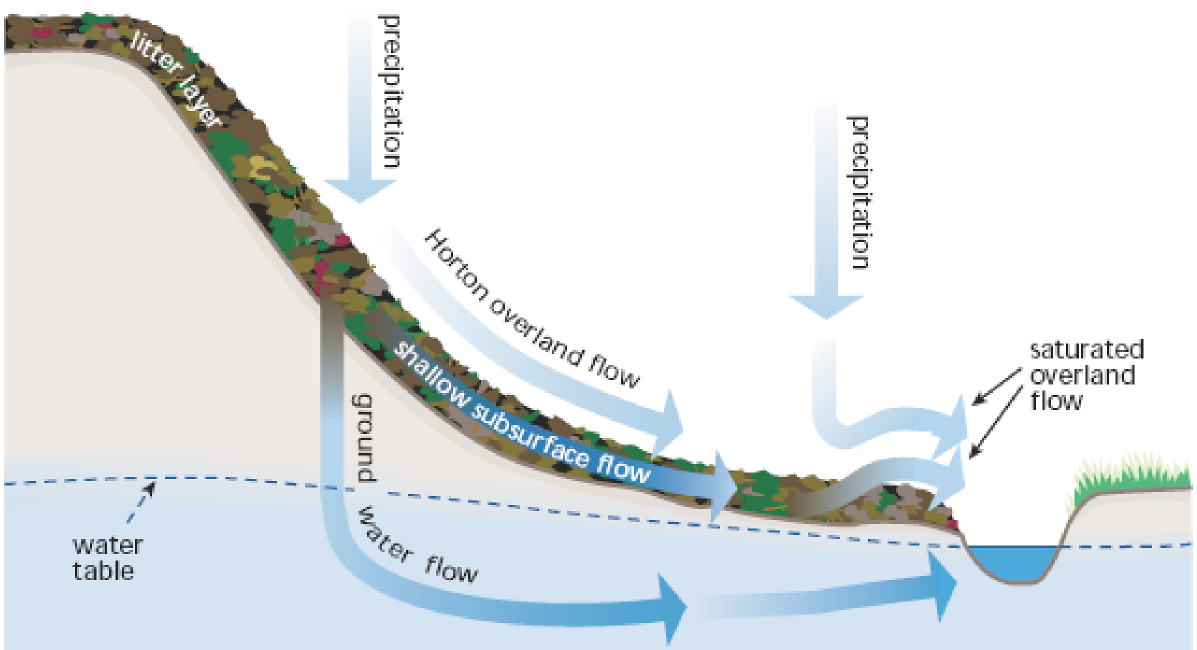

Figure 2.10: Flow paths of water over a surface. *The portion of precipitation that runs off or infiltrates to the ground water table depends on the soil's permeability rate; surface roughness; and the amount, duration, and intensity of precipitation.*

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Saturated Overland Flow

- Ground water breaks out of soil and travels to stream as overland flow or *quick return flow*
- Rainfall becomes > infiltration rate, and all rainfall flows downslope as overland runoff
- Combination of direct precipitation and quick return flow is called *saturated overland flow*

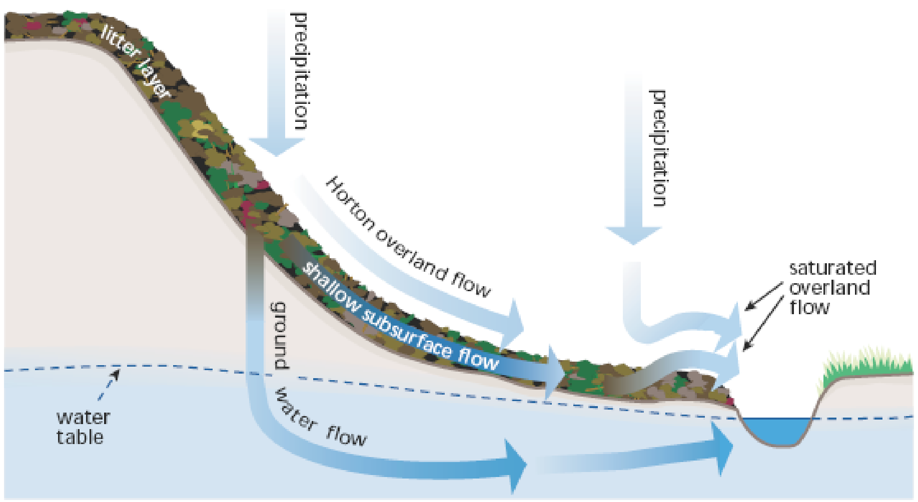

Figure 2.10: Flow paths of water over a surface. The portion of precipitation that runs off or infiltrates to the ground water table depends on the soil's permeability rate; surface roughness; and the amount, duration, and intensity of precipitation.

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Primary Factors Influencing Runoff

- Land use/land cover
- Hydrologic soil groups

Table 1 HSG based on USDA soil classification

HSG	Soil Texture
A	Sand, loamy sand or sandy loam
B	Silt or loam
C	Sandy clay loam
D	Clay loam, silt clay loam, sandy clay, silty clay, or clay

- Precipitation intensity
- Topography
- Antecedent watershed conditions
  - Saturated soils
  - Frozen soils/snowcover

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Runoff Curve Numbers – developed urban lands

Cover description		Curve numbers for hydrologic soil group			
		A	B	C	D
Open space (lawns, parks, golf courses, cemeteries, etc.)	Poor condition (grass cover <50%)	68	79	86	89
	Fair condition (grass cover 50 to 75%)	49	69	79	84
	Good condition (grass cover >75%)	39	61	74	80
Impervious areas	Paved parking lots, roofs, driveways, etc. (excluding right of way)	98	98	98	98
Streets and roads	Paved; curbs and storm sewers (excluding right-of-way)	98	98	98	98
	Paved; open ditches (including right-of-way)	83	89	92	93
	Gravel (including right of way)	76	85	89	91
	Dirt (including right-of-way)	72	82	87	89
Western desert urban areas	Natural desert landscaping (pervious area only)	63	77	85	88
	Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)	96	96	96	96
Urban districts	Commercial and business (85% imp.)	89	92	94	95
	Industrial (72% imp.)	81	88	91	93
Residential districts by average lot size	⅛ acre or less (town houses) (65% imp.)	77	85	90	92
	¼ acre (38% imp.)	61	75	83	87
	⅓ acre (30% imp.)	57	72	81	86
	½ acre (25% imp.)	54	70	80	85
	1 acre (20% imp.)	51	68	79	84
	2 acres (12% imp.)	46	65	77	82

Runoff Curve Numbers for agricultural lands

Cover description			Curve numbers for hydrologic soil group			
Cover type	Treatment	Hydrologic condition	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T + R	Poor	65	73	79	81
		Good	61	70	77	80

Runoff Curve Numbers for agricultural lands

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing.	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element.	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30[C]	48	65	73
Woods—grass combination (orchard or tree farm).	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods.	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

Near Surface Water Movement

- Forests moderate runoff
- Interception
  - Leaf shape & texture
  - Time of year
  - Vertical and horizontal density
  - Vegetation age
- Throughfall
- Stemflow

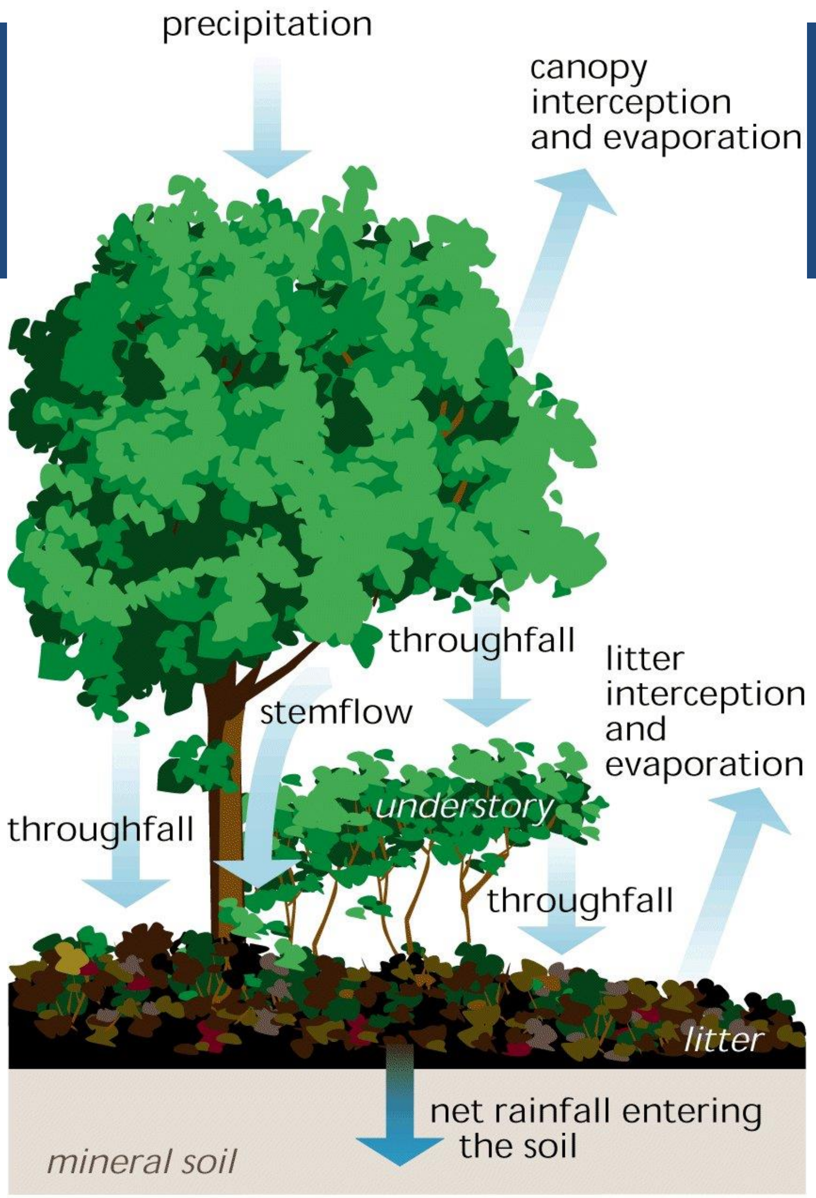
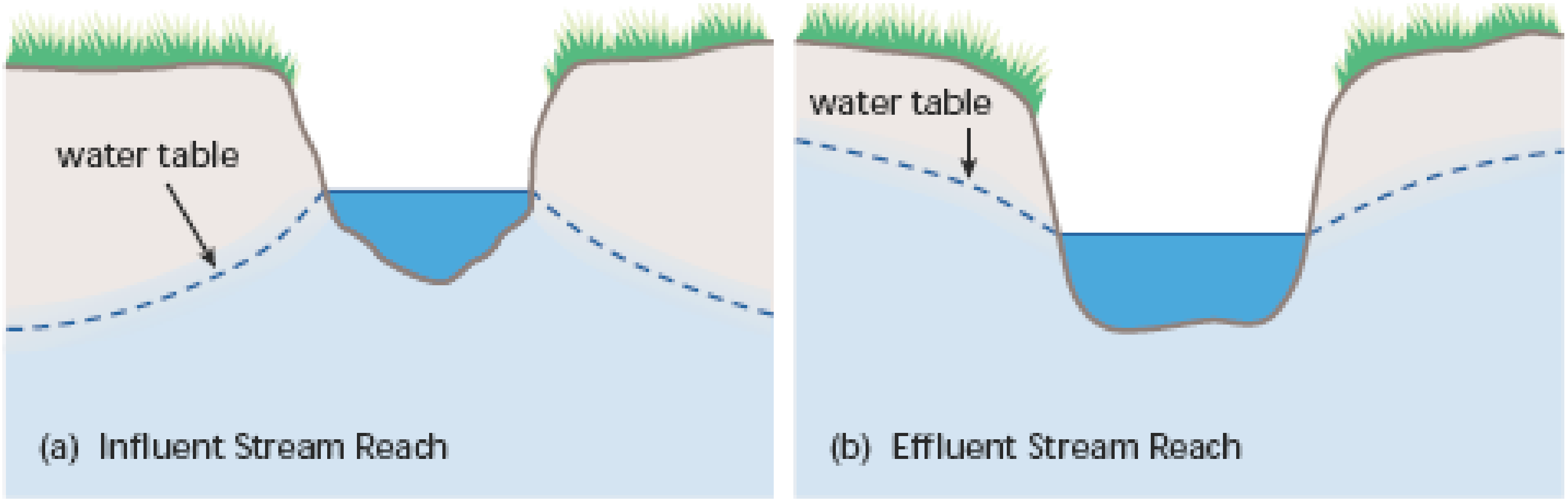


Fig. 2.3 -- Typical pathways for forest rainfall. A portion of precipitation never reaches the ground because it is intercepted by vegetation and other surfaces.
In Stream Corridor Restoration: Principles, Processes, and Practices (10/98).
Interagency Stream Restoration Working Group (15 federal agencies)(FISRWG).

Ecological Infiltration Benefits

- Supports stream flow during dry weather periods
- Water is cleaned of pollutants and nutrients by soil organisms and plant roots



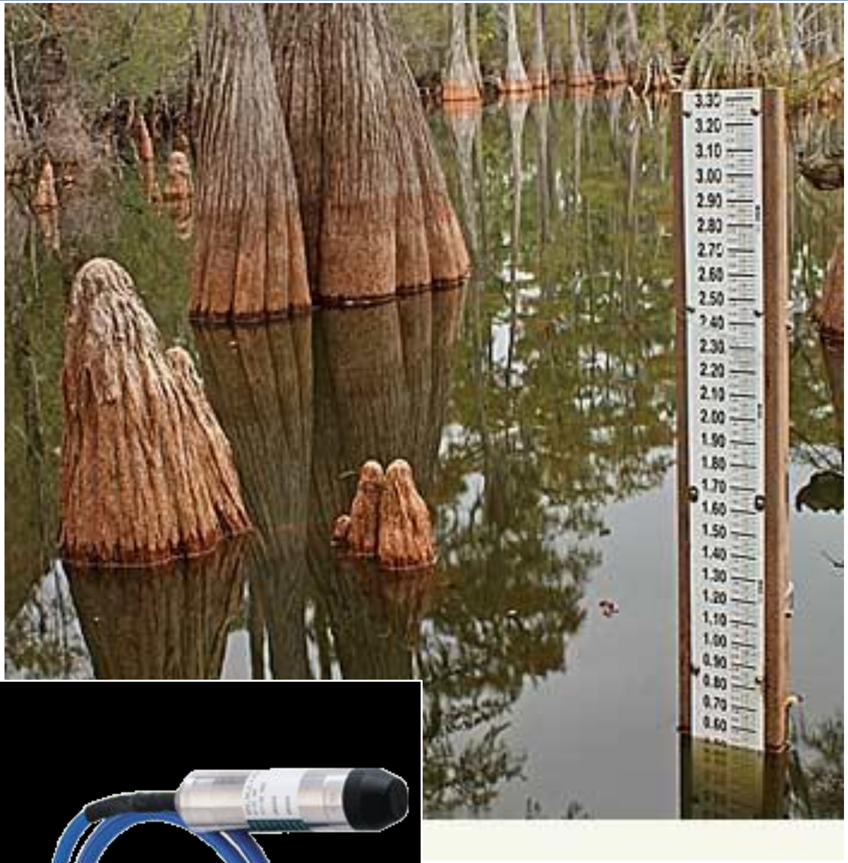
Stream Flow

- Perennial – permanently flowing (precip or groundwater abundant)
- Ephemeral – flow only during or immediately after precipitation (runoff dominated)
- Intermittent – flow only during certain times of the year (typically seasonal groundwater table intersecting channel)

  - Seasonal and typically flowing >30 days/yr

River Stage – What is it?

- Water level at some arbitrary reference point
  - Usually with zero being near streambed but also could be referenced to actual elevation above sea level
  - Historically measured with graduated staff gage – but pressure transducers now in addition



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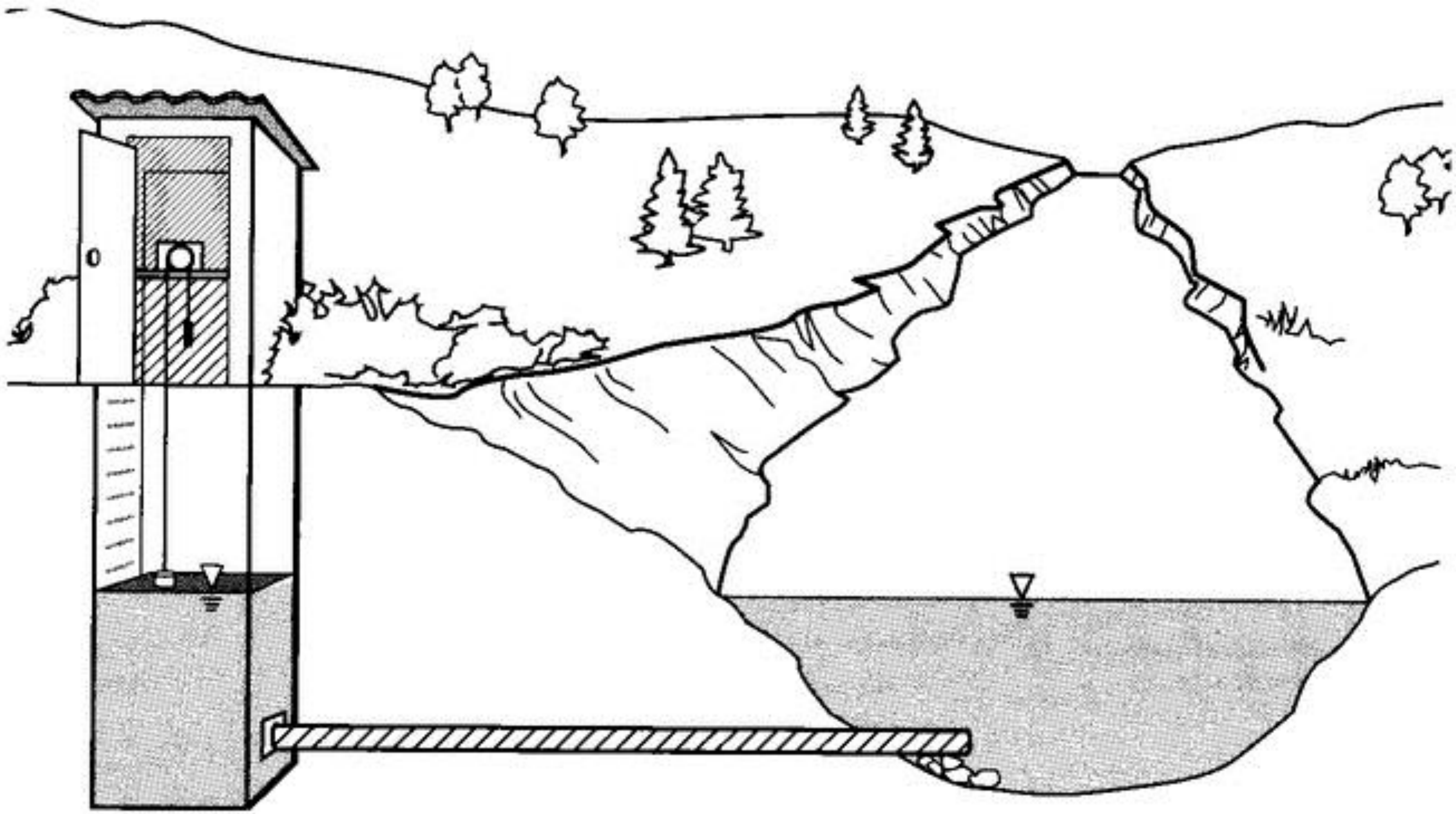
Stream Gage



