FROM THE RAINDROP TO THE RIVER: THE BASICS OF FOREST HYDROLOGY

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OBJECTIVES FOR TODAY

- *Review basic forest hydrology principles that relate to the supply of high quality water*
- *Identify key watershed features that regulate processes*
- *Discuss how management affects water yield and water quality*

BASIC ⟷ **TECHNICAL**

Freshwater is a critical resource

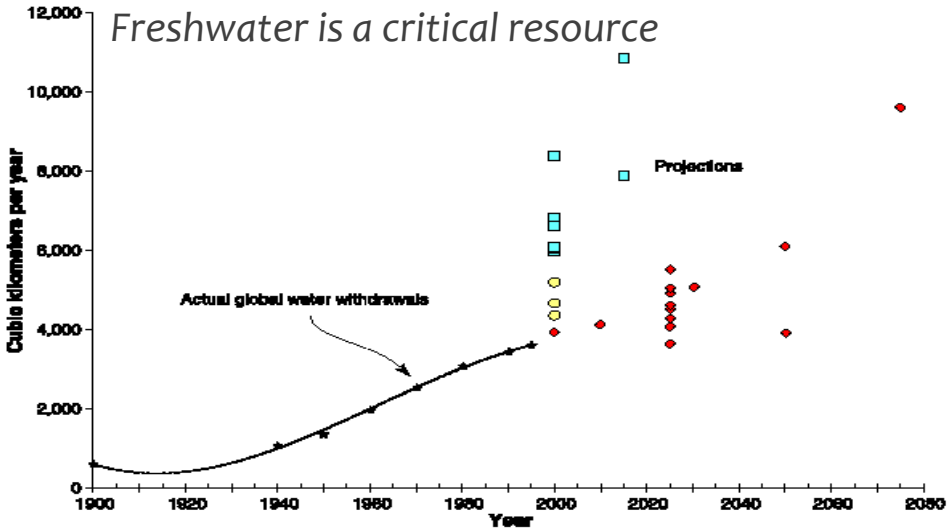


Fig. 3. Projections of water use and actual global water withdrawals, as compiled from various projections of global water withdrawals made since the 1960s (*44*), together with an estimate of actual global water withdrawals, as estimated in (*45*). Note that projections made before 1980 forecast very substantial increases in water use; more recent forecasts have begun to incorporate possible improvements in water productivity to reflect recent historical experience. Symbols: squares, projections made before 1980 (includes forecasts for 2000 or 2015); circles, projections made between 1980 and 1995 (includes forecasts for 2000); diamonds, projections made after 1995 (includes forecasts for 2000, 2010, 2025, 2030, 2050, and 2075).

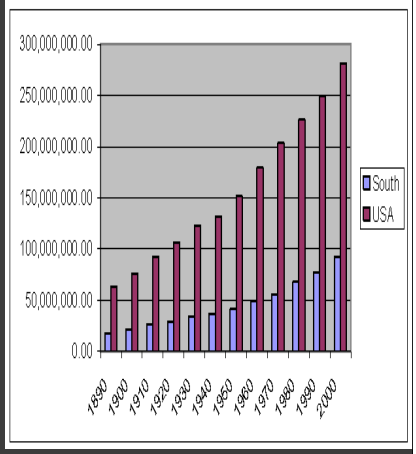
Drought-stricken city scrambles for water source

STATESVILLE, NC — This city is taking emergency measures to increase its water supply and avoid shutting down industry.

The flow of the city's water source, the South Yadkin River, is so low the city could not pump water one day a few weeks ago, the *Charlotte Observer* reported.

The South Yadkin River, which supplies water to two other towns, could dry up by September, state environmental officials said.

The city will enter an unusual agreement with an electric cooperative to divert South Yadkin River water from another city's supply to Statesville, according to the article, which also said officials authorized emergency funds to build three wells in the city and a dam to raise water flow on a creek



FORESTS AND WATER

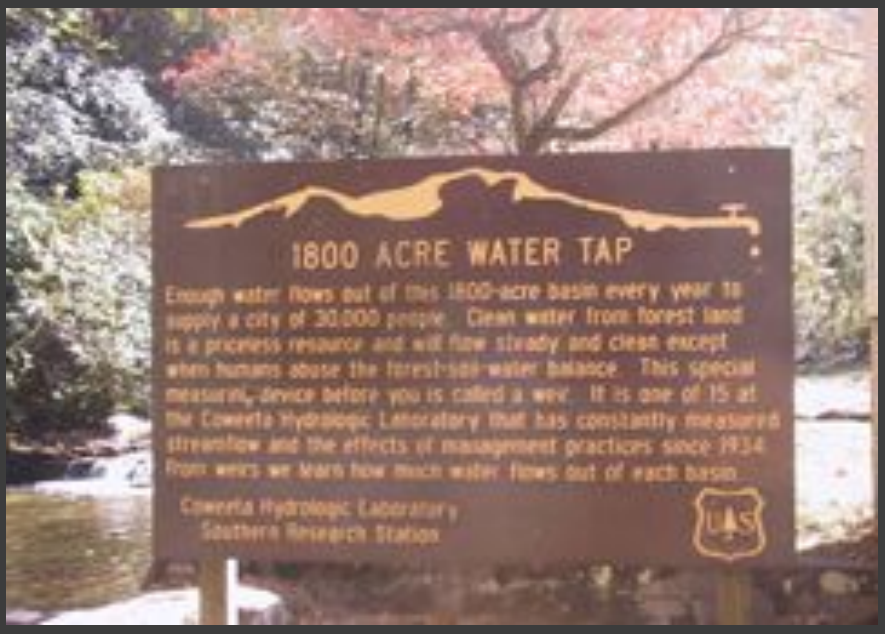
We know that…

- *Cleanest and most regulated supplies of water come from forested landscapes,*
- *Forests can be managed in ways that do not negatively impact water resources, and*

