Watershed Structure and Function: How Does a Watershed Accommodate Life History-Based Fish Habitat Needs?

The Effects of Forest Management on Fish Habitat:

Science, Fundamentals and Best Management Practices

Workshop by the Western Forestry and Conservation Association

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Components of Fish Habitat

- Clean
- Cold
- Complex
- Connected

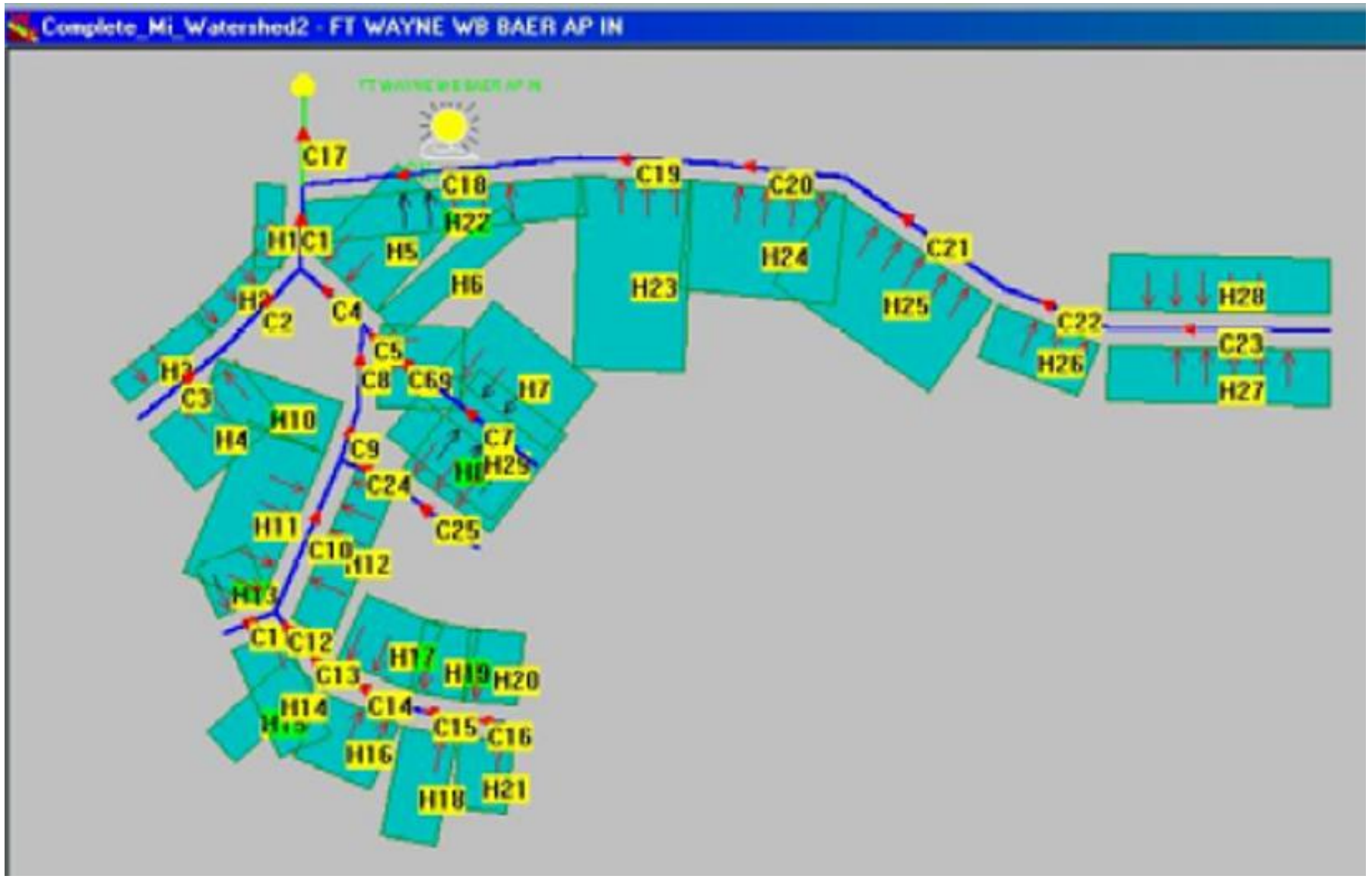
- How does nature supply these critical fish habitat components in forested watersheds?

Watershed Structure

- Keep it simple.
  - Hillslopes
    - Vegetation
    - Slope
    - Soils
    - Geology
  - Channels
    - Slope
    - Bed sediment
    - Geology

Watershed Structure

- Hillslopes are largely independent functioning units.
- Channels have strong interactions between their adjacent hillslopes and other upstream channel segments.



Hillslopes

- Directly affect **Clean**, **Cold** and **Connected**.
- **Clean** – infiltration rates are extremely high compared to rainfall and snowmelt rates, so almost all water moves through soil. Very little overland flow erosion and sediment delivery to streams. Concentrations of dissolved chemicals are low…limiting???
- **Cold** – subsurface water (and groundwater) is generally cold…about the average annual air temperature.
- **Connected** – subsurface flow paths support streamflow even during extensive dry periods.

Watershed Structure - Hillslopes

- Fire is probably the largest “natural” agent of change.
- What do you think our hillslopes looked like under natural disturbance regimes?

Channels

- Directly affect **Complex** and **Connected**.
- **Complex** – different types of channel reaches meet different fish habitat needs to varying degrees.
- **Connected** – while generally channels are inherently “connected”, some natural features (such as waterfalls) are barriers to fish movement.

Watershed Structure - Channels

- Beavers are probably the largest “natural” agents of change.
- What do you think our channel systems looked like before we started killing beavers (Cold, Clean, Complex and Connected) ?
- In the past we “managed” for removal.
- What’s the future?

Watershed Structure - Channels

- Large mass wasting events are also “natural” agents of change.
- May create channel blockages or clean channels to the point of water slides (no fish habitat there!)

Watershed Structure – Fish Needs

Fish Habitat Component	Hillslopes	Channels
Clean	X	
Cold	X	
Complex	x	X
Connected	X	X

Watershed Structure

- By managing these structures, we affect watershed processes. Which in turn can change watershed structure.
- The processes we are discussing here are the production and maintenance of fish habitat.

Fish Life History

- Keep it simple. Three parts:
  - **Spawning and Egg Incubation**.
  - **Rearing** (juveniles to smolts for anadromous; juveniles to adults for residents).
  - **Migration** (anadromous and resident; upstream and downstream).

Watershed Structure – Fish Needs

Fish Habitat Component	Spawning	Rearing	Migration
Clean	x	x	
Cold	X	X	x
Complex	X	X	x
Connected		x	X

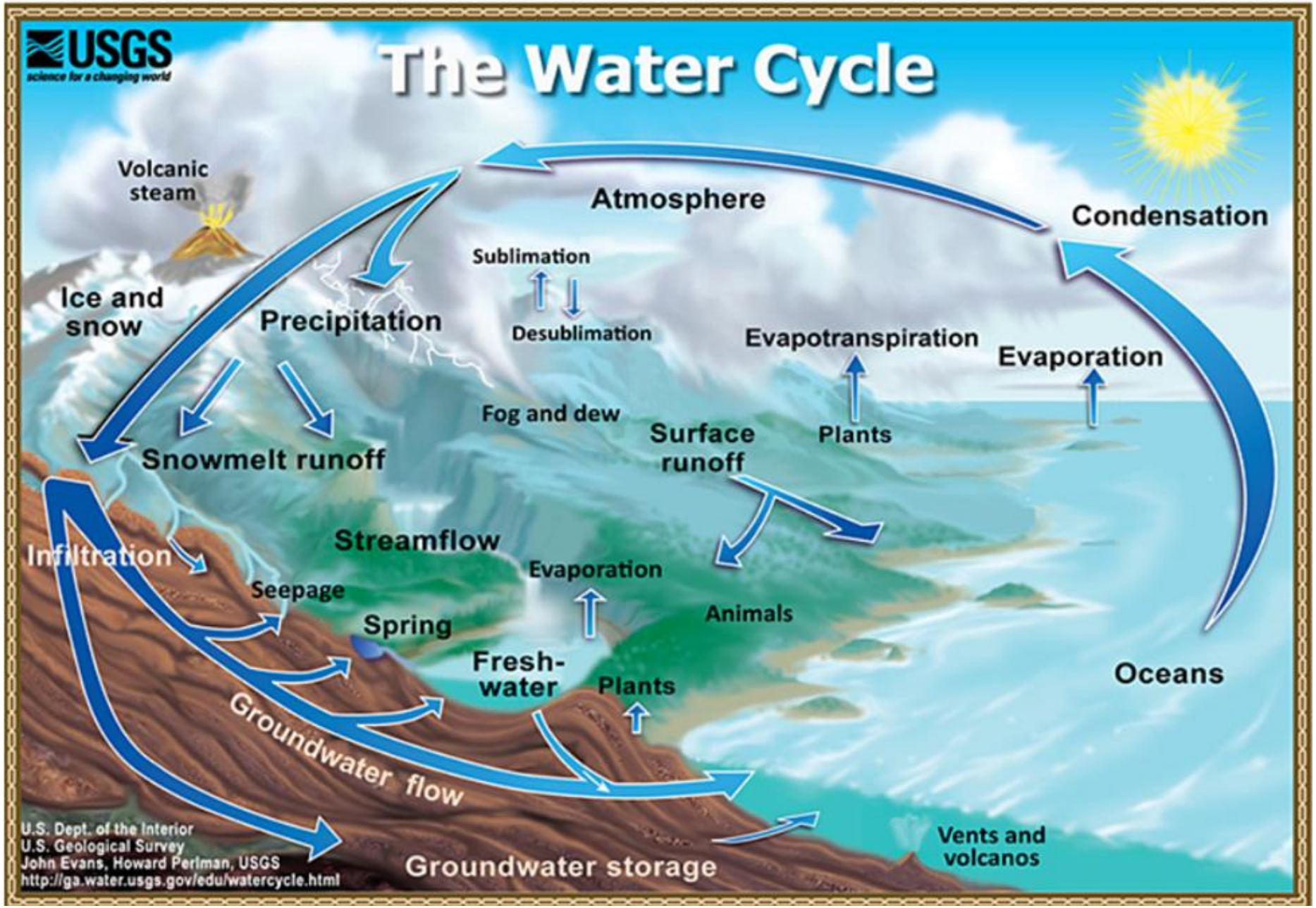
Watershed Functions

- Keep it simple.
- Watersheds process:
  - Water
  - Dirt
  - Energy
- All of these processes form fish habitat (or not).
  - Water - seems pretty important (and obvious if you are a fish!).
  - Dirt – provides habitat structure for free swimming fish, substrate for food, nursery for eggs and very young fish.
  - Energy – fish food and water temperature.

Watershed Functions – Fish Needs

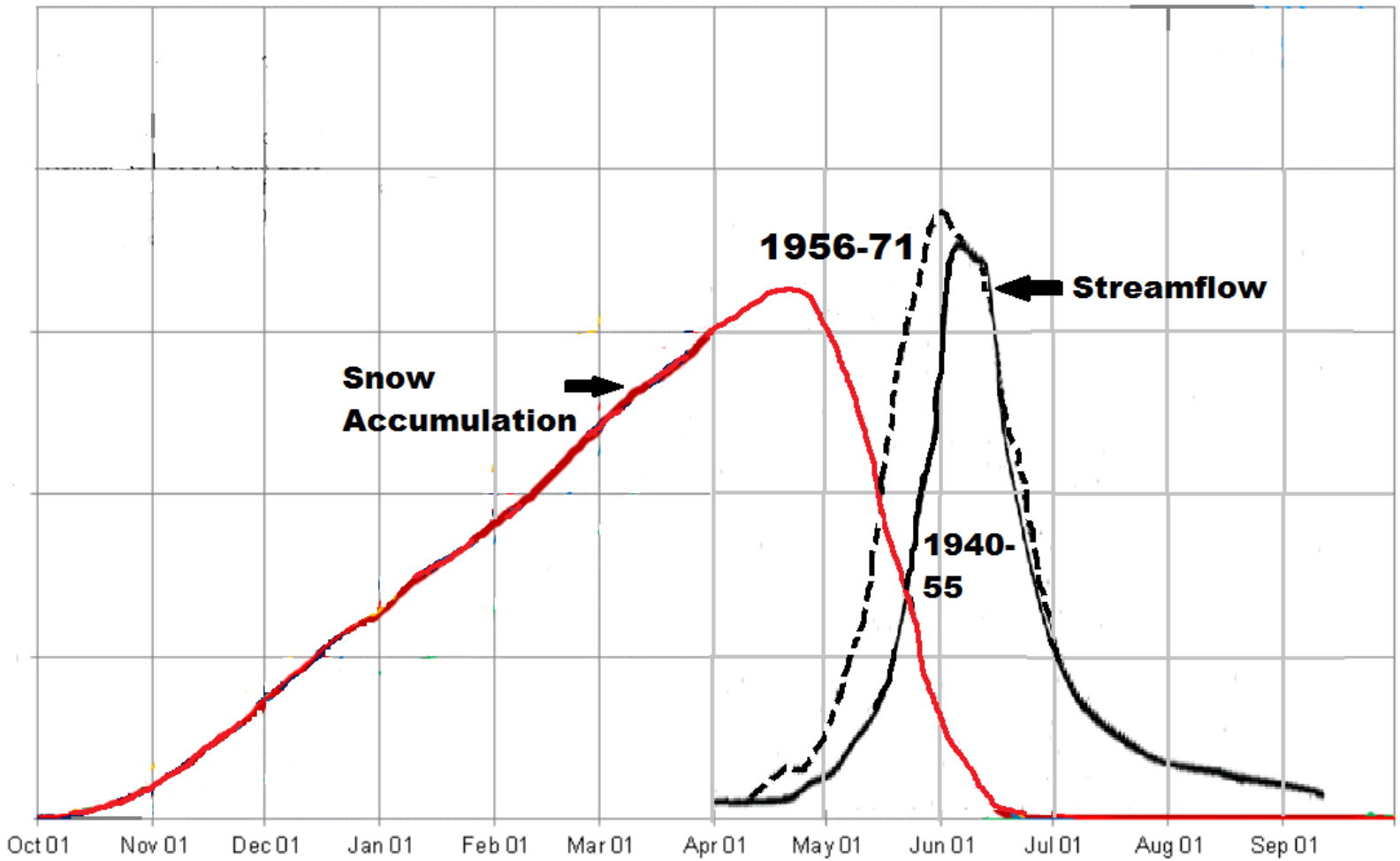
Fish Habitat Component	Water	Dirt	Energy
Clean	X	X	x
Cold	X		X
Complex	x	X	x
Connected	X	x	

