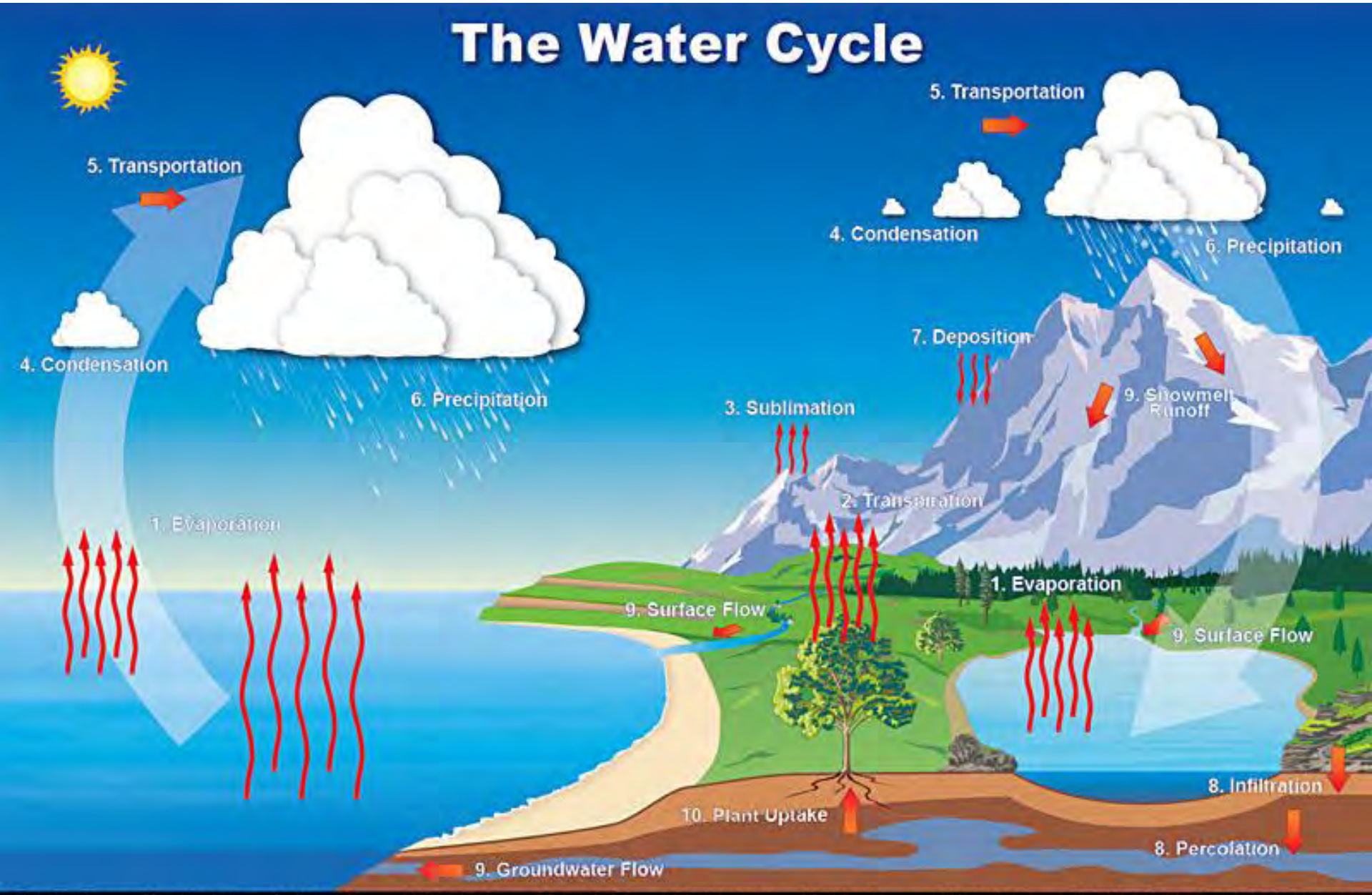
Water Movement on the Landscape

-Basic Stream and Watershed Function-

Steve Fisher
Resource conservationist
USDA – Natural Resources Conservation Service

The Water Cycle



1. Evaporation is the change of state of water (a liquid) to water vapor (a gas). On average, about 47 inches (120 cm) is evaporated into the atmosphere from the ocean each year.

2. Transpiration is evaporation of liquid water from plants and trees into the atmosphere. Nearly all (99%) of all water that enters the roots transpires into the atmosphere.

3. Sublimation is the process where ice and snow (a solid) changes into water vapor (a gas) without moving through the liquid phase.

4. Condensation is the process where water vapor (a gas) changes back into a water droplets (a liquid). This is when we begin to see clouds.

5. Transportation is the movement of solid, liquid and gaseous water through the atmosphere. Without this movement, the water evaporated over the ocean would not precipitate over land.

6. Precipitation is water that falls to the earth. Most precipitation falls as rain but includes snow, sleet, drizzle, and hail. On average, about 39 inches (990 mm) of rain, snow and sleet fall each year around the world.

7. Deposition is the reverse of sublimation. Water vapor (a gas) changes into ice (a solid) without going through the liquid phase. This is most often seen on clear, cold nights when frost forms on the ground.

8. Infiltration is the movement of water into the ground from the surface. Percolation is movement of water past the soil going deep into the groundwater.

9. Surface flow is the river, lake, and stream transport of water to the oceans. Groundwater the flow of water underground in aquifers. The water may return to the surface in springs or eventually seep into the oceans.

10. Plant uptake is water taken from the groundwater flow and soil moisture. Only 1% of water the plant draws up is used by the plant. The remaining 99% is passed back into the atmosphere.

www.srh.noaa.gov/jetstream

Field Drainage

- Water Convergence


Upland Drainages

Ponds or Lakes

Wetlands or Wet Prairies

Bottomland Drainages

Perennial Streams

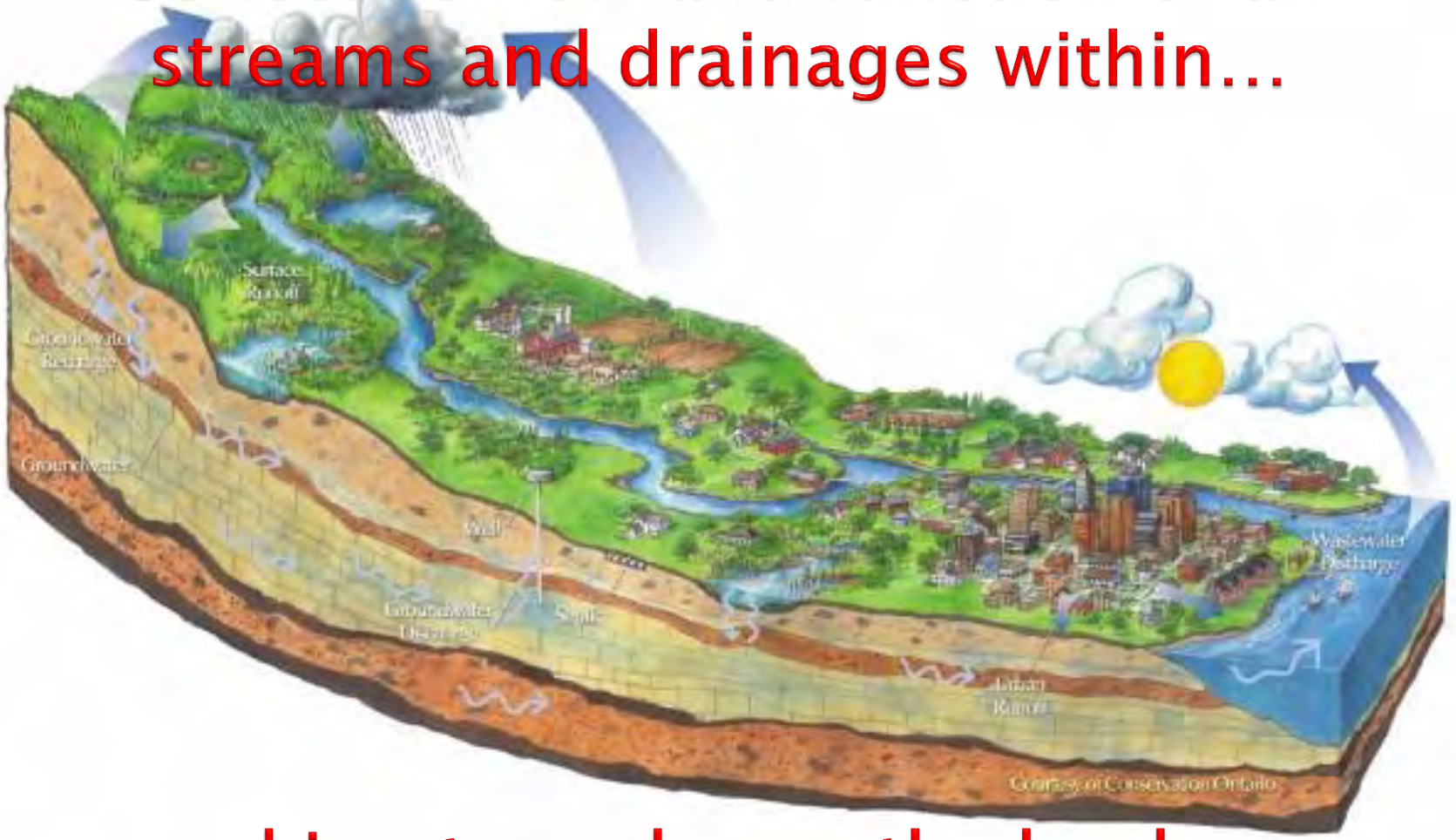
Rivers

Large Rivers

Mississippi River Basin

- To the Gulf of Mexico outlet…

Watershed Function =
Collective flow and function of all streams and drainages within…



…working to recharge the landscape and deliver water to a stable outlet.

Remember:

RIVERS LIKE TO MEANDER AND FLOOD

(typically, those are natural river functions)

Let your river be a river!...

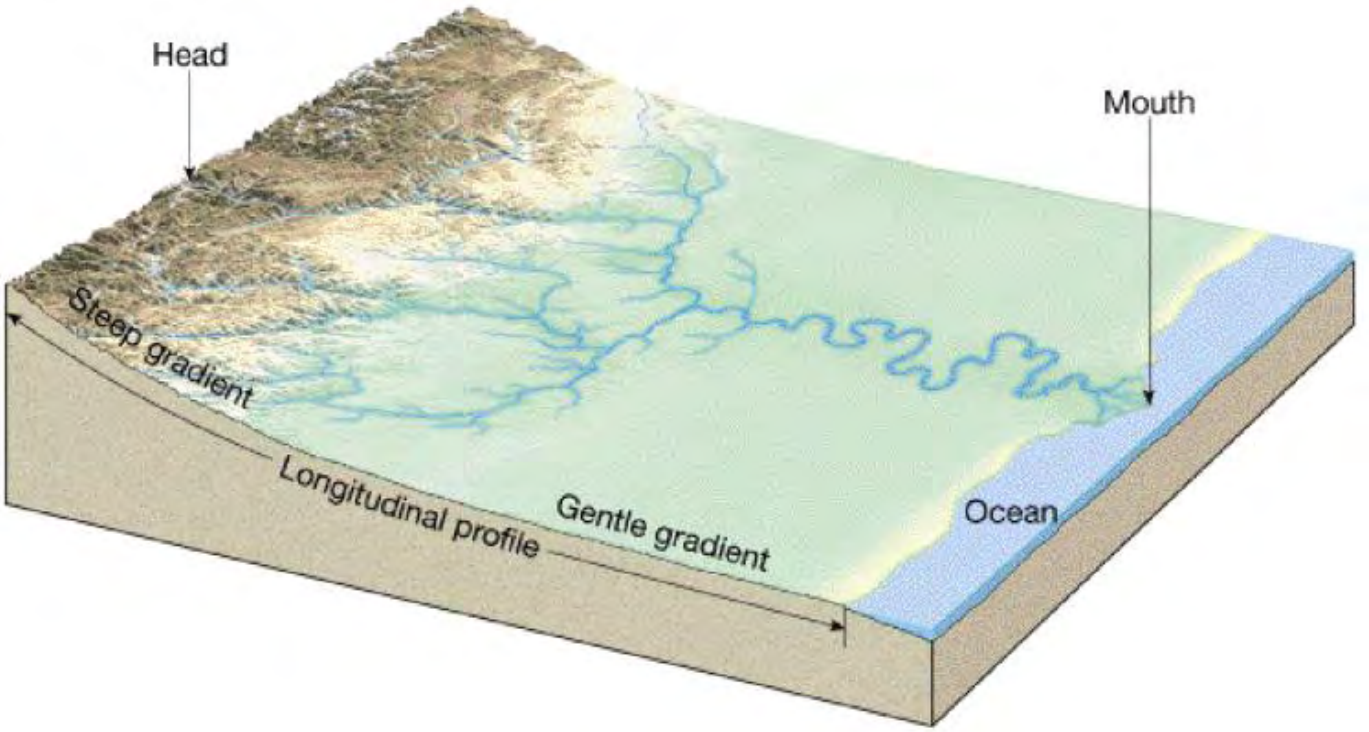
...Let it breathe and have some freedom!

- Dave Derrick -

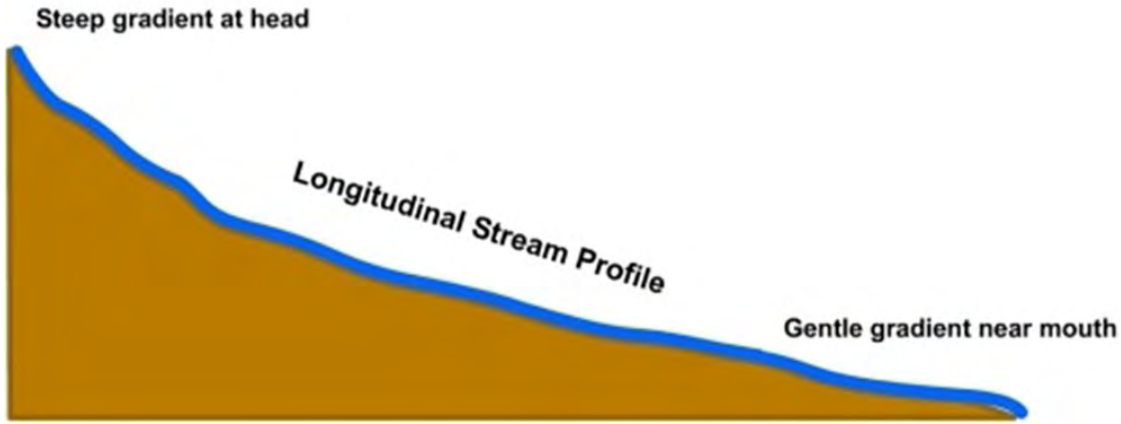
YOU HAVE TO
THINK LIKE WATER
AND
SEE WHAT WATER SEES!!!

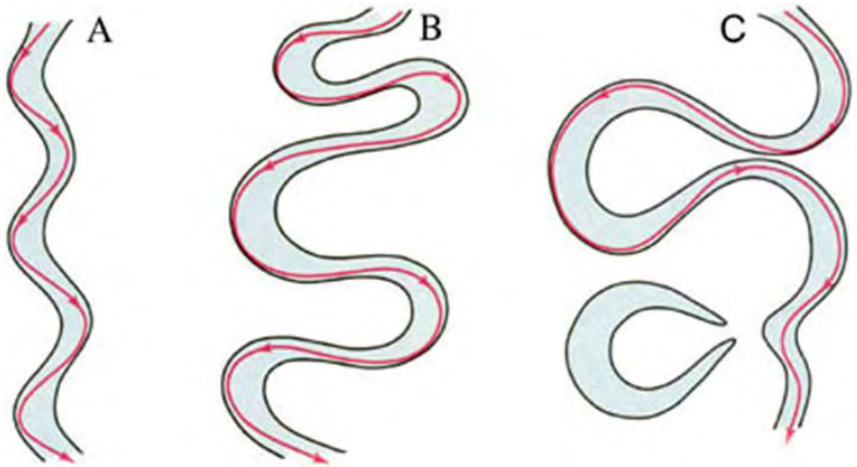
- Dave Derrick -

Typical water movement: NOT a strait line!!!