"…settled science…National Research Council (2008)"

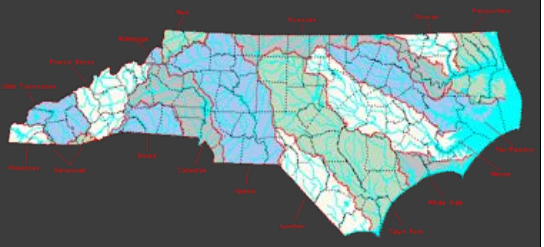
About 60% of the nation's drinking water originates from forests

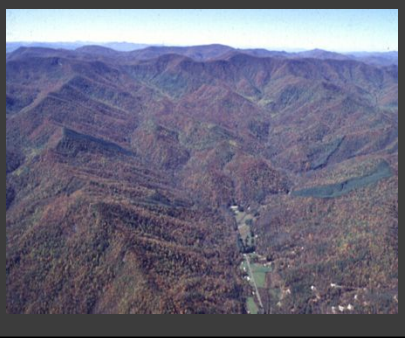
HOW DO WE KNOW THIS?



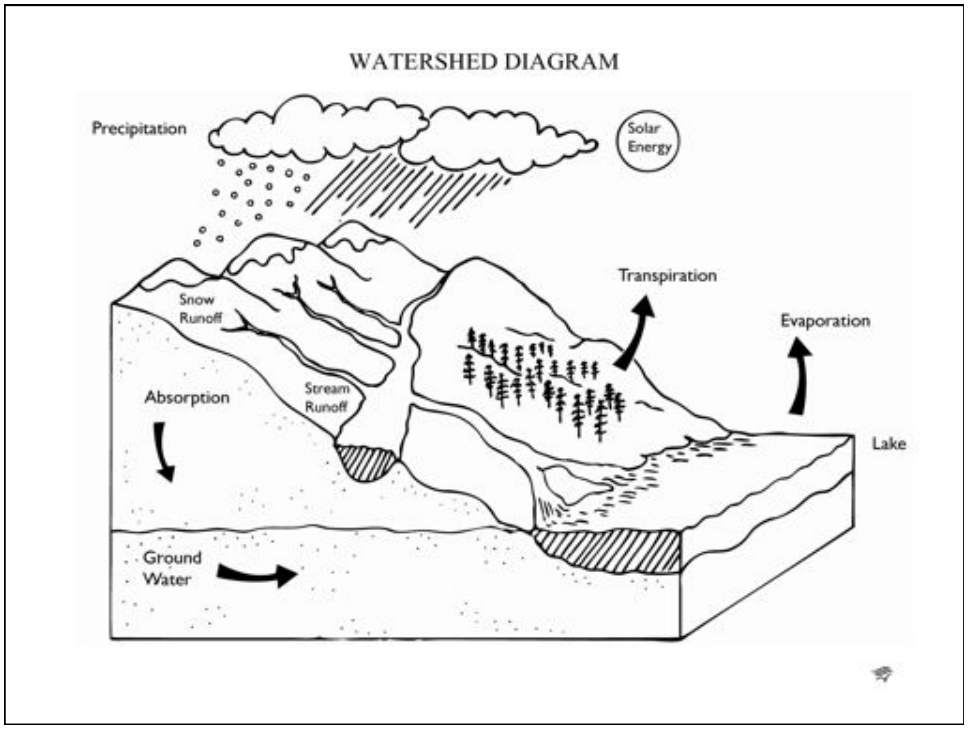
WHAT IS A WATERSHED?