Watershed Function



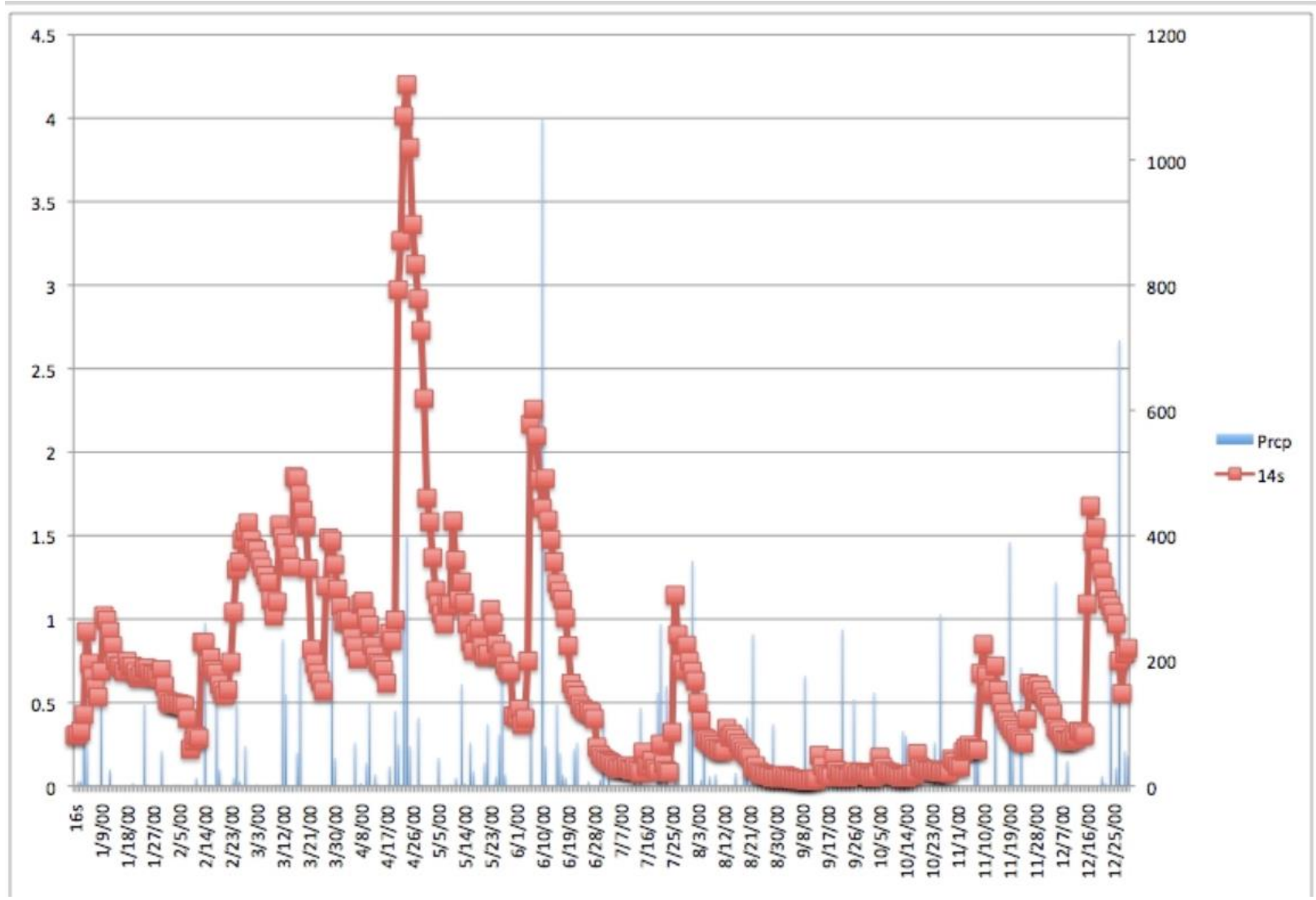
Watershed Function - Water

- Snow dominated – high elevation, generally above 3000 feet elevation. Develops a seasonal snowpack and maintains that snowpack over the winter



Watershed Function - Water

- Rain dominated – low elevation, generally below 1000 feet elevation.
- Rarely gets snow at all. The rare snowfall melts in a matter of hours to days.



Watershed Function - Water

- Rain-on-snow – medium elevation, generally between 1000-3000 feet elevation.
- Snow comes and goes multiple times over the winter.
- Lots of possible interactions between weather, vegetation and snow-accumulation and snow-melt.
- In marginal snow conditions (T near 32), snow may be captured in tree crowns and melt. So, rain to forest floor, but snow accumulation in openings.
- During a subsequent rain event, larger energy inputs to accumulated snow in openings due to wind and condensation. So, rain event delivers rain to forest floor; but rain event delivers rain plus snowmelt in openings.

Watershed Function - Water

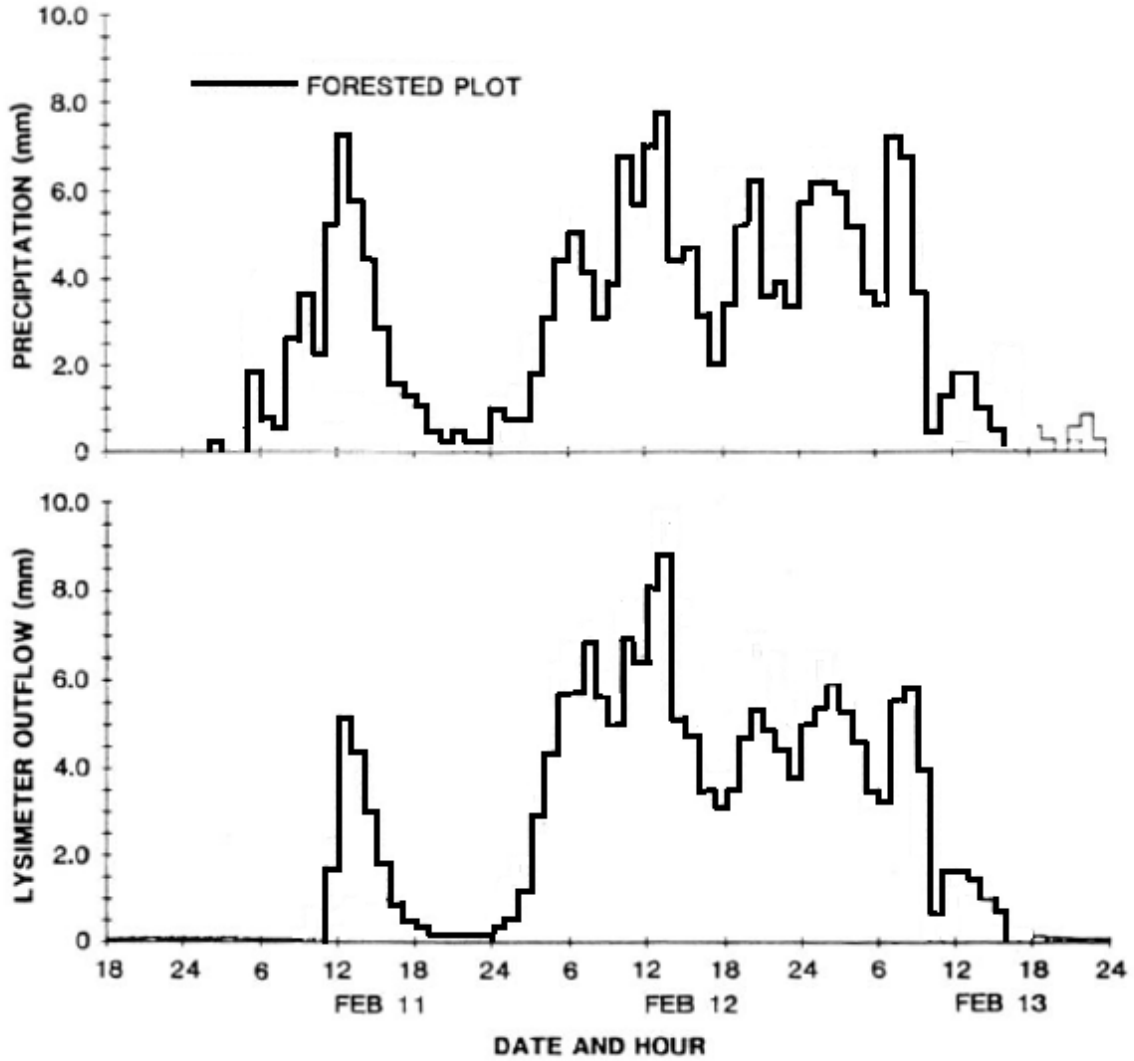
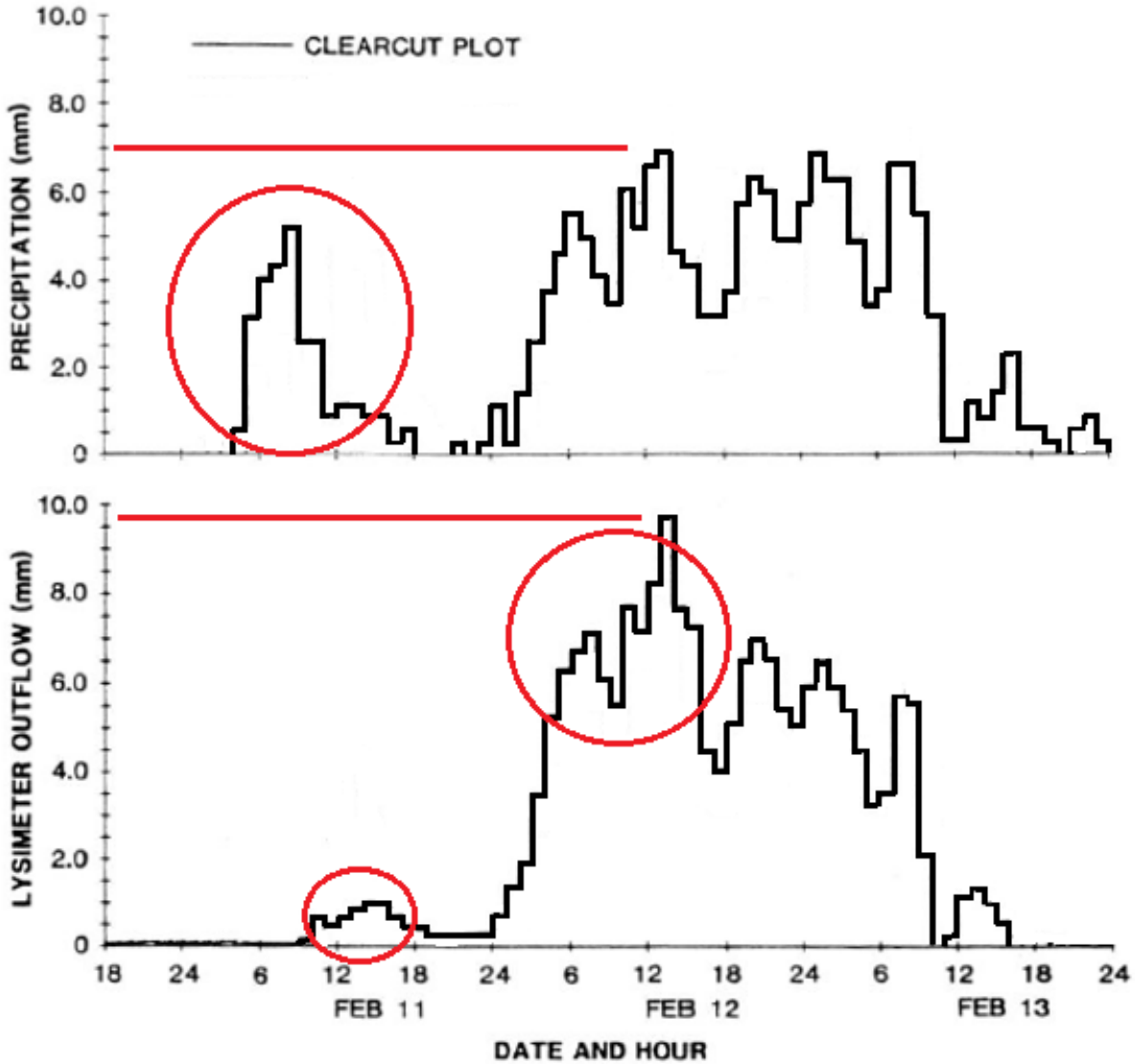


Fig. 2. Precipitation intensity and lysimeter outflow, February 10–13, 1984.