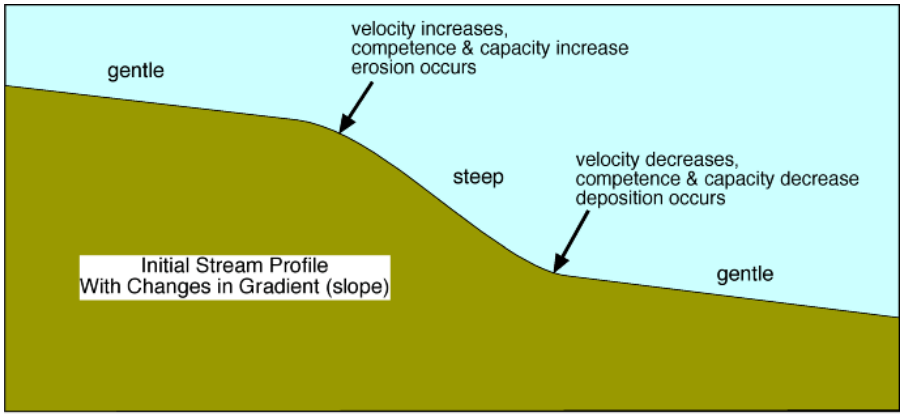


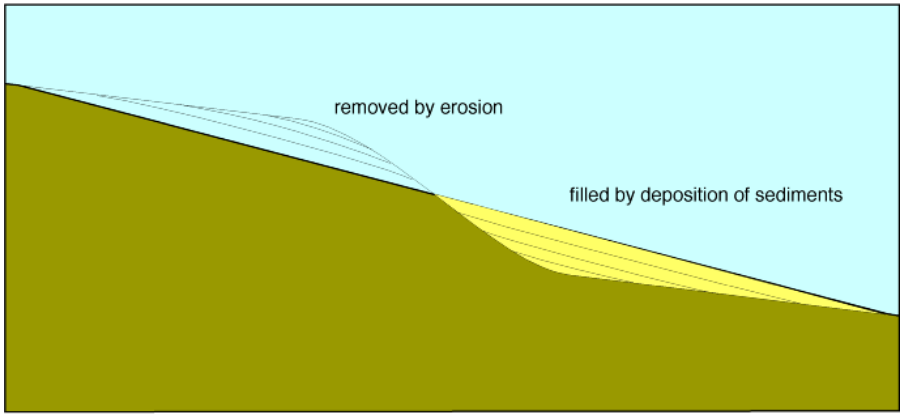
Vertical and Horizontal Movement…

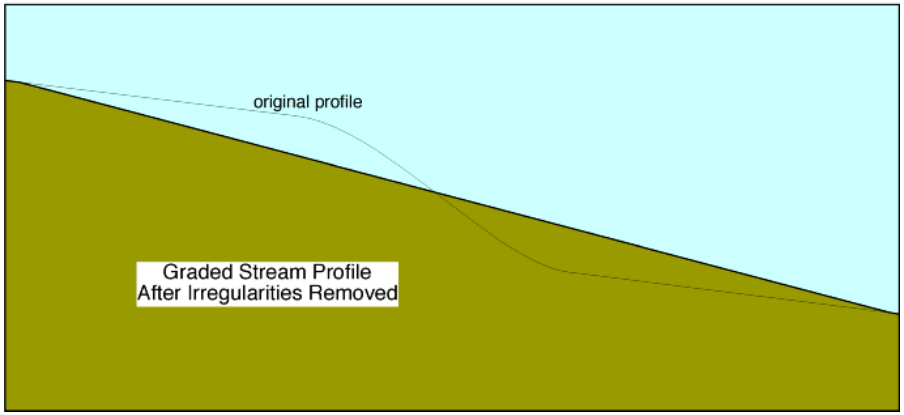




…serves to dissipate energy and stabilize the system!

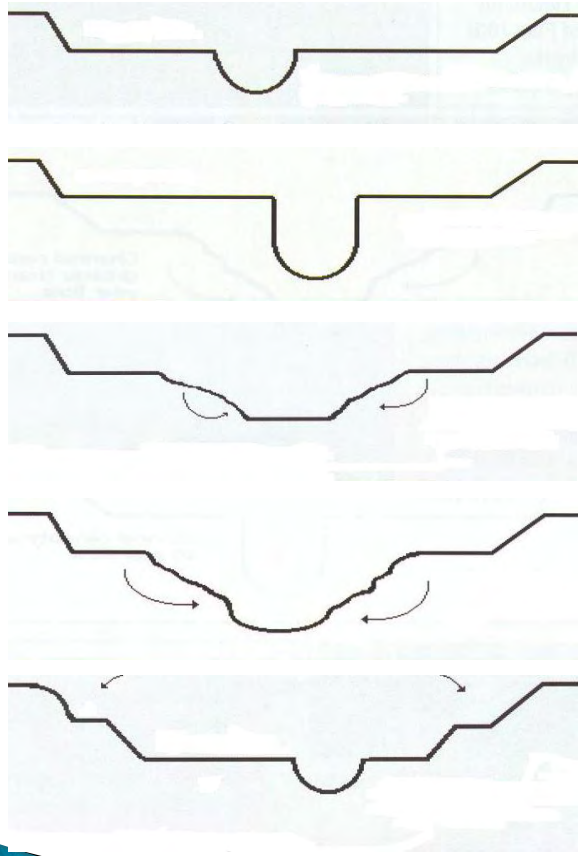






Greater slope = higher energy!!!

A closer look at natural stream flow

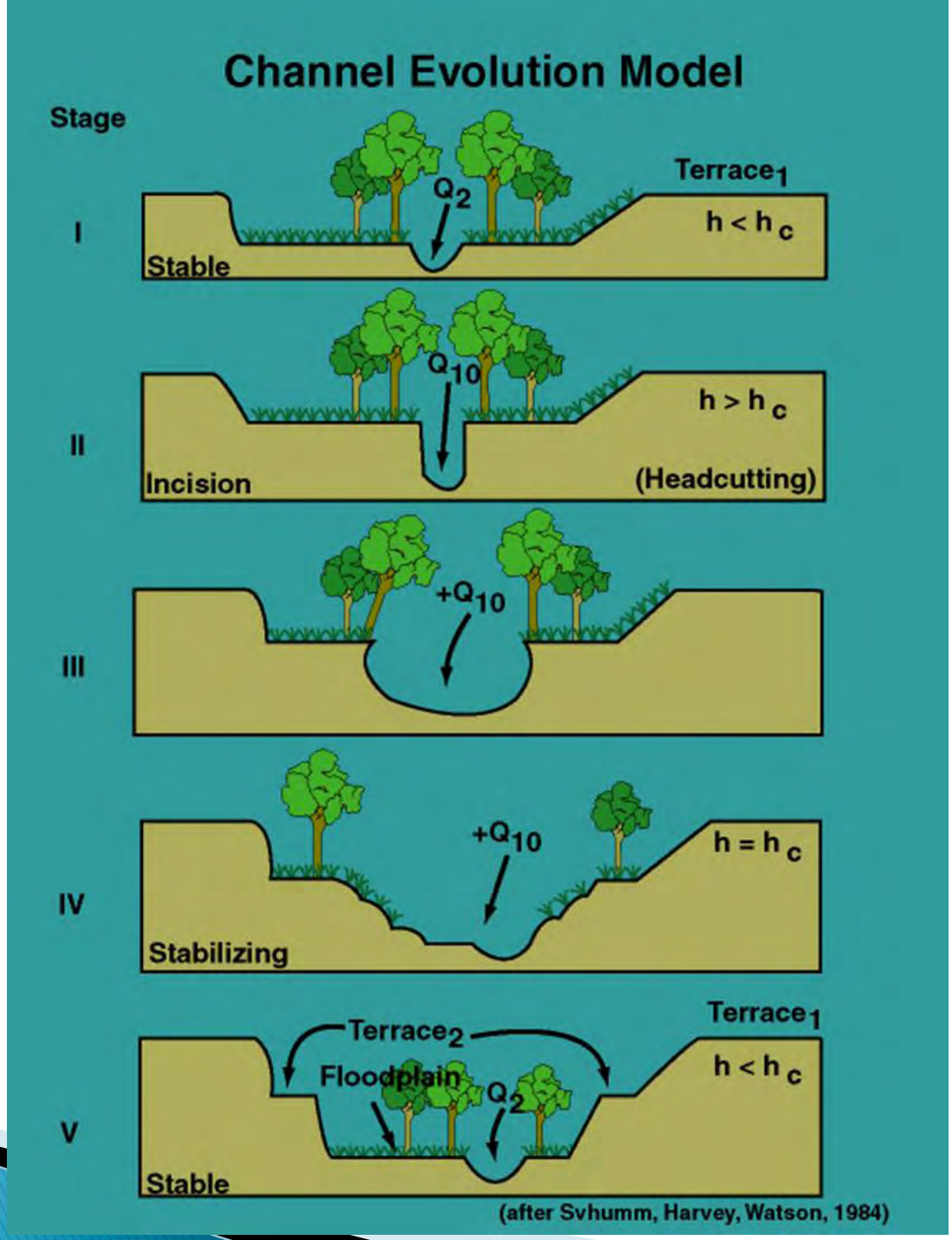


The Channel Evolution Model (CEM)

Identifies phases of Stream Channel Evolution

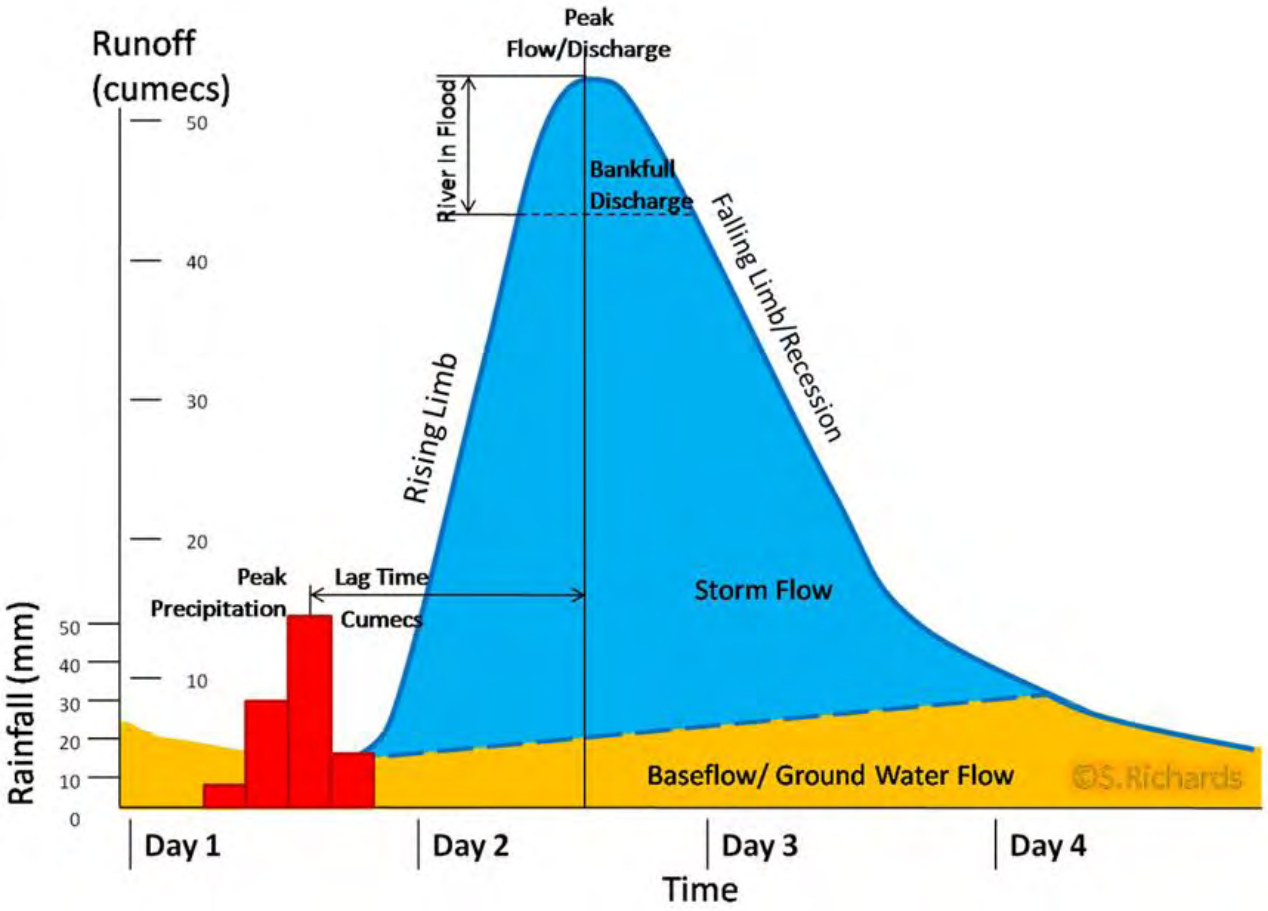
and

Points toward changes to expect over time

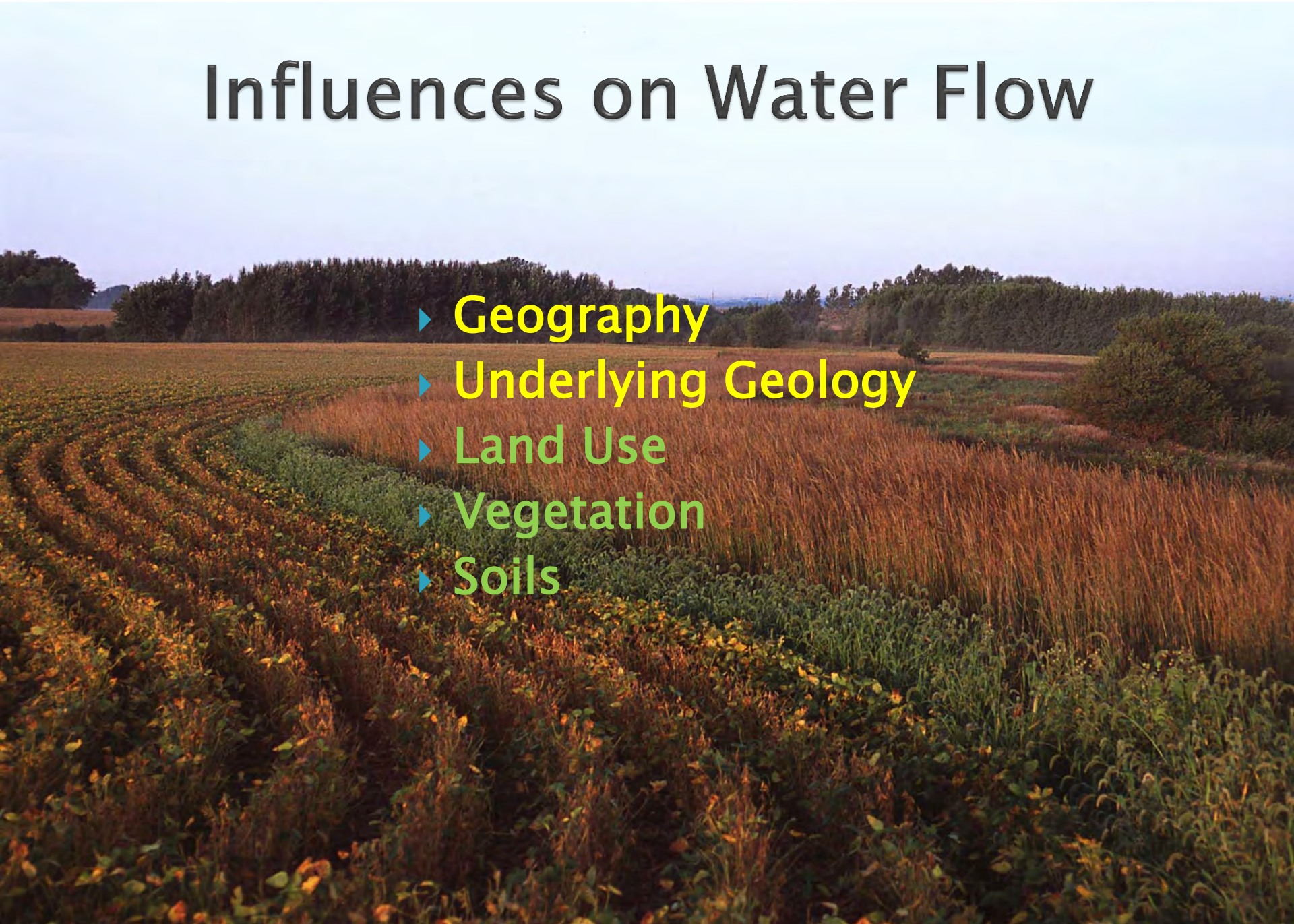

Channel Evolution Model
Stage
I
Stable
Q2
Terrace1
h < hc
II
Incision
Q10
h > hc
(Headcutting)
III
+Q10
IV
Stabilizing
+Q10
h = hc
V
Stable
Terrace2
Floodplain
Q2
Terrace1
h < hc
(after Svhumm, Harvey, Watson, 1984)

Measuring Watershed Function

What is a Hydrograph?