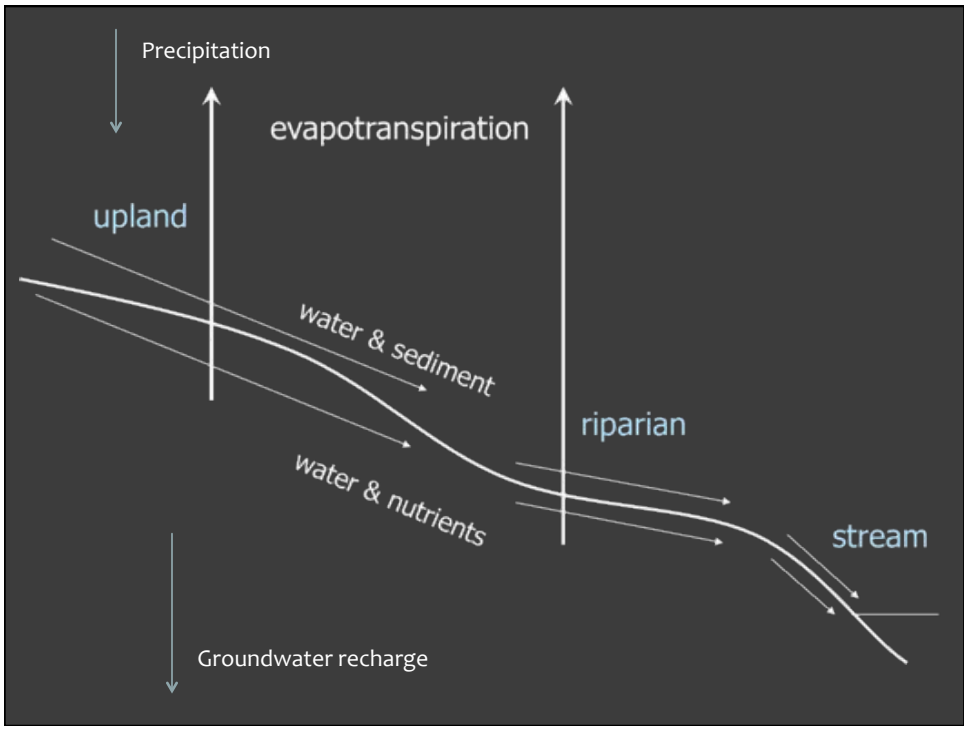
"a unit area of land that ***receives, modifies, stores,*** *and* ***distributes*** *precipitation"*





WHAT ARE THE ATTRIBUTES THAT MAKE FORESTED WATERSHEDS SO VALUABLE FOR SUPPLYING CLEAN WATER?


WATERSHED DIAGRAM
Precipitation
Solar Energy
Transpiration
Evaporation
Snow Runoff
Absorption
Stream Runoff
Lake
Ground Water


Precipitation
evapotranspiration
upland
water & sediment
riparian
water & nutrients
stream
Groundwater recharge

Key Components of Watershed Processes:

INPUTS
- precipitation
- snow

VEGETATION-SOIL-WATER INTERACTIONS
- evapotranspiration – water yield → *Streamflow Amount*
- overland flow - erosion
- storage & filtering - nutrients → *Streamflow Timing*

OUTPUTS
- streamflow
- groundwater

FOREST WATER BALANCE DETERMINES HOW MUCH WATER IS AVAILABLE FOR STREAMS & GROUNDWATER RECHARGE

Annual Runoff = *precipitation – evapotranspiration*

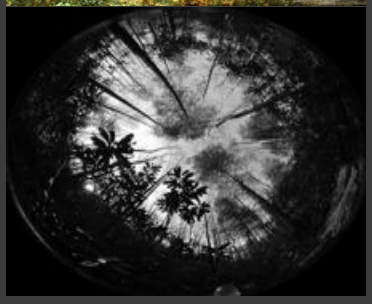
Evapotranspiration = *transpiration + interception evaporation*

INTERCEPTION

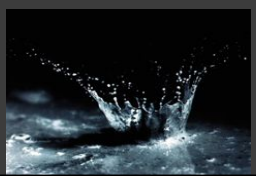
Drops of rainfall first interact with leaves, branches, and stems….

A portion of that rainfall never reaches the forest floor – it evaporates back into atmosphere

10 to 15% hardwood forest
15 to 25% conifers



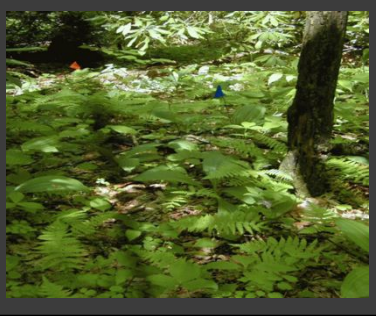
Most of what actually reaches the forest floor is throughfall and stemfow



INFILTRATION

Throughfall and stemflow moves through the forest floor and into the forest soil

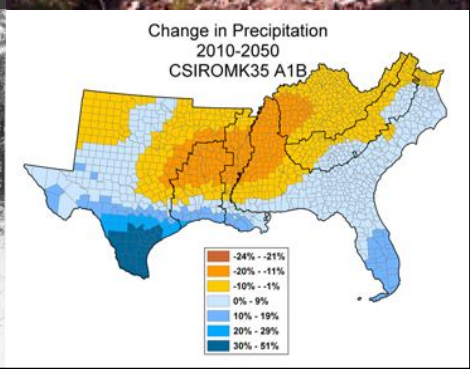
Infiltration expressed as amount of water per unit time (inches per hour)



WHAT DETERMINES INFILTRATION RATES IN FOREST SOILS?

	High	Low
Thickness of litter layer and humus layer	*Thick*	*Thin*
Soil Texture	*Sandy*	*Clayey*
Soil Organic Matter	*High Soil OM*	*Low Soil OM*
Soil Moisture	*Unsaturated*	*Saturated*
Compaction	*Low*	*High*

In many forests, infiltration rates are high enough that water rarely flows along the soil surface except during high intensity rainfall, and in disturbed and heavily compacted areas.