Measurement of Discharge

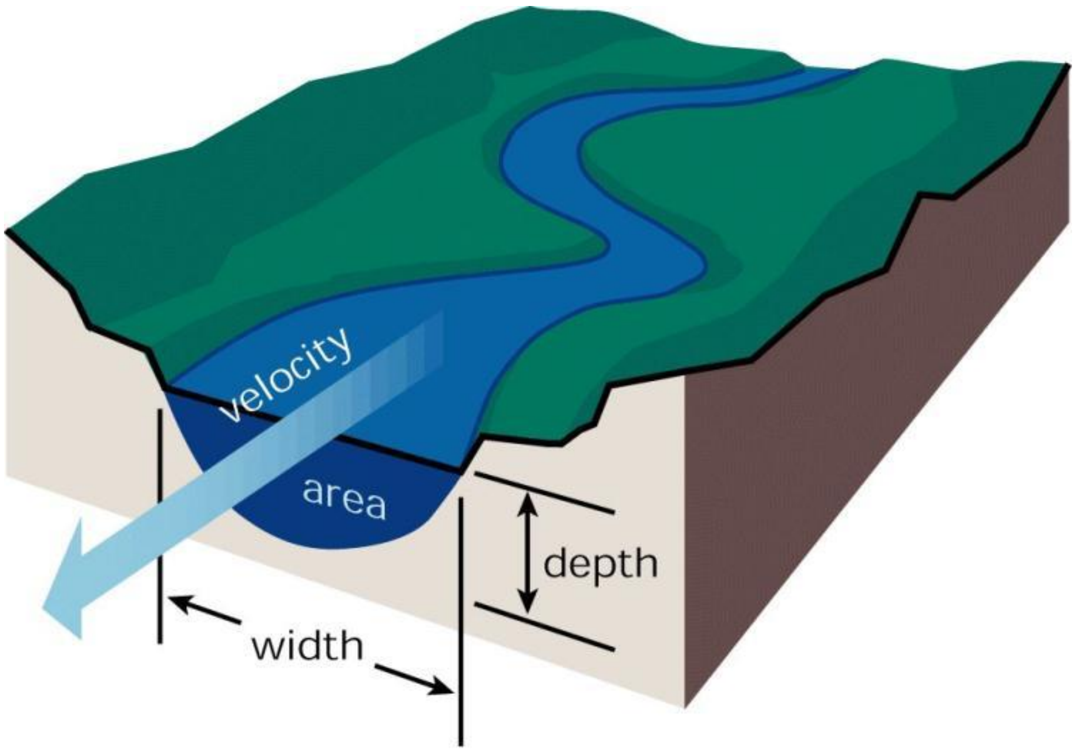
- Discharge – volume of water passing point in channel per unit time
- Channelized Streamflow - Q = A * v

  Q = discharge, m^3/s

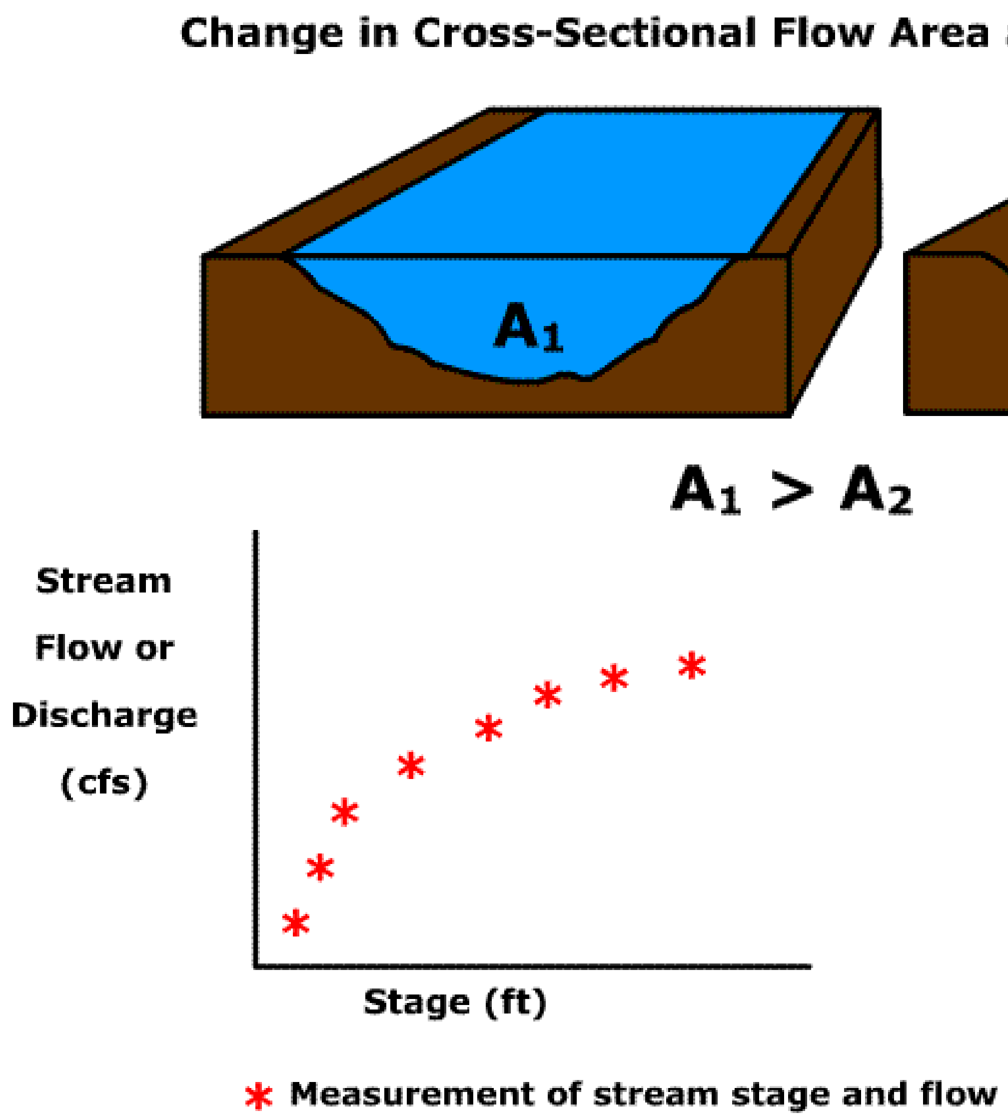
  A = x-sectional area

  (m^2) = Depth * Width

  v = velocity (m/s)



Rating Curves



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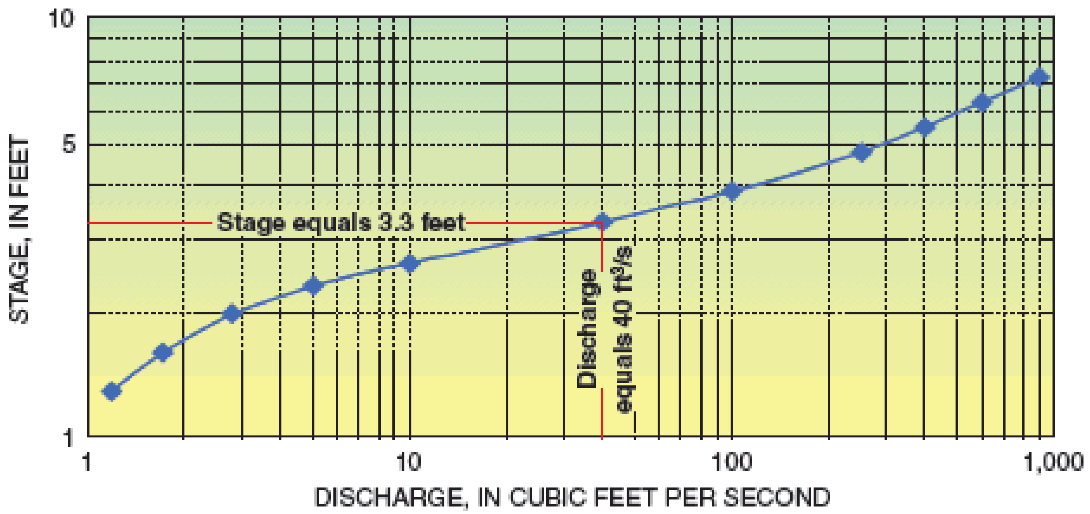
Rating curves



Example of a typical stage-discharge relation; here, the discharge of the river is 40 cubic feet per second (ft^3/s) when the stage is 3.30 feet (ft). The dots on the curve represent concurrent measurement of stage and discharge.

- Plot of river stage vs. discharge
- Based on cross-sectional area

http://water.usgs.gov/edu/streamflow3.html

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Anatomy of the Hydrograph

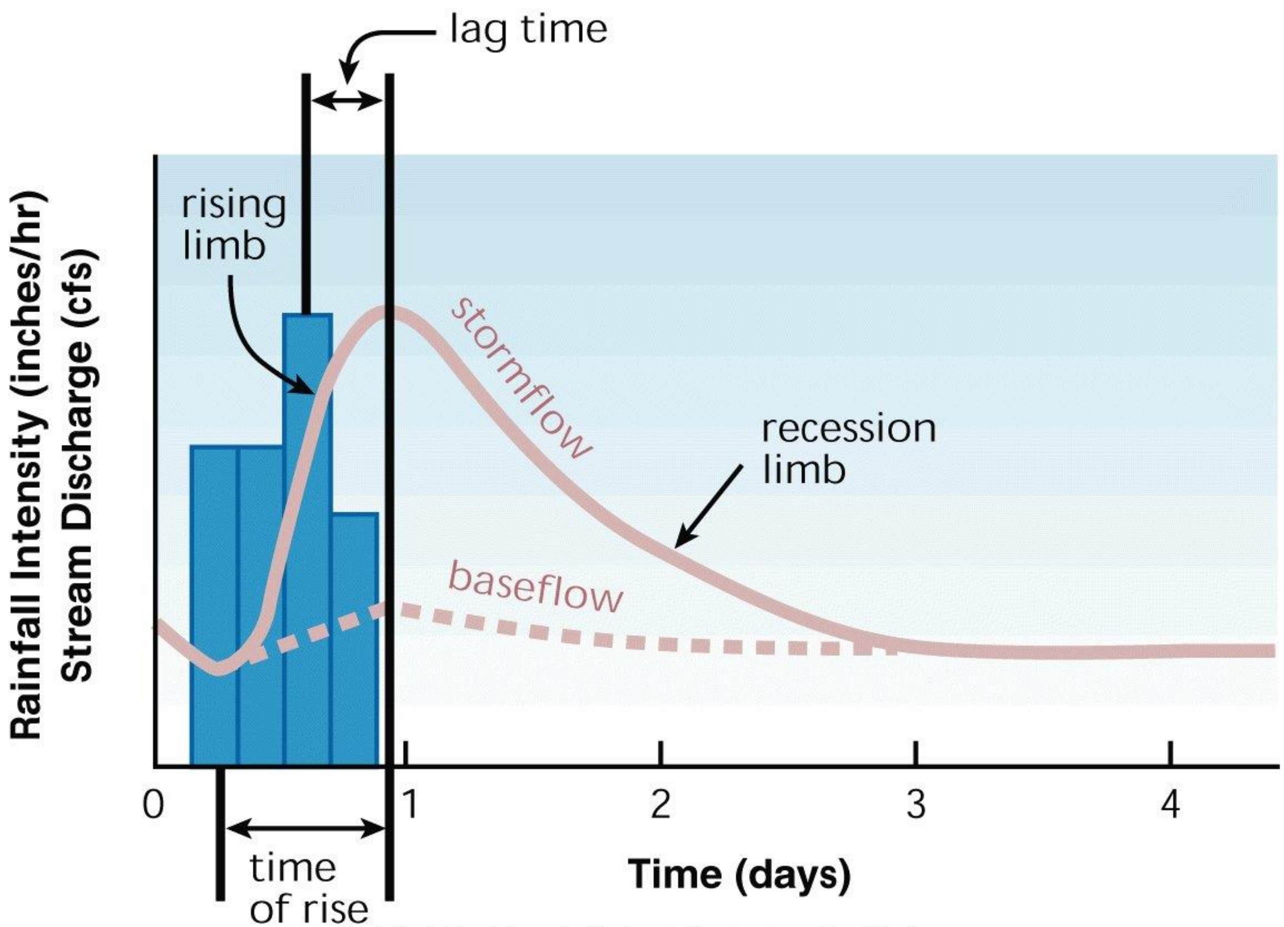

Fig. 1.14 – A storm hydrograph. A hydrograph shows how long a stream takes to rise from baseflow to maximum discharge and then return to baseflow conditions. In Stream Corridor Restoration: Principles, Processes, and Practices (10/98). Interagency Stream Restoration Working Group (15 federal agencies)(FISRWG).

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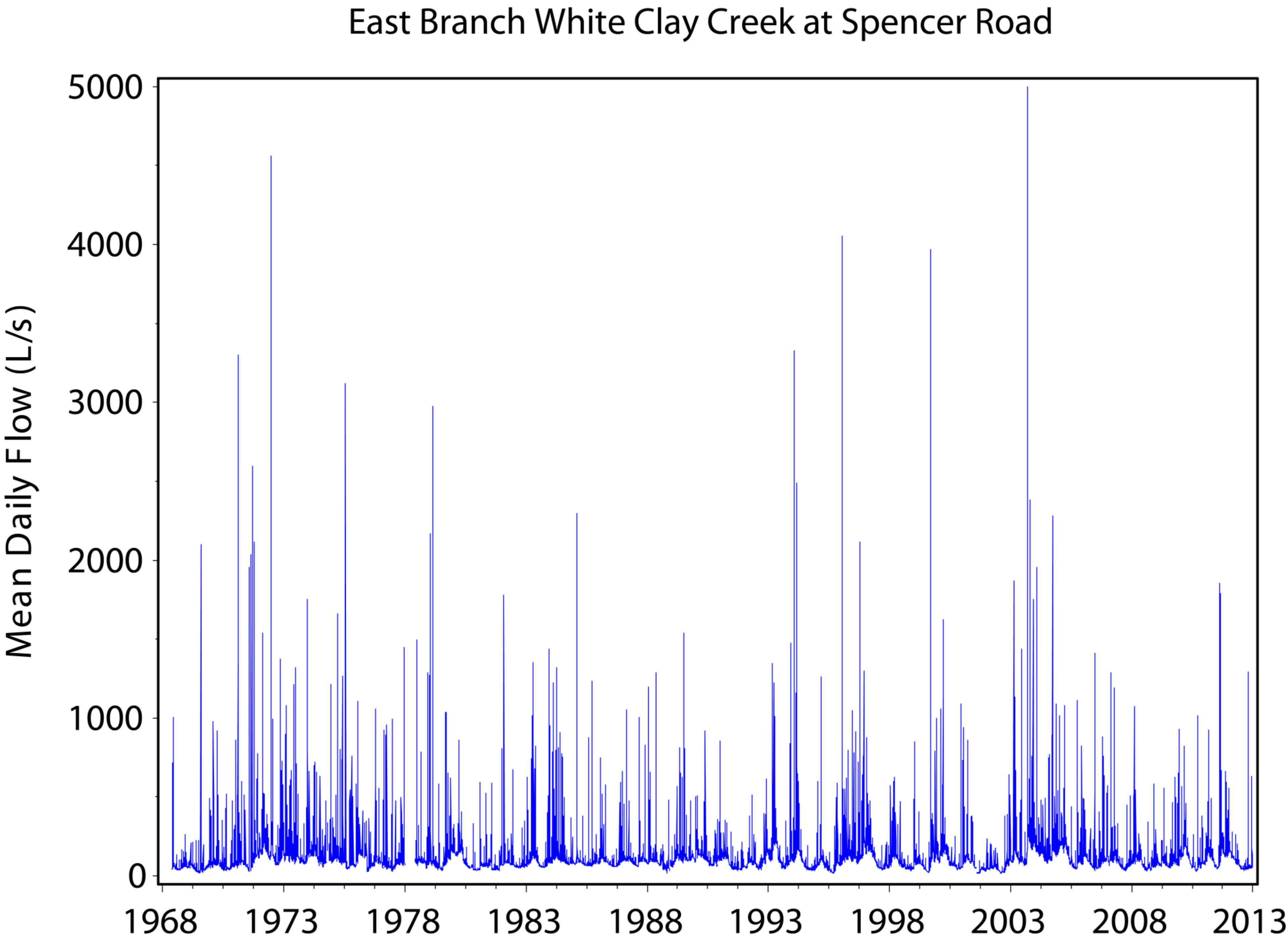
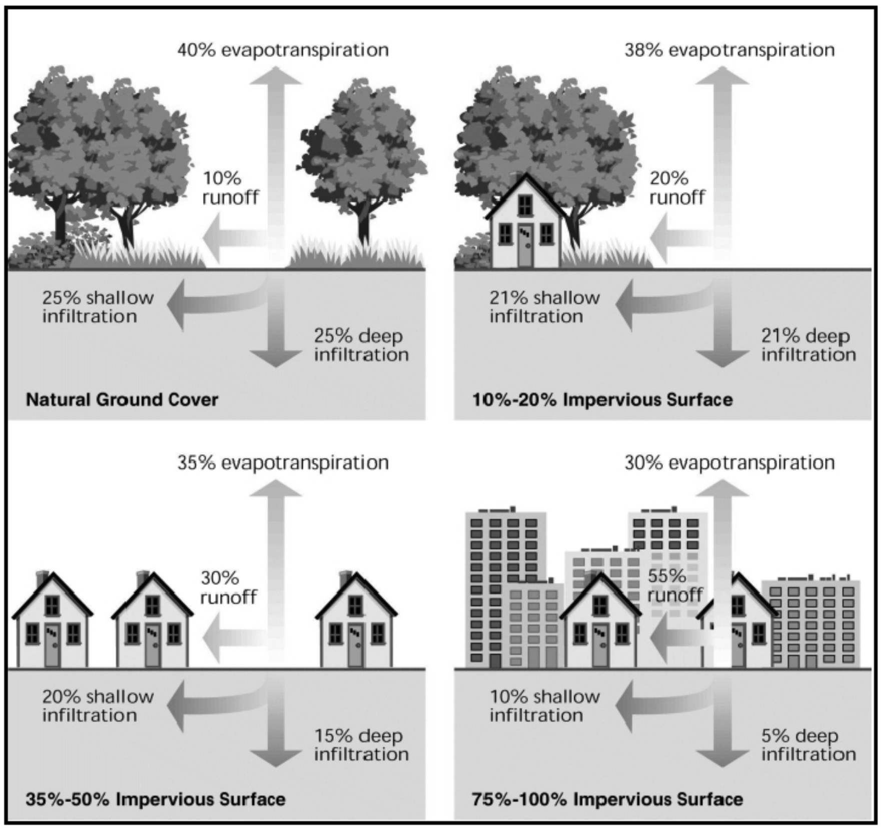
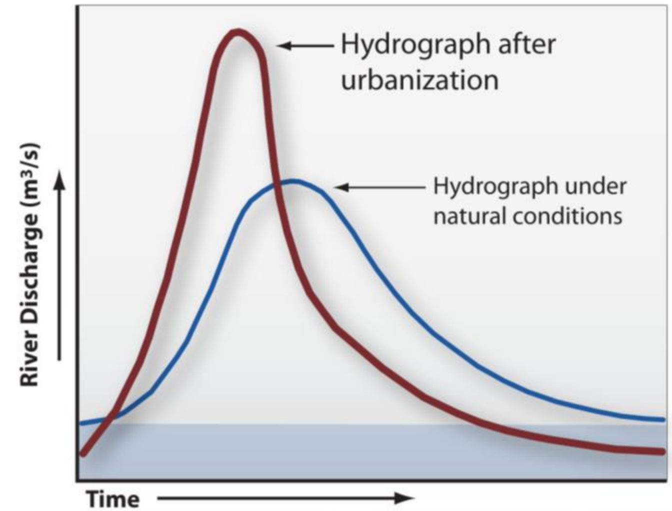

East Branch White Clay Creek at Spencer Road
Mean Daily Flow (L/s)
5000
4000
3000
2000
1000
0
1968
1973
1978
1983
1988
1993
1998
2003
2008
2013

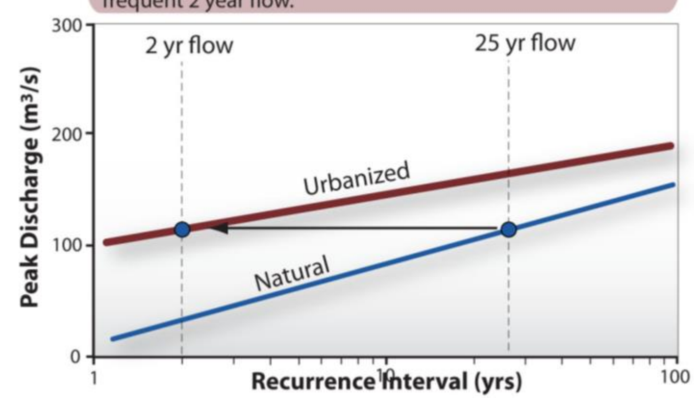
Watershed Land Use Change





Before development, rainfall followed a more convoluted path through the landscape - held in detention storage by pit and mound topography, infiltrating into organic-rich forest soil and moving slowly to the channel. The infiltrating water fed baseflow during times when it was not raining. Flood peaks were lower and came later.