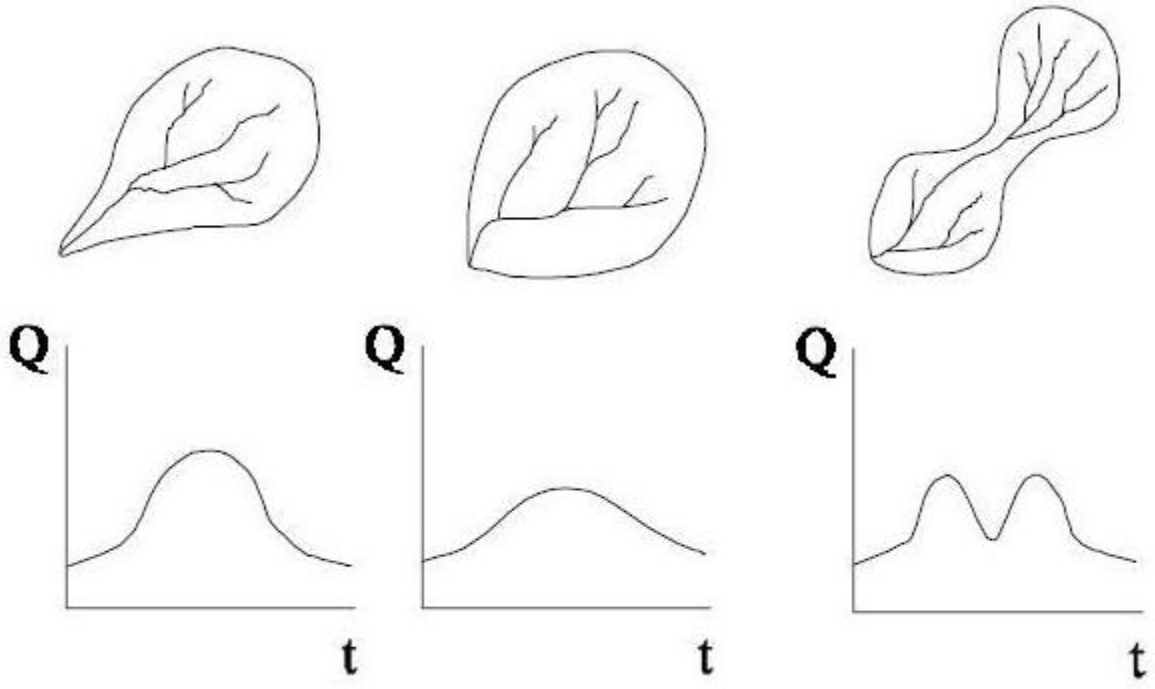
Influences on Water Flow

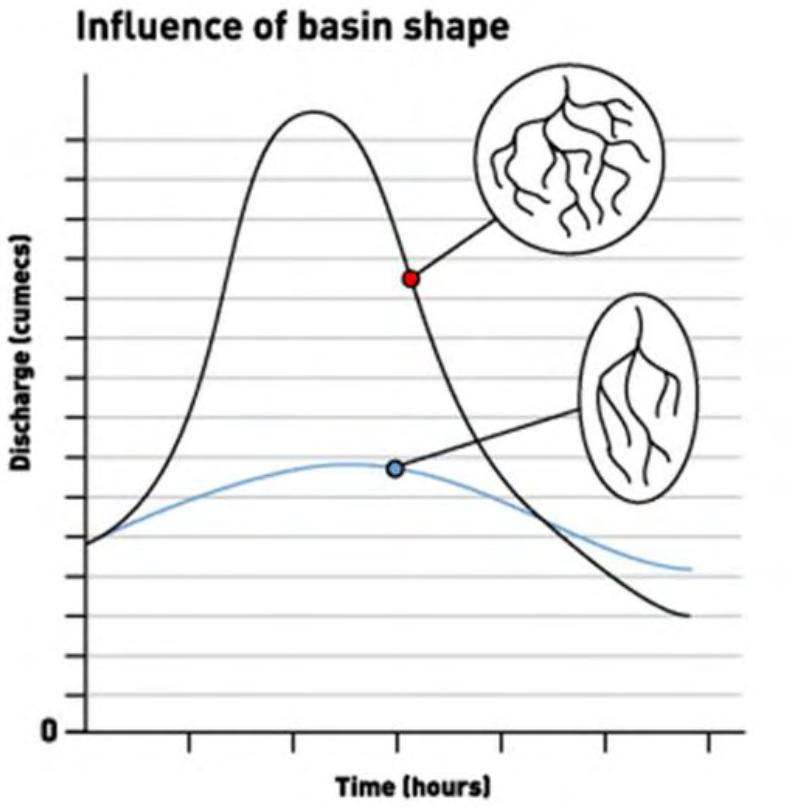


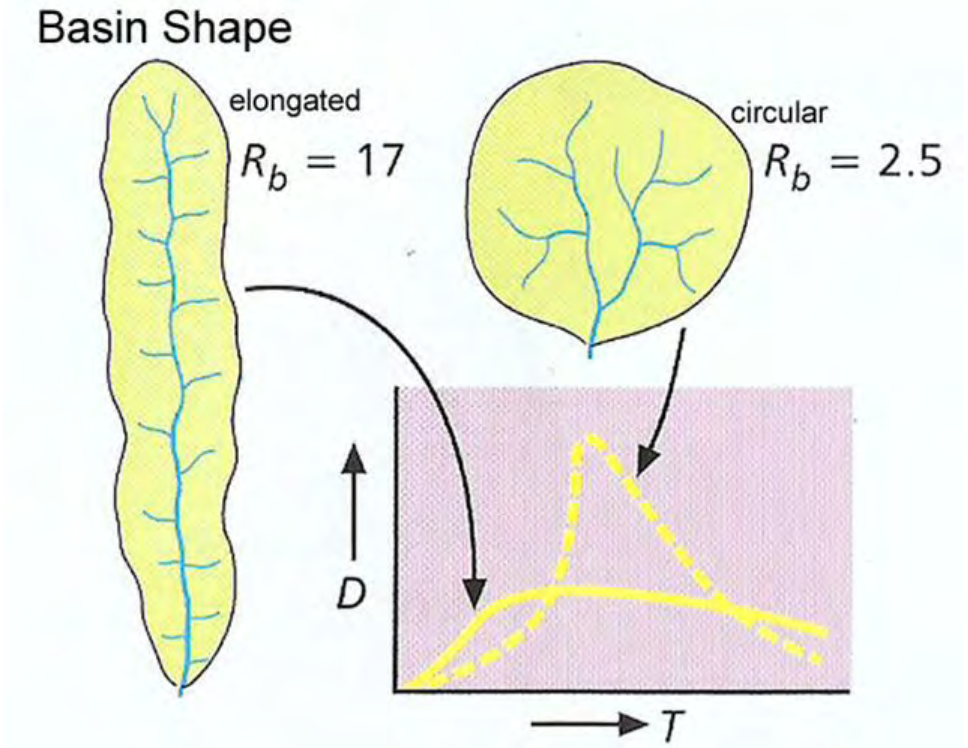
- Geography
- Underlying Geology
- Land Use
- Vegetation
- Soils

Geography

- Slope / Topography
- Basin Shape

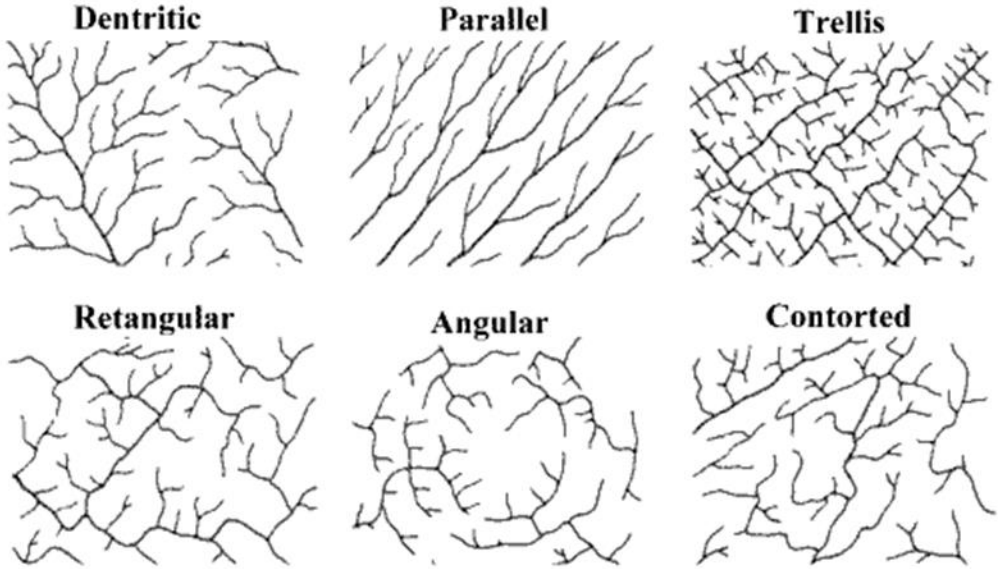



Influence of basin shape
Discharge (cumecs)
0
Time (hours)

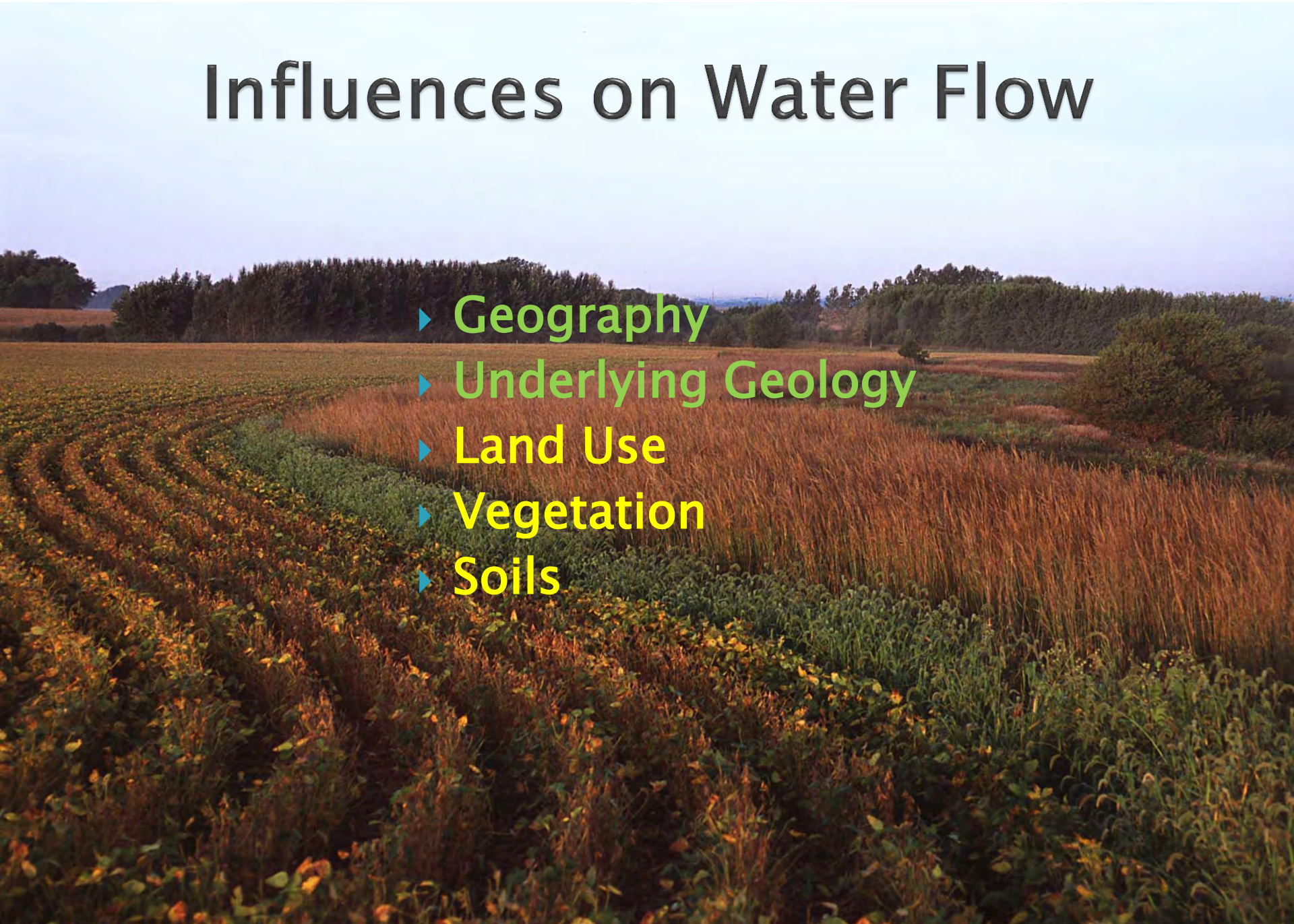

Basin Shape
elongated
$R_b = 17$
circular
$R_b = 2.5$
D
T

Geology

- Parent Material (i.e. bedrock, loess, alluvium)
- Water Tables and/or Aquifers
- Karst/Sinkhole/Underground Caverns



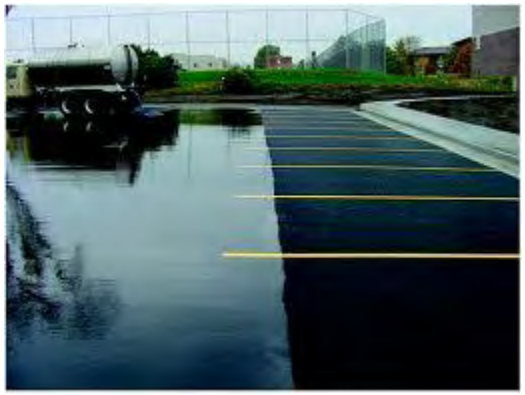
Influences on Water Flow



- Geography
- Underlying Geology
- Land Use
- Vegetation
- Soils

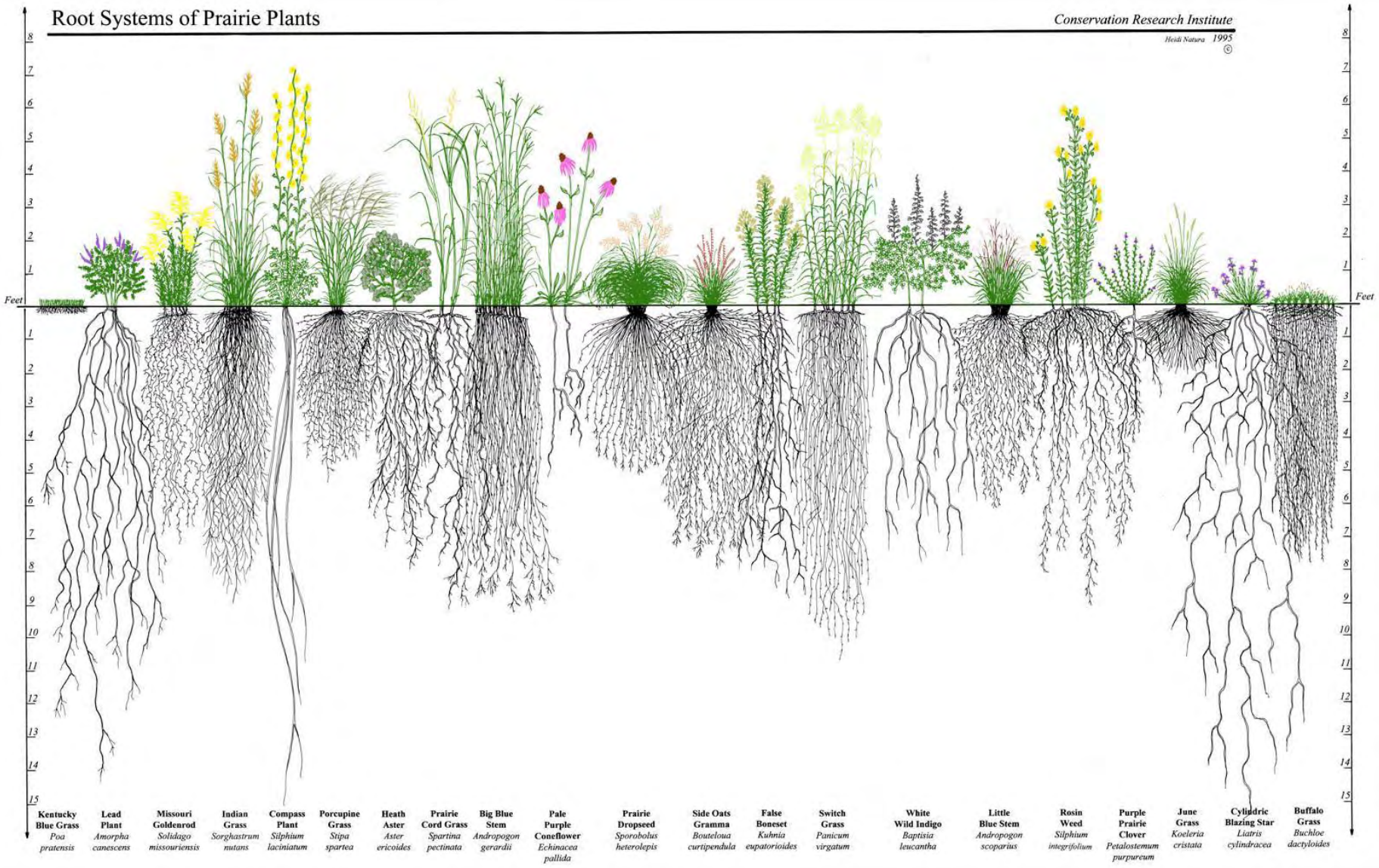
Land Use

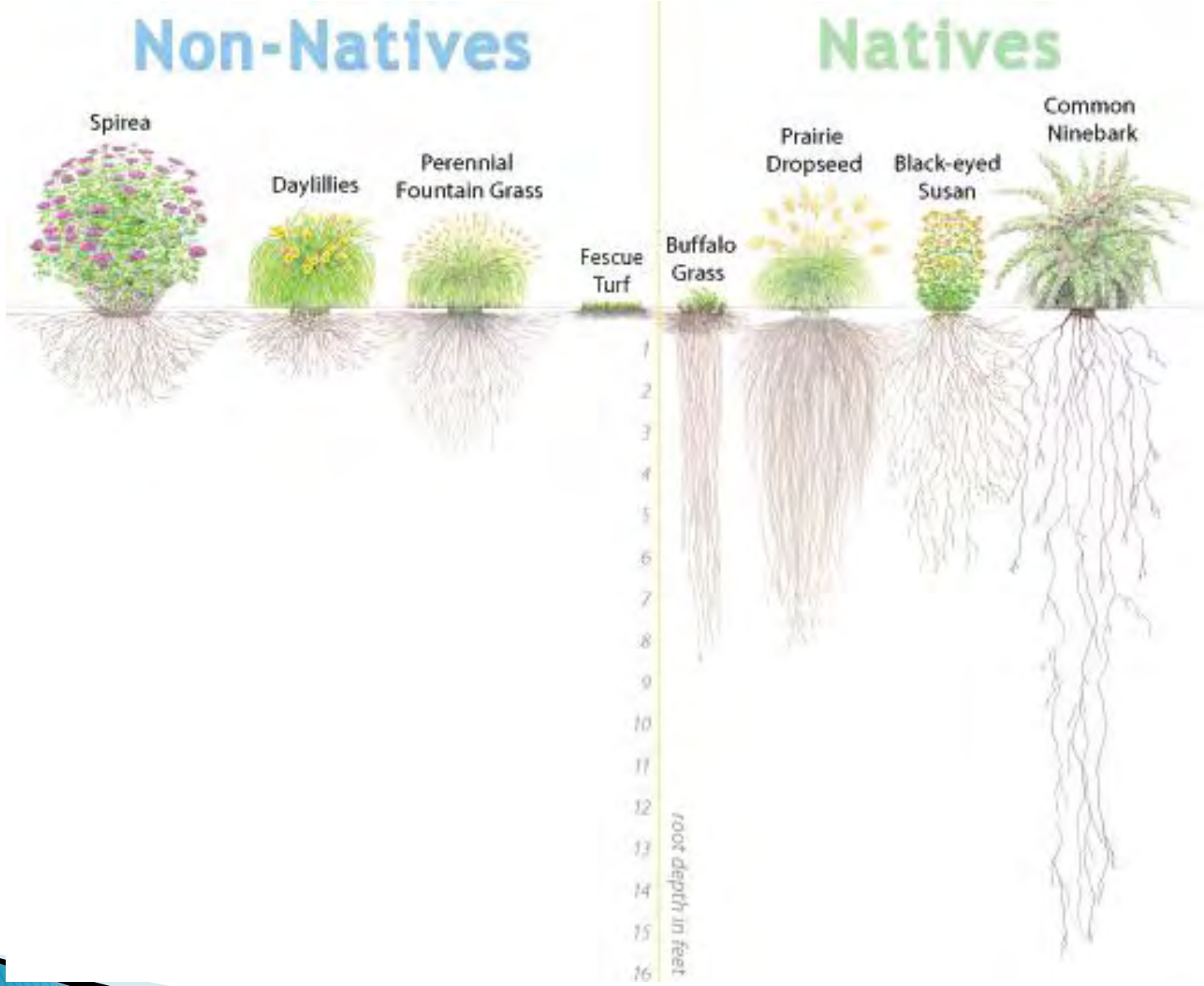
- Vegetation vs. Water Storage vs. Pavement
- Pavement vs. Pervious Pavement
- Short term vs. Long term
- Widespread vs. Isolated