WHAT ARE THE MOST VULNERABLE AREAS IN A FOREST WATERSHED FOR OVERLAND FLOW, EROSION, AND SEDIMENT DELIVERY TO STREAMS?

Roads and Stream Crossings!

Disconnecting the road from the stream….

- proper sizing and location of culverts
- brush/vegetation barriers
- sediment traps
- broad based dips
- stream crossings

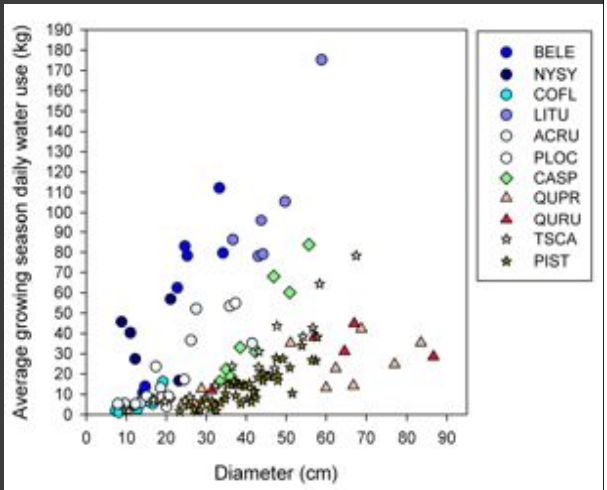
TRANSPIRATION

Transpiration rates (inches, gallons, or lbs of water per day) vary among species, time of year, climate, tree age, tree size

Driven by energy (sunlight) and the gradient between moisture in the air and inside the leaf

A large part of the water budget!

Vose & Ford 2012



12" tree up to 30 gallons per day

THE AMOUNT OF FOREST TRANSPIRATION VARIES BY FOREST TYPE, CLIMATE, AND SOILS

~900,000 gallons per acre per year!

Vegetation Type	Transpiration (mm yr-1)
Longleaf pine savannah	244
Old field pine	250
Upland oak	313
Mixed pine hardwood	450
Loblolly pine plantation (piedmont)	490
Slash pine flatwoods	563
Loblolly pine plantation (coastal plain)	~900
Oak-pine-hickory	278

SOIL WATER STORAGE AND **EVAPORATION**

Evaporation

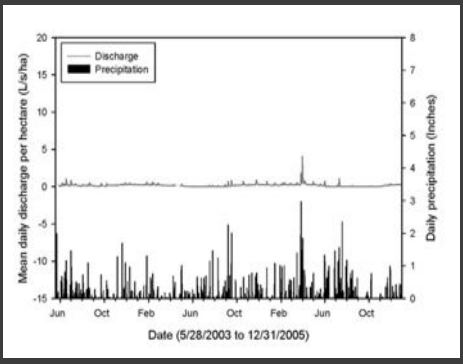
In most forests, forest cover and a thick forest litter layer minimizes soil evaporation

Soil Water Storage

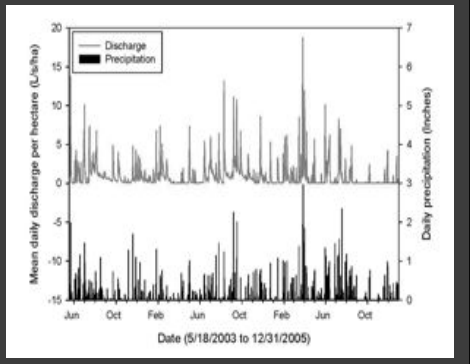
Forest soils act like a sponge, holding onto soil water and slowly releasing it to groundwater recharge and streams.

Forest Soils Act like A Sponge…..