Watershed Function - Water



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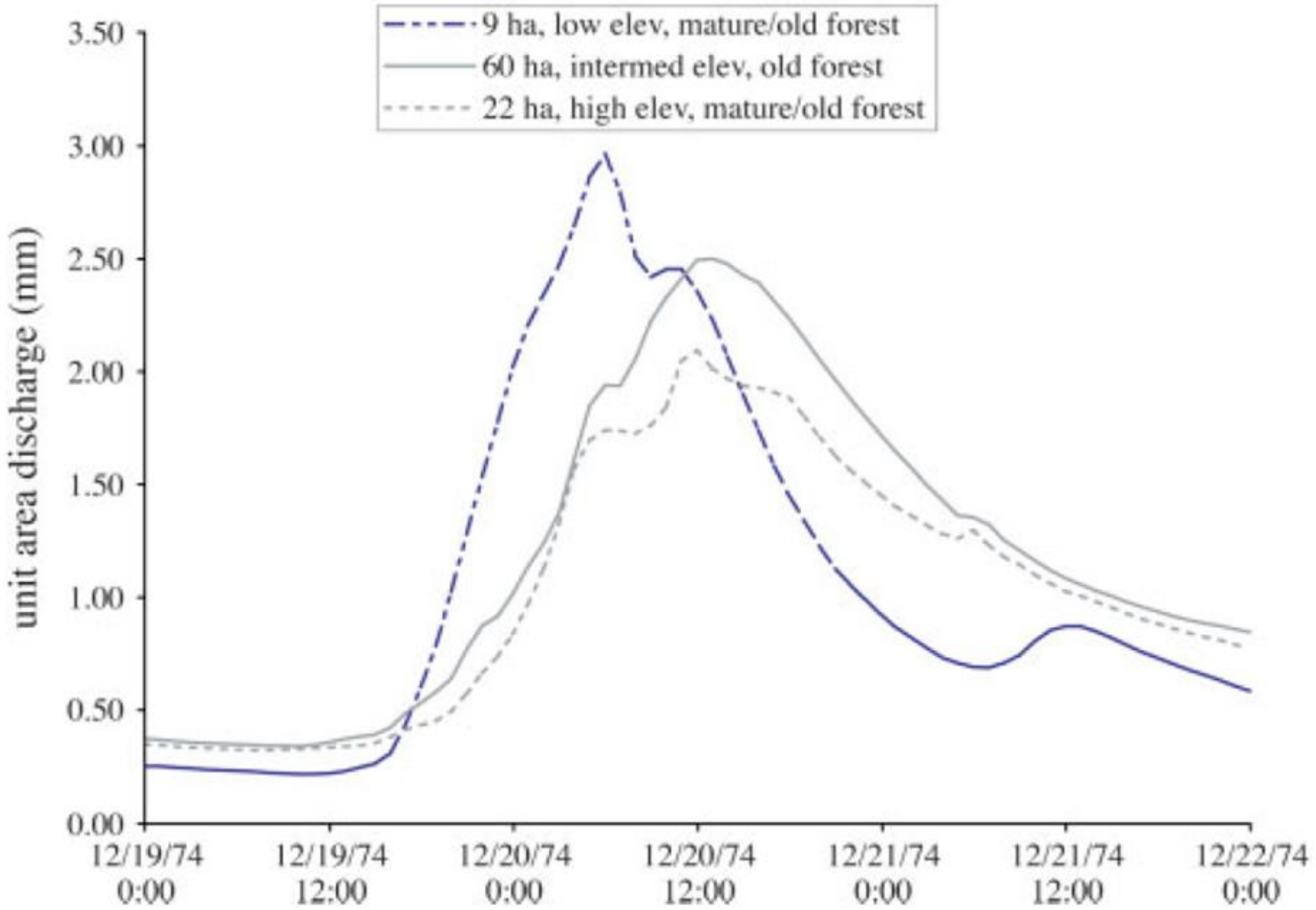
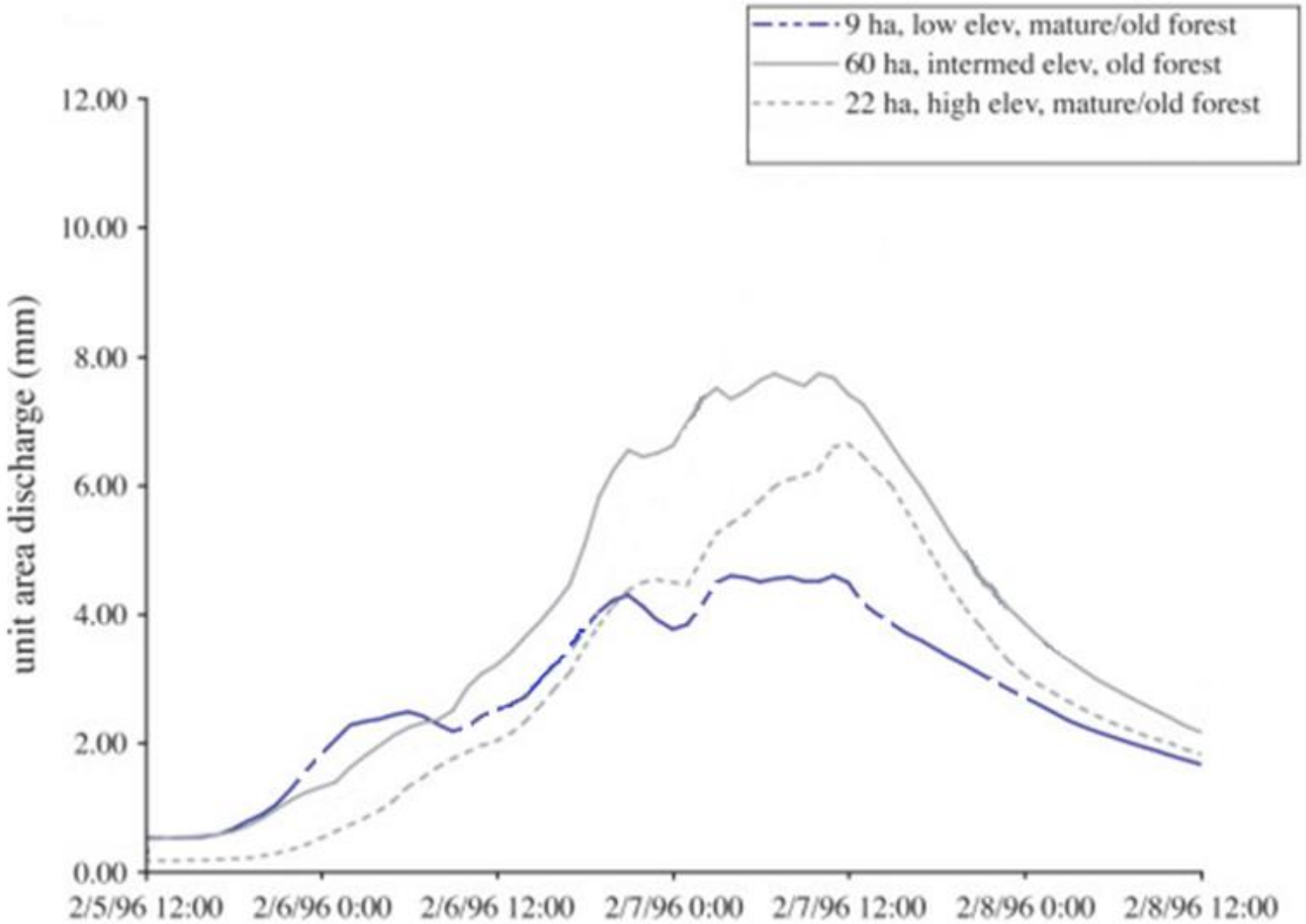
Watershed Function - Water

- Rain event



Watershed Function - Water

- Rain-on-snow event



Watershed Function - Water

- Water processing is strongly influenced by watershed structure…
  - Changes in vegetation affect snow accumulation and melt.
  - Changes in vegetation affect water storage and use…which in turn affect streamflows.

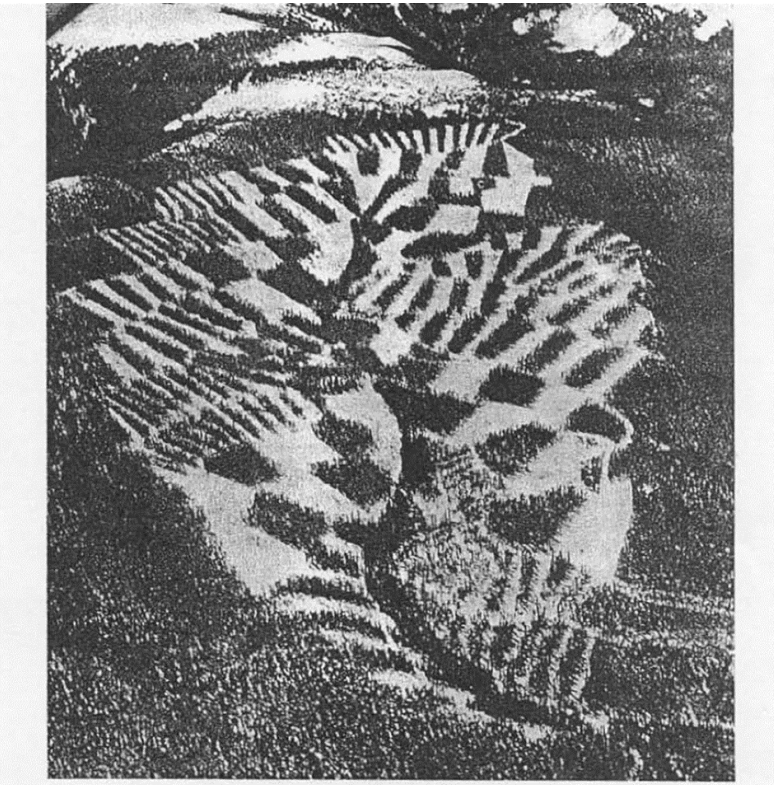
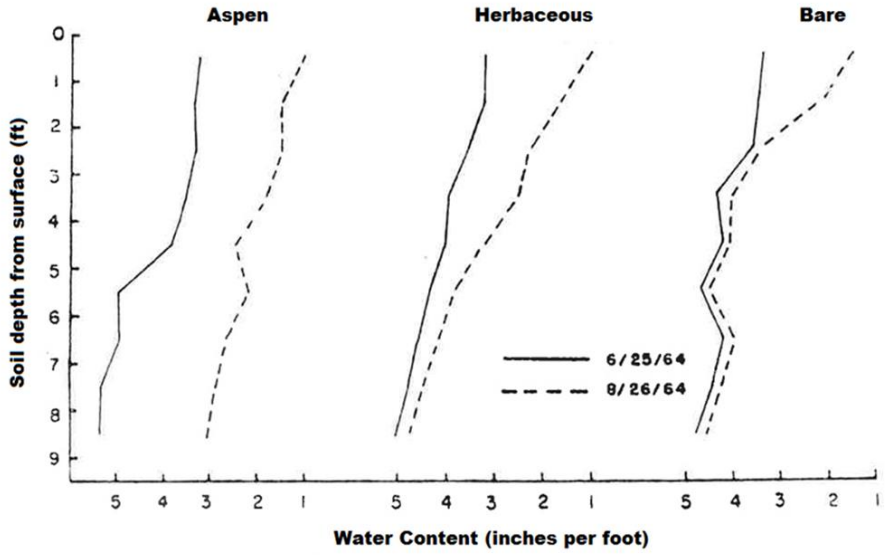


Fig. 1. Fool Creek watershed, Fraser experimental forest. Photo taken in 1958, 2 years after harvest.