After urbanization, rainfall moves rapidly to the channel with little chance to infiltrate during storms, thus baseflow is reduced. Flowing directly off impervious surfaces such as parking lots, runoff enters streams quickly raising their level. Flood peaks now come sooner and are higher, increasing flood hazards and the tempo of geomorphic change. For example, the natural 25 yr flow becomes the much more frequent 2 year flow.



Anthropogenic Extensions of the Stream Network

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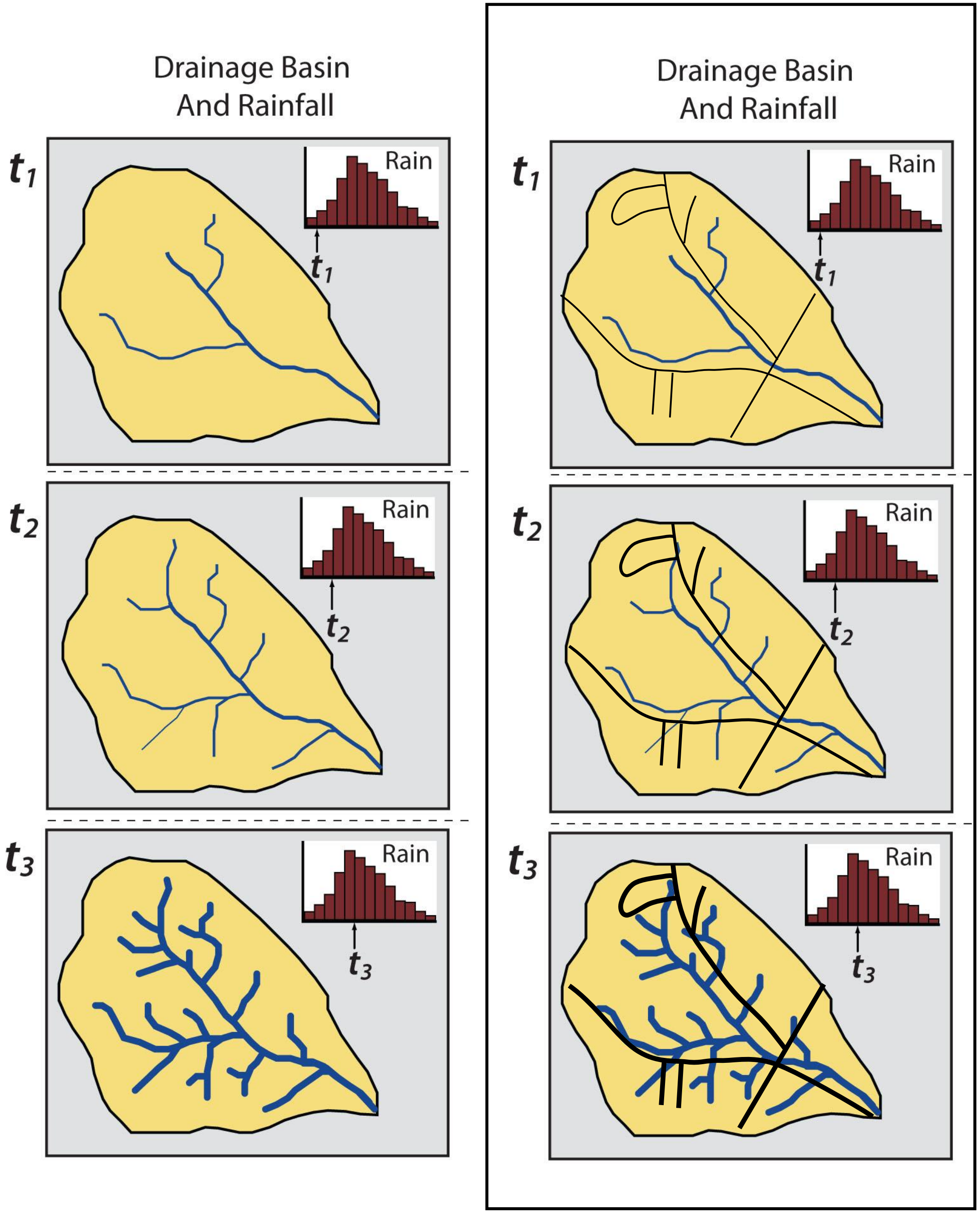
Baseflow

Early Stormflow

Peak Stormflow



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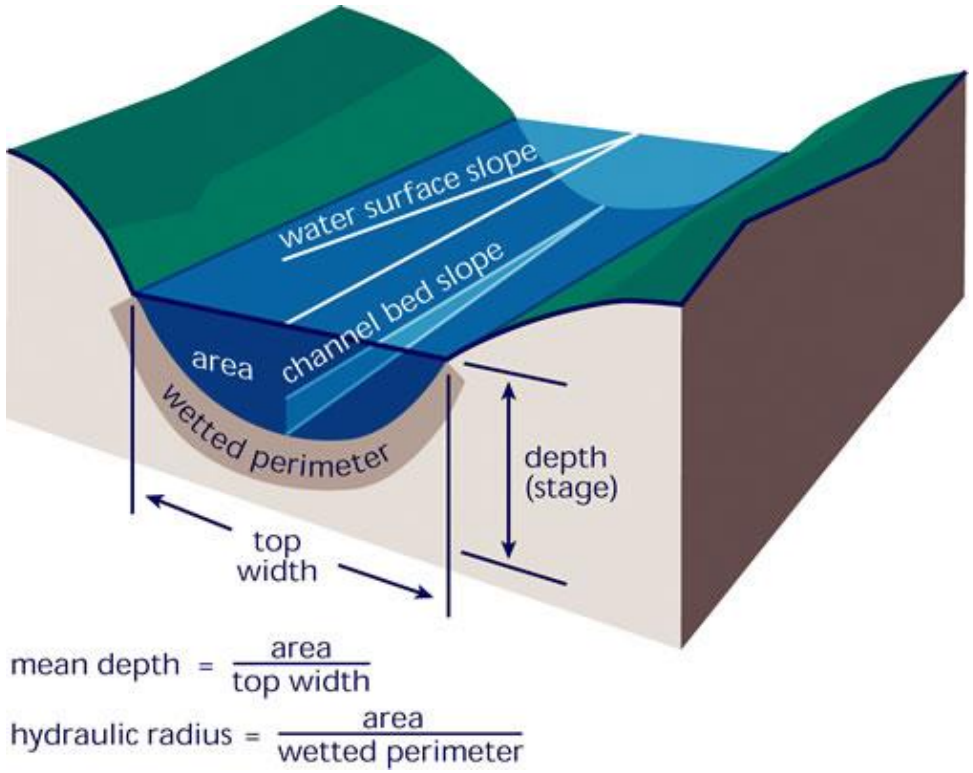
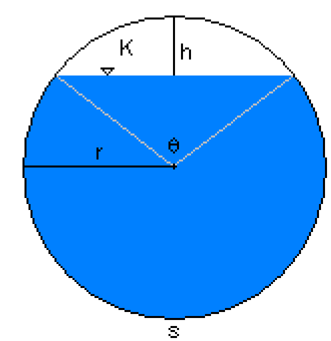
Stream Channel Geometry





- Cross-Sectional Area A = W * D
- Wetted Perimeter WP = W + 2D
- Hydraulic Radius R = A/WP

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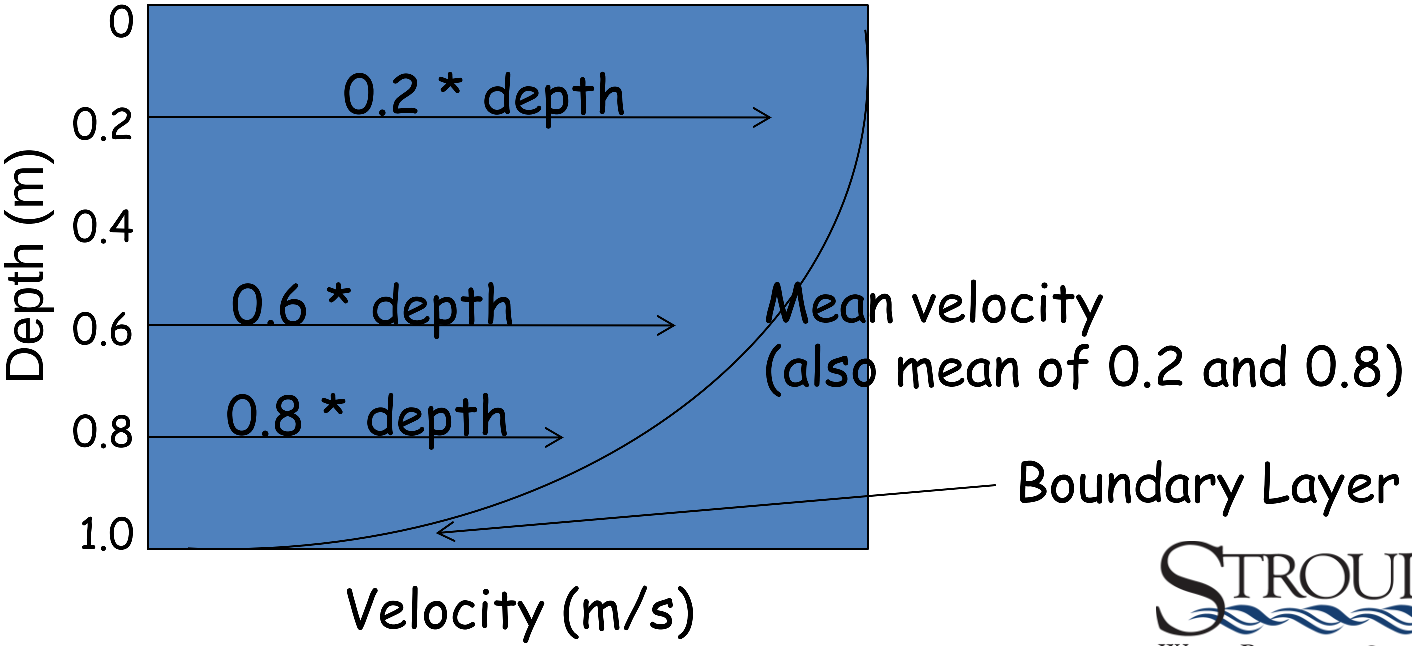
Current Velocity (V)

- Perhaps most significant characteristic affecting the biology in streams
- Mean V related to Q, D, W, and bed roughness

Current Velocity

- Near bed velocity depends on bed roughness
- Drag from Banks and air-water interface



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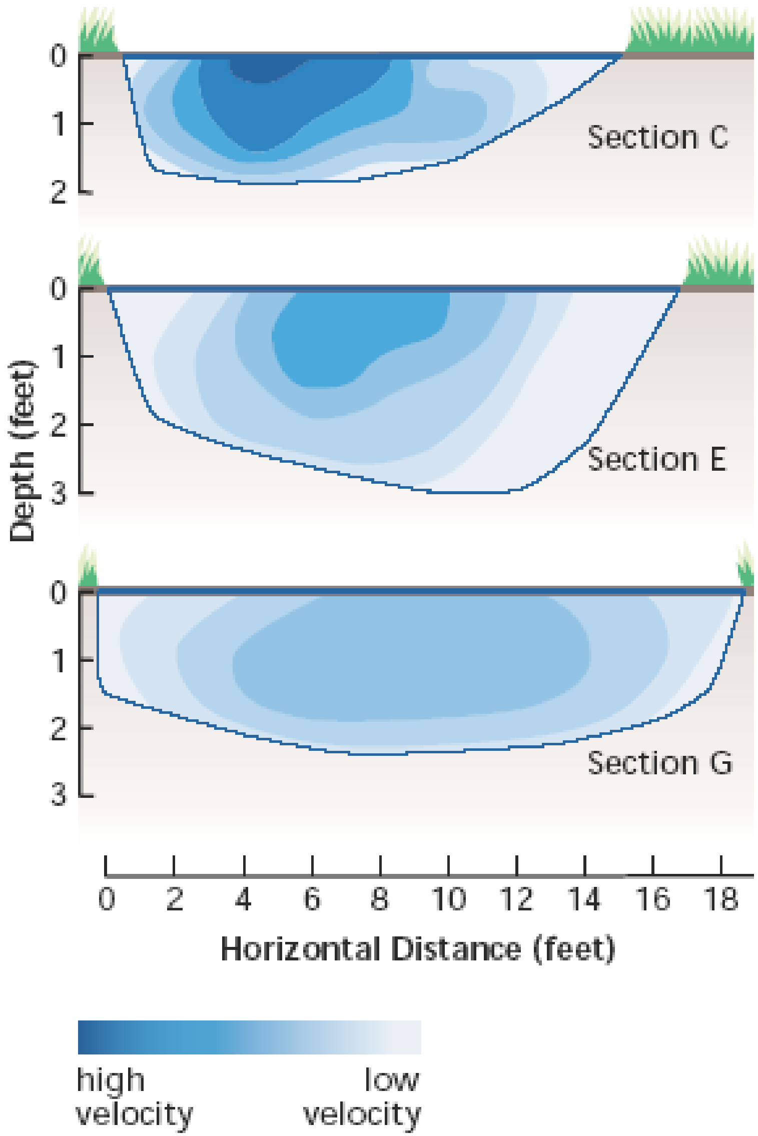
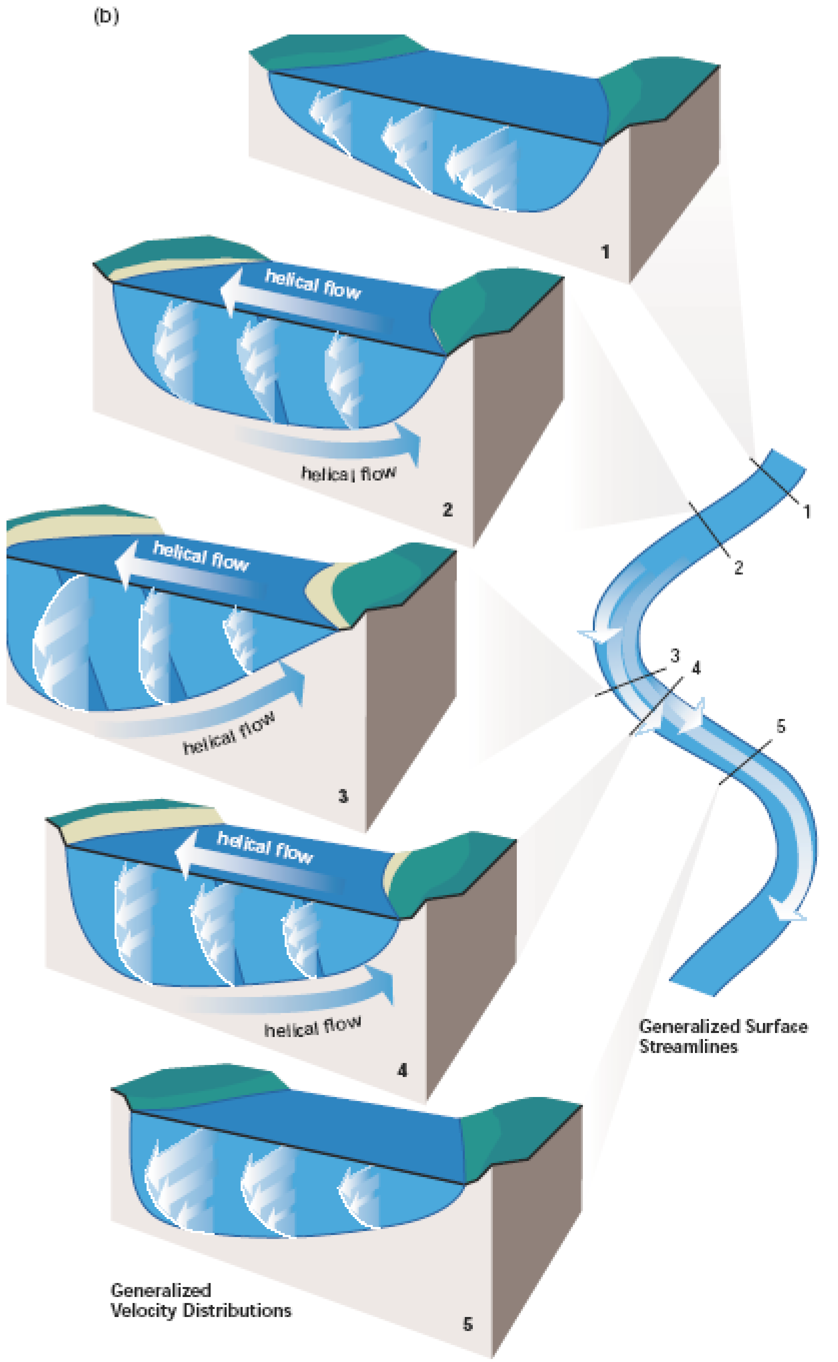
Channel Velocity





FLUVIAL GEOMORPHOLOGY

Learning objectives:

Understand the nature and sources of sediment loads in streams

Understand how scientists measure stream water and sediment discharge

Watershed's location and condition - determines the physical, chemical (and biological) conditions of the ecosystem

- Topography (mountains, valley, ridges, slopes) – determines climate, flow direction and speed
- Climate - determines precipitation, temperature, and humidity
- Geology (soils, bedrock) – water chemistry, water inputs to streams
- Vegetation - Influences organic and water inputs, water chemistry, temperature, shading

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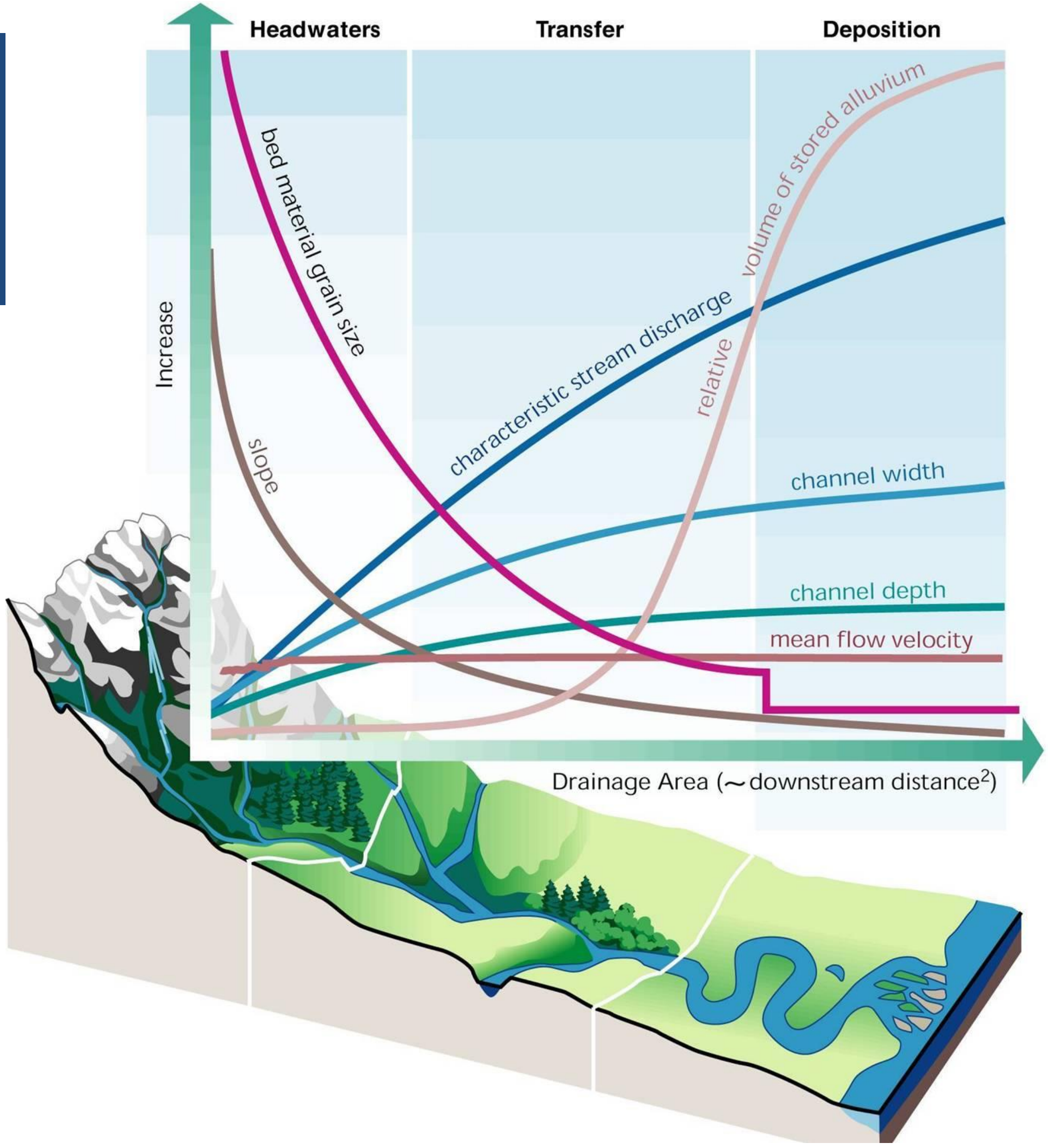
Longitudinal Trends