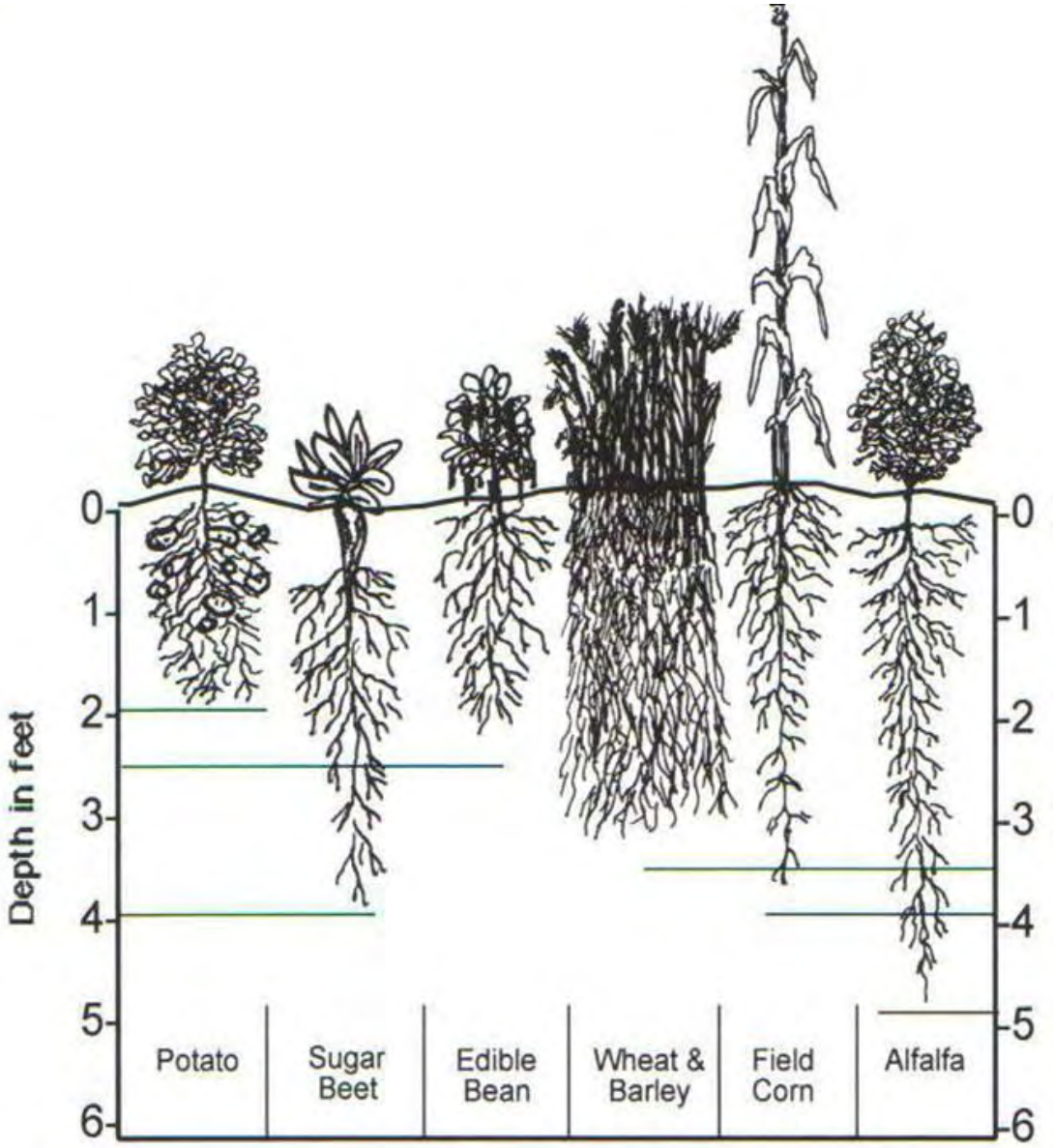


Vegetation

- Vegetated vs. Non-vegetated
- Grass vs. Crop vs. Forest
- Annual vs. Perennial
- Native vs. Exotic
- Deep-rooted vs. Shallow-rooted
- Management – Lush vs. Sparse
- Residue vs. No Residue

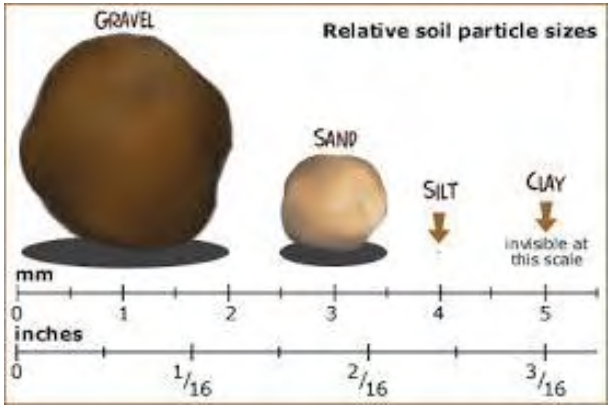

Root Systems of Prairie Plants
Conservation Research Institute
Heidi Natura 1995 ©
Feet
Feet
Kentucky Blue Grass Poa pratensis
Lead Plant Amorpha canescens
Missouri Goldenrod Solidago missouriensis
Indian Grass Sorghastrum nutans
Compass Plant Silphium laciniatum
Porcupine Grass Stipa spartea
Heath Aster Aster ericoides
Prairie Cord Grass Spartina pectinata
Big Blue Stem Andropogon gerardii
Pale Purple Coneflower Echinacea pallida
Prairie Dropseed Sporobolus heterolepis
Side Oats Gramma Bouteloua curtipendula
False Boneset Kuhnia eupatorioides
Switch Grass Panicum virgatum
White Wild Indigo Baptisia leucantha
Little Blue Stem Andropogon scoparius
Rosin Weed Silphium integrifolium
Purple Prairie Clover Petalostemum purpureum
June Grass Koeleria cristata
Cylindric Blazing Star Liatris cylindracea
Buffalo Grass Buchloe dactyloides

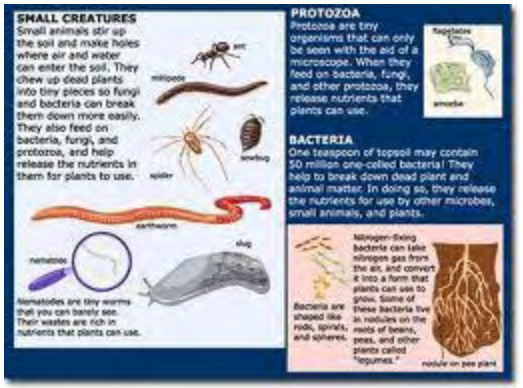

Non-Natives
Natives
Spirea
Daylillies
Perennial Fountain Grass
Fescue Turf
Buffalo Grass
Prairie Dropseed
Black-eyed Susan
Common Ninebark
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
root depth in feet


Depth in feet
0
1
2
3
4
5
6
Potato
Sugar Beet
Edible Bean
Wheat & Barley
Field Corn
Alfalfa

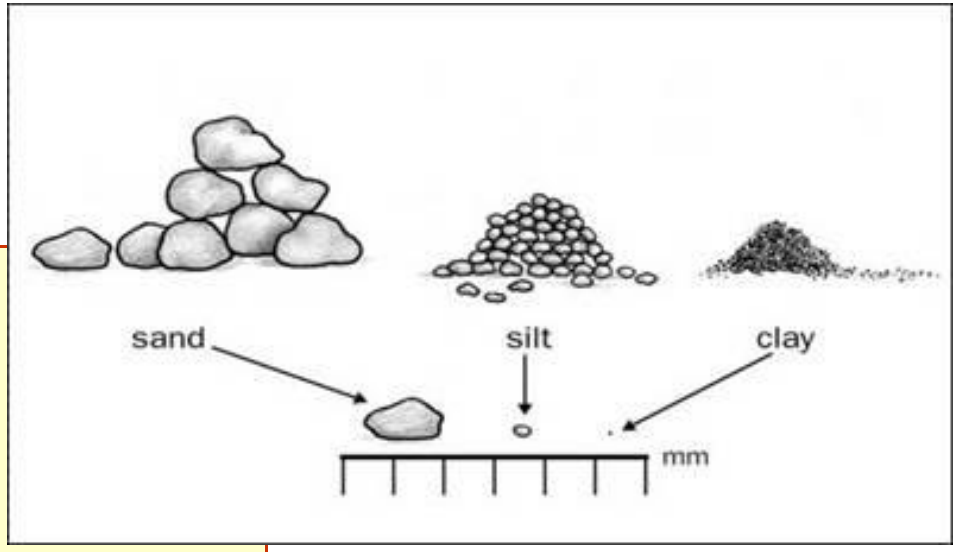
Soils

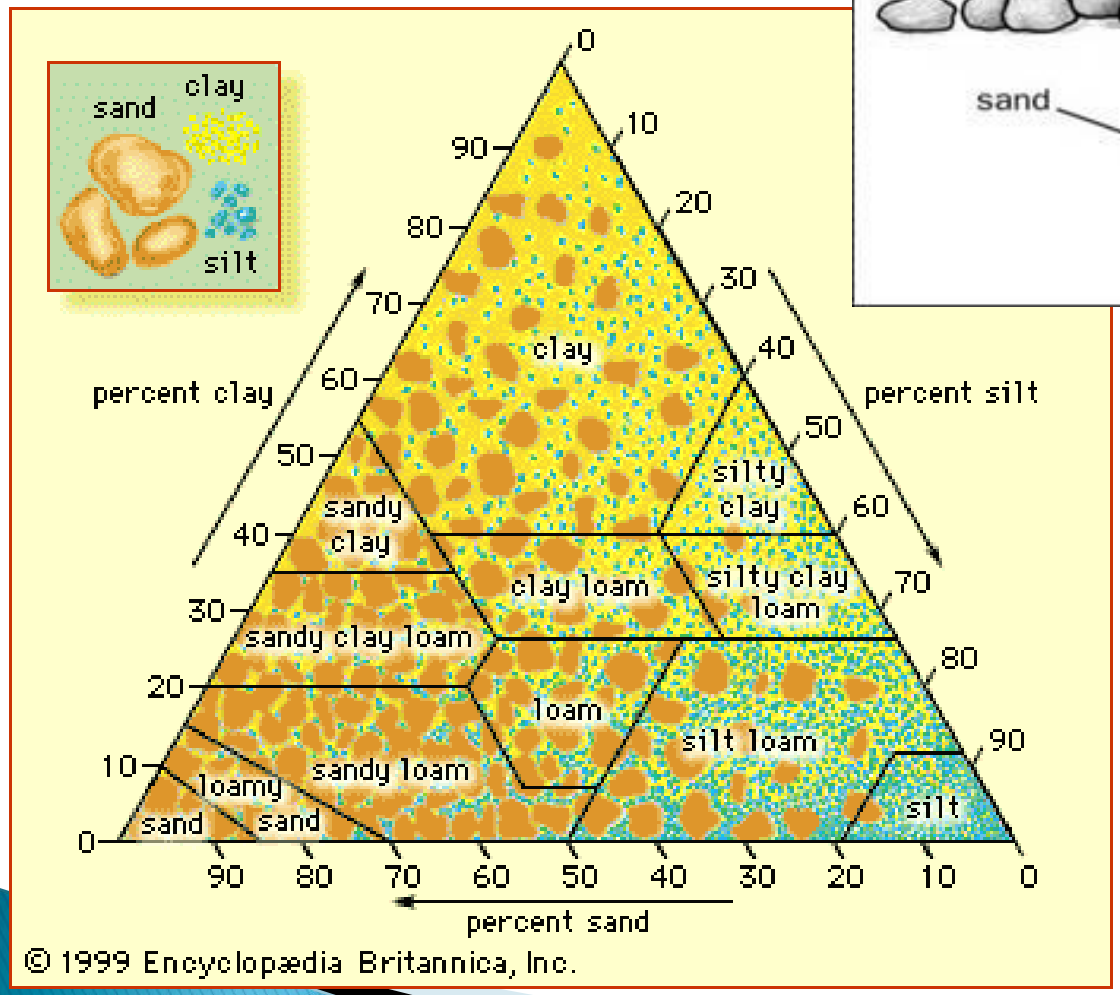
- Texture – Percentage of Sand, Silt, and Clay
- Structure
- Influence from:
  - Vegetation (O.M)
  - Biological Activity
  - Mechanical Treatment



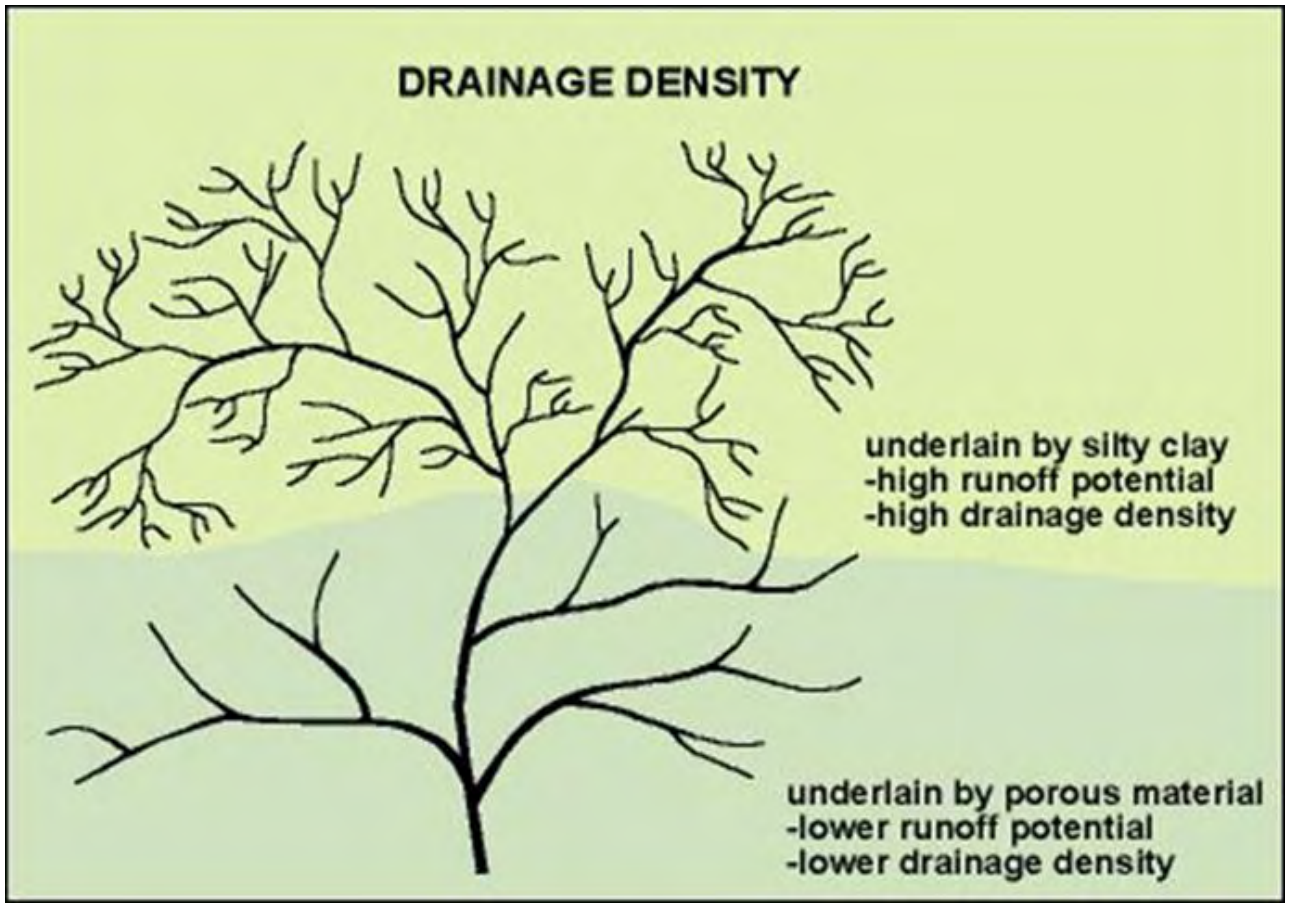


Soil Texture

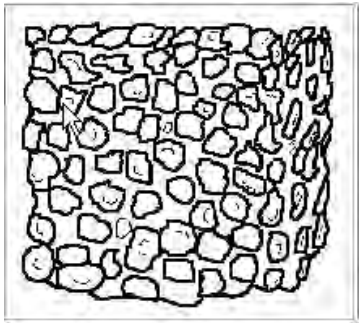
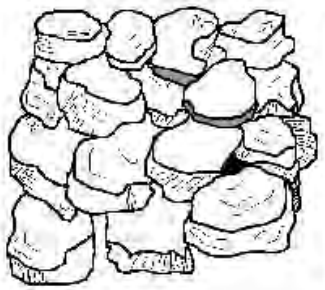
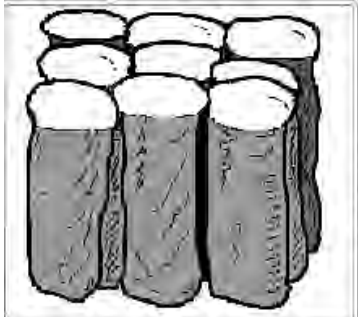
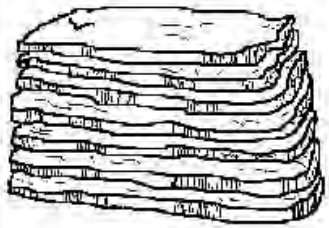