Evapotranspiration - soil moisture withdrawal

Water and Fish

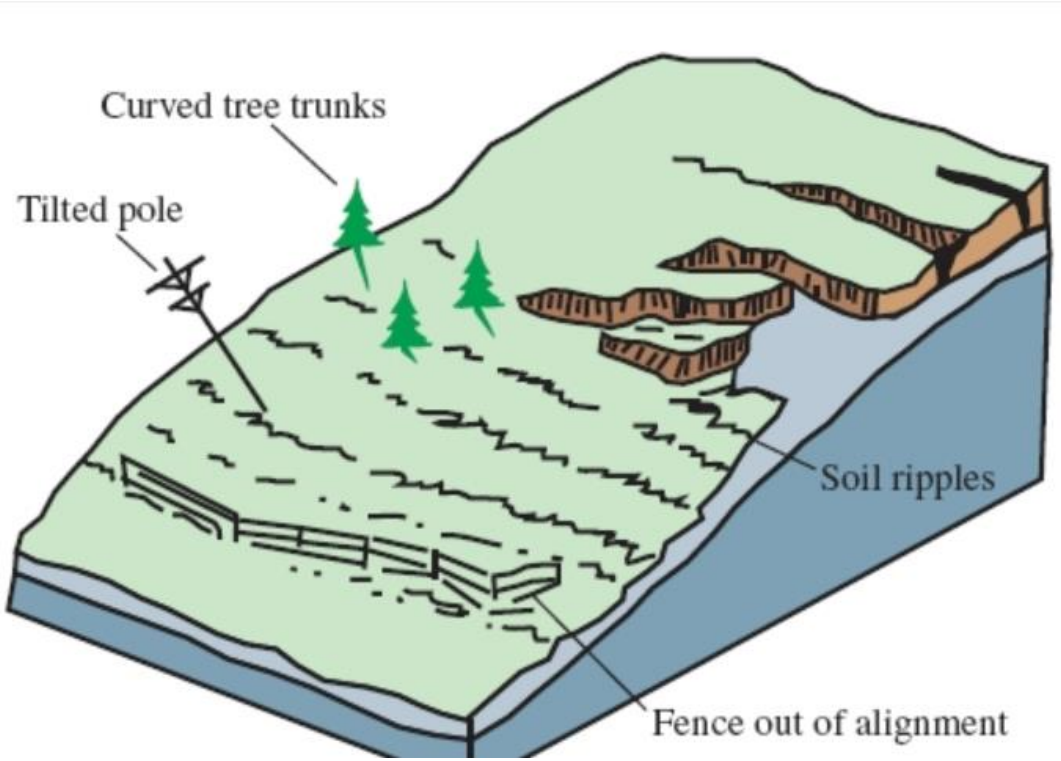
- Generally speaking, there is plenty of water to sustain fish populations west of the Cascade crest. Regardless of rain, rain-on-snow, or snow dominated systems.
- **Conventional wisdom suggests that fish populations in the rain-on-snow zone are at greatest risk from high flows that can directly affect free swimming and incubating eggs/pre-emergent fish via sediment movement. So, watershed structure is most important here: elevation (also slope and aspect) are fixed watershed structures; but vegetation structure is something we manage.**

Watershed Function - Sediment

- The northwest coast (Cascade crest and west) is among the most geologically active areas on the planet.
- Tectonic forces causing uplift.
- Erosional forces causing lowering.
- This all seems to be happening at rates on the order of 0.1 – 1.0 mm/year. (1-10 tons/ac/yr).

Watershed Function – Sediment Delivery to Streams

- Mass wasting and soil creep are the dominant processes delivering sediment to streams.



Watershed Function – Sediment Delivery to Streams

- Overall surface erosion is almost non-existent (unlike agricultural fields)…only roads.
- Bedrock type makes a huge difference in erodibility and the resulting stream sediment.
  - Coast range with marine sandstones are not particularly strong and material erodes to fine particles relatively quickly.
  - Basalt bedrock is relatively strong and maintains cobble and gravel sizes to a higher degree.

Watershed Function – Sediment Delivery to Streams

- Topography is a large factor in determining the rate of mass wasting and soil creep. Steeper means more soil movement.
- Weather is another huge factor as most mass wasting occurs in response to extreme rainfall events (or rain-on-snow).
  - Shallow-rapid failures strongly related to individual precipitation events.
  - Deep-seated, slow failures more strongly related to seasonal or annual precipitation.

Watershed Function – Sediment Transport Within Streams

- Sediment transport within streams is tightly tied to streamflow. A rule of thumb: 80% of the sediment movement comes with the top 20% of the water movement. So weather (not climate) dominates.
- Debris flows and debris floods are nuances to this rule.

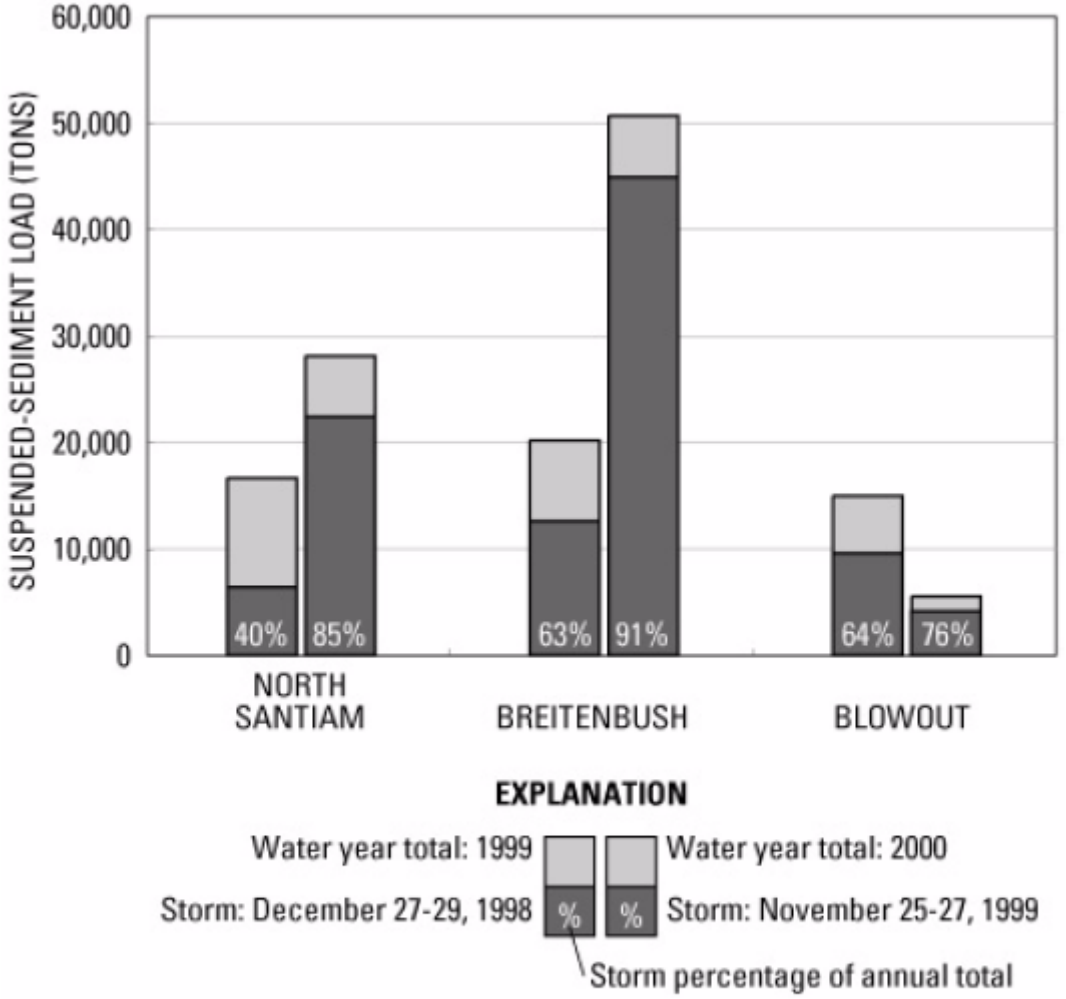
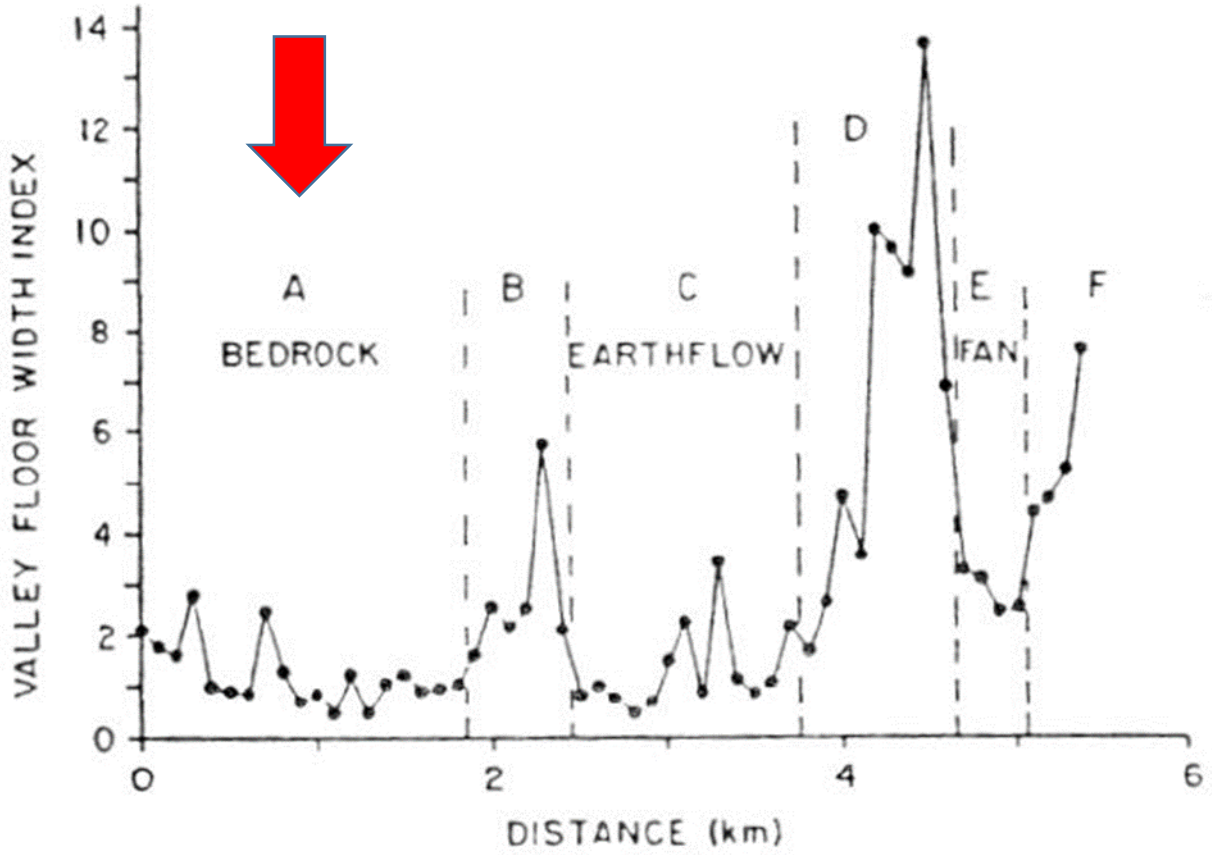


Figure 11. Estimated annual and peak storm suspended-sediment loads at three monitoring sites in the upper North Santiam River Basin, water years 1999 and 2000.

Watershed Function – Stream Reach Type

- The balance of stream power and sediment supply (volume and particle size) largely determine how a given stream reach appears.



Watershed Function – Stream Reach Type

- Stream power much greater than sediment supply.
- Sediment delivered from upstream or adjacent hillslopes will move on through quickly.
- Stream is NOT moving within floodplain.

Watershed Function – Stream Reach Type

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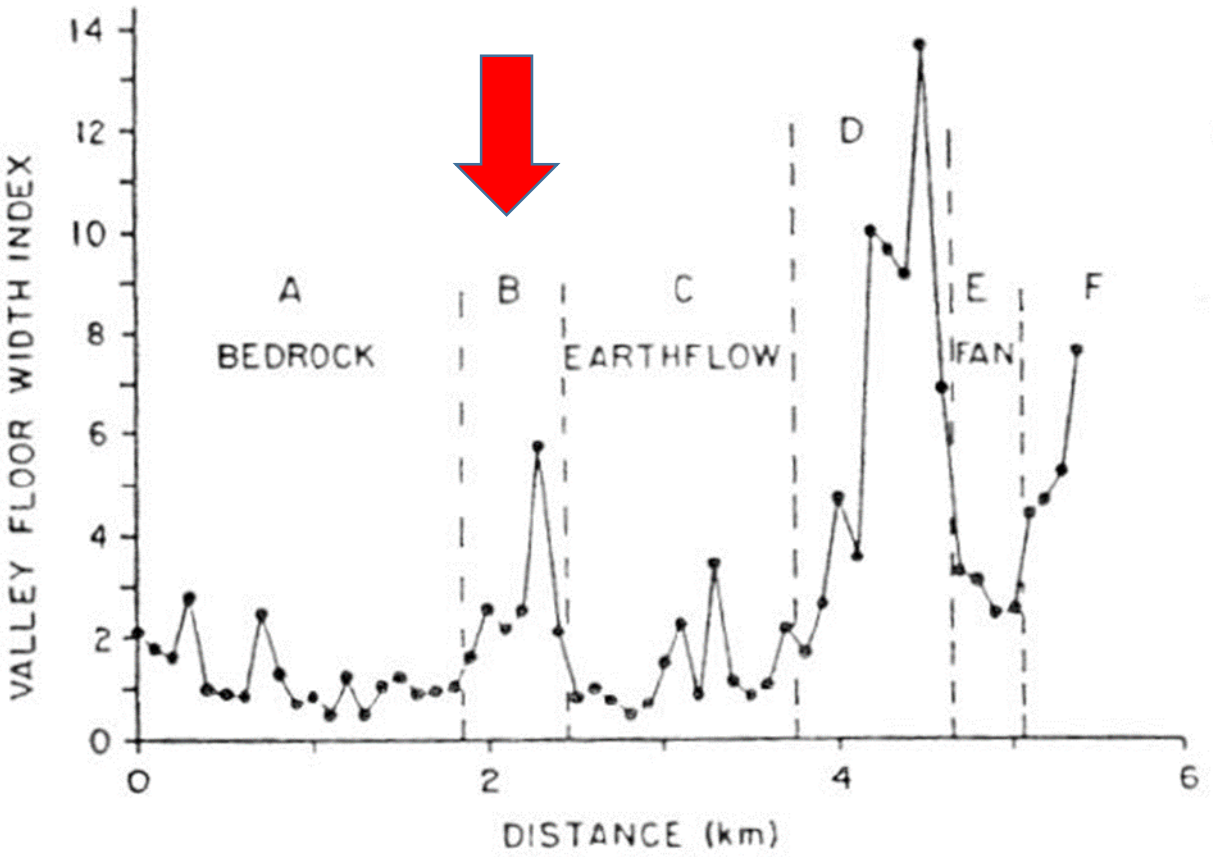

Watershed Function – Stream Reach Type

- Stream power and sediment supply roughly in balance.
- Sediment from upstream and adjacent hillslopes goes in and out of storage over long time scales. Waves of sediment may move through these reaches.
- Stream has a floodplain and it may move across the valley bottom over time.