- Slope
- Bed material grain size
- Discharge
- Channel width and depth
- Mean flow velocity
- Relative volume of stored alluvium



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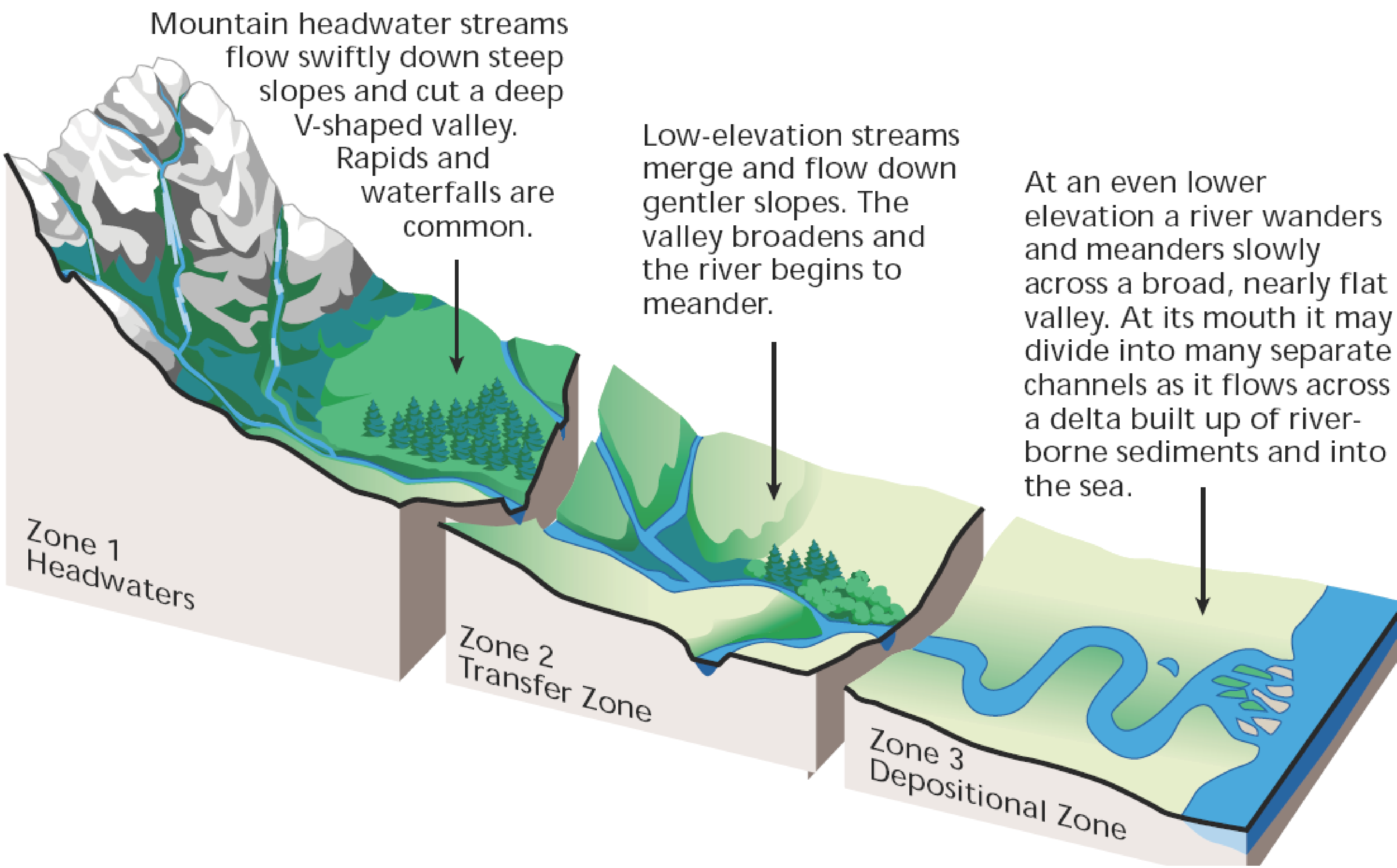
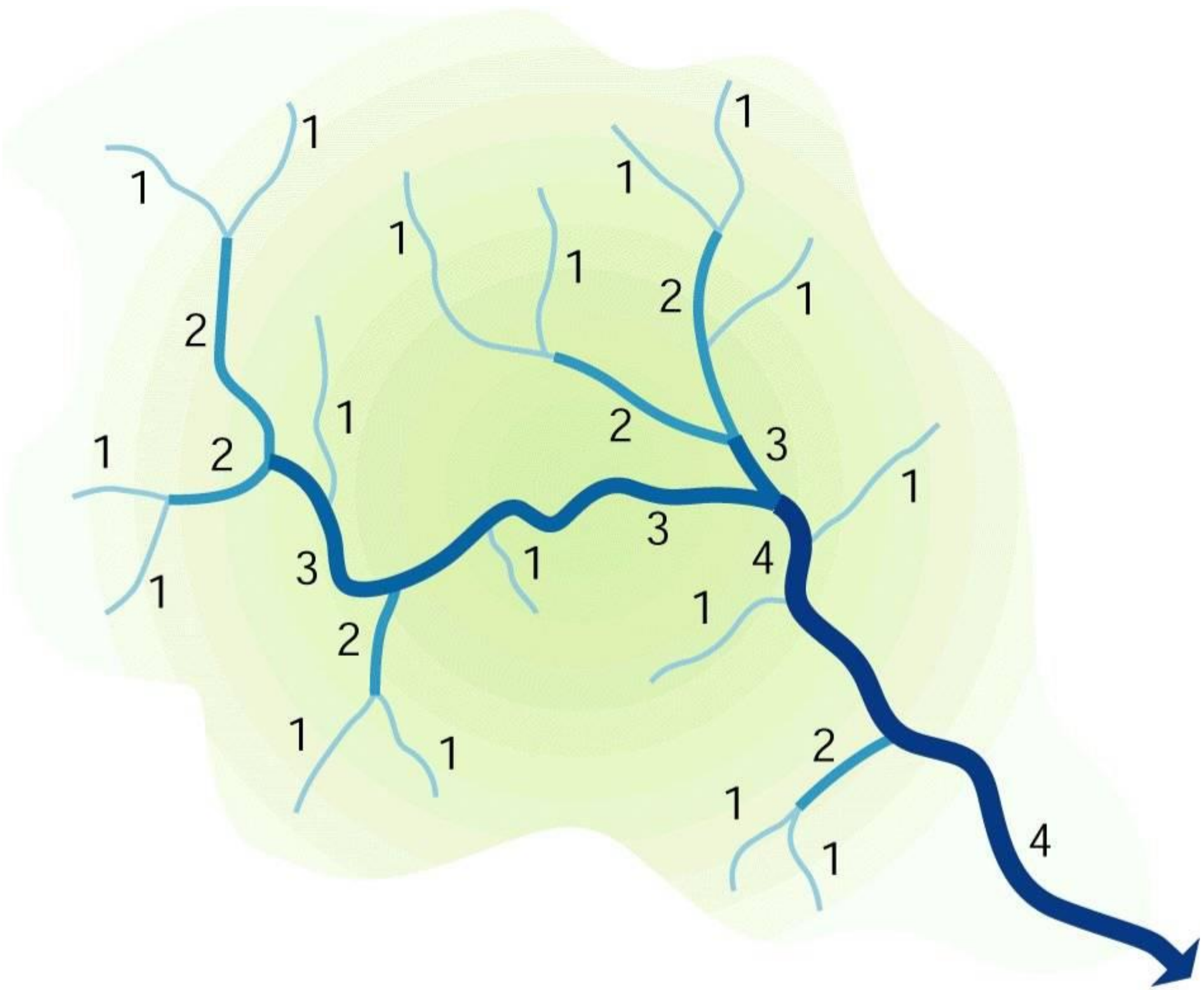


Figure 1.27: Three longitudinal profile zones. *Channel and floodplain characteristics change as rivers travel from headwaters to mouth.*

Source: Miller (1990). ©1990 Wadsworth Publishing Co.

Stream order



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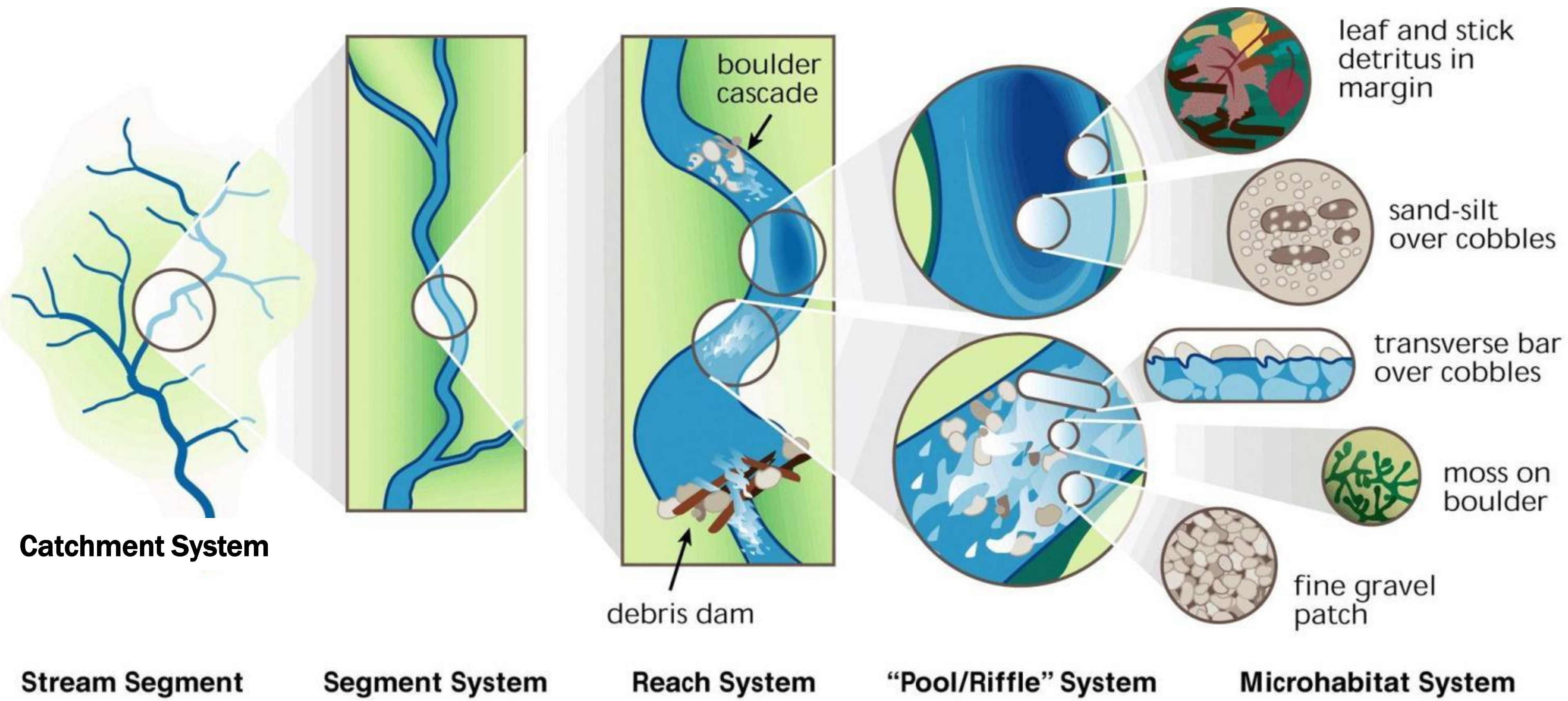
How Do We Study Streams?



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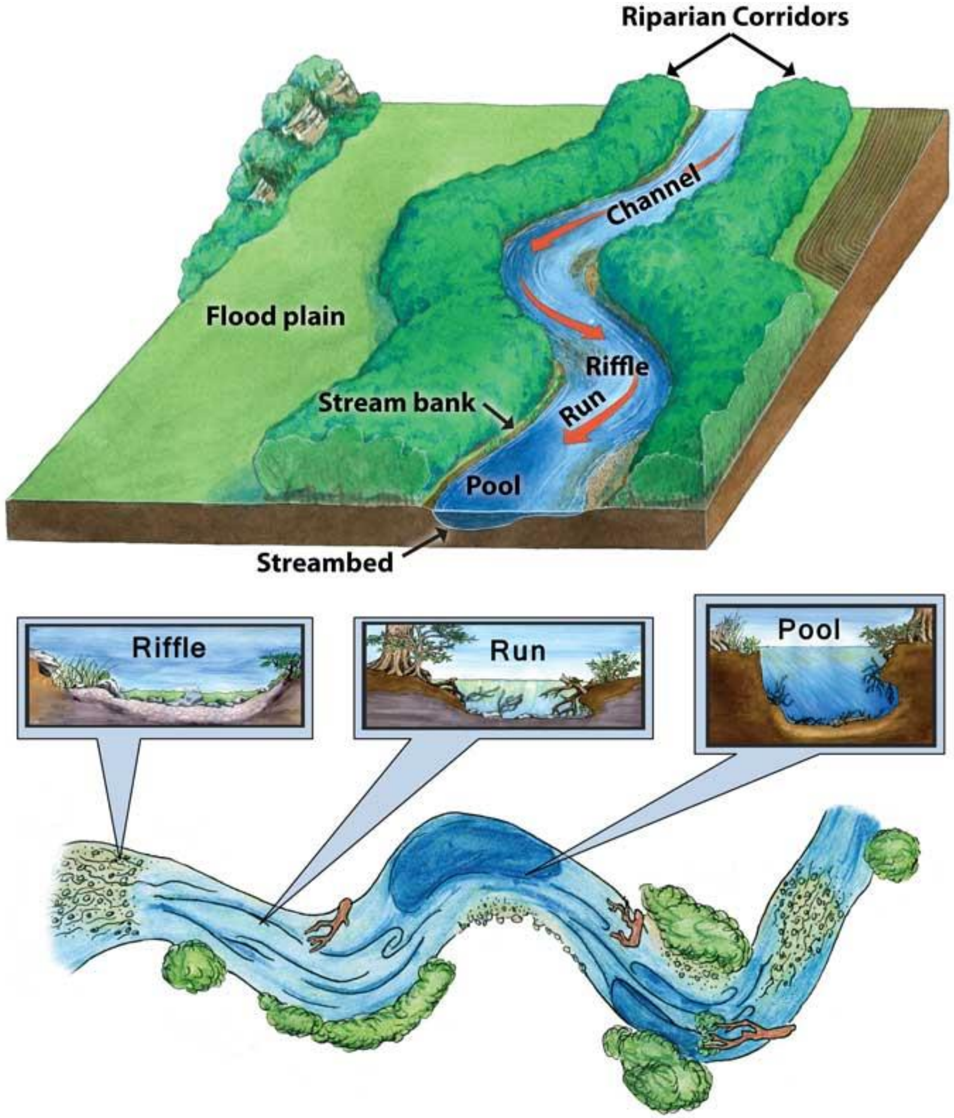
Stream features



http://texasaquaticscience.org/wp-content/uploads/2013/07/C8_fig_8.1-aquatic-science-texas.jpg

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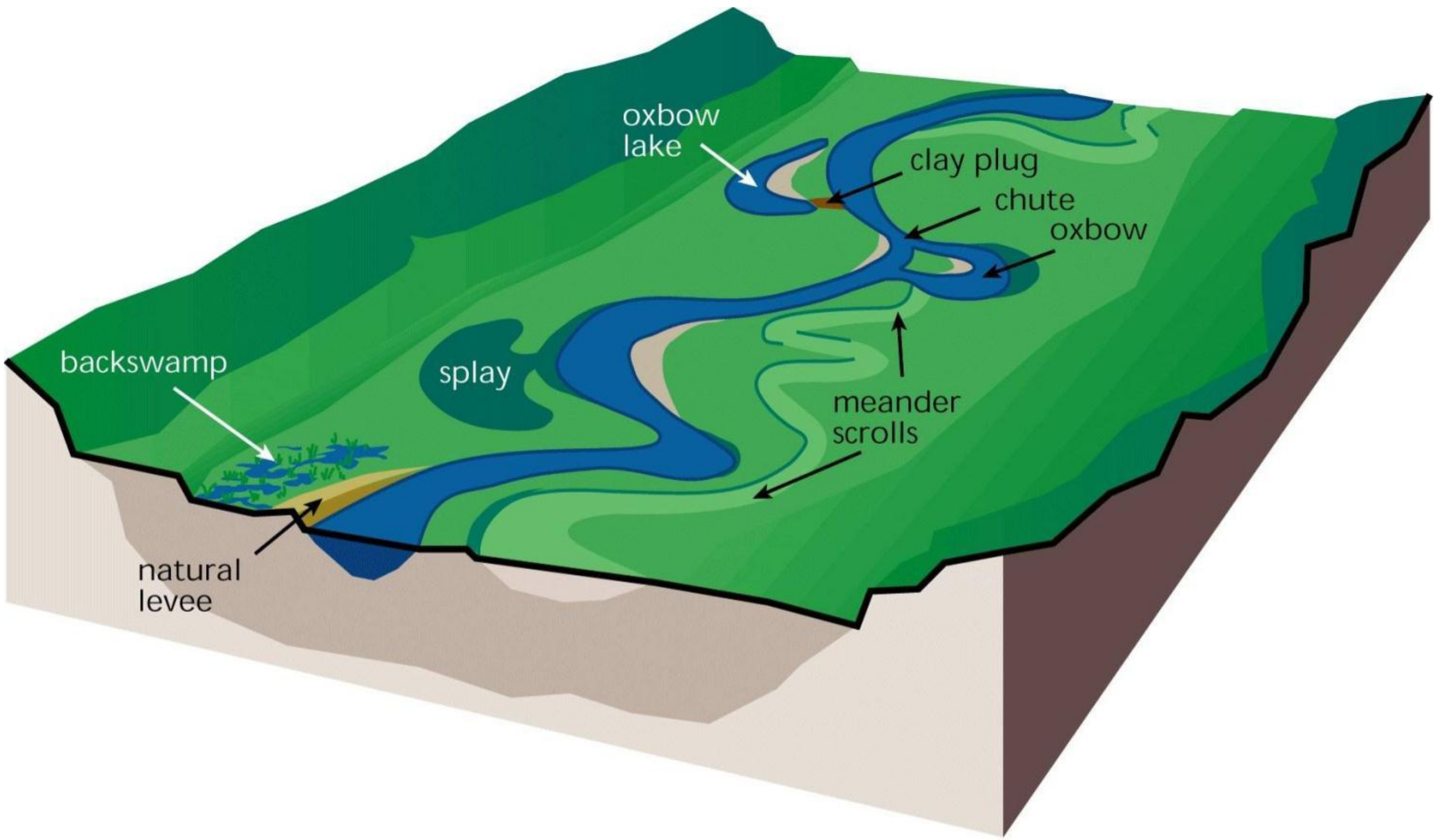
Stream system features