FOREST



URBAN

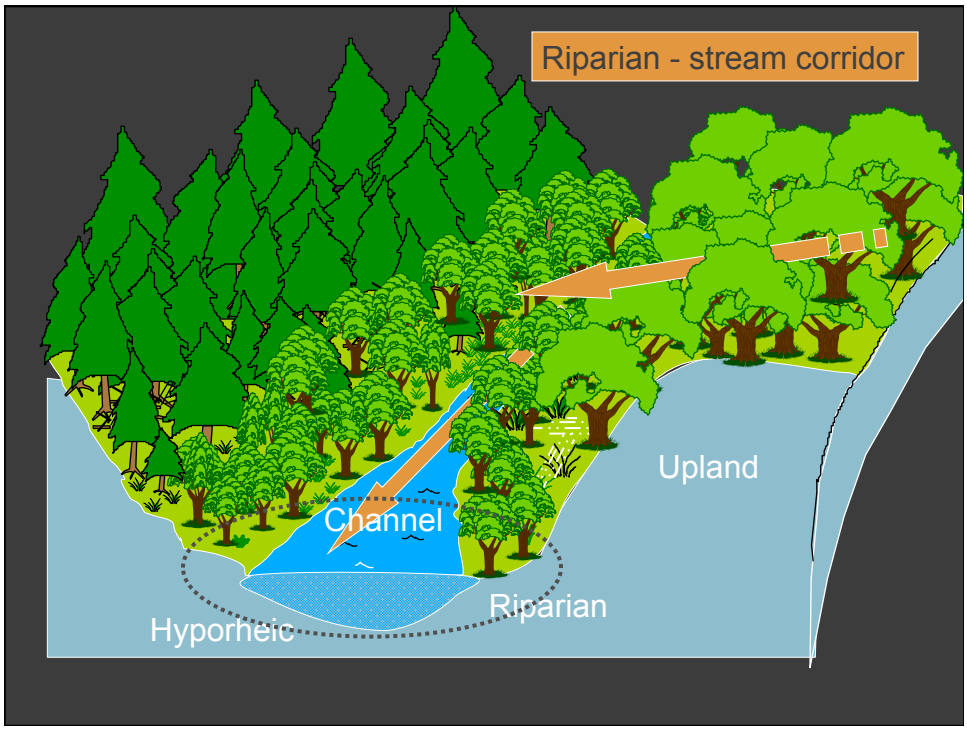


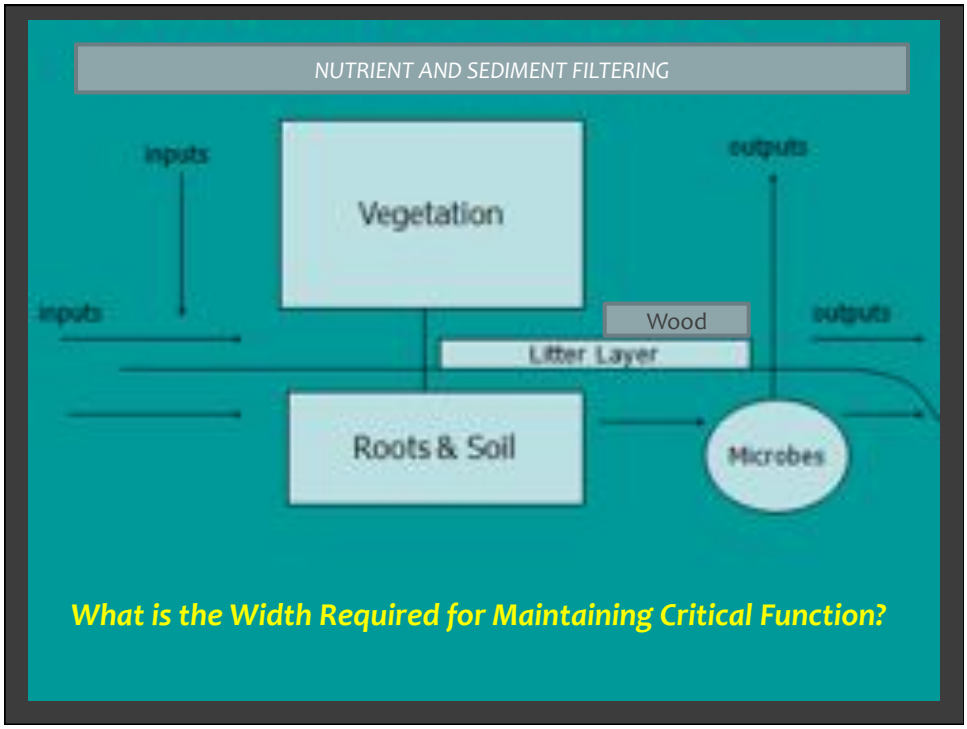
From Lockaby et al. (in press)

THE RIPARIAN ZONE IS THE CRITICAL INTERFACE BETWEEN THE UPLAND AND STREAM

Key Riparian Functions:

- *Sediment & Nutrient Filtering*
- *Stream Bank Stabilization*
- *Wildlife Habitat and Corridors*
- *Wood and OM Supply*
- *Stream Temperature*
- *Biodiversity*