Watershed Function – Stream Reach Type

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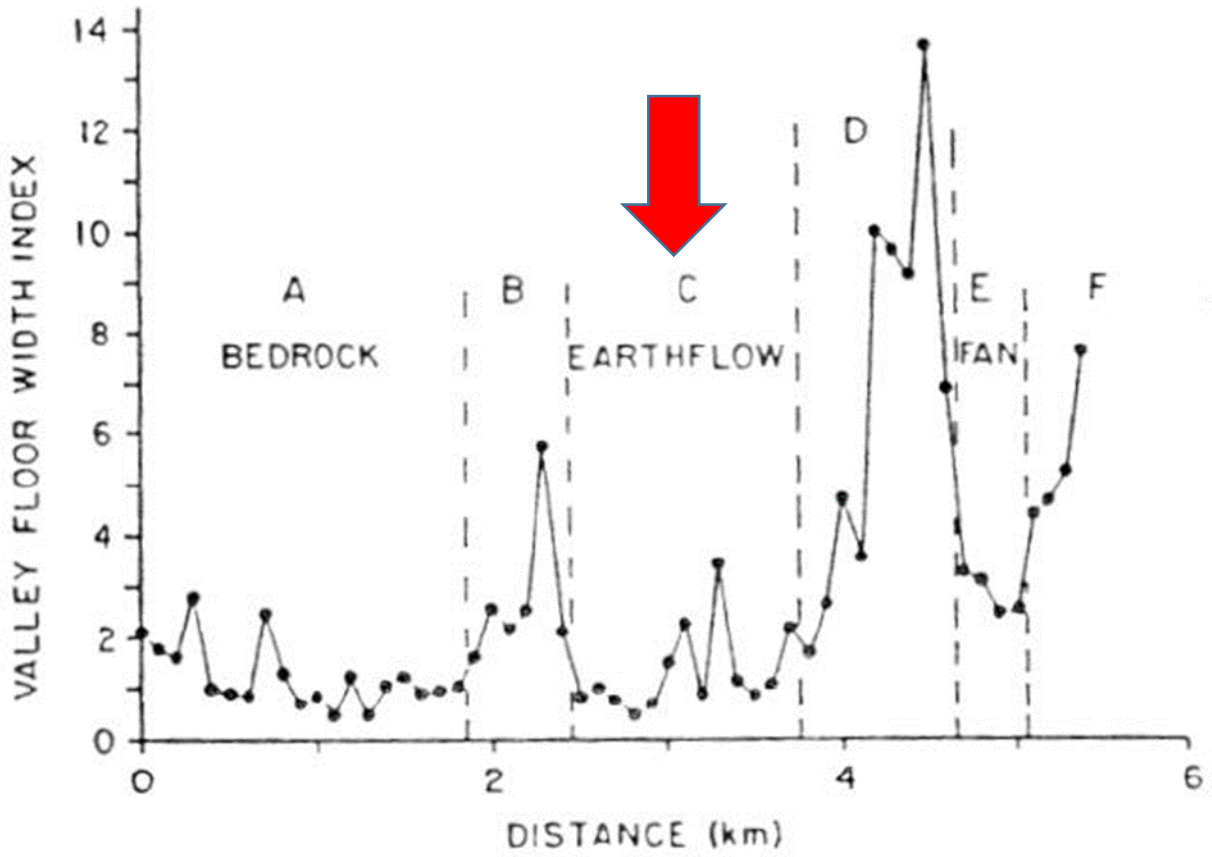
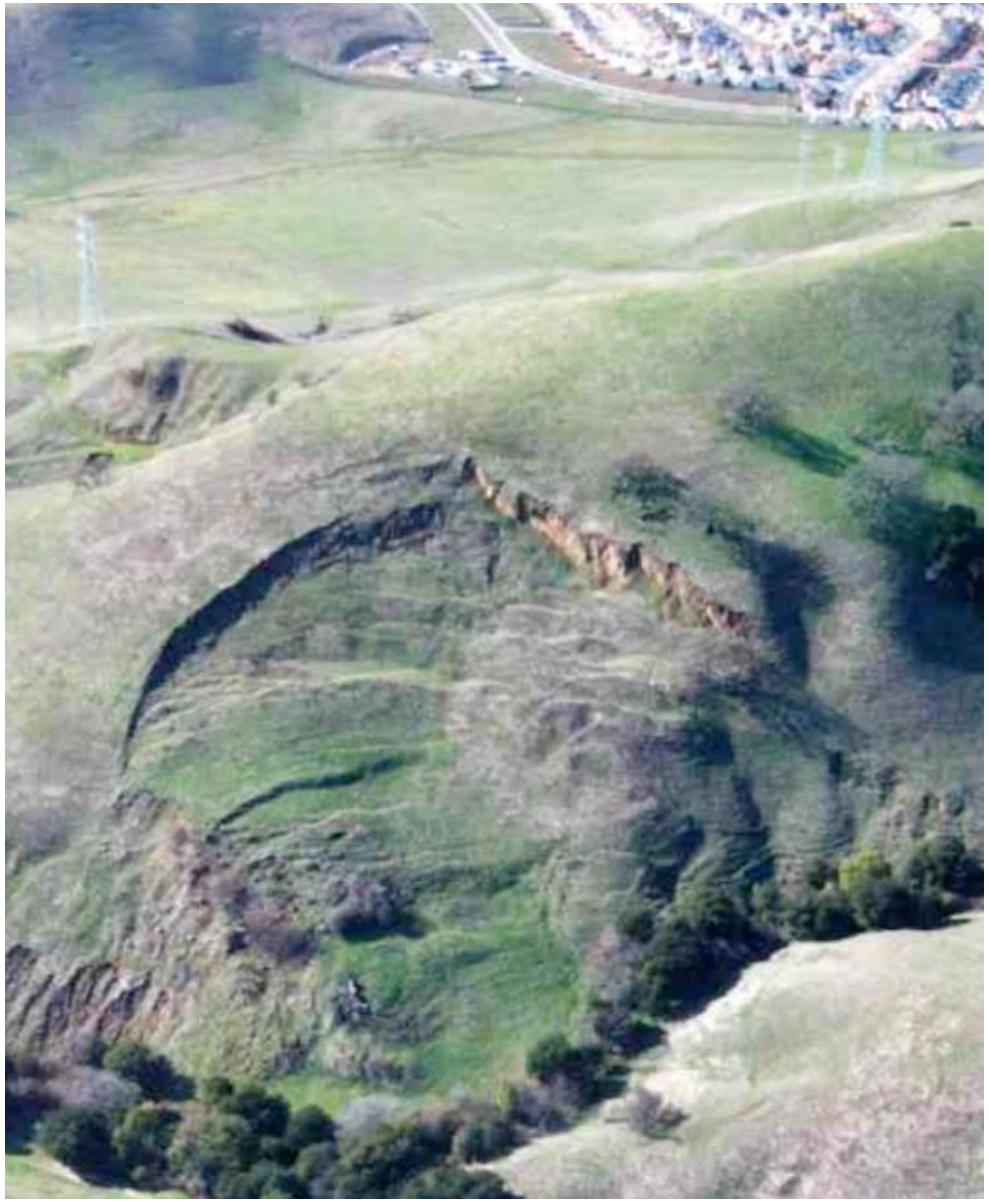


Watershed Function – Stream Reach Type

- Earthflow impinging on the stream channel.
- Stream power much less than sediment supply.
- Stream is pushed across valley bottom.
- Stream may actually be dammed temporarily by fast moving earthflow.



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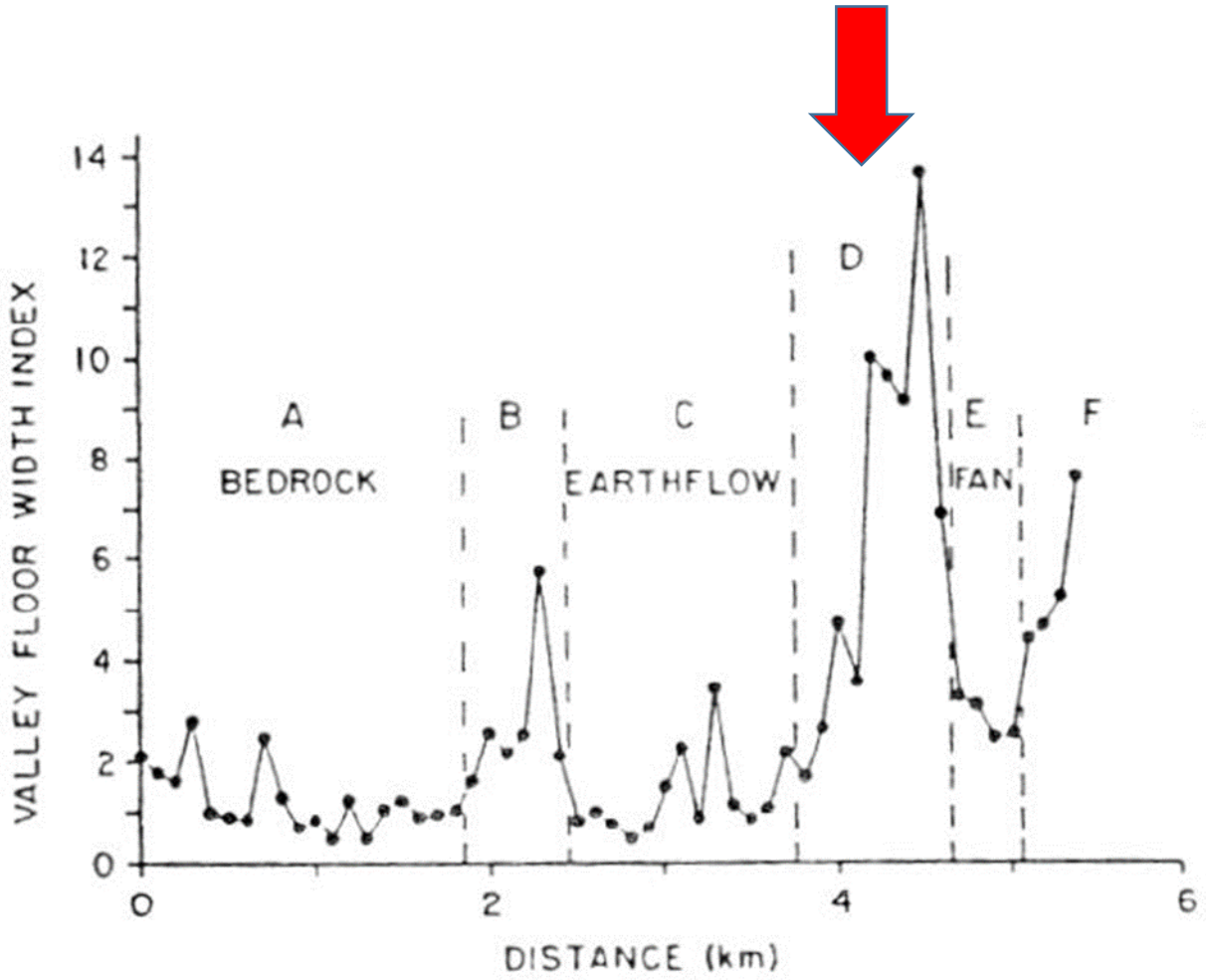

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Watershed Function – Stream Reach Type