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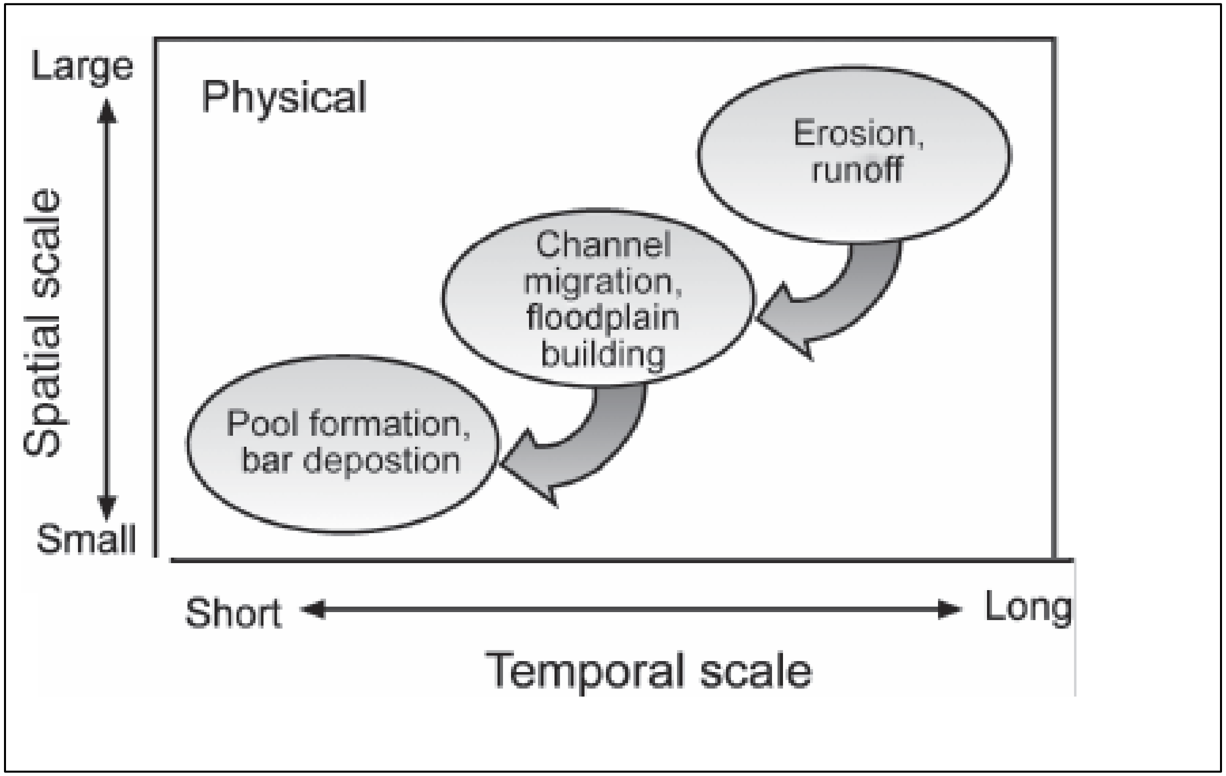
Important to evaluate landscape to local scales

Natural River

Driving Disturbance Agents

Altered River



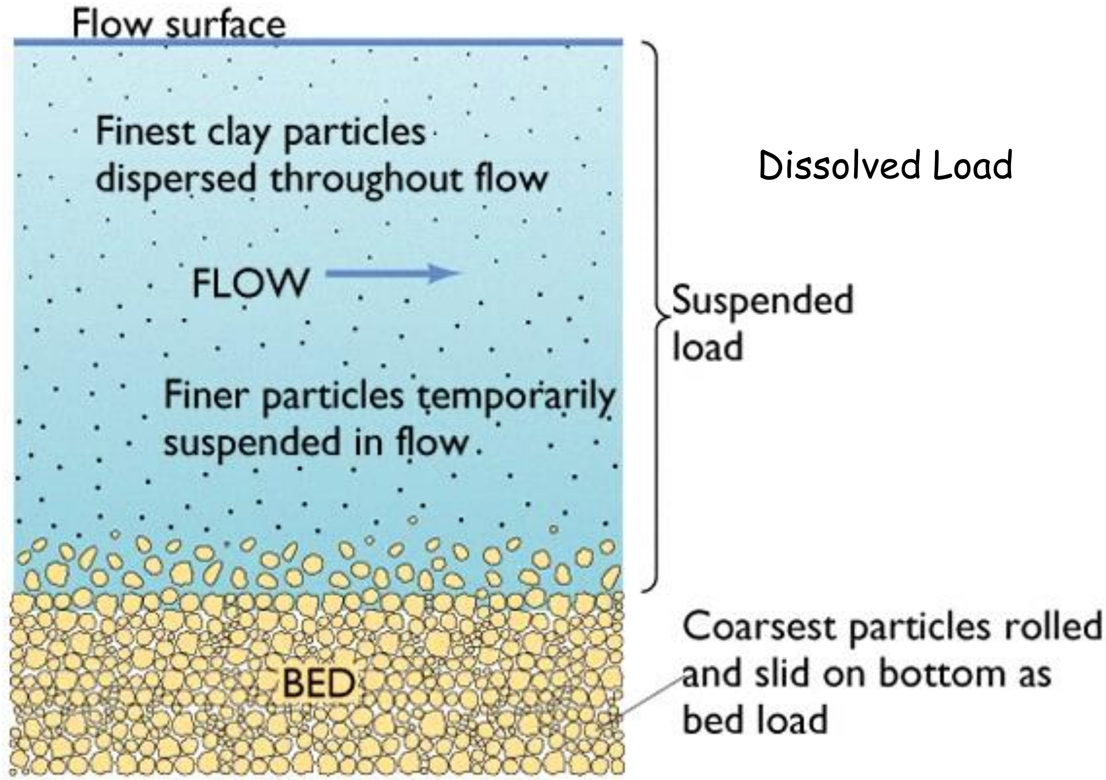
Beechie et al. 2010

Sediment Transport

- Basic process-form link in fluvial geomorphology
- Intermediate step linking flow to form of channel
- Channel change achieved through erosion, transport and deposition of sediment

Flowing water carries load

- Dissolved Load
- Suspended load
- Bed Load



Dissolved Load

Suspended Load

- Wash Load
  - Very fine particles (clay, silt) that are suspended in the flow
  - Essentially independent of hydraulic conditions

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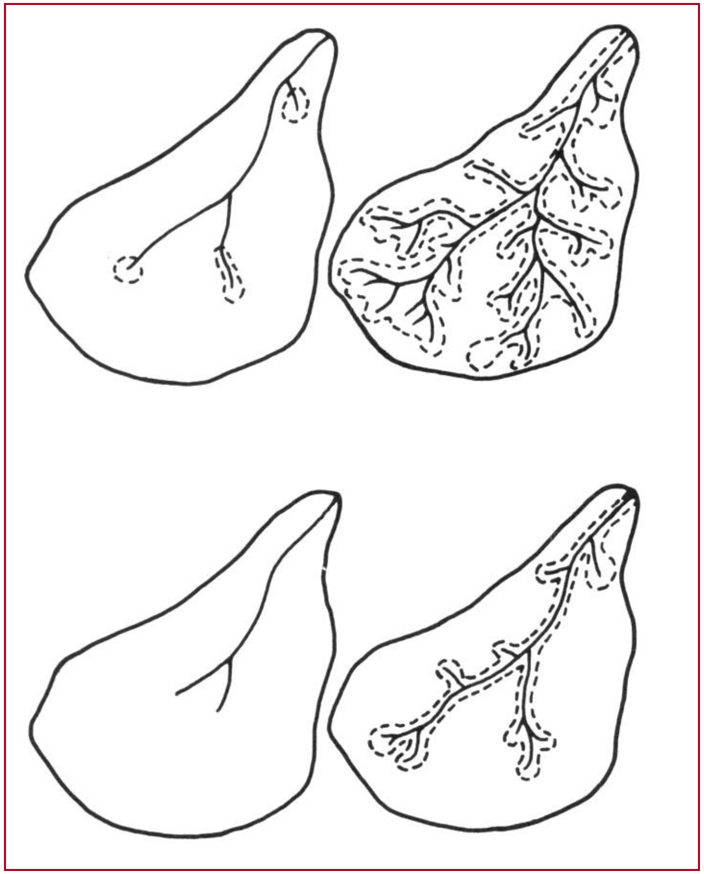
Suspended Load

- Little or no energy needed to keep fines suspended
- Rate of transport depends on…

  - stream capacity (Q)
  - supply of fines
  - **Variable source area concept**



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Bedload

- Course particles that roll, bounce, or saltate along the bed of the stream
- Strongly dependent on hydraulic conditions
- Major role in channel formation and change

Bedload on White River, OR, after Nov. 2006 floods

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Bed Material Load

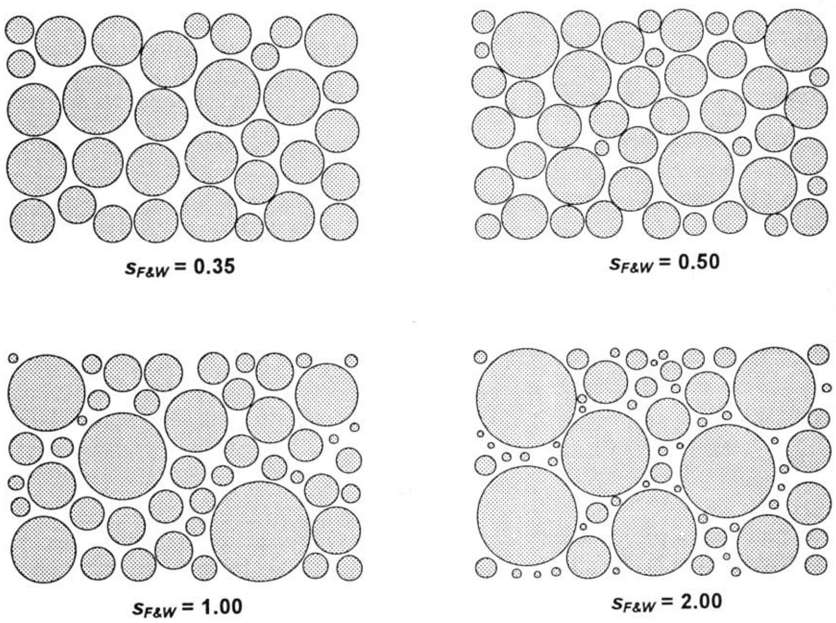
- Bedload transport
  - At lower flows: sand transported over stable gravel armor layers
  - At higher flows: armor layer is destroyed releasing more sediment
  - Two phase flow

Getting Bedload Moving: Entrainment

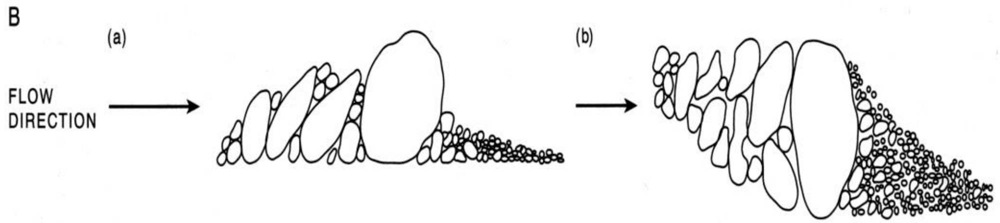
- Position of particle relative to surrounding particles

Armor Layer

Sorting



Shadowing & Imbrication



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Sediment Yield & Large Animals

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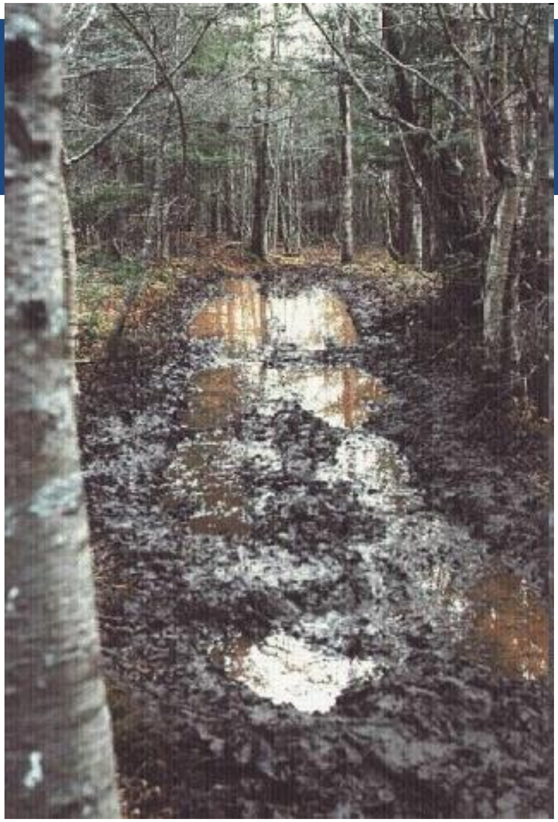
ATV Access



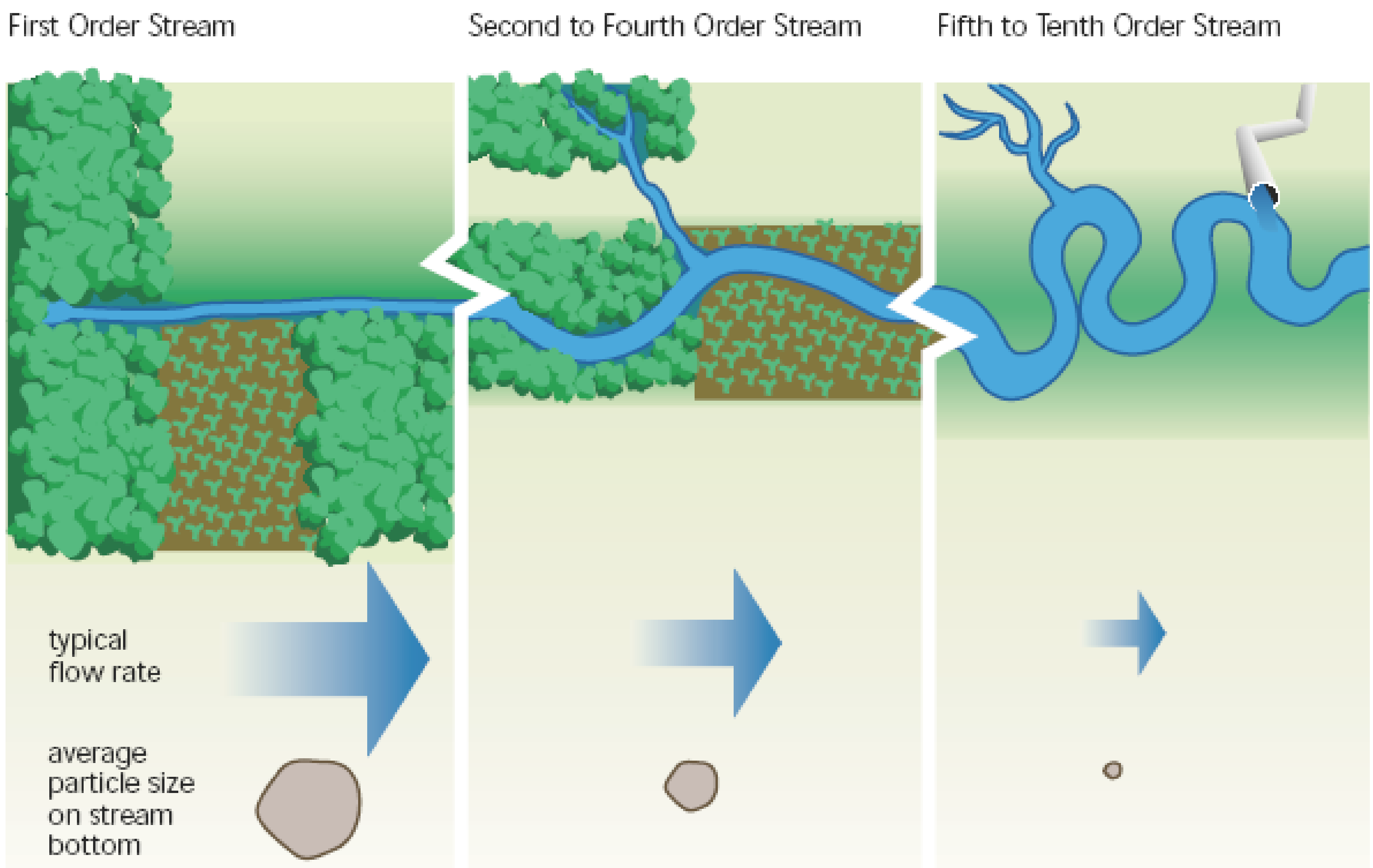


***Figure 2.15: Particle transport.** A stream's total sediment load is the total of all sediment particles moving past a defined cross section over a specified time period. Transport rates vary according to the mechanism of transport.*

Sediment Discharge Relations

- Complicated
  - Sediment waves move more slowly than flood waves
  - Exhaustion of sediment supply may occur
  - Seasonality of variability
  - Differences between rising and falling limbs of hydrographs

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Watershed Sediment Budgets

Components:

- Soil erosion
  - Rainfall detachment
  - Freeze/thaw
  - Overland flow
- Landslides
- Stream bank erosion
- Dust/deposition

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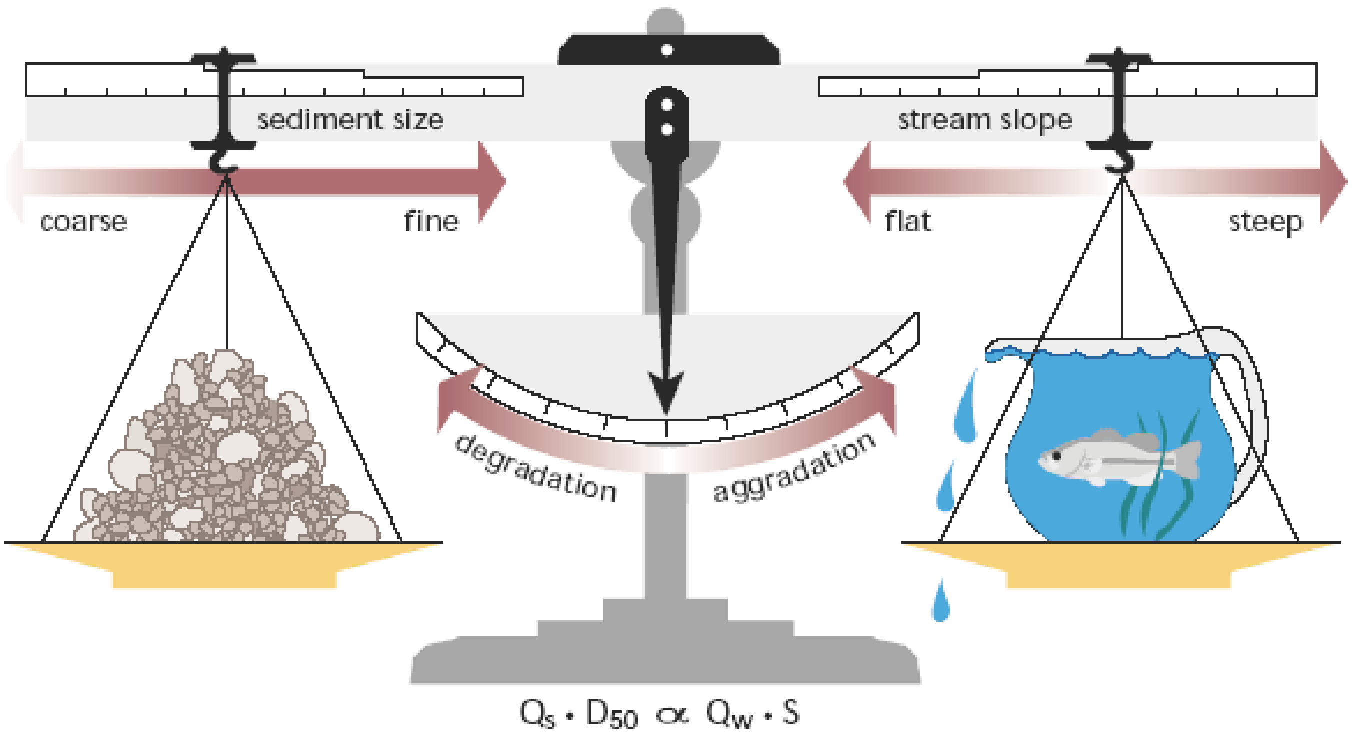
Mass Failures

Land Use Change

Response to Change

- Change in sediment size, sediment quantity, discharge, or slope will result in a change in at least one of the other variables, and that aggradation and degradation depend on the proportionality of sediment supply and transport capacity.