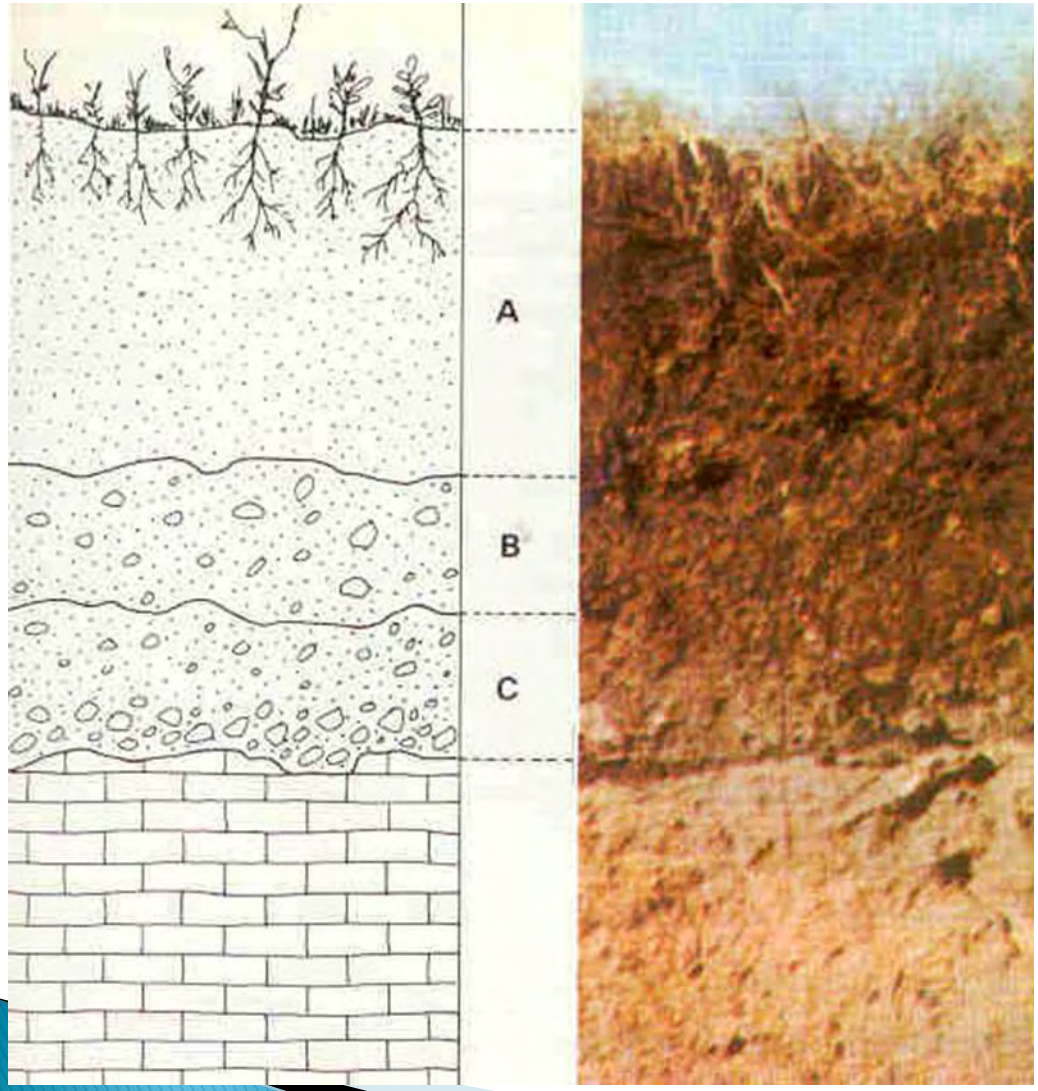
Soil Texture Influences on a Watershed



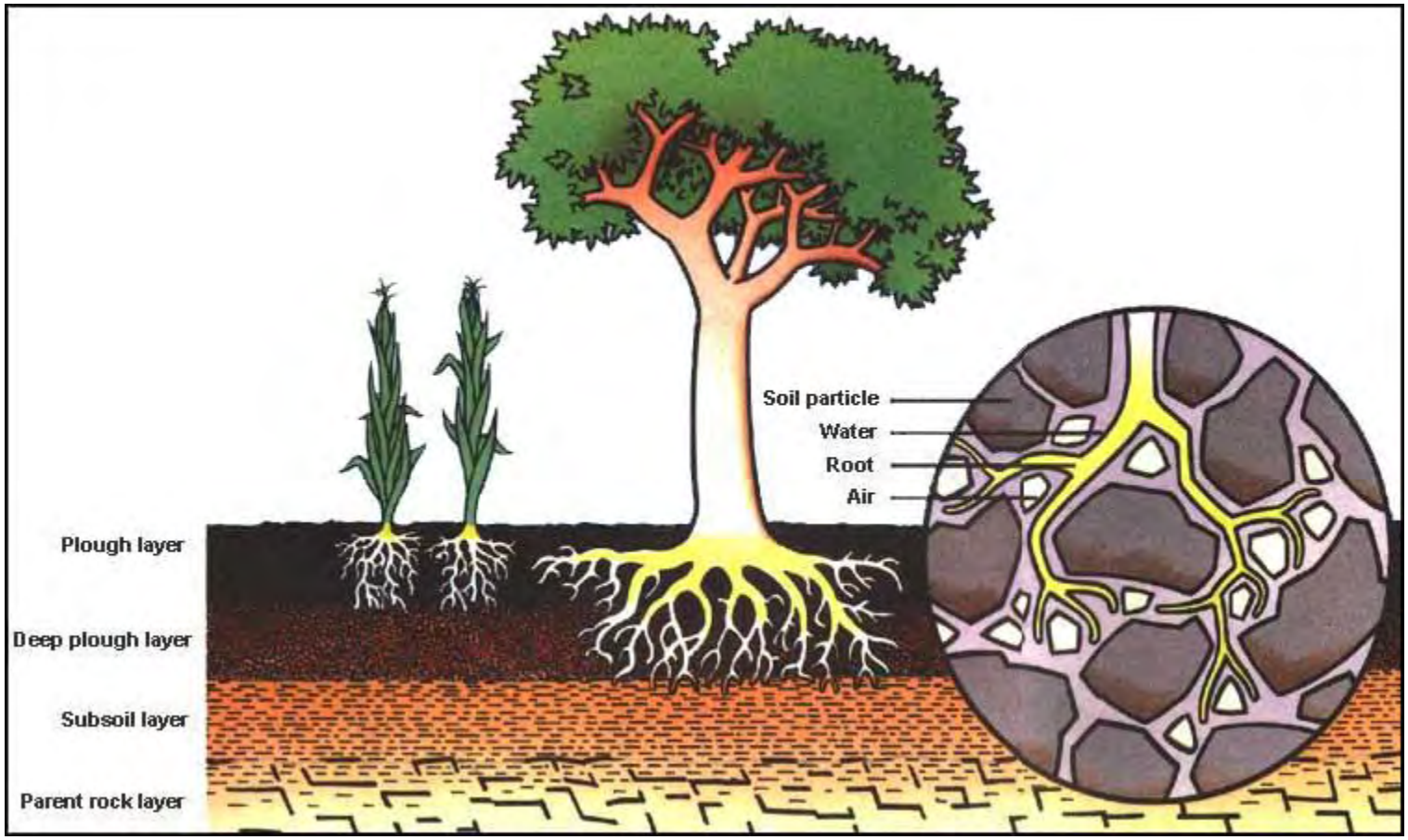
Soil Structure

		
Granular: Resembles cookie crumbs and is usually less than 0.5 cm in diameter. Commonly found in surface horizons where roots have been growing.	**Blocky**: Irregular blocks that are usually 1.5 – 5.0 cm in diameter.	**Prismatic**: Vertical columns of soil that might be a number of cm long. Usually found in lower horizons.
		
Columnar: Vertical columns of soil that have a salt "cap" at the top. Found in soils of arid climates.	**Platy**: Thin, flat plates of soil that lie horizontally. Usually found in compacted soil. Soil Science Society of America	**Single Grained**: Soil is broken into individual particles that do not stick together. Always accompanies a loose consistence. Commonly found in sandy soils.

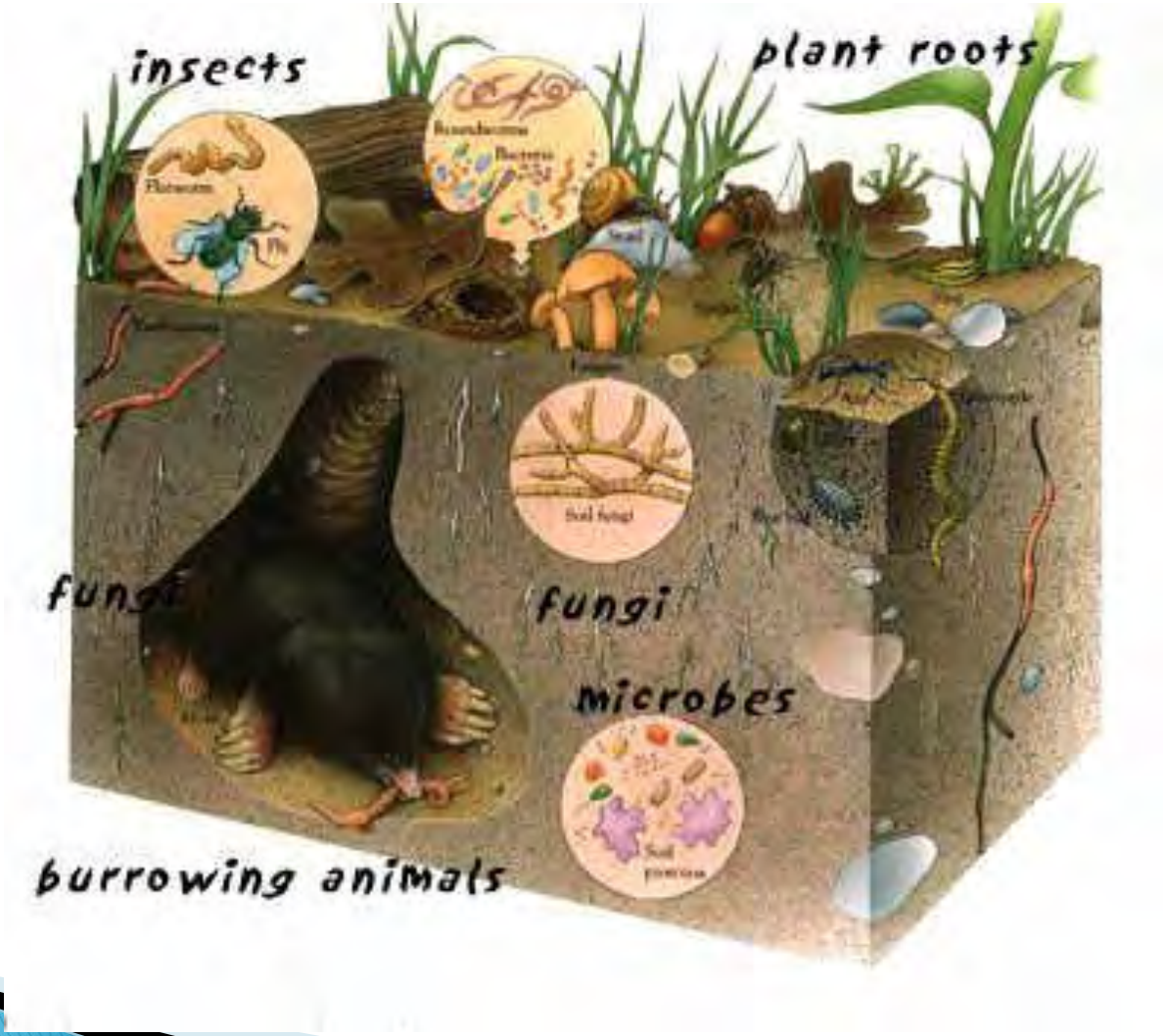
Soil Structure – Continued



Vegetation Influence on Soils



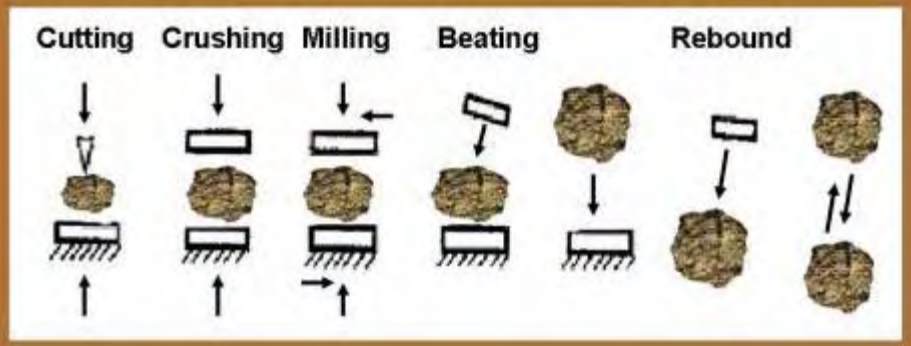
Biological Activity Influence on Soils



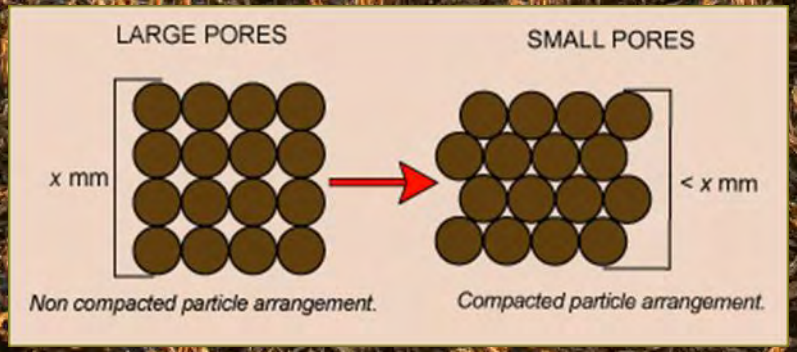
Influence from Mechanical Treatment

on soils

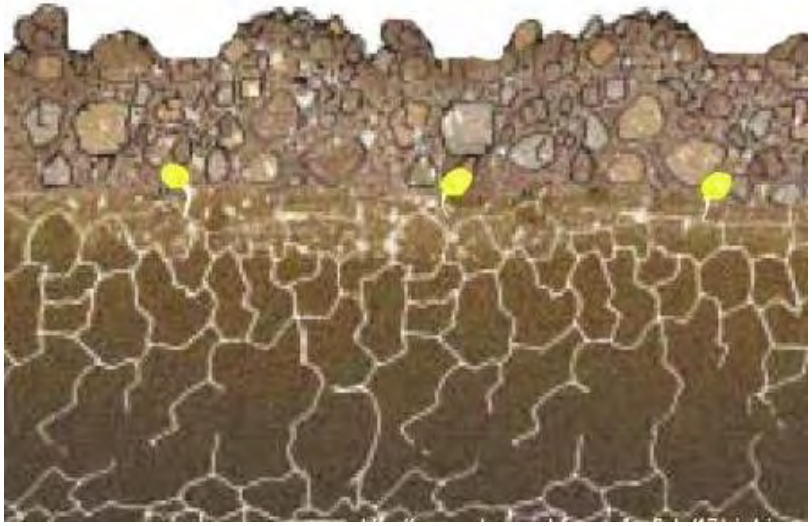
What is tillage ?