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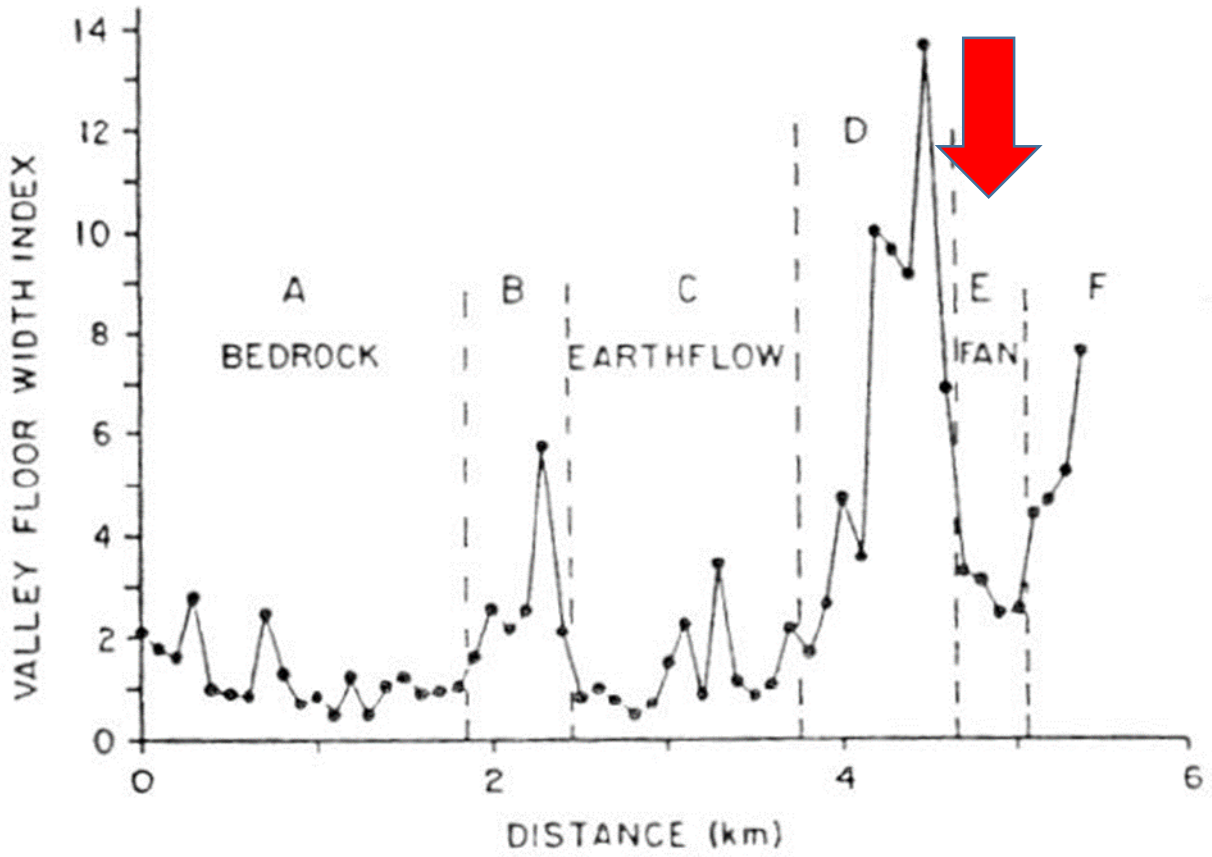


Watershed Function – Stream Reach Type

- Landslide or debris flow fan locally constrains the channel.
- Sediment supply exceeds stream power locally.
- Sediment supply constrains the stream (or may push it across the valley bottom). Dams are also possible.

Watershed Function – Stream Reach Type

Braided river – sediment supply much, much greater than stream power.

Watershed Function – Stream Reach Type

- Some reach types are fixed in space for all time.

- Others may move around or come and go over time.

Stream Type, Sediment and Fish

- The different types of stream reaches provide different types and quality of fish habitat. The reach types supporting differing fish needs may “move around” in the stream network over time.
- The sediment characteristics of the bed are often related to the reach types, but not perfectly.
- Spawning and egg incubation – salmon and trout prefer lower gradient reaches with gravel-sized sediment. Requires sufficient water flow through the sediment to aerate eggs. **COMPLEXITY** creates the gravel accumulations, **COLD**, then Clean.
- Rearing – **COMPLEXITY**! Complexity may result from sediment or large wood (a later chapter in the story). Resting habitat, feeding habitat, hiding cover from predators, hydraulic cover from high flows.
- Migration – sufficient water depth (duh! **CONNECTED**) and Complexity for rest.
- **CLEAN** - Suspended sediment or turbidity (not exactly the same thing but closely related) is its own story.

Watershed Function – Fish Needs

Reach Type	Spawning/Incubation	Rearing	Migration
Sediment Source		x	x
Sediment Transport	X	X	x
Sediment Deposition	x	X	x

Suspended Sediment and Fish

- Suspended sediment (or turbidity, not exactly the same thing but closely related) is its own story.
- High suspended sediment (or turbidity) is commonly believed to be detrimental to fish (**CLEAN**).
- Spawning and Incubation – eggs and fish in stream bottom sediments are only affected as the suspended sediment settles in lower velocity water.
- Rearing - free swimming fish may have direct health effects (abrasion).
- Rearing - free swimming fish may have indirect health effects (inability to gather food).
- Migration – local migration might be spurred or inhibited by high suspended sediment.

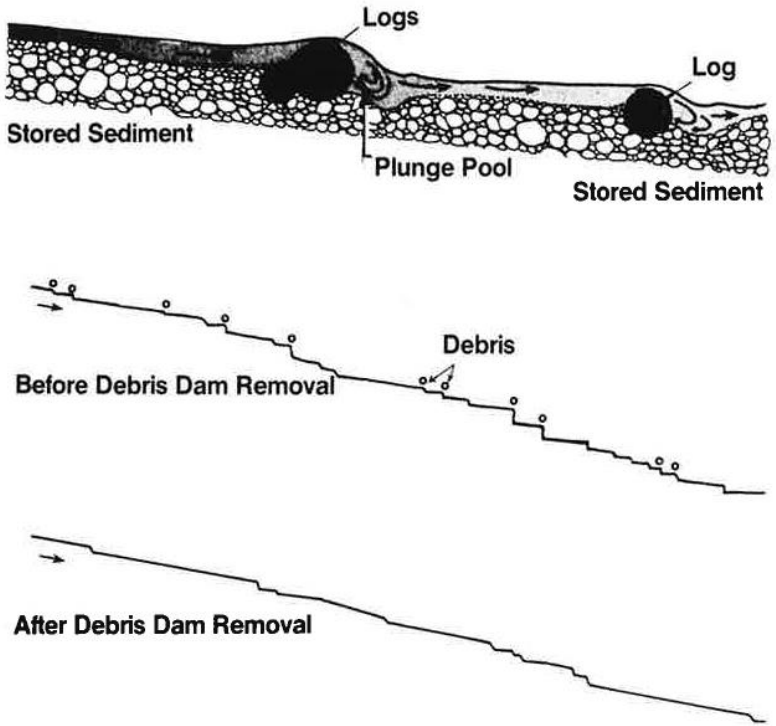
Watershed Function – Suspended Sediment

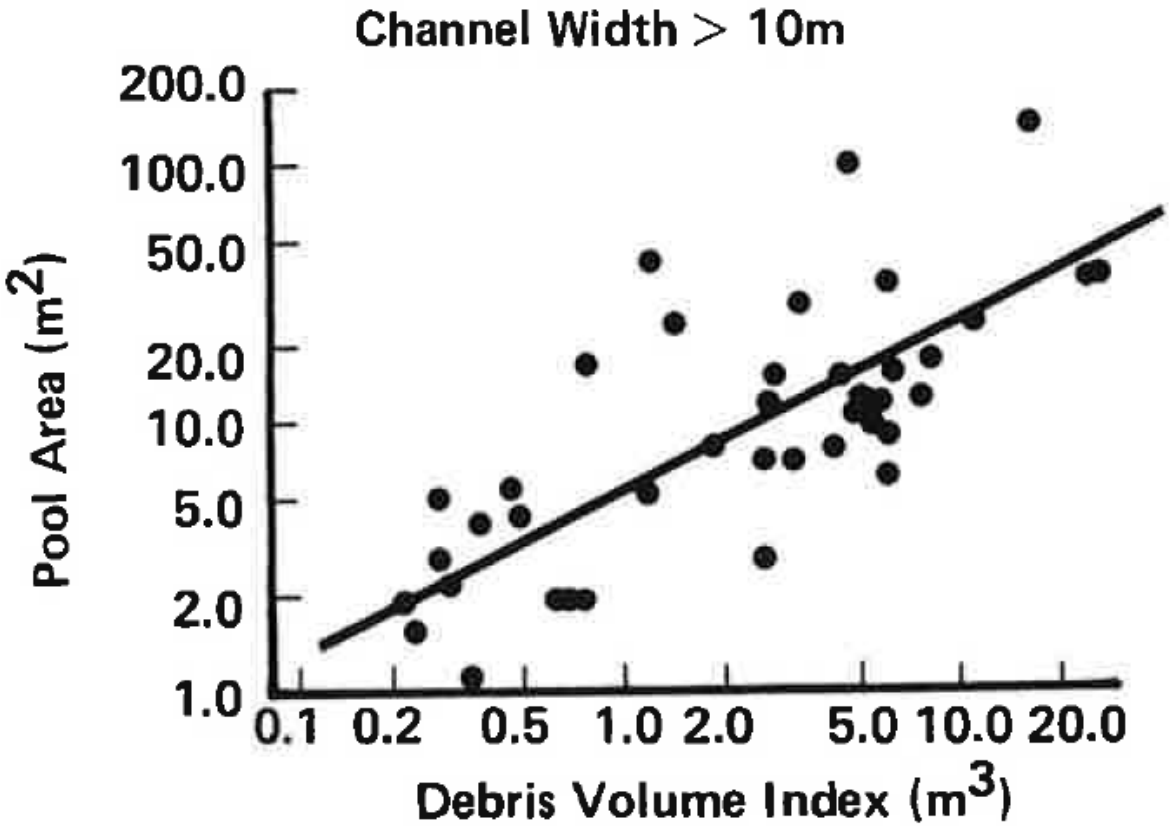
Function	Spawning/Incubation	Rearing	Migration
Suspended Sediment (CLEAN)	**x**	**x**	**x**

Sediment and Fish

- We need to discuss large woody debris to fill in the rest of the sediment-fish story.

Watershed Function – Large Woody Debris

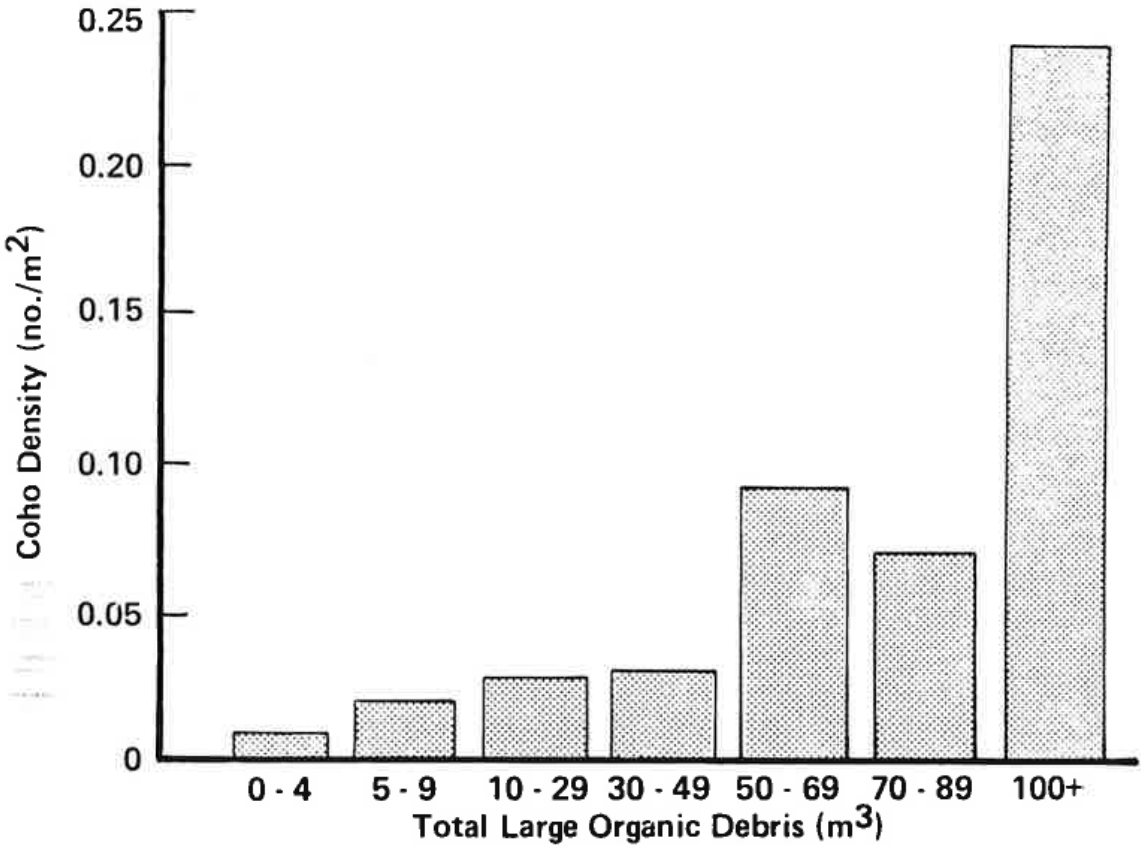




COMPLEXITY!!!