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Unit Stream Power

- $\omega = \gamma(QS)/w$
  w = width
  Q = discharge
  S = slope
- Rate of potential energy expenditure over unit length of channel
- Rate of doing work

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Potential for Geomorphic Response

- High:
  - High stream power
  - High hydrologic variability
  - Course bed material
  - Low bank resistance

Potential for Geomorphic Response

- Low:
  - Low stream power
  - Low hydrologic variability
  - Fine bed material
  - High bank resistance

Learning Objectives

- Understand how restoration measures can address altered hydrologic and sediment regimes
- Understand effective means of monitoring watershed hydrology, sediment loads, and physical habitat quality

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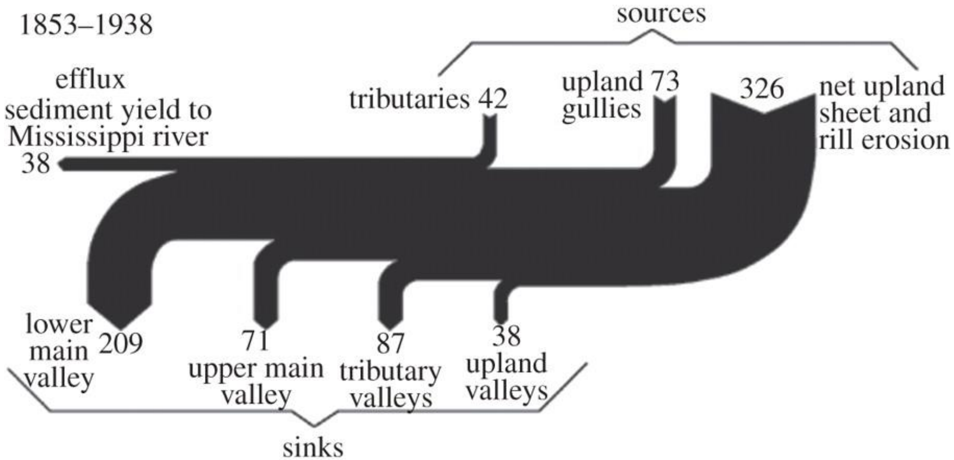
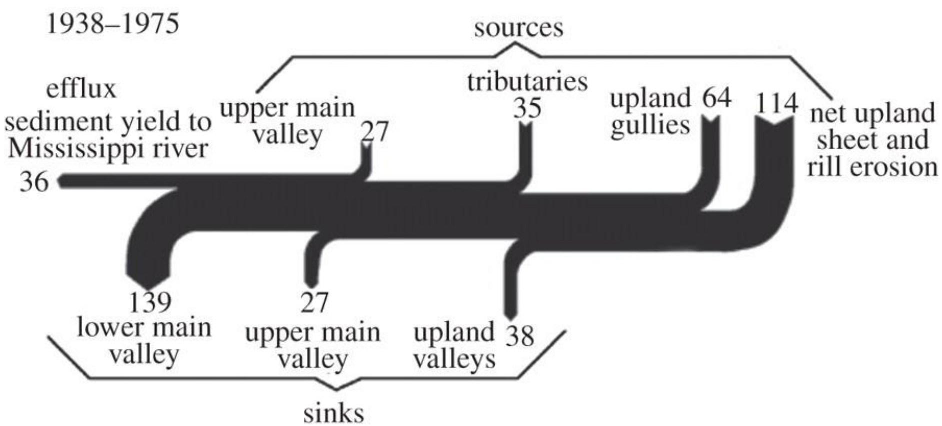
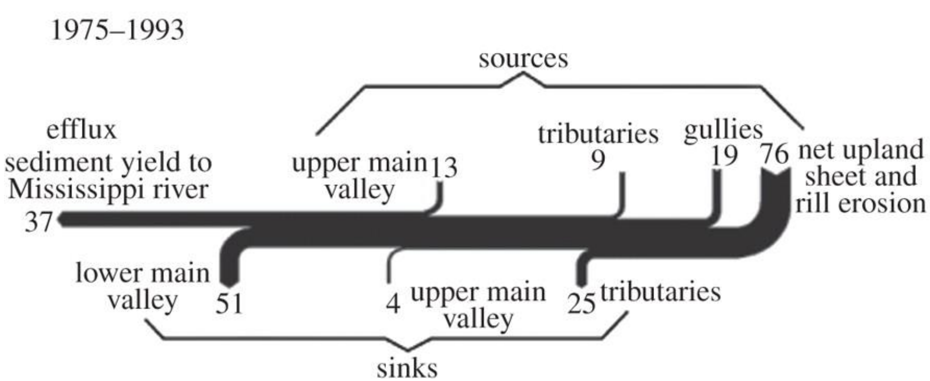


Settlement, land clearing, poor farming practices



Soil Conservation Service, improved farming practices



Improved farming practices

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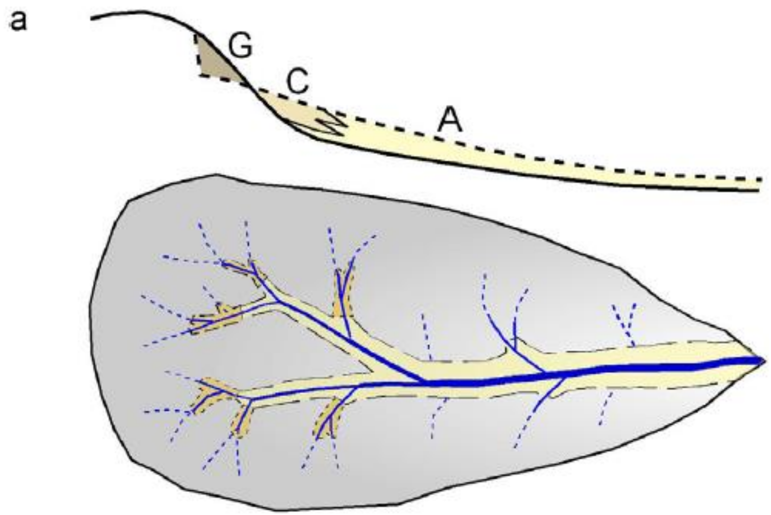
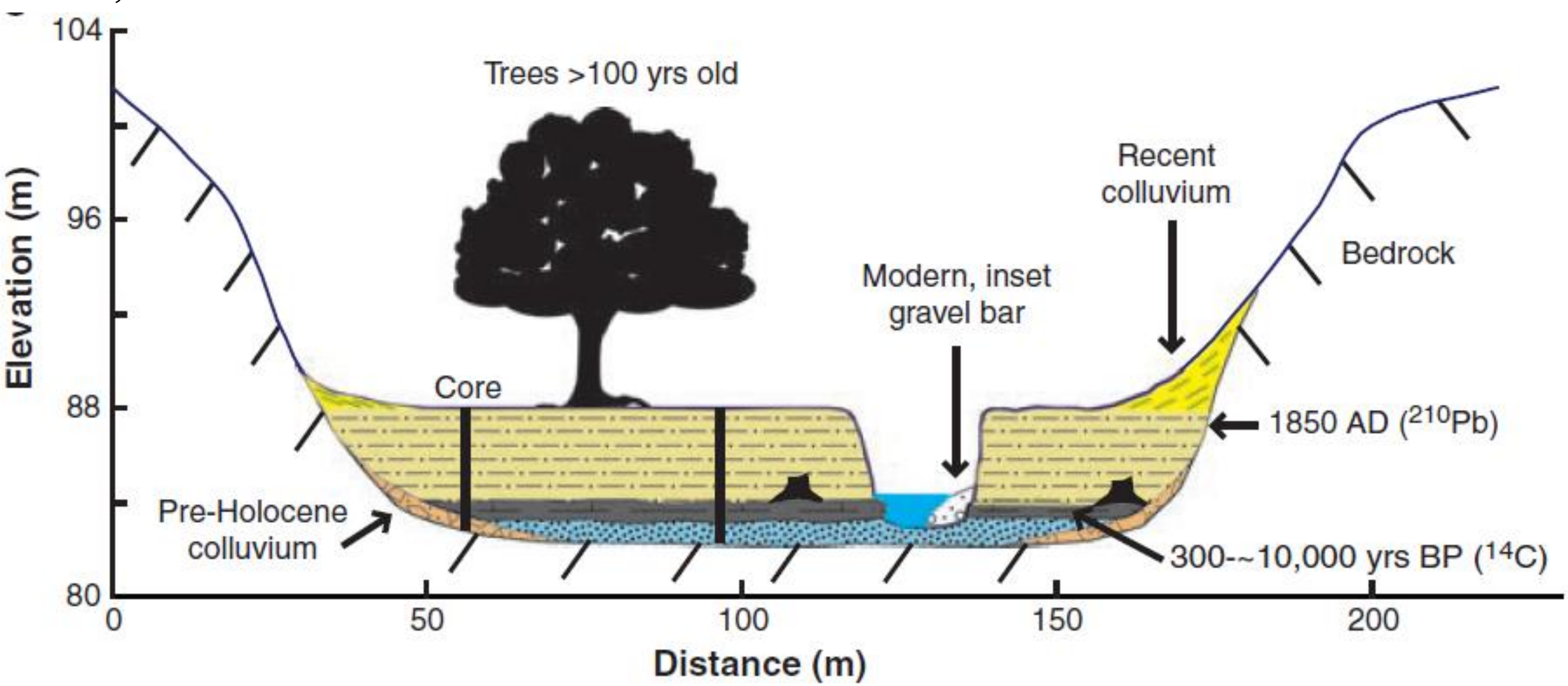


Concern about the contributions that **legacy sediments** may make to sediment and nutrient pollution of modern streams

James, L.A. 2013.



Walter, R. and Merritts, D. 2008.

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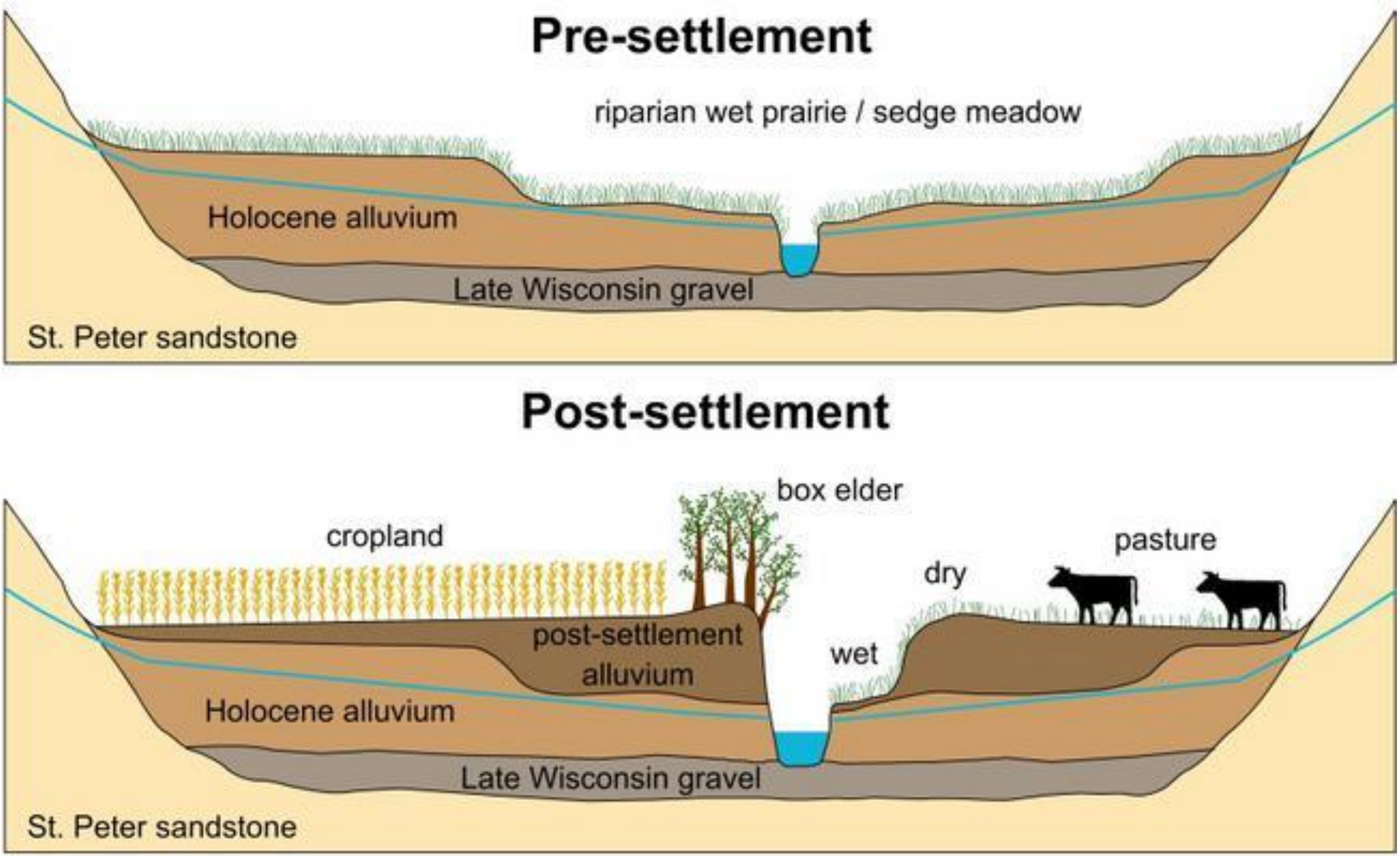

http://serc.carleton.edu/details/images/36342.html

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post-settlement alluvium

organic buried soil

sub-soil

Planform

- Influences distribution of energy across and along the channel
  - Controls sediment transport rates and patterns
- Pattern controlling process:

Pattern ⟶ Sinuosity ⟶ Stream Power ⟶ Sediment Load

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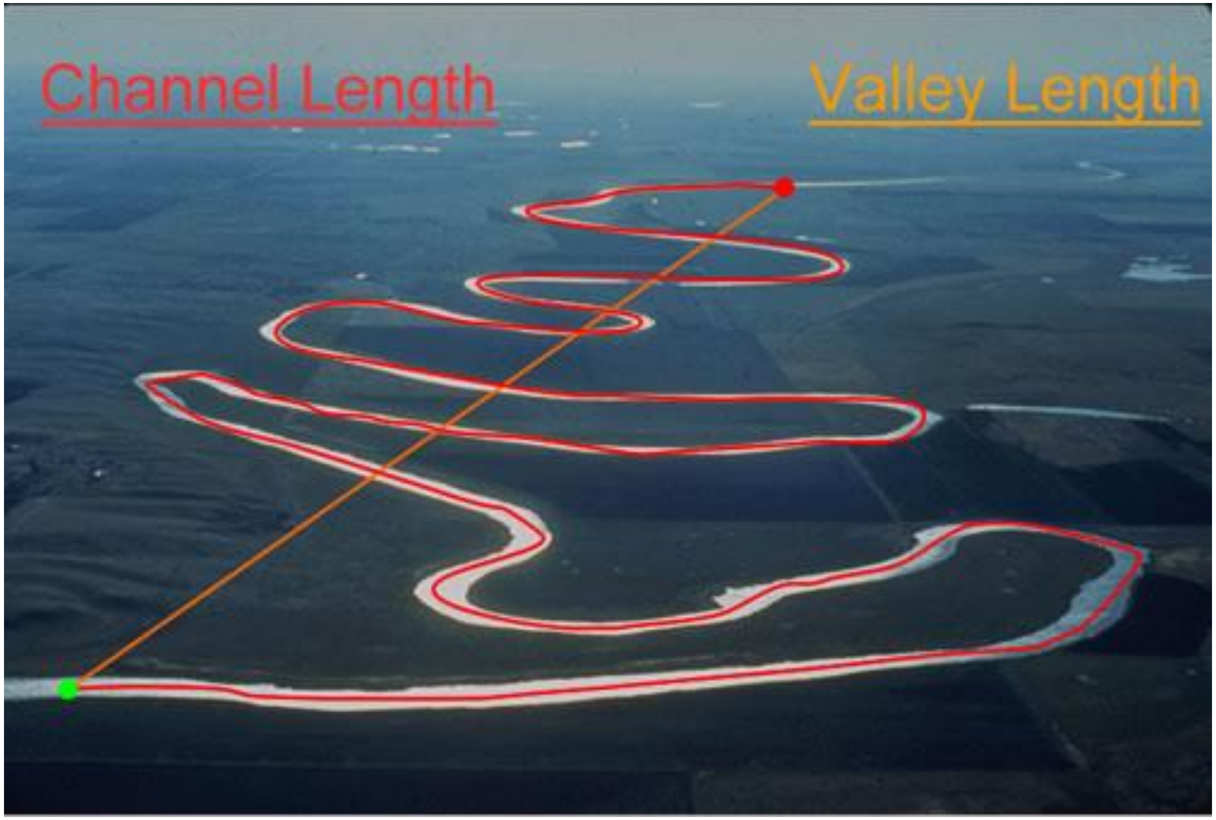
Channel Sinuosity

- Channel length/straight line valley length



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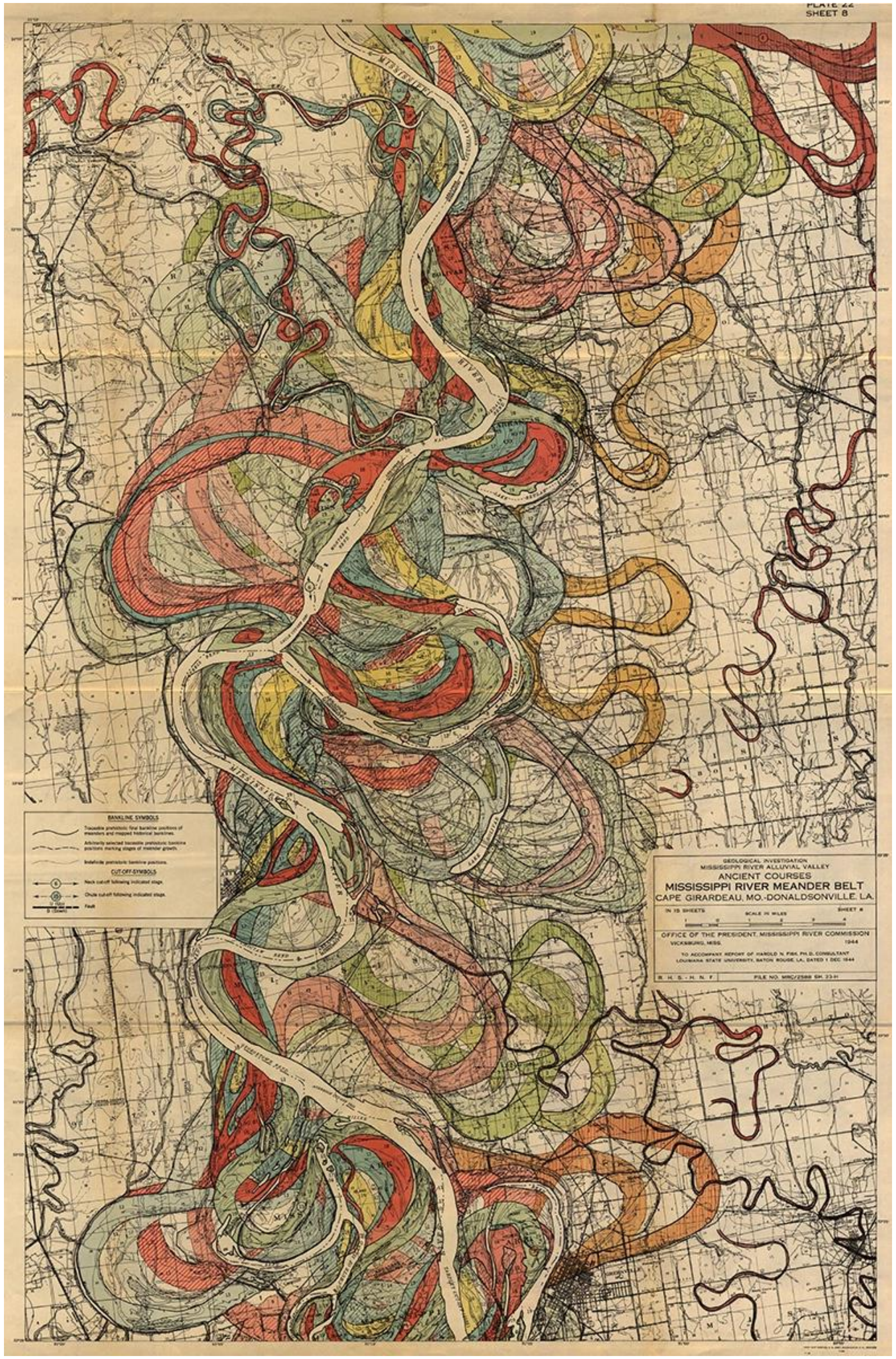