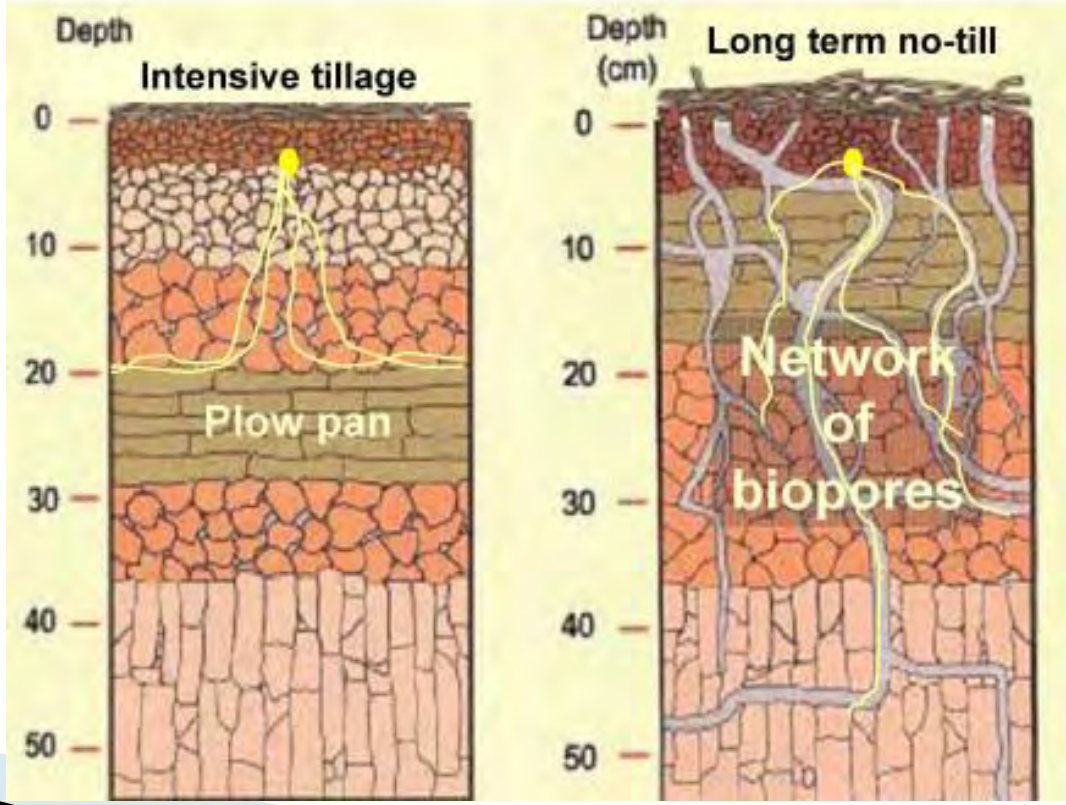


Mechanical modification of soil structure



Mechanical Influence – Continued





Mechanical Influence – Continued

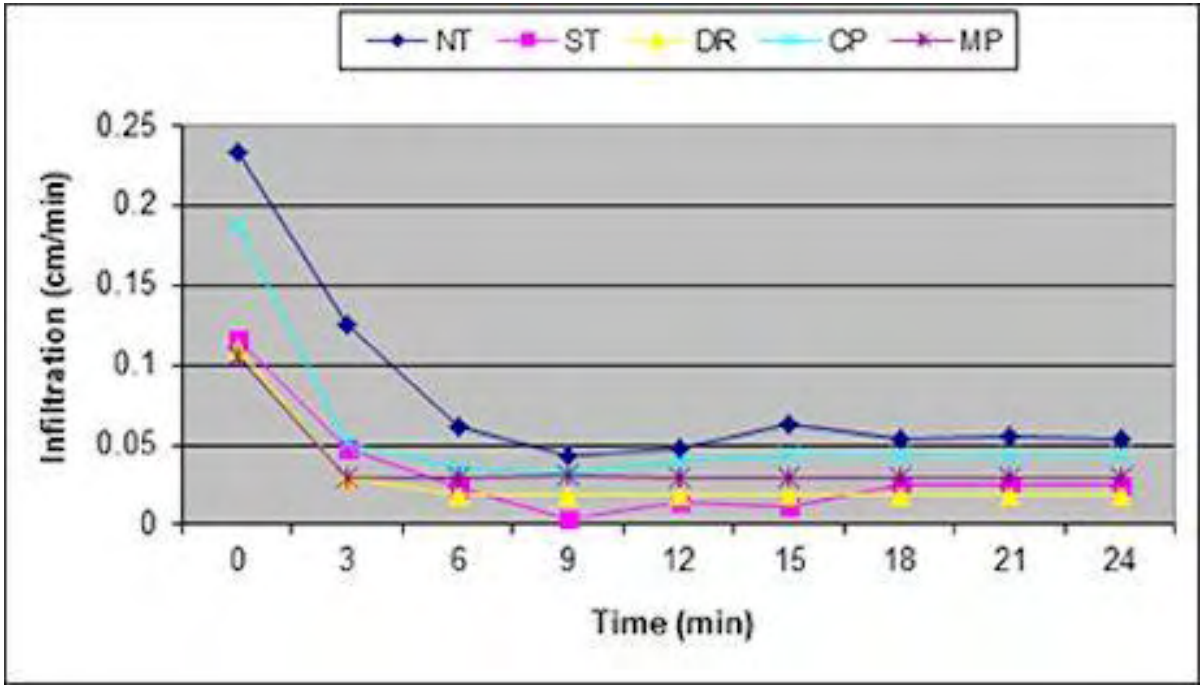


Figure 1. Water infiltration with five different tillage systems. NT=No-till, ST=Strip-tillage, DR=Deep Rip, CP=Chisel Plow and MP=Moldboard Plow. (Al-Kaisi, 2011). (Courtesy Iowa State University). The picture above illustrates a field with a likely relatively high water infiltration rate.

Mechanical Influence – Continued

16 Years No-Till Versus First Year No-Till and Conventional Tillage
Near Pendleton, Oregon

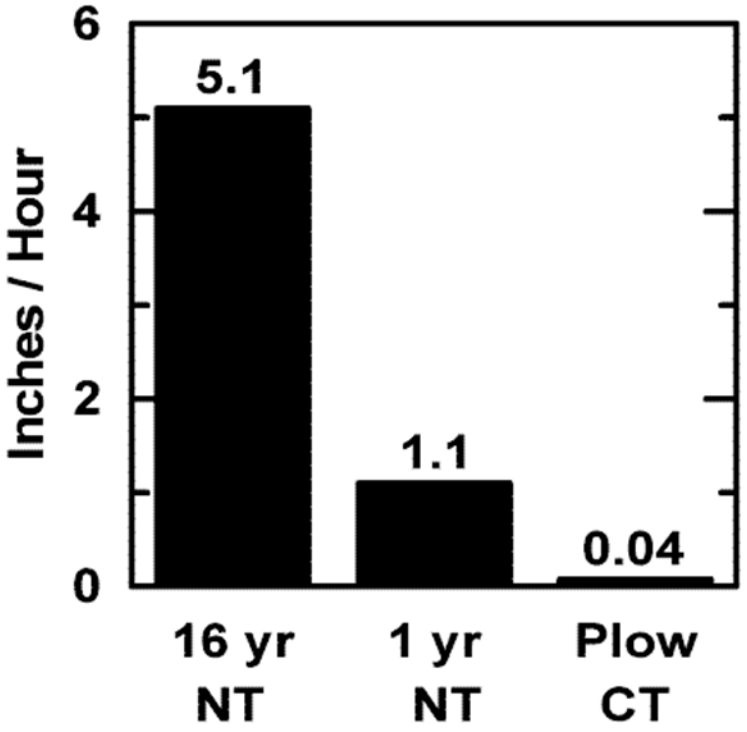


Fig 6. Water Infiltration Rate

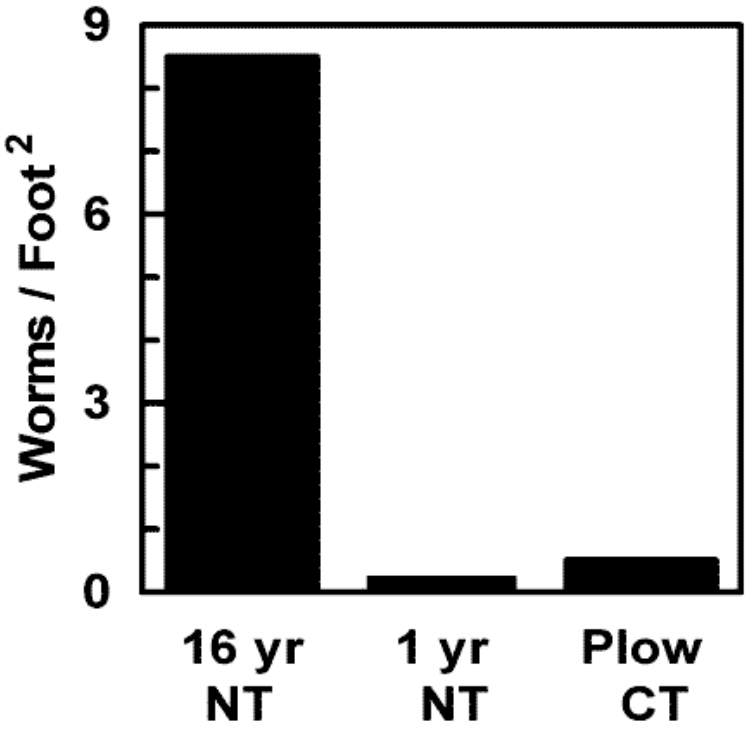


Fig 5. Earthworms

How is a watershed *supposed* to function?

IT DEPENDS!!!...

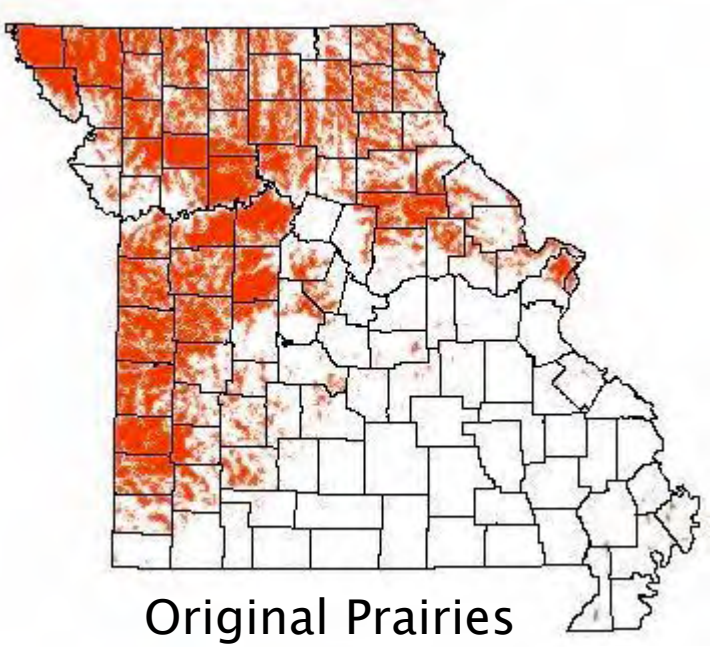
with

- Pre-settlement Prairies, Wetlands, and Forests???

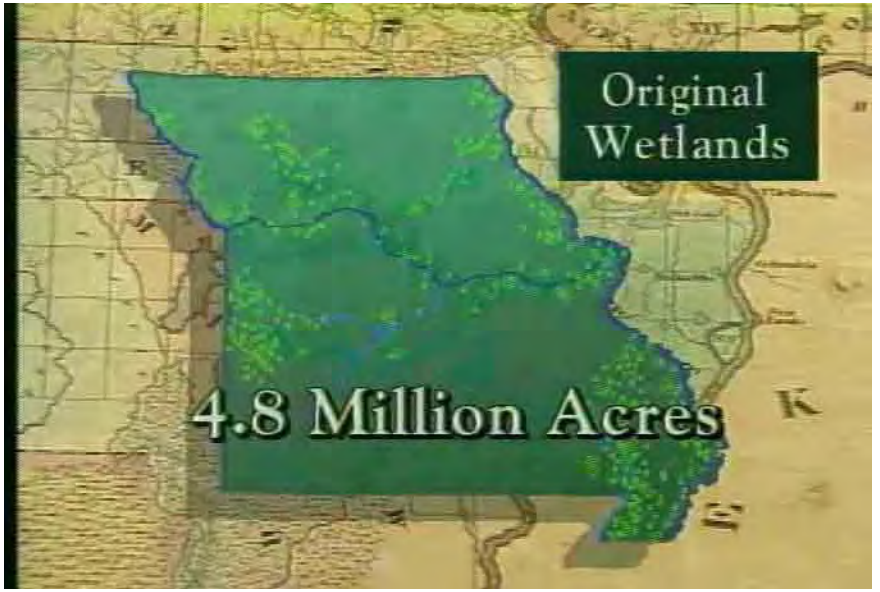
or with

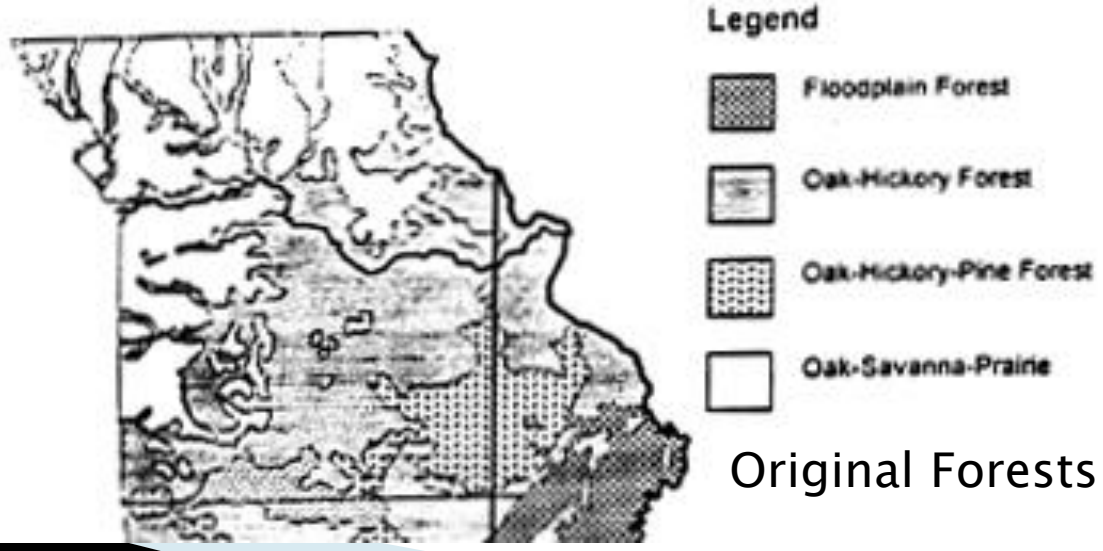
- Very few native Prairies or Wetlands, limited amounts of forest, and a high percentage of the watershed in long term conventionally tilled cropland and heavily stocked pasture with introduced grasses???