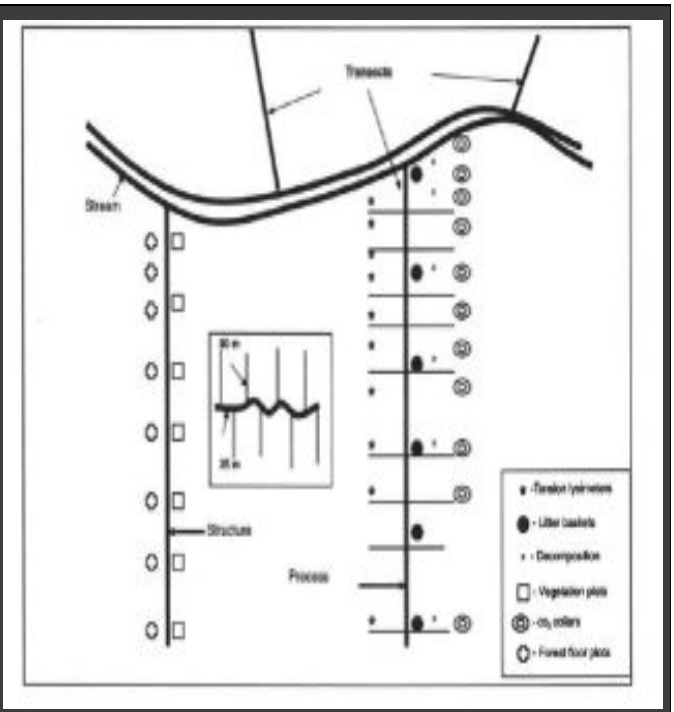




RIPARIAN ZONE WIDTH

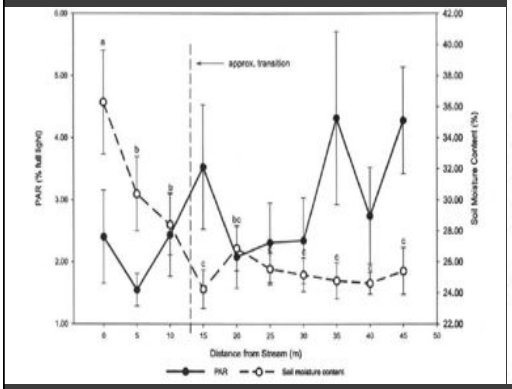
- *What are the critical functions?*
- *How wide should a riparian zone be to mitigate upland disturbances?*
- *How much can the riparian zone be disturbed and still provide critical function?*

Vegetation
Litterfall
Forest Floor
Coarse Wood
Soil Moisture
Soil Temperature
Soil Nutrients
Soil Nutrient Cycling



Clinton et al. 2010

In this setting, most of the parameters that characterize critical function were located within a 30 foot zone



Parameter	Approximate transition (m)	Direction of change*
Aboveground		
Forest floor		
Humus mass (Oe+Oa)	10–20	Increase
Humus C	10–20	Increase
Litter mass (Oi)	10–20	Increase
Litter N	10–20	Increase
Litter C	10–20	Increase
Litterfall		
N input rate†	20–30	Decrease
Woody debris		
Mass	<10	Decrease
N	<10	Decrease
C	<10	Decrease
Belowground		
Soil moisture		
0–20 cm	10–15	Decrease
Soil A horizon		
Total C	7–10	Decrease
Total N	7–10	Decrease
Soil solution‡		
NO_3 — Do, S	10–13	Decrease
NO_3 — G, S	10–13	Decrease
NO_3 — Do, D	16–20	Decrease

Clinton et al. 2010

EFFECTS OF FOREST MANAGEMENT ON WATER YIELD

What do we know?

1. *Stream flow increases proportional to the amount of forest cut,*
2. *Responses vary depending on what vegetation regrows or is planted,*
3. *Increases diminish as the forest re-grows.*

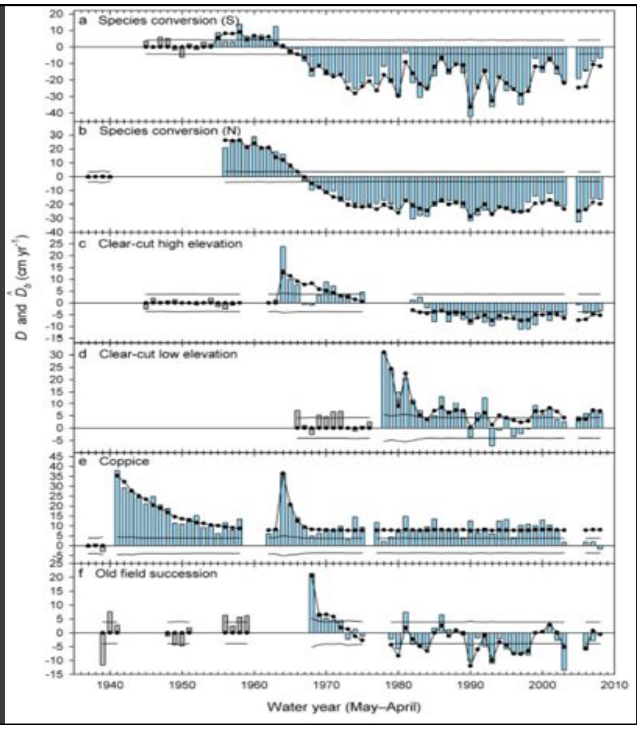
HOW DO WE KNOW THIS?

Decades of Research from Paired Watershed Studies

What Happens to The Water Balance When You Cut a Forest?