Rivers are dynamic, not static or “stable”

Bank Erosion

- Normal, expected process
- Wet banks are more easily eroded
  - Repeated wetting and drying
  - Frost action
- Summer flows may be less effective than frequent winter flows
- Multi-peaked flows may be more effective
- Local site characteristics are important
  - Bank material composition, flow asymmetry, and channel geometry

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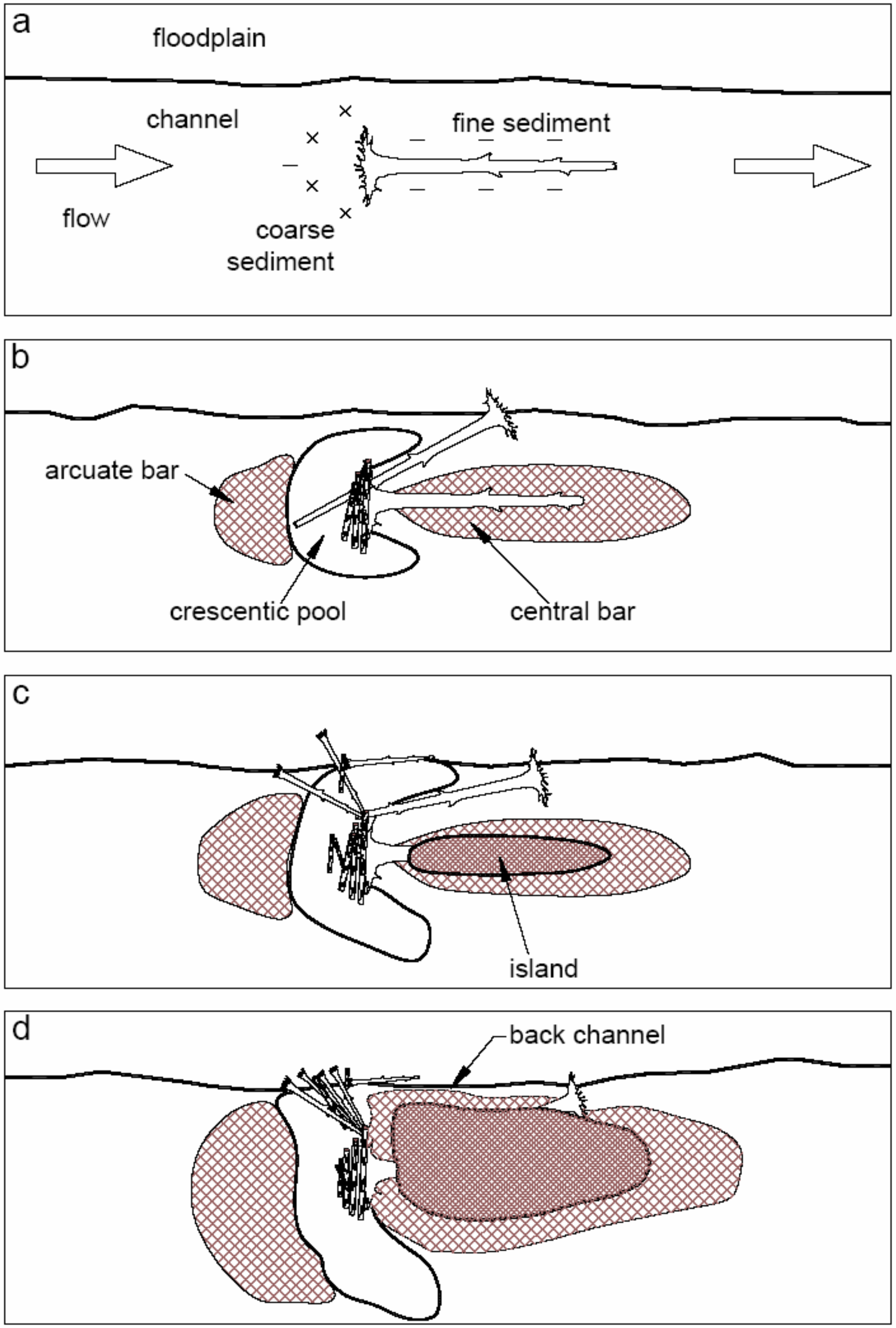
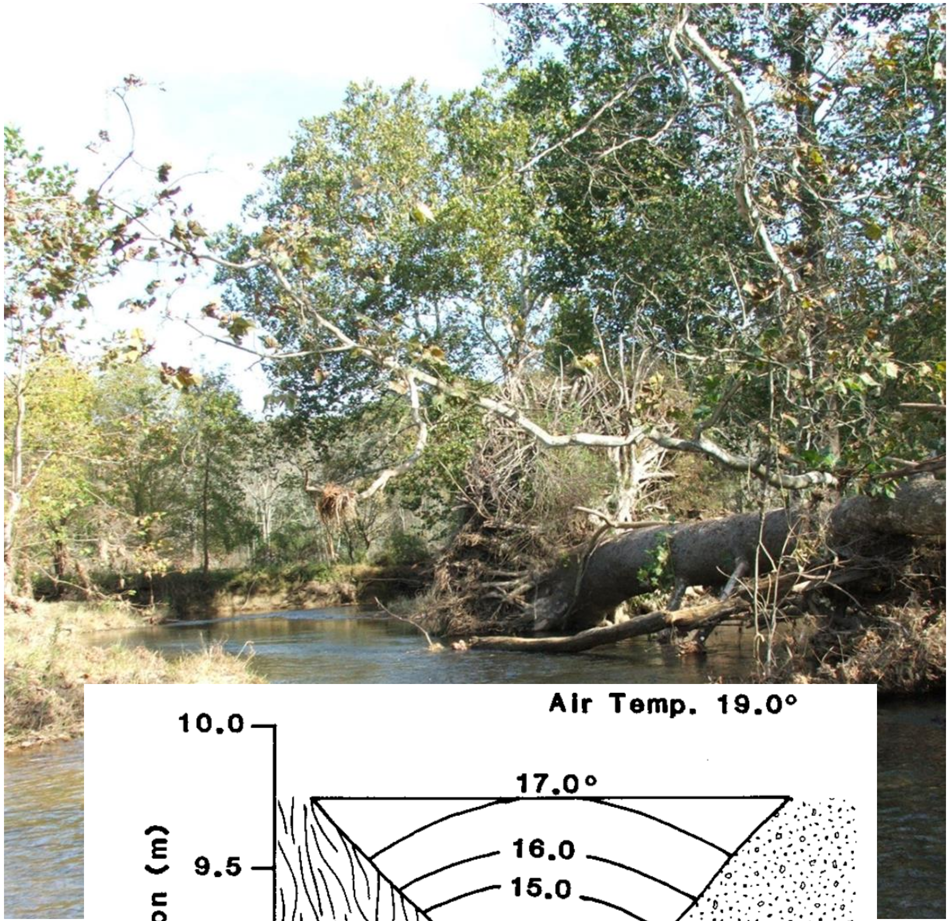
Highly susceptible vertical bank

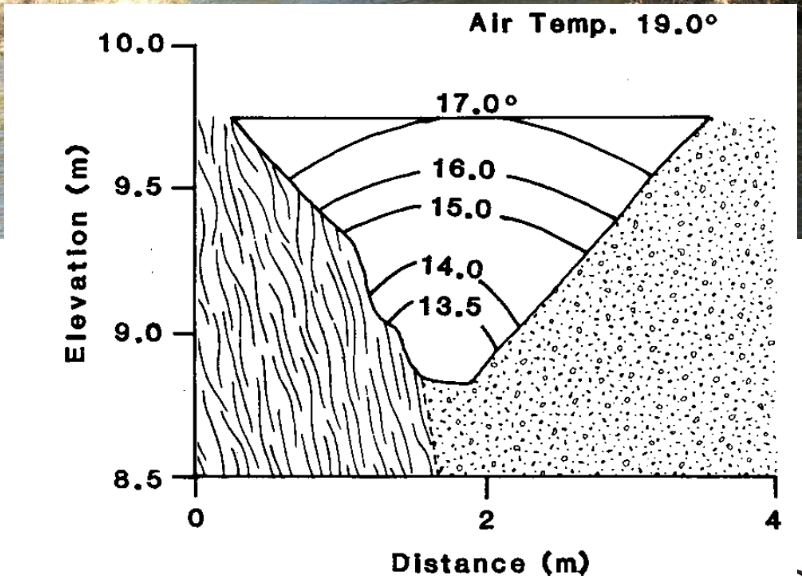
Grass does little to protect banks – root depths too shallow

Vegetation bank stabilization



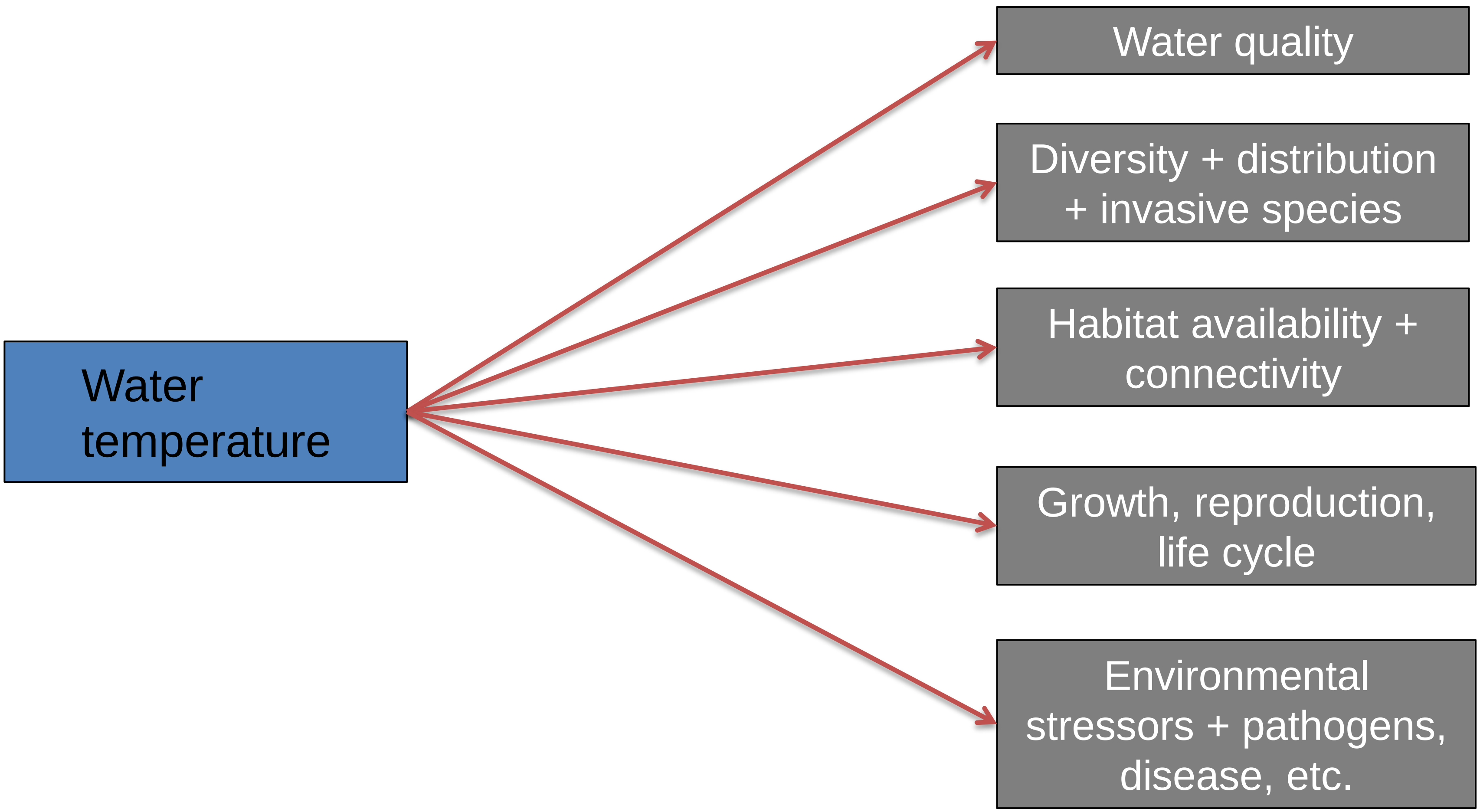
Saldi-Caromile et al., 2004





Nielson et al., 1994

Water temperature



And more…

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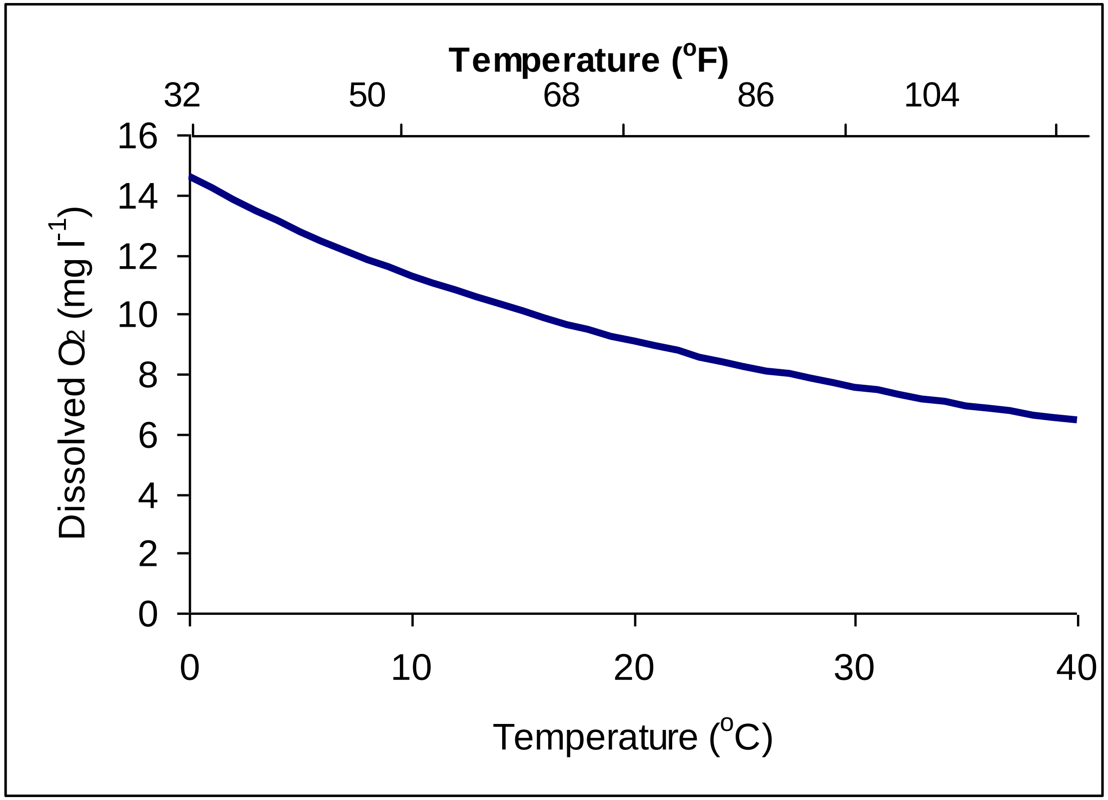
Water Temperature

Water temperature → Water quality

Influence on O_2 Concentration



O_2 concentration influences:

- chemical reactions, phosphate release

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Water Temperature

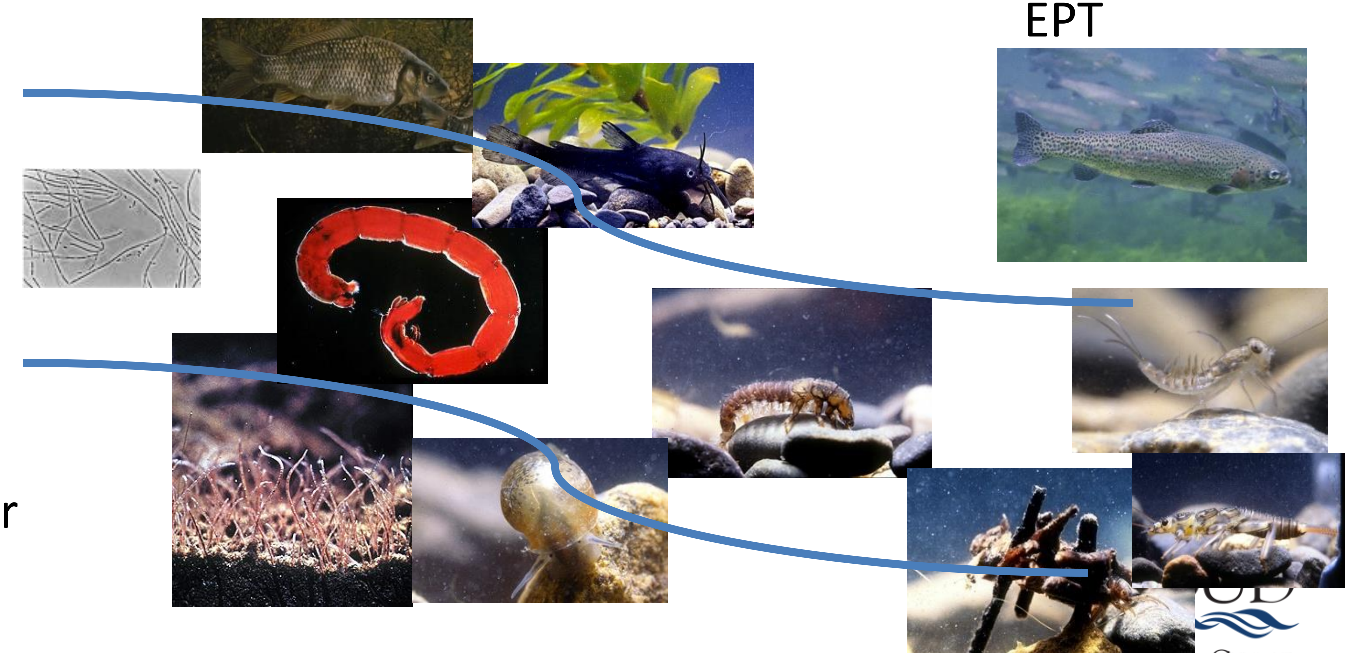
Water temperature → Water quality

Nearly all organisms require DO for respiration

Large variation in adaptations and responses to low DO

Tolerant

Sensitive, Intolerant
EPT



Indices of Biological or Biotic Integrity (IBIs)

Drivers of the temperature regime:

- Exposure
  - Lack of riparian shading
- Turbidity
  - Suspended solids which absorb and scatter light
- Reach volume to surface area
  - Shallow water is usually more dynamic: warming and cooling processes
- Groundwater
  - Cooler in summer, warmer in winter
  - Can acts as a thermal refuge

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Physical Monitoring and Metrics

Learning objective:

- Understand effective means of monitoring watershed hydrology, sediment loads, and physical habitat quality

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Turbidity

- Fine sediment transport (suspended load)
- Cloudiness or haziness of a fluid caused by large numbers of individual particles that are generally invisible to the naked eye, similar to smoke in air

Mississippi River at its confluence with the St. Croix

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Turbidity

- Measured by shining a light through the water and is reported in nephelometric turbidity units (NTU)

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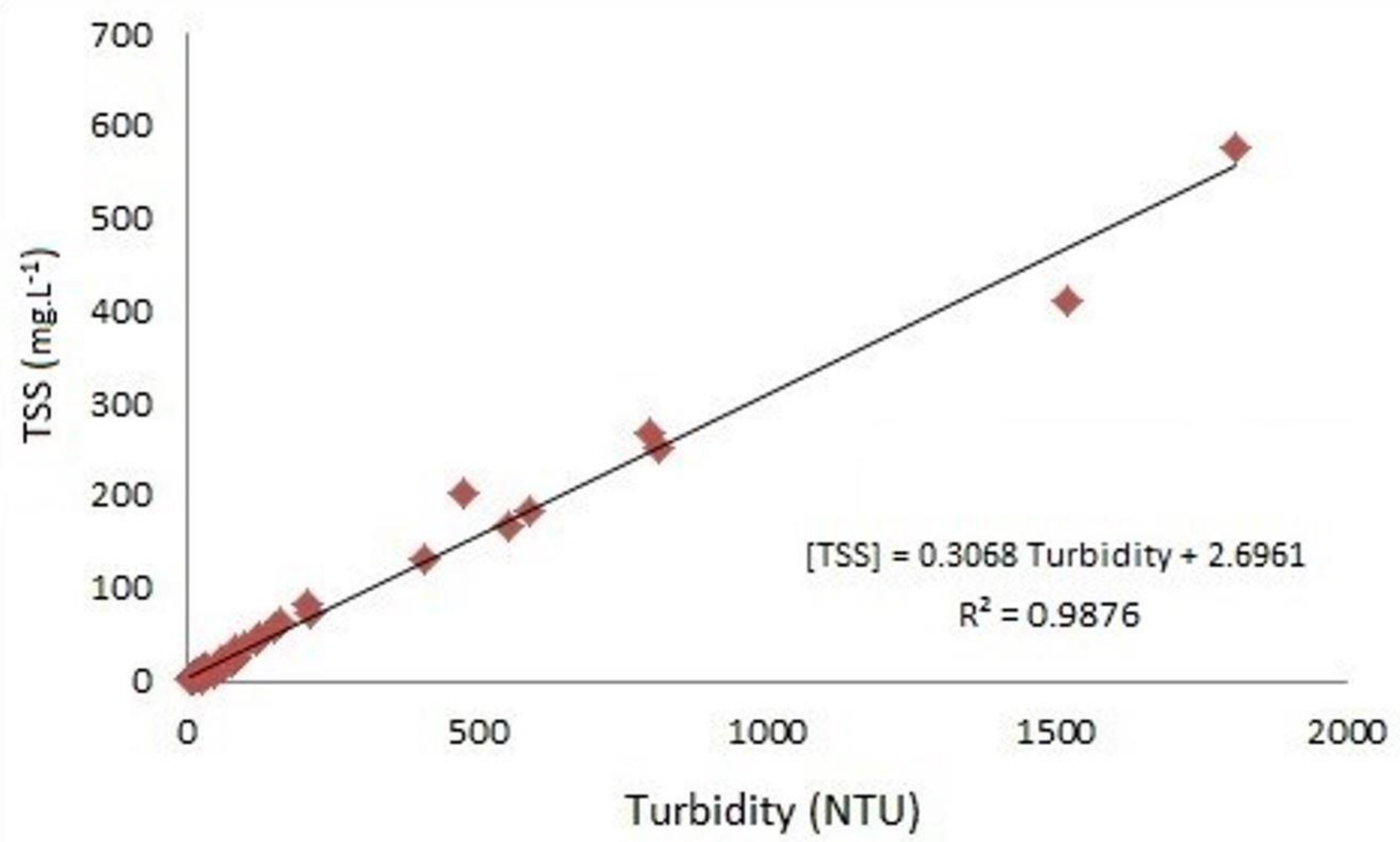

http://dx.doi.org/10.1590/2318-0331.011615099

Turbidity

- Affects light penetration and productivity, recreational values, and habitat quality, and cause lakes to fill in faster.