Pre-settlement Conditions



Original Prairies

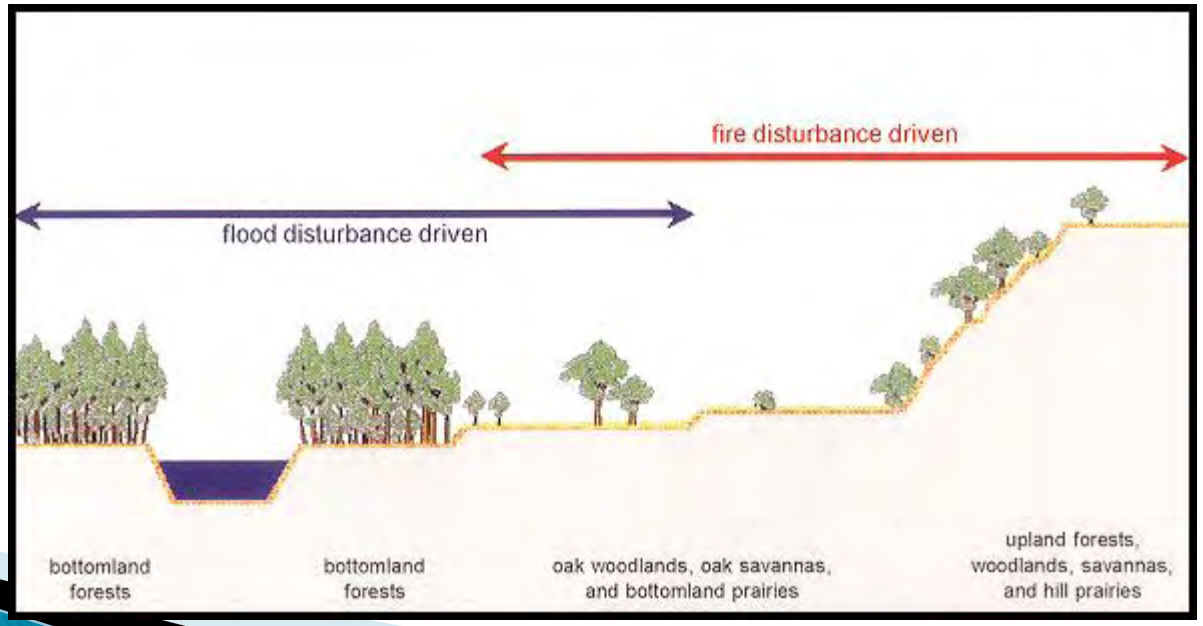


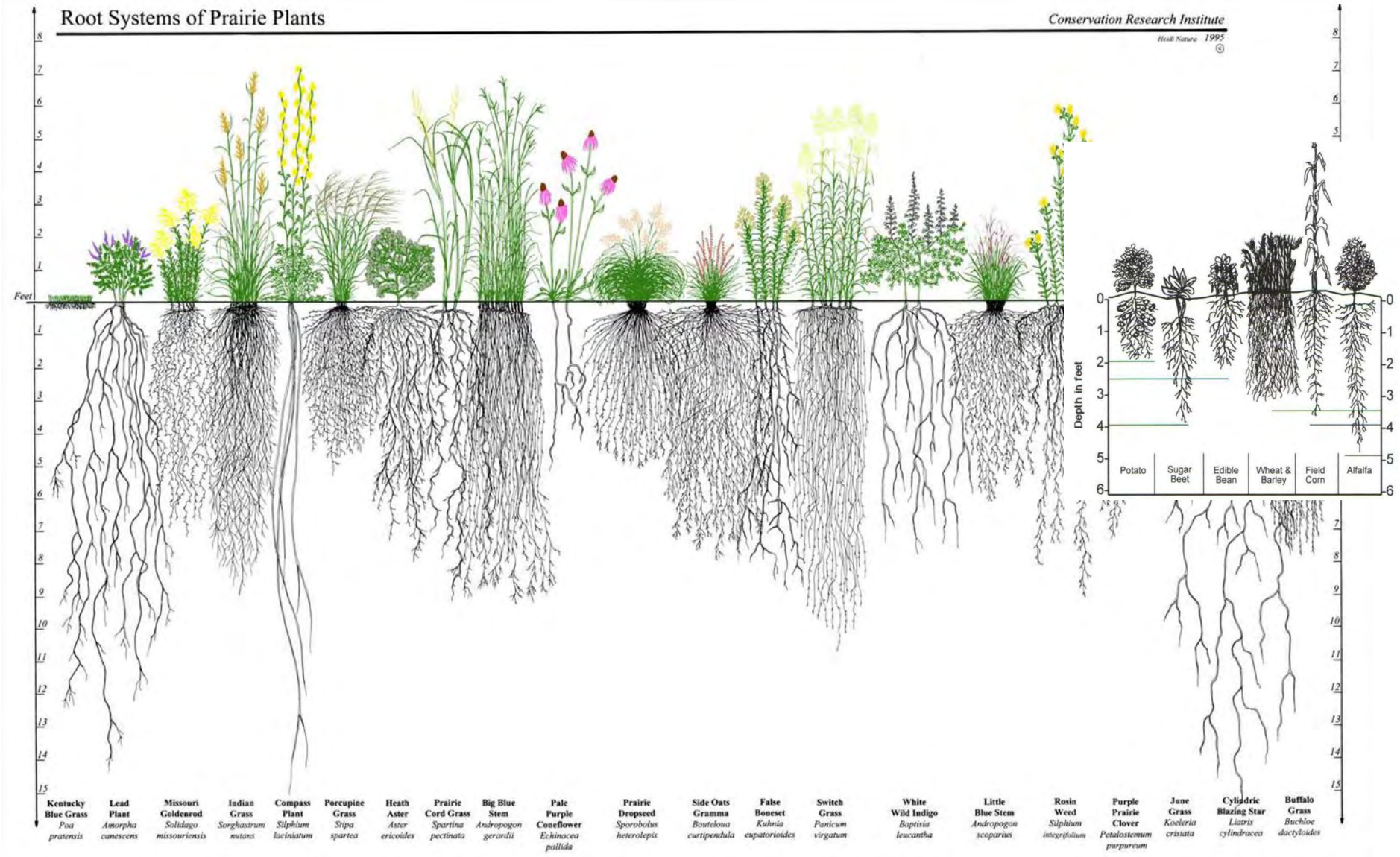


Original Forests

Prairies

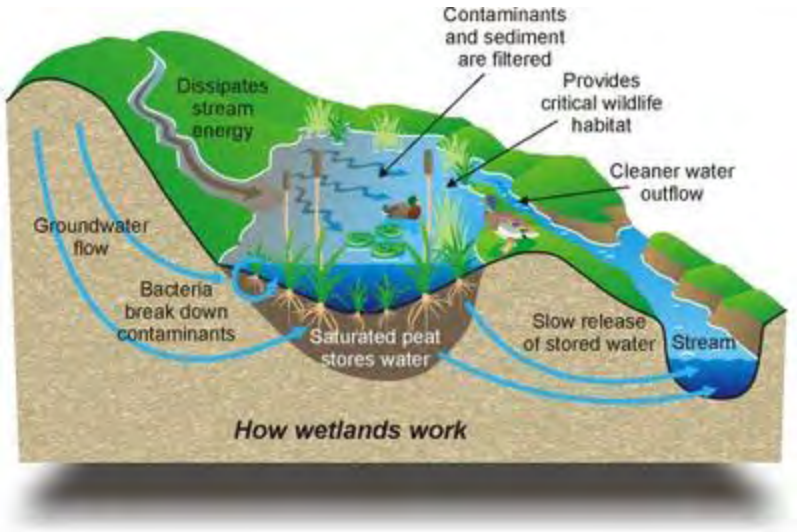
- Prairie Soils were deep and loose, containing very high organic matter with root channels from native plants up to 15’ deep. They were very absorbent with high infiltration, and in Missouri it is estimated that now only 0.1% of native prairies remain.




Root Systems of Prairie Plants
Conservation Research Institute
Heidi Natura 1995 ©
Feet
Depth in feet
Potato
Sugar Beet
Edible Bean
Wheat & Barley
Field Corn
Alfalfa
Kentucky Blue Grass Poa pratensis
Lead Plant Amorpha canescens
Missouri Goldenrod Solidago missouriensis
Indian Grass Sorghastrum nutans
Compass Plant Silphium laciniatum
Porcupine Grass Stipa spartea
Heath Aster Aster ericoides
Prairie Cord Grass Spartina pectinata
Big Blue Stem Andropogon gerardii
Pale Purple Coneflower Echinacea pallida
Prairie Dropseed Sporobolus heterolepis
Side Oats Gramma Bouteloua curtipendula
False Boneset Kuhnia eupatorioides
Switch Grass Panicum virgatum
White Wild Indigo Baptisia leucantha
Little Blue Stem Andropogon scoparius
Rosin Weed Silphium integrifolium
Purple Prairie Clover Petalostemum purpureum
June Grass Koeleria cristata
Cylindric Blazing Star Liatris cylindracea
Buffalo Grass Buchloe dactyloides

Wetlands and Wet Prairies

- Wetlands once provided an unbelievable amount of water storage and lined nearly all bottom land drainages. These natural filters slowed water delivery to streams and facilitated ground water recharge. Now, it is estimated that less than 5% of natural wetlands remain.



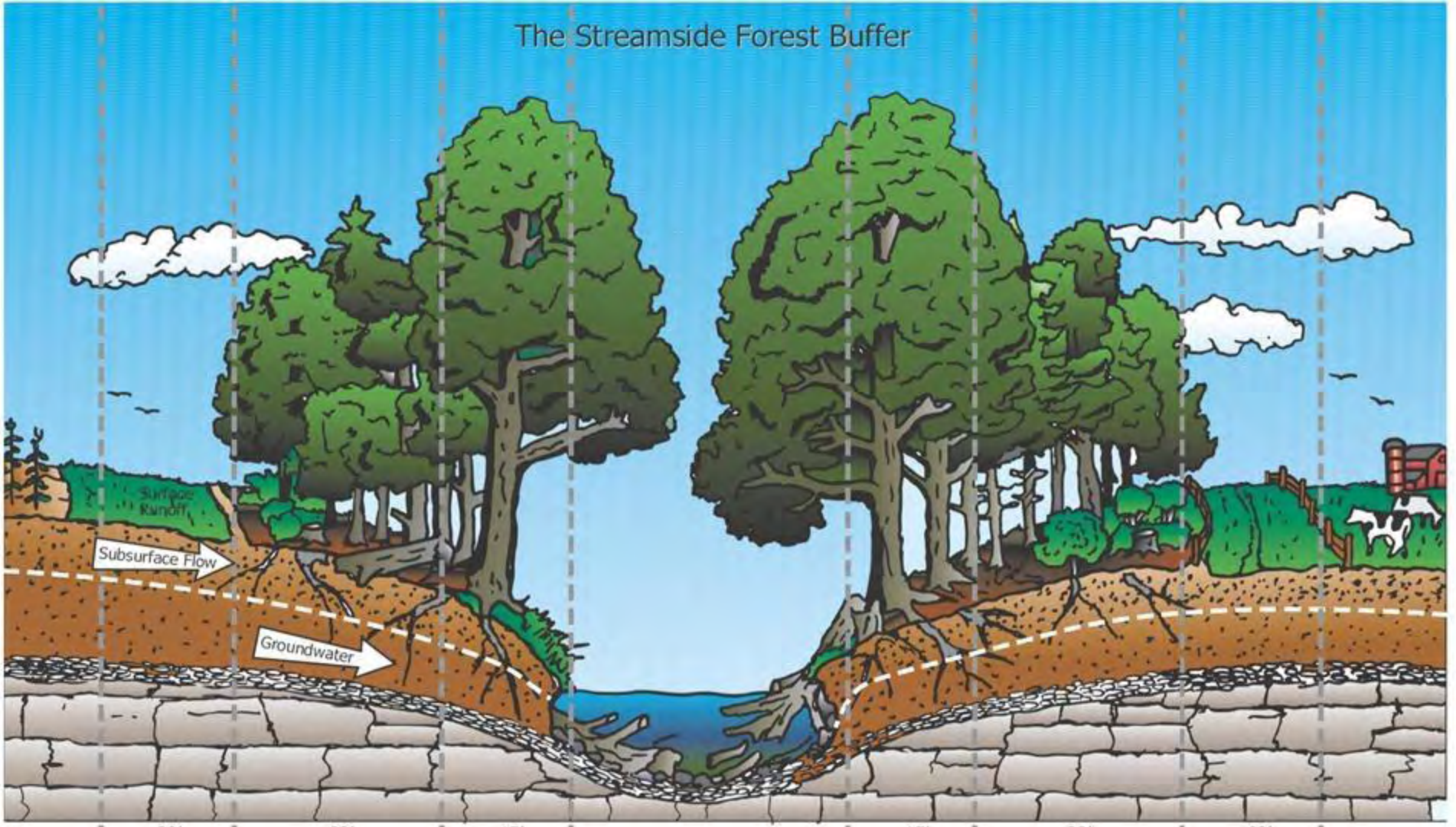

Water Storage???


Or Water Storage???

Forests

- Forests established along riparian corridors and moist, wetter areas in the absence of fire (generally north and eastern aspects and low drainages). They slowed sediment hungry water, increased infiltration, armored the stream bank during high flows, and provided bank soil stabilization (roots act like rebar – especially in saturated soils).

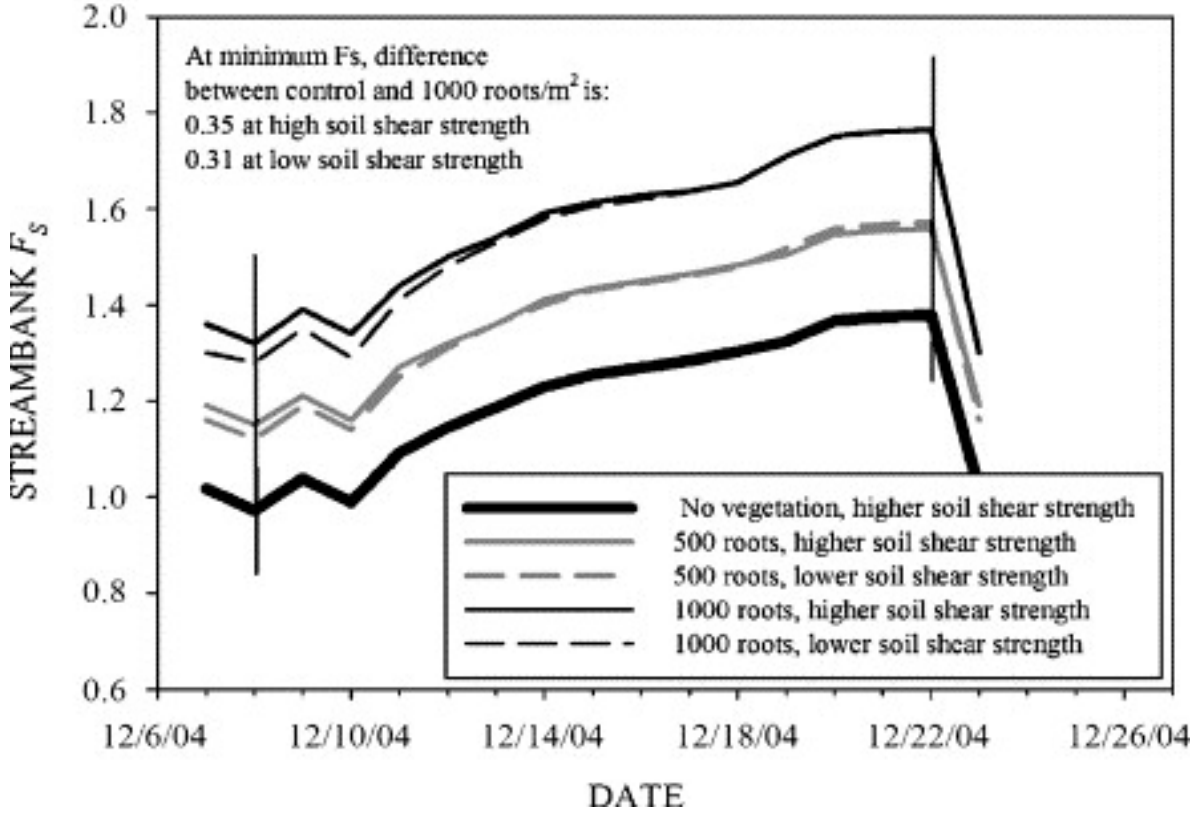
The Streamside Forest Buffer



CROPLAND	20′ ZONE 3 RUNOFF CONTROL	60′ ZONE 2 MANAGED FOREST	15′ ZONE 1 UNDISTURBED FOREST	STREAMBOTTOM	15′ ZONE 1 UNDISTURBED FOREST	20′ ZONE 2 MANAGED FOREST	60′ ZONE 3 RUNOFF CONTROL	PASTURE
Sediment, fertilizer and pesticides are carefully managed.	Concentrated flows are converted to dispersed flows by water bars or spreaders, facilitating ground contact and infiltration.	Filtration, deposition, plant uptake, anaerobic denitrification and other natural processes remove sediment and nutrients from runoff and subsurface flows.	Maturing trees provide detritus to the stream and help maintain lower water temperature vital to fish habitat.	Debris dams hold detritus for processing by aquatic fauna and provide cover and cooling shade for fish and other stream dwellers.	Tree removal is generally not permitted in this zone.	Periodic harvesting is necessary in Zone 2 to remove nutrients sequestered in tree stems and branches and to maintain nutrient uptake through vigorous tree growth.	Controlled grazing or haying can be permitted in Zone 3 under certain conditions.	Watering facilities and livestock are kept out of the Riparian Zone insofar as practicable.

Shear strength of Streambank Soil

At maximum *Fs* difference
between control and 1000 roots/m^2 is:
0.36 at high soil shear strength
0.36 at low soil shear strength



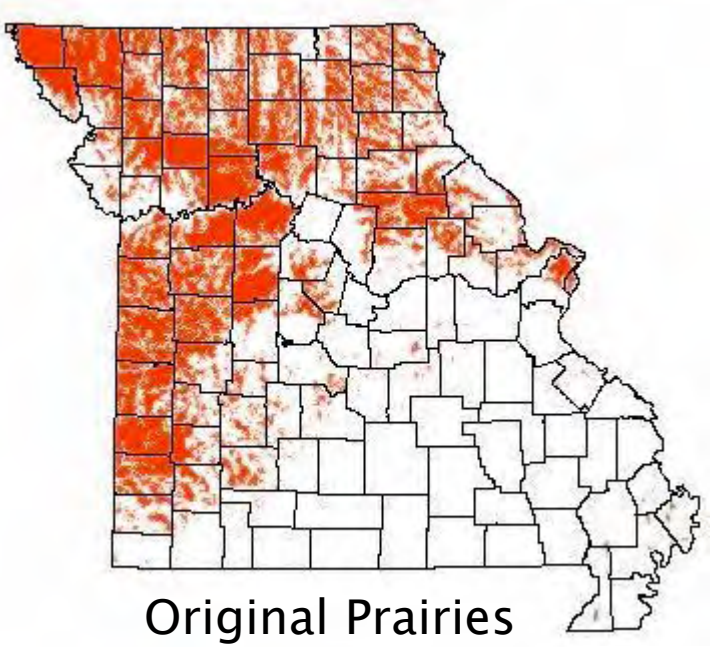
Take Home Messages:

- In a properly functioning watershed, each resource plays a specific role and serves to protect the others, providing a relatively stable watershed system over the long term.
- Naturally functioning system = ⇧ sustainable
- The effects of manipulating one variable in the watershed are complex and far reaching.
- Soil characteristics play a major role in overall watershed health.