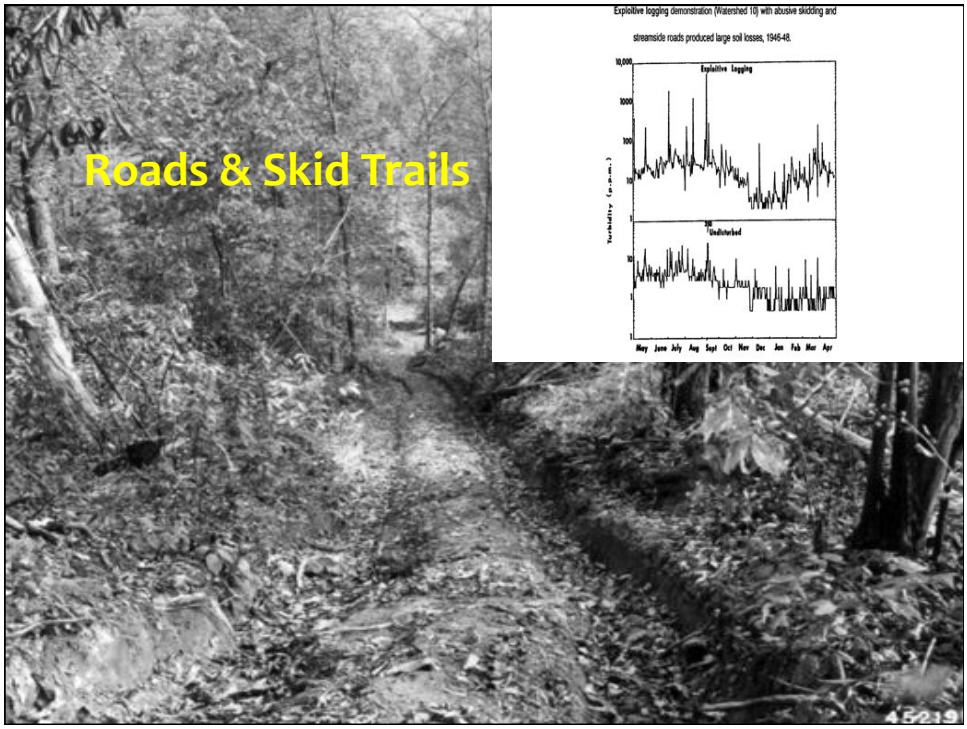
1st year increase as much as ~400,000 gallons per acre!

Ford et al. 2010



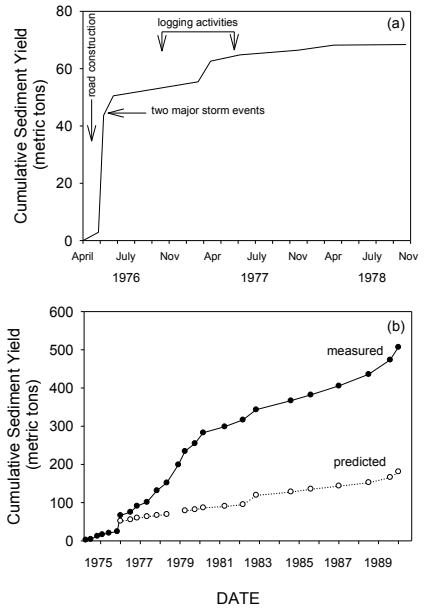
IN AN EARLIER GRAPH, I SHOWED THAT TRANSPIRATION WAS GREATER IN MOST HARDWOODS THAN IN PINES…..WHY DID CONVERTING FROM A HARDWOOD FOREST TO A PINE FOREST DECREASE STREAMFLOW?

Greater interception and year-round transpiration in the pine watershed!

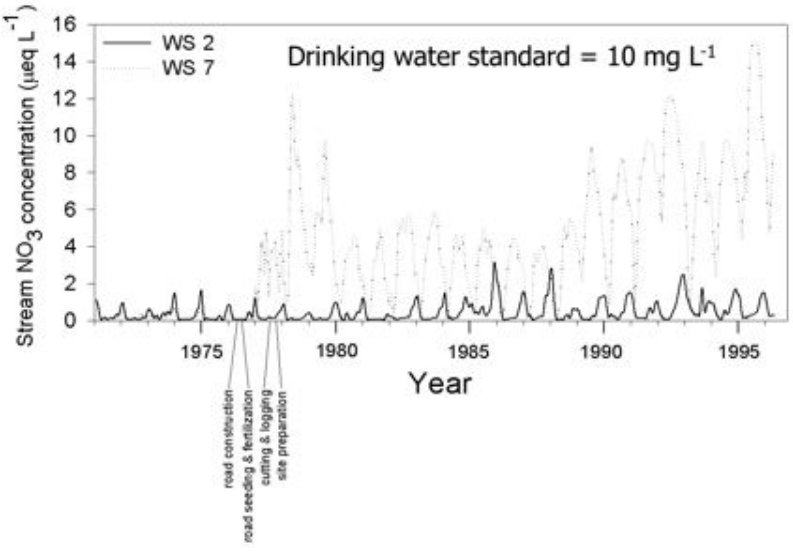

Roads & Skid Trails
Exploitive logging demonstration (Watershed 18) with abusive skidding and streamside roads produced large soil losses, 1946-48.
Exploitive Logging
Undisturbed
Turbidity (p.p.m.)
10,000
1000
100
10
1
May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr


Sediment Movement from Roads

Sediment Response



Nitrogen Response



EFFECTS OF FOREST CUTTING ON WATER QUALITY

Key Points:

1. *Cutting alone does not cause elevated erosion and stream sediment – it's how you get the logs out of the woods,*
2. *Stream nutrient (especially nitrogen) losses are typically small and tightly controlled by vegetation re-growth*

What about fire and water quantity and quality?