Large Woody Debris and Fish

Site	Total Salmonid Densities (fish/m^2)				
type	Individual sites			Average	
natural	0.54	0.64	1.35	0.85	
treated	1.18	0.72	1.43	1.11	*
untreated	0.33	0.46	0.32	0.37	*



Watershed Function – Large Woody Debris

Function	Spawning/Incubation	Rearing	Migration
Large Woody Debris (COMPLEXITY)	X	X	x

Large Woody Debris

- Where does the wood come from?
- Streamside adjacent. Most common. A function of channel migration (small) and forest stand dynamics (large)…including major disturbances (fire and windthrow).
- Transported from upstream/uphill by mass wasting or floods.
  - For small forested streams that we deal with most often, floods are not moving big wood.
  - Mass wasting may deliver wood very locally…debris fans or landslide deposits.

Watershed Function - Energy

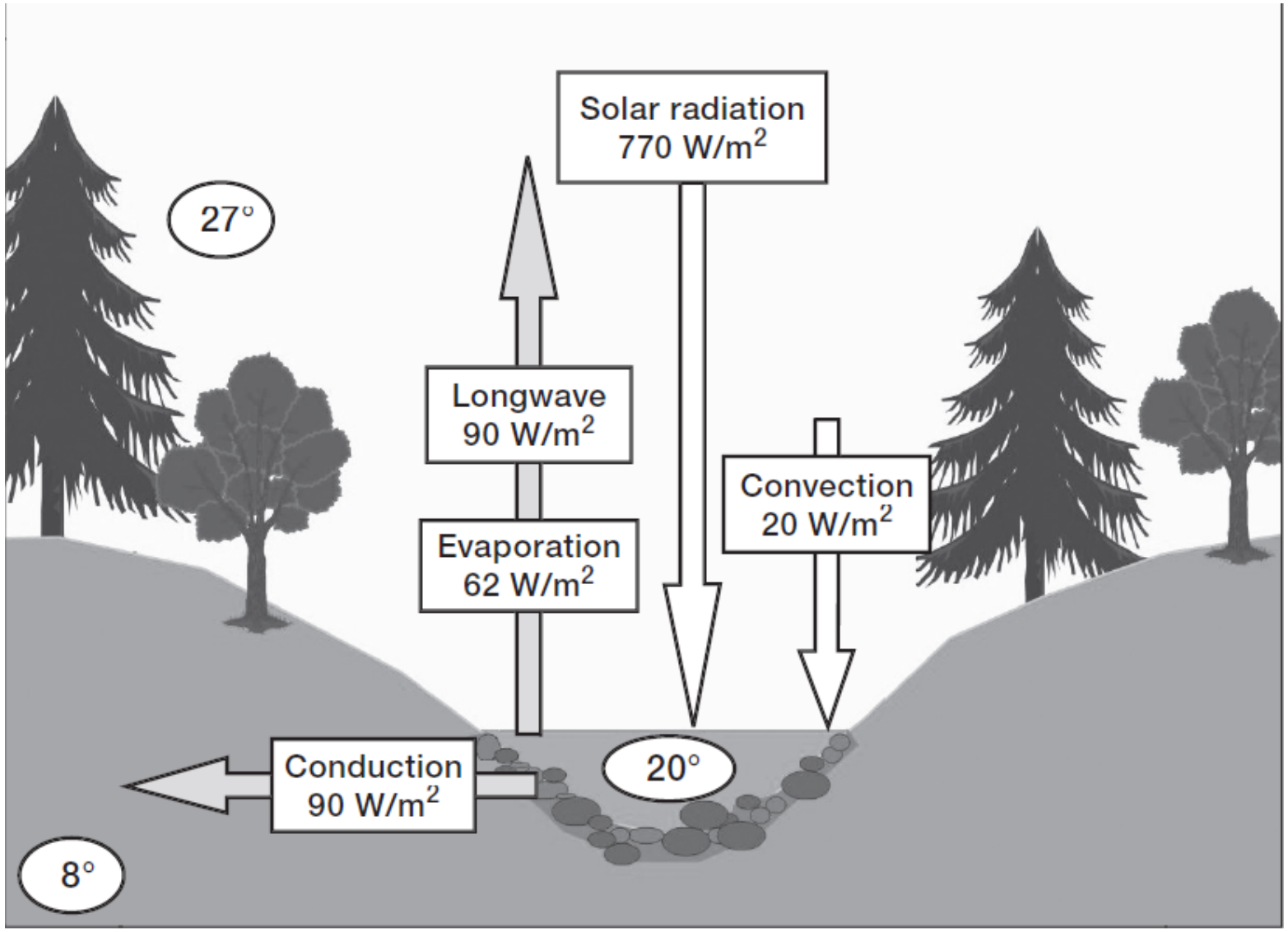
- Snowmelt
- Stream temperature (COLD)
- Fish food (CLEAN)

Energy and Forest Structure

- Snowmelt – we already discussed snowmelt during the hydrology review.

Energy and Forest Management

Stream temperature – riparian shade has a large influence. Streamside trees already discussed with respect to large woody debris. Only nuance is that more tree retention is needed to maintain shade than is needed to maintain or even increase LWD.



A simplified heat budget shows the complexity of inputs and outputs of heat in a stream.

Energy and Forest Management

Fish food – decreasing shade (and increasing sunlight) generally increases fish food via increases in primary production…but there is a speed limit!

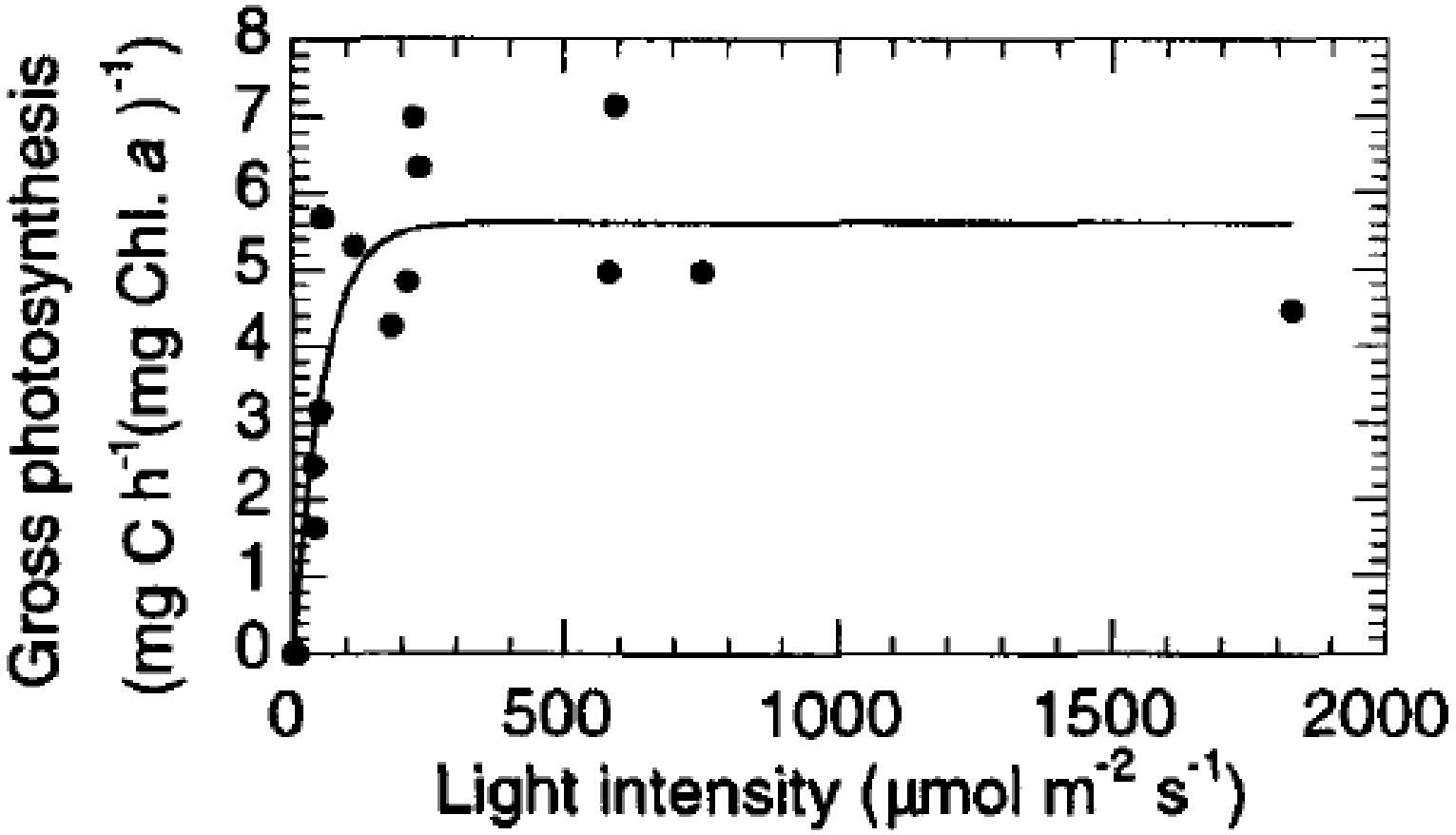


Fig. 4 Example of measured photosynthesis-irradiance response (circles) with Equation 1 fitted.

Energy and Forest Management

But, the decrease in shade increases stream temperature…so we are at cross-purposes here. The rational manager would seek to balance these competing goals on a case-by-case basis; but we don't operate in a rational world.

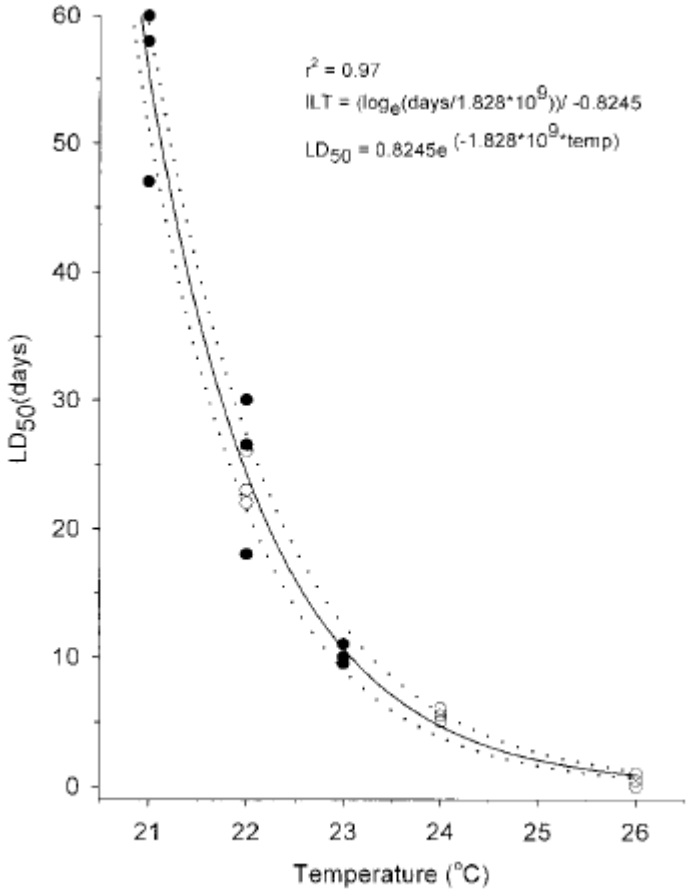


FIGURE 1.—Survival of bull trout in relation to temperature and exposure time during 60-d trials. Only re-

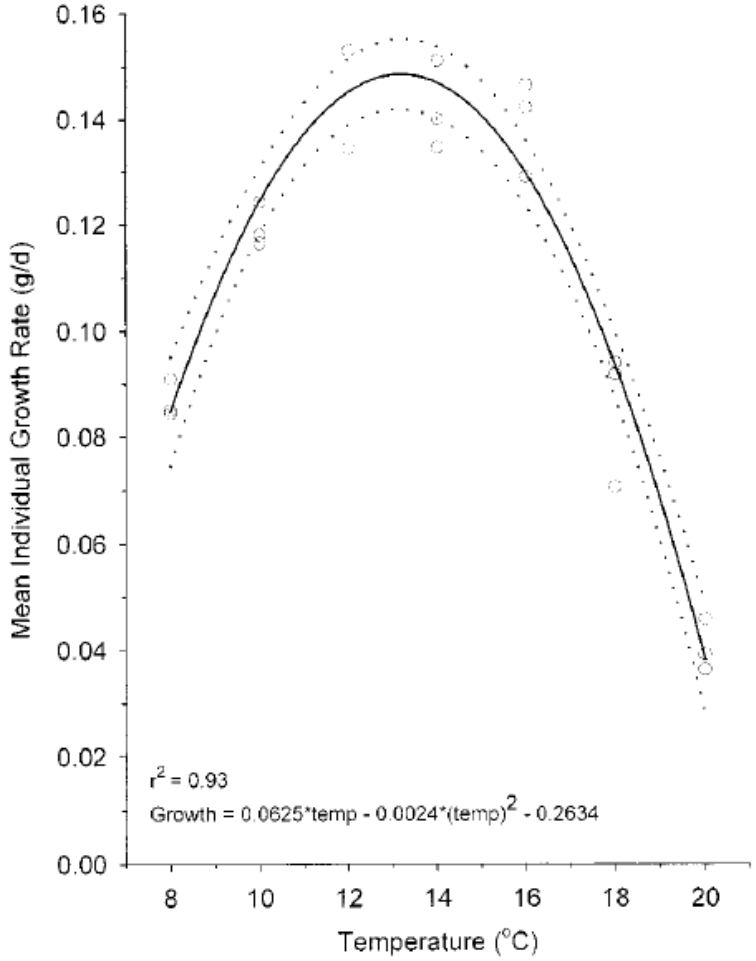


FIGURE 2.—Growth of bull trout in relation to temperature. Each circle represents the mean individual

Summary – Managing Forests is Managing Watershed Structure and Function

- Watershed structure is largely something we are given. Significant changes in upland vegetation do affect watershed function…particularly water flow.
- Changes in water flow (in particular rain-on-snow) can change sediment dynamics…both delivery (mass wasting) and in-stream transport.
- Stream channel structure is largely given. Dramatic local changes can result from sediment and large wood delivery via mass wasting.