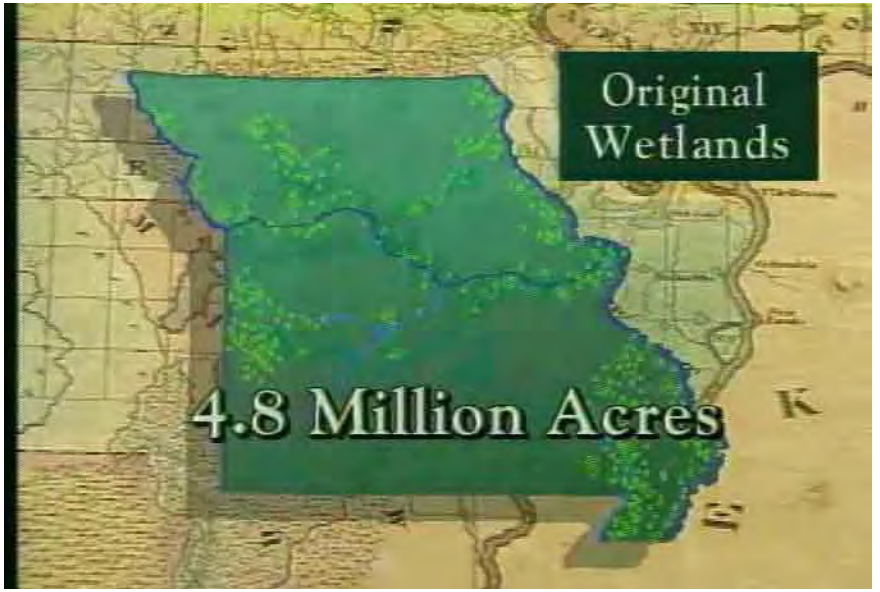
- TRANSITION -

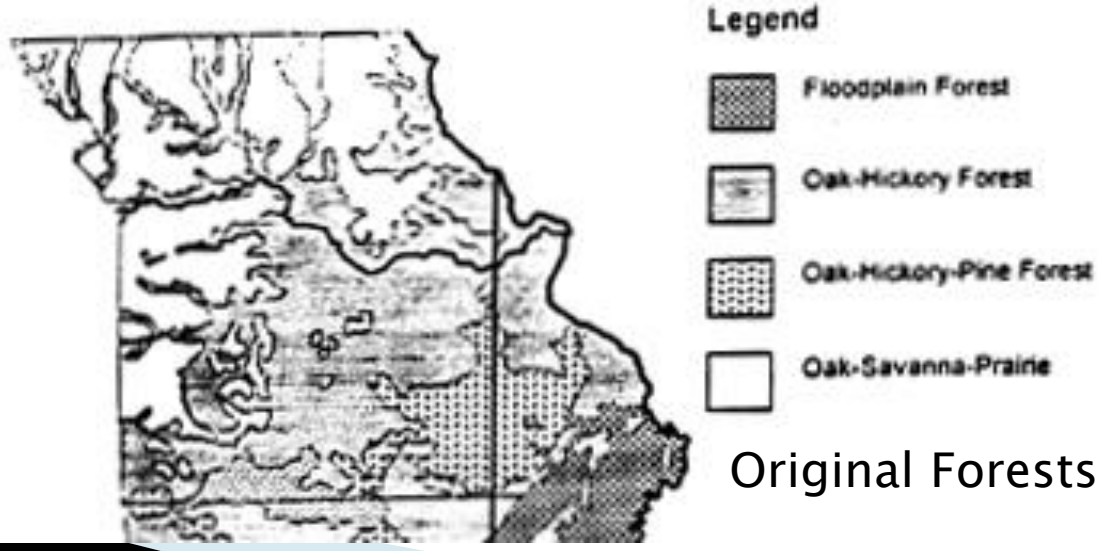
Watershed Impairments

Pre-settlement Conditions

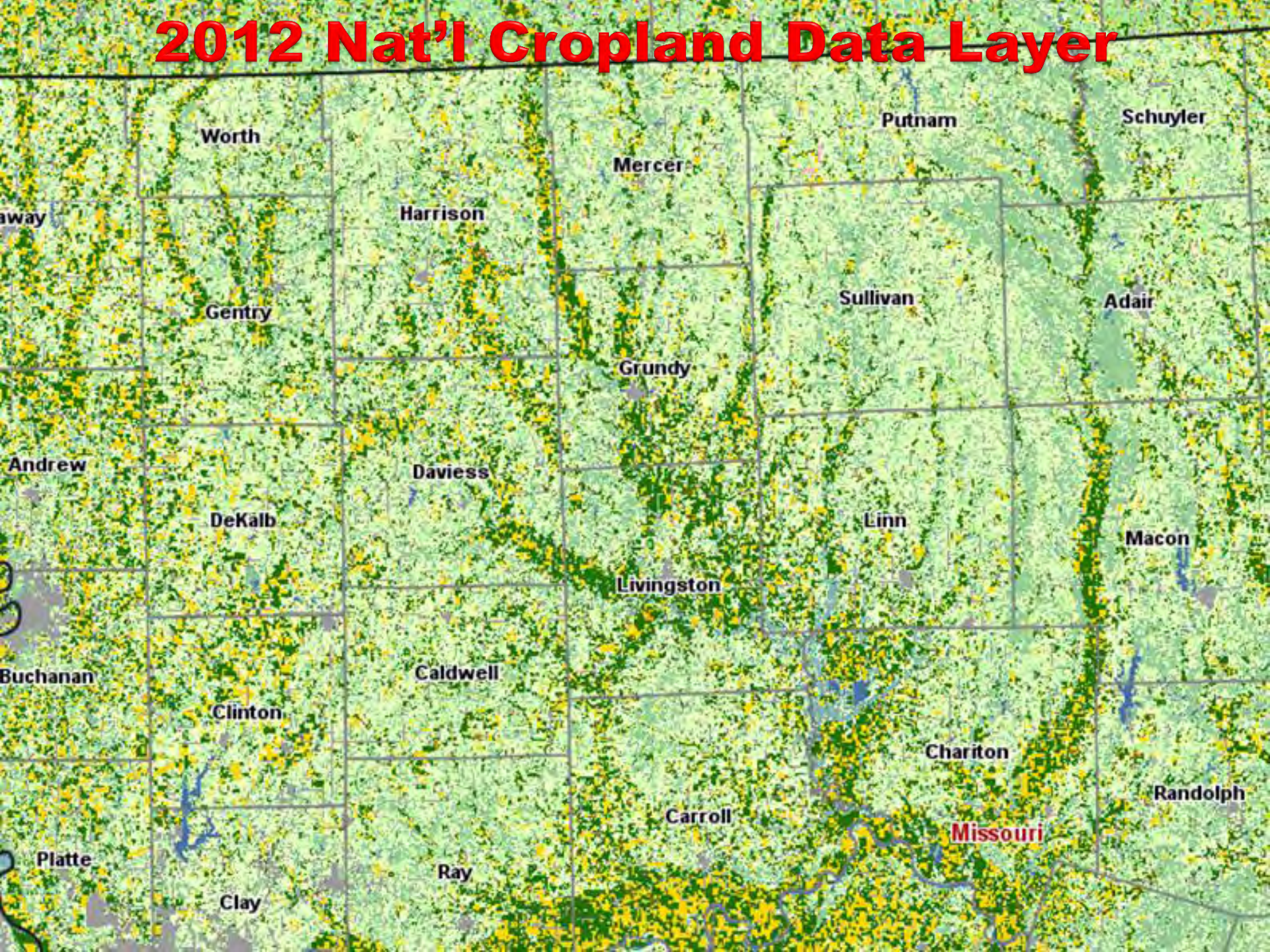


Original Prairies



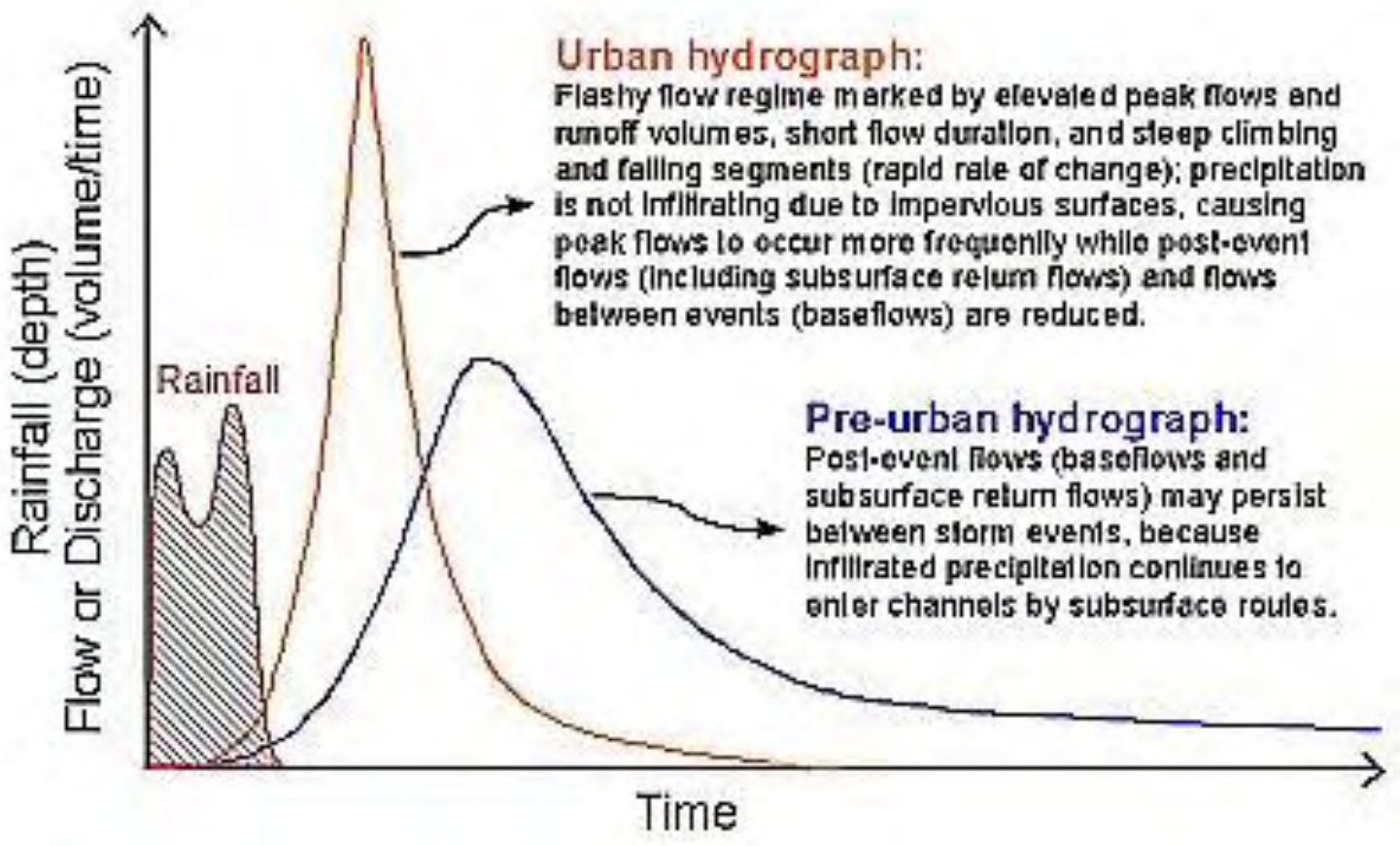


Original Forests

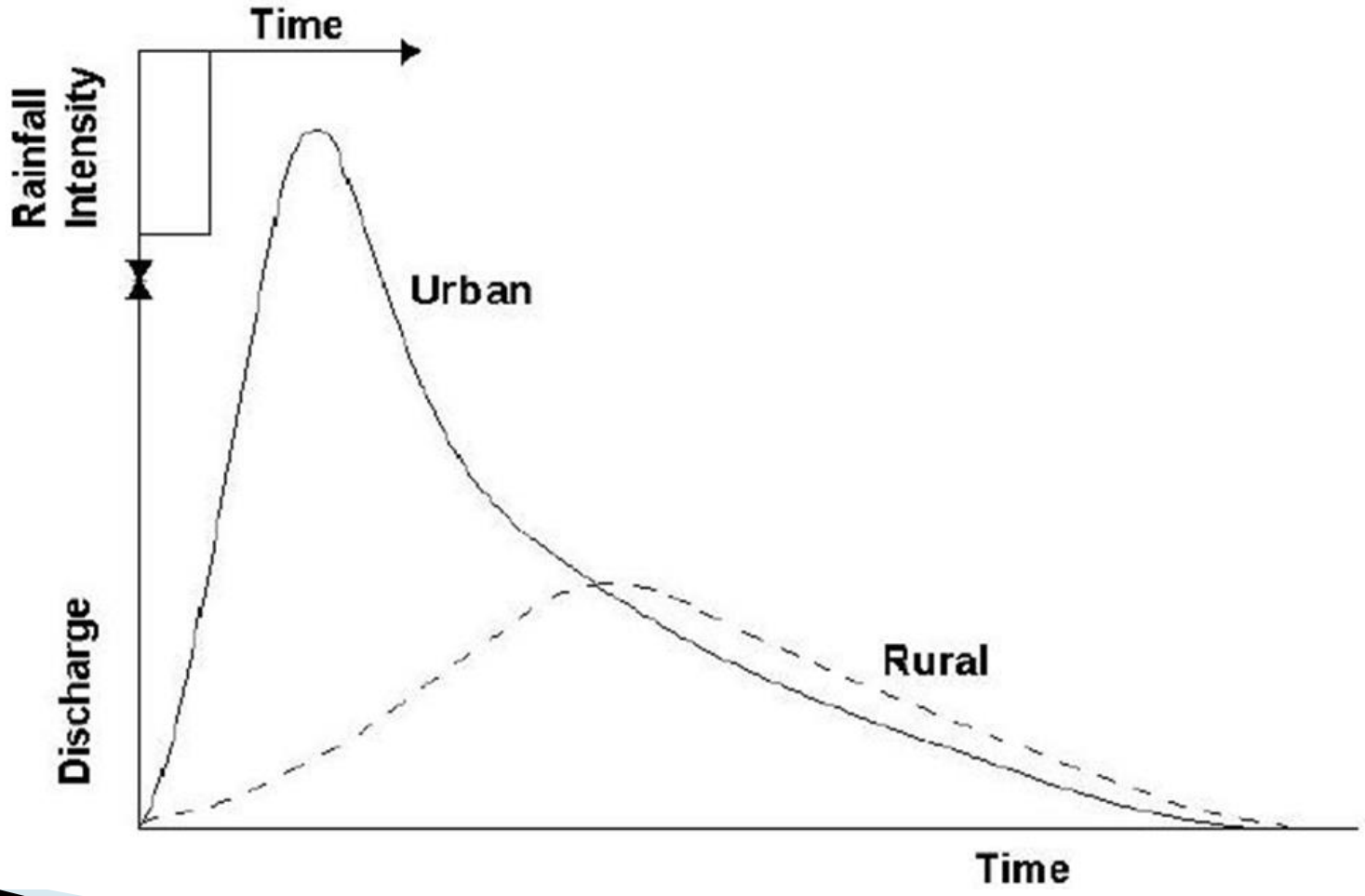

2012 Nat'l Cropland Data Layer
Worth
Putnam
Schuyler
Mercer
Harrison
Gentry
Sullivan
Adair
Grundy
Andrew
Daviess
DeKalb
Linn
Macon
Livingston
Buchanan
Caldwell
Clinton
Chariton
Randolph
Carroll
Missouri
Platte
Ray
Clay

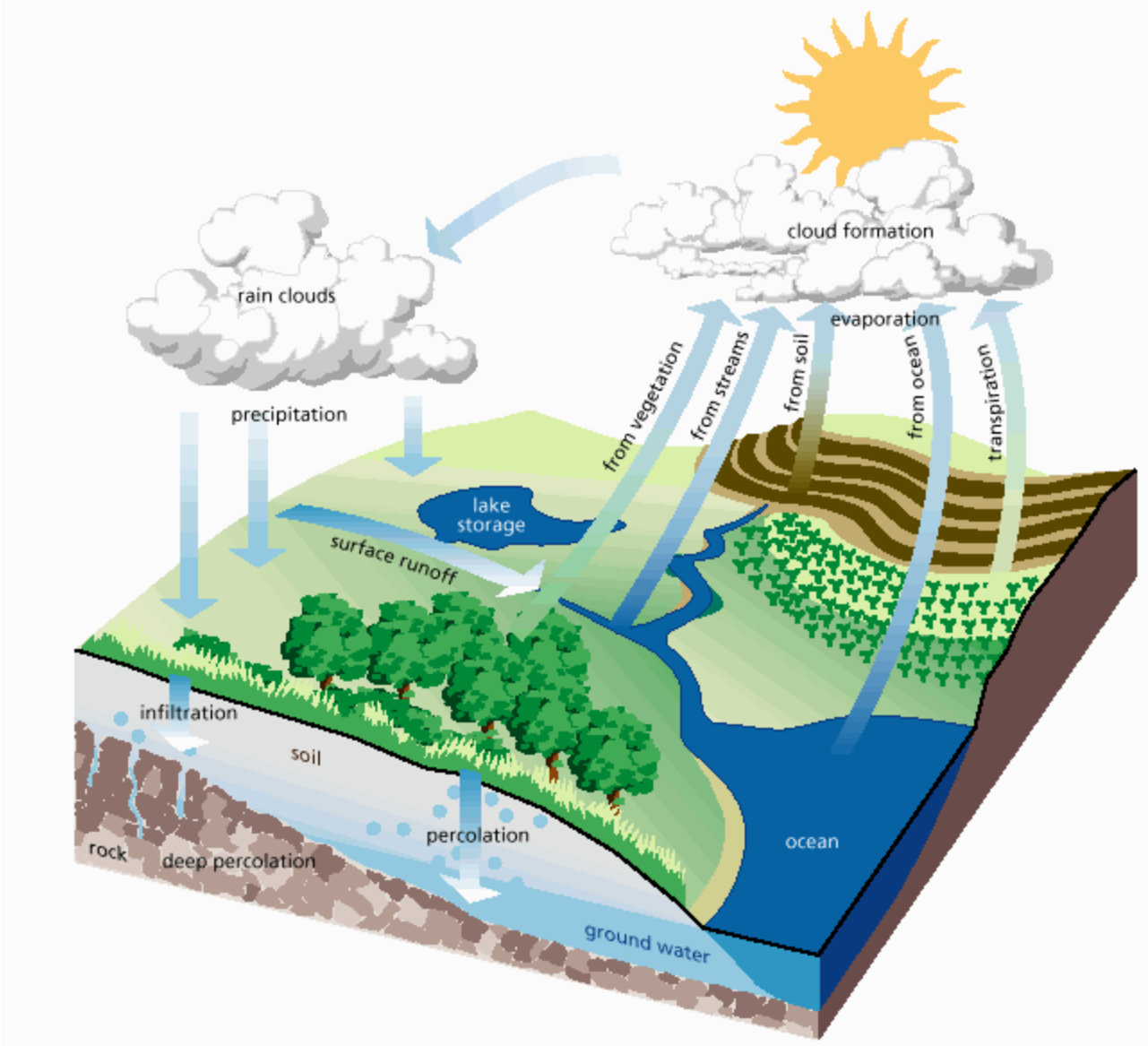
Hydrograph Comparison…