Turbidity

- Affects light penetration and productivity, recreational values, and habitat quality, and cause lakes to fill in faster.

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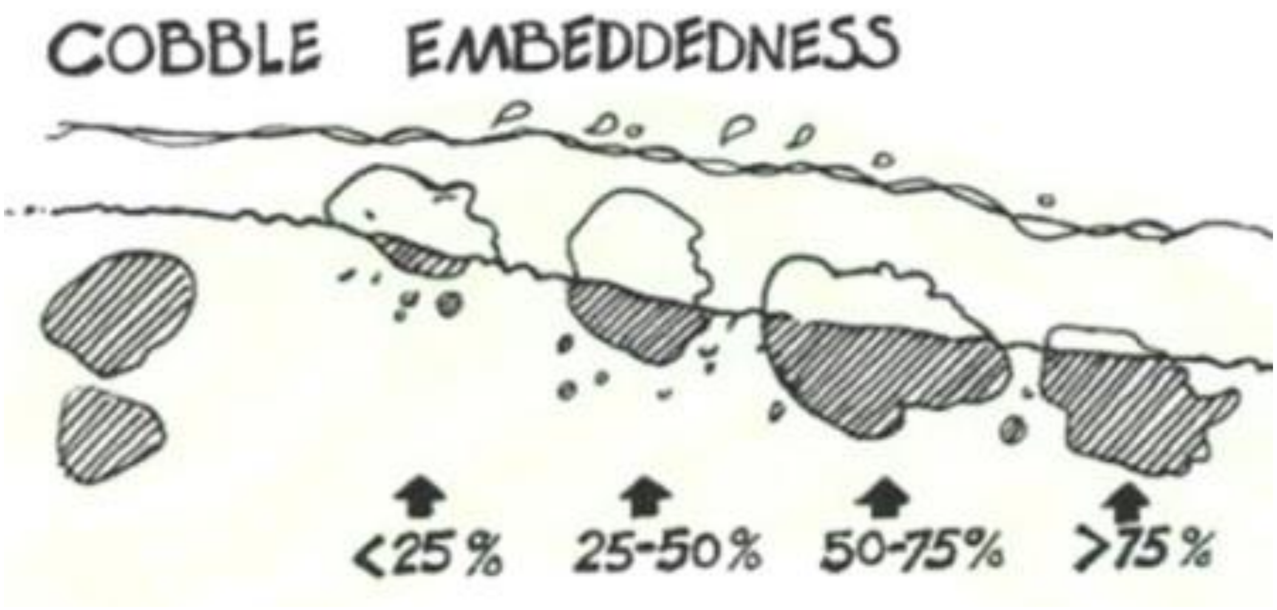
Turbidity

- Increases sedimentation and siltation, resulting in harm to habitat areas for fish and other aquatic life
- Particles also provide attachment places for other pollutants and pathogens (e.g. metals and bacteria)

Turbidity

- Substrate Embeddedness
  - Smothers gravels
  - Eliminates invert and fish habitats



http://www.dep.wv.gov/WWE/getinvolved/sos/Pages/SOPhabitat.aspx

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Turbidity

- Pool infilling (V* metric)

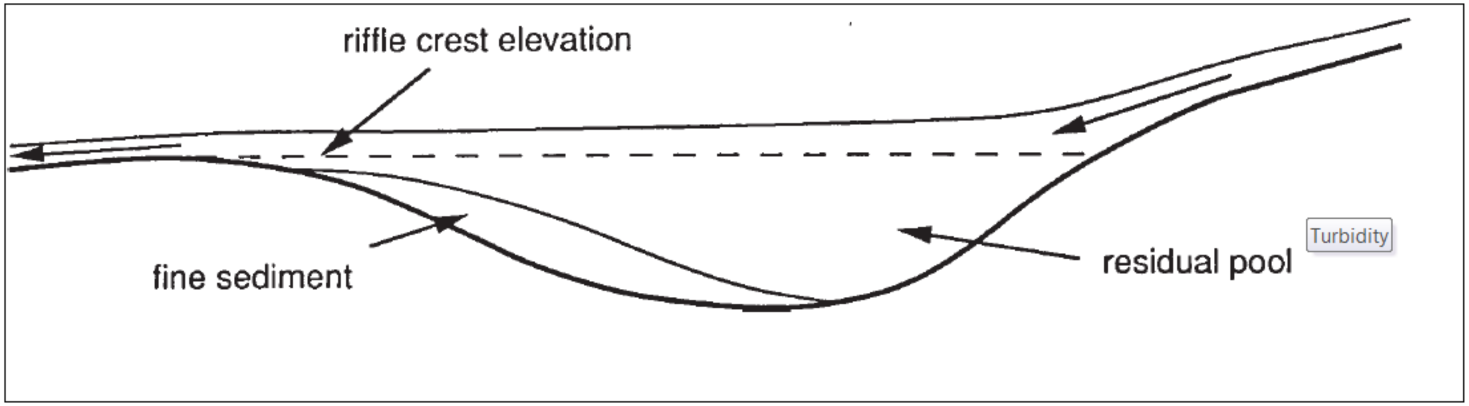

Figure 1. Representative pool in Three Creeks, a tributary to Willow Creek in Six Rivers National Forest

Lisle, T.E. 1989. http://www.fs.fed.us/psw/publications/lisle/currents06.pdf

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Velocity/flow/depth/stage

- Many streams have USGS gages to measure stage and flow
- This information is sometimes needed on at a specific location on a stream and/or on streams without a USGS gage.
- Monitoring the velocity/stage/flow in a stream can give us information about variations in inputs to streams

Method Selection based on Physical Setting

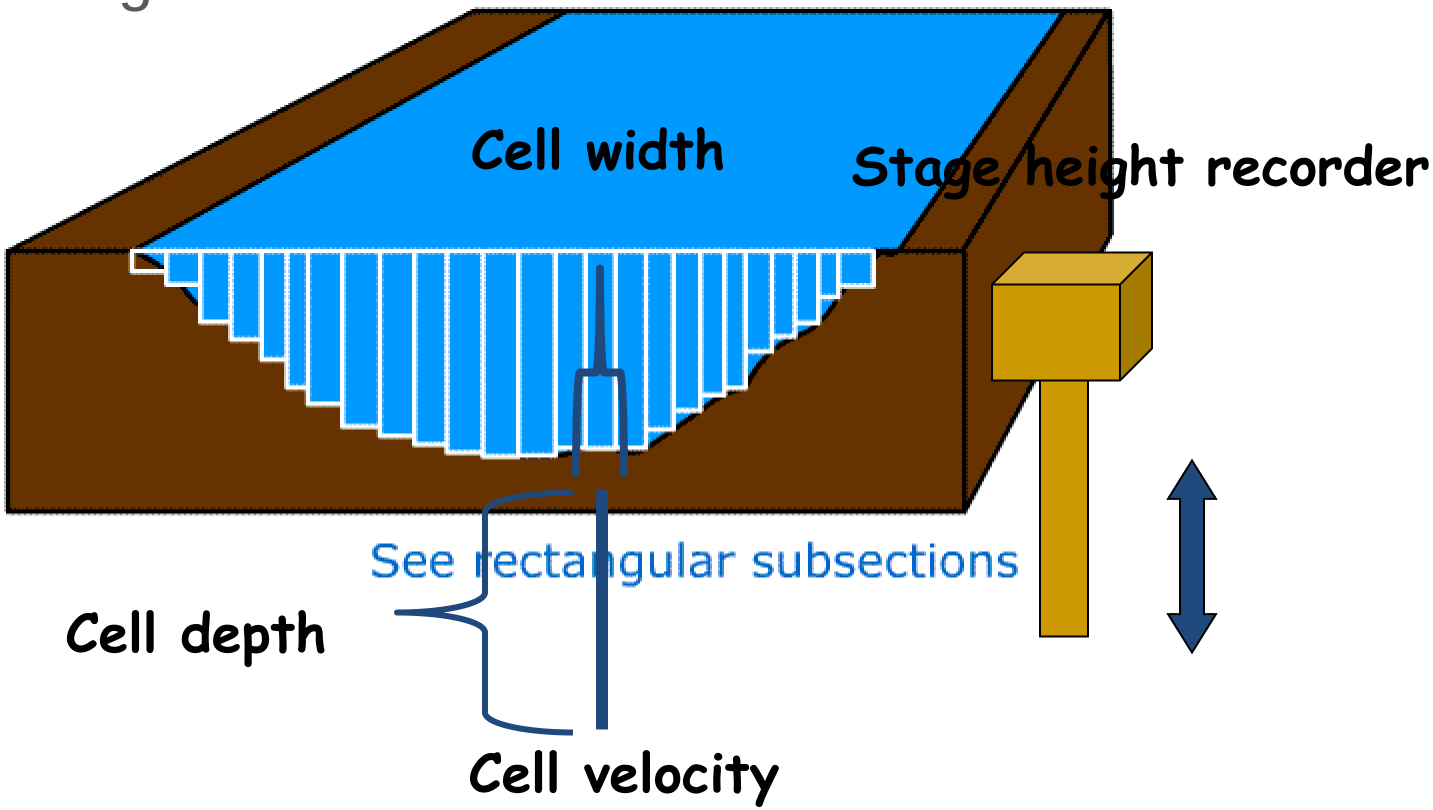
- 3 factors to consider: physical setting, velocity, water depth
- Small channel – flume/v-notch weir or salt dilution method
- Medium – velocity profile via wading rod/current meter
- Large – velocity profile from bridge or tethered profiler (ADCP)

Figure 10-2.—Equipment for making wading measurements with a current meter. Note tag line for marking stations.

Figure 10-4.—Type A crane and current-meter assembly in position on bridge.

Measurement of Discharge

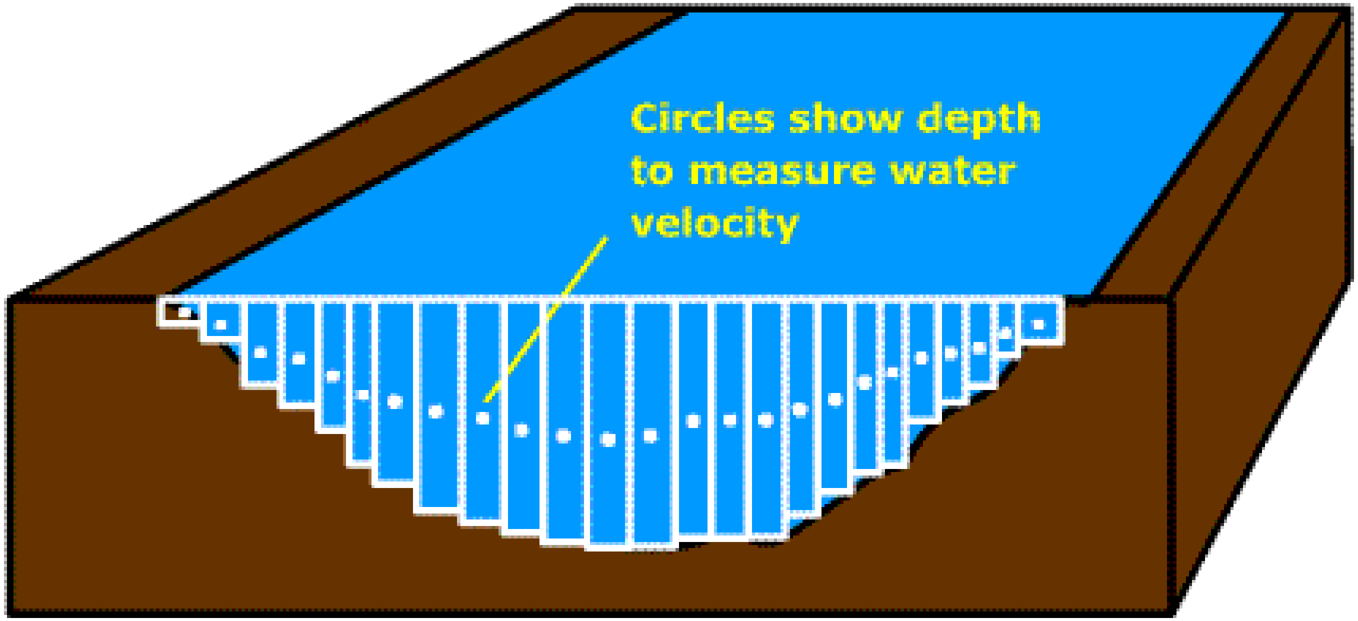
- Velocity profiling method



Velocity Measurements

- 0.6 method (60% below surface)
- Also, need average of velocity (20-40s)

Measurement depth = 0.4 * depth



See rectangular subsections

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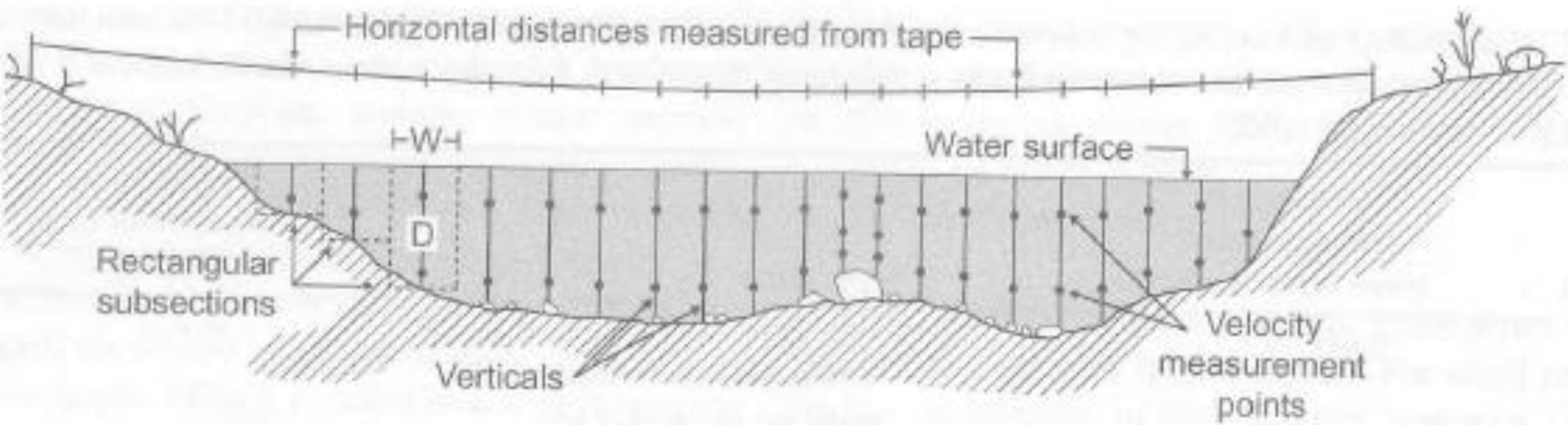
Current meter set-up showing position of the tape and depth/velocity stations

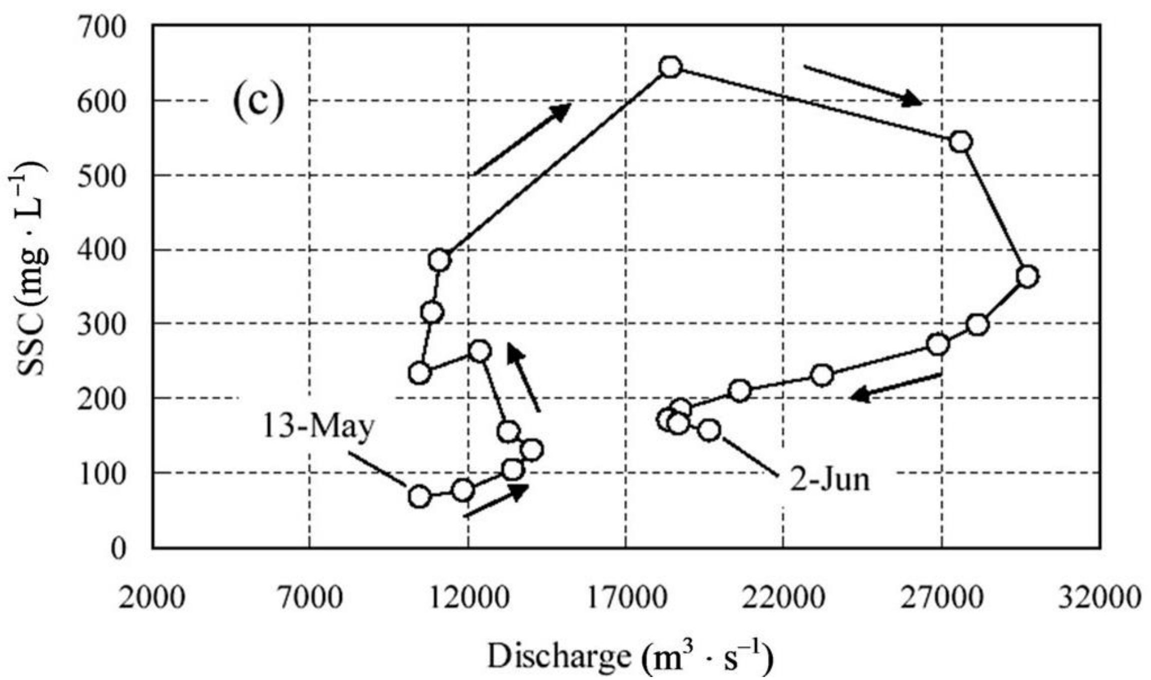
Shows the 0.8 and 0.2 method



Gordon et al., 2004

Advantages of Continuous Data Collection

- Can adjust for seasonal impacts on sediment transport



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