THE END

Parking Lot

- Watershed Structure and Functions (what processes form habitat; not all streams equal; fish distribution by species along a network). How does a watershed accommodate the fish's life history-based habitat needs? Such as:
  - Hydrology of forested watersheds - Peak and Low Flows
  - Cascade and Coast ranges - snow/rain differences
  - Stream processes: sediment movement (turbidity, suspended sediment, bedload); large wood
  - Stream classification: HIP streams, Montgomery and Buffington or Rosgen channel types and what they mean for fish.
  - Other Biology? – Beavers; Invasive species;

Watershed Structure

- We directly manage hillslope structure.
  - Vegetation manipulation.
  - Road construction.

Watershed Structure

- We rarely directly manage channel structure.
  - Road crossings.
  - Large woody debris placement.
- Everyone is operating with the goal of road crossings being “transparent” to fish.

Watershed Structure – Forest Management

Structure	Forest Harvesting	Road Construction/Maintenance	Wildcard = Beavers
Hillslopes	X	X	x
Channels		X	X

Watershed Structure – Fish Needs

Structure	Spawning	Rearing	Migration
Hillslopes		x	
Channels	X	X	X
Wildcard = road stream crossings			X

Watershed Function – Fish Needs

Function	Spawning	Rearing	Migration
Water	X	X	X
Dirt	X	X	x
Energy		X	

Watershed Function - Water

- Forest harvesting affects both snow accumulation and snowmelt.
  - Snow interception by trees can be important.
  - Wind patterns and therefore snow deposition patterns are affected by trees.
  - Forest canopy has major effect on energy budget of snowpack.

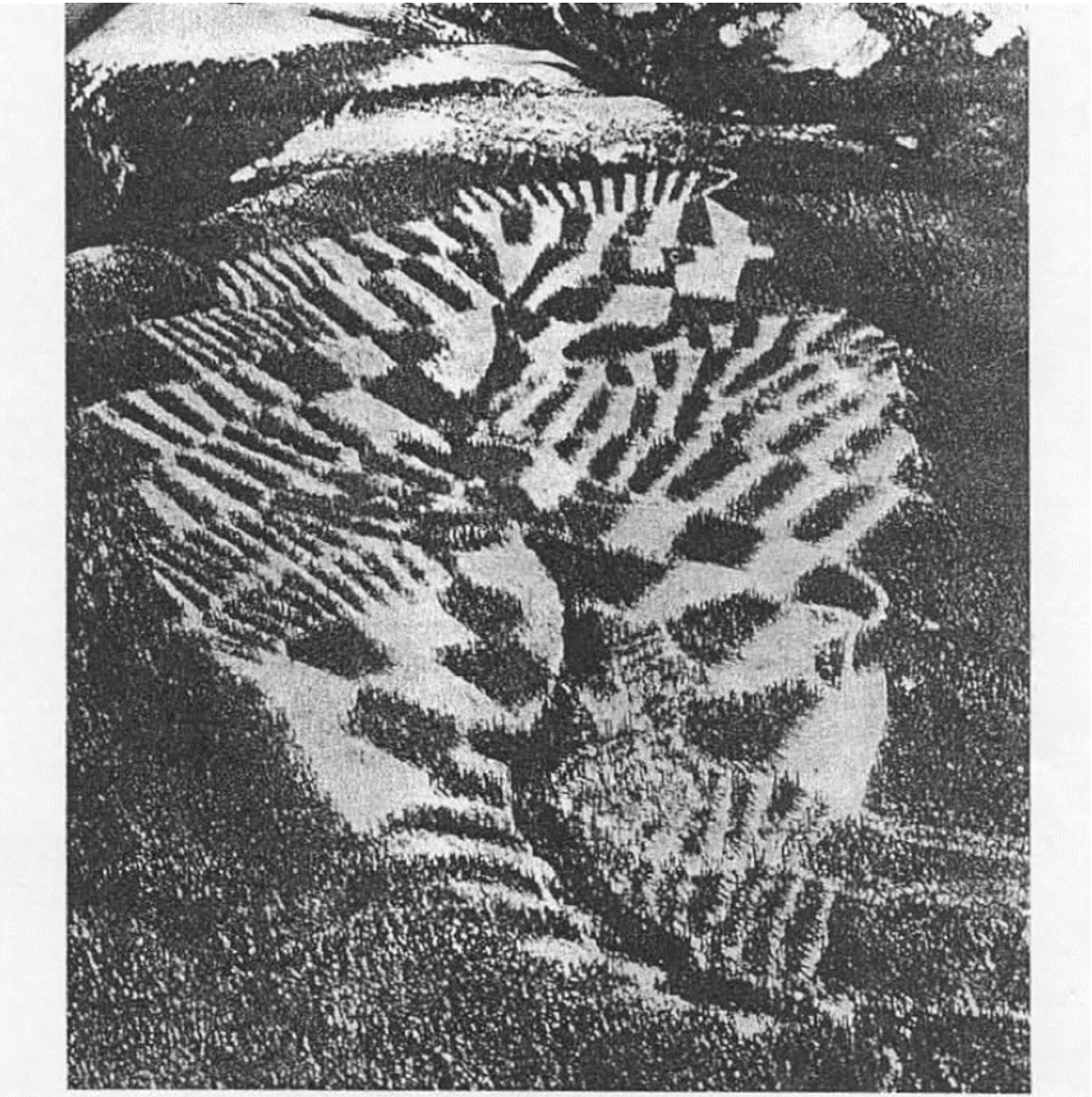
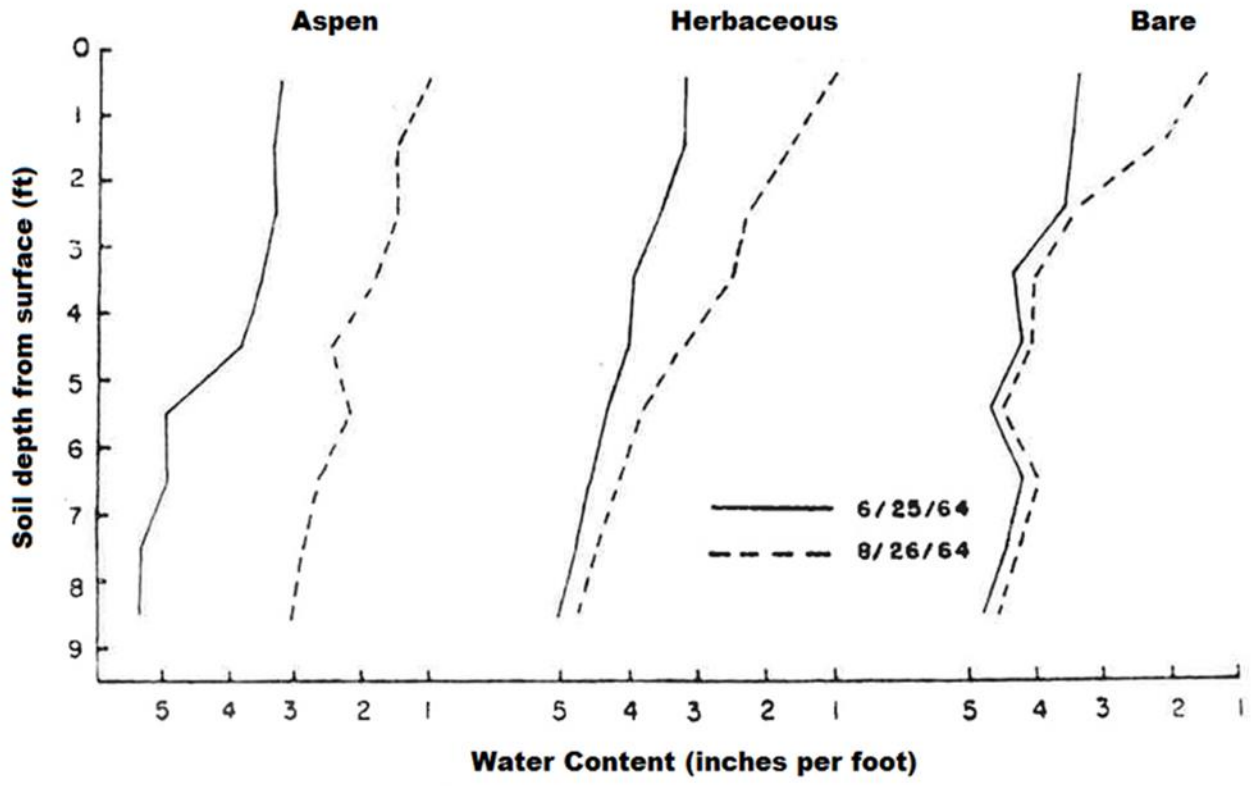


Fig. 1. Fool Creek watershed, Fraser experimental forest. Photo taken in 1958, 2 years after harvest.

Watershed Function - Water

- Water flow is strongly influenced by our management of vegetation on hillslopes in all cases by evapotranspiration.
- Forest harvesting tends to increase flows during the dry-to-wet seasonal transition, and the wet-to-dry seasonal transition.



Evapotranspiration - soil moisture withdrawal

Watershed Function - Water

- Forest road construction can change some water pathways:
- Overland flow on the road surface itself.
- Interception of subsurface flow by the road cut.
- These two reasons are why we are so focused on disconnecting roads from streams. Get the water back onto the forest floor where it will infiltrate.

Water and Fish

- Generally speaking, there is plenty of water to sustain fish populations west of the Cascade crest. Regardless of rain, rain-on-snow, or snow dominated systems.
- Forest harvesting almost always increases annual water flow…and in particular during summer low flow when fish are probably most vulnerable.
- Conventional wisdom suggests that fish populations in the rain-on-snow zone are at greatest risk from high flows that can directly affect free swimming and incubating eggs/pre-emergent fish via sediment movement.
- We need to discuss sediment (dirt) to fill in the rest of the story.

Large Woody Debris and Forest Management

- Streamside tree retention requirements are now standard operating procedure.
- We continue to debate some minor questions:
  - How much is enough?
  - Are different tree species really different?
  - What size material do we need/desire?
  - Is there a role for silviculture in streamside areas?
  - Why in God's green earth would I leave trees so they "might" fall in the stream when I have people and equipment right there who can make "sure" they fall in the stream?

Summary – Managing Forests is Managing Watershed Structure and Function

- Watershed structure is largely something we are given. We make significant modifications in upland vegetation that do affect watershed function…particularly water flow.
- Changes in water flow (in particular rain-on-snow) can change sediment dynamics…both delivery (mass wasting) and in-stream transport.
- Stream channel structure is largely given. Dramatic local changes can result from sediment and large wood delivery via mass wasting. Legacy road crossings may have significant local effects on structure.
- The most manageable aspect of stream channel structure is LWD size and abundance.

Summary – Managing Forests is Managing Fish Habitat

- The overall goal is to be “transparent” on the landscape.
- Disperse cutting units to minimize hydrologic changes at larger scales.
- Road BMPs to minimize incremental sediment production from roads.
- Stream crossings should minimize stream structural changes.
- Road management programs to reduce legacy effects of roads.
- Streamside BMPs to minimize reduction in shade and maintain a source of future LWD.
- The only thumb print we want to leave is the occasional LWD addition to make us feel good.

Large Woody Debris and Fish

- Biomass of age 1 + and older salmonids was closely related to section **pool volume** ($r^2=0.92$, $P=0.0006$).
- Standing crop (kilograms per hectare) and individual weights of age 1 + and older coho salmon (Oncorhynchus kisutch) and cutthroat trout (O. clarki) were significantly greater ($P<0.02$) in **complex** than in simple sections.

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