RESPONSES DEPEND ON FIRE SEVERITY

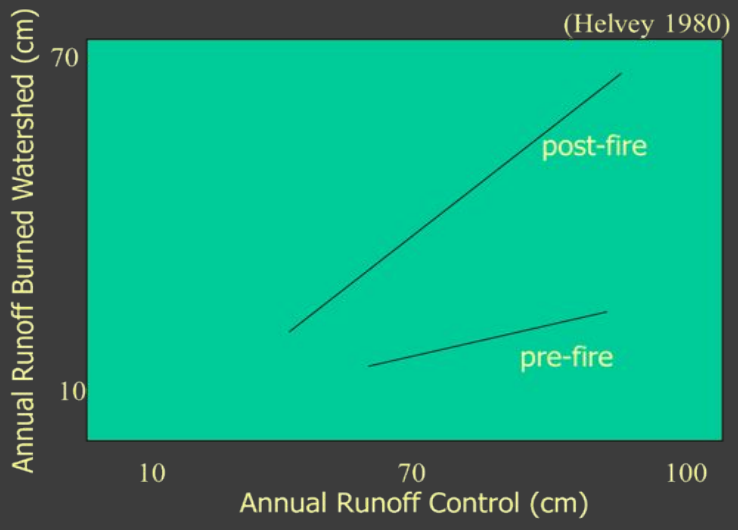
1. *Responses to prescribed fire are usually minimal*
2. *Responses to wildfire can be substantial, but depend on burn severity, post-fire climatic conditions, topography*

WATERSHED RESPONSE FACTORS

- *Loss of forest floor*
- *Overstory mortality*
- *Vegetation Recovery*
- *Infiltration Rates*

- *Post-fire rainfall intensity*
- *Topography*

Annual Runoff = *precipitation – evapotranspiration*

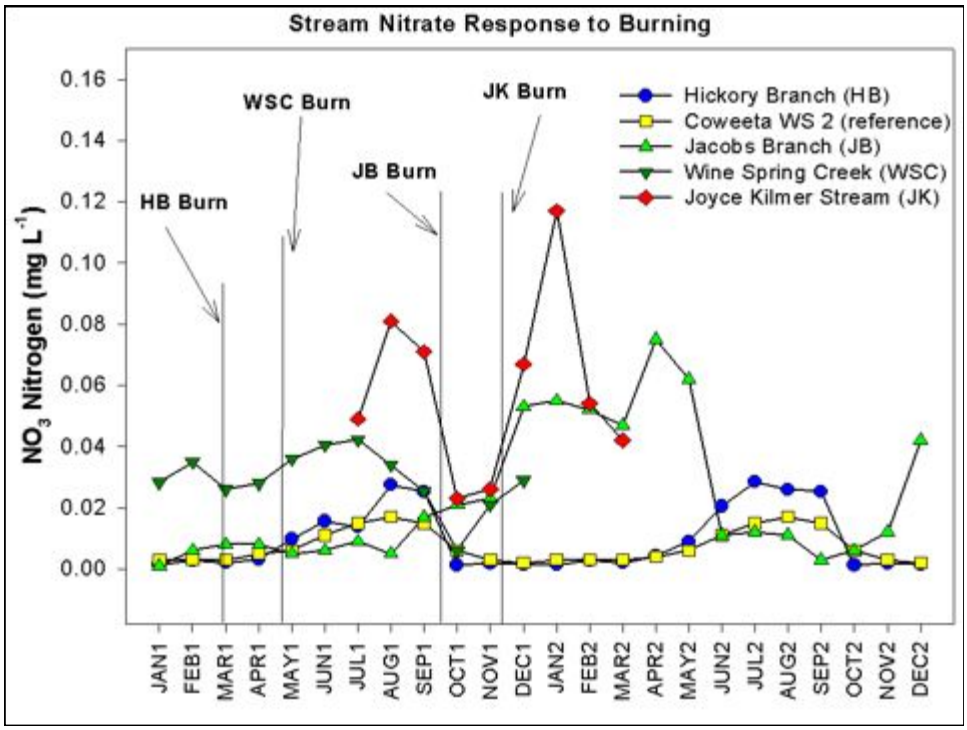


EROSION & SEDIMENTATION

HIGH

LOW


No Movement of
Charcoal and
Sediment Offsite
Why not ?
Duff layer
Coarse woody debris
Intact Riparian Zone


Stream Nitrate Response to Burning
HB Burn
WSC Burn
JB Burn
JK Burn
Hickory Branch (HB)
Coweeta WS 2 (reference)
Jacobs Branch (JB)
Wine Spring Creek (WSC)
Joyce Kilmer Stream (JK)
NO3 Nitrogen (mg L-1)
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
JAN1
FEB1
MAR1
APR1
MAY1
JUN1
JUL1
AUG1
SEP1
OCT1
NOV1
DEC1
JAN2
FEB2
MAR2
APR2
MAY2
JUN2
JUL2
AUG2
SEP2
OCT2
NOV2
DEC2

SUMMARY OF KEY POINTS

- *Forests provide the cleanest and most regulated flows of freshwater among all other land uses*
- *The climate-vegetation-soil interaction determines overall site water balance and water quality*
- *Riparian zones are a critical watershed feature*
- *Forests can be managed in ways that protect water quality*
- *Protecting the forest floor and ensuring infiltration and vegetation regrowth is key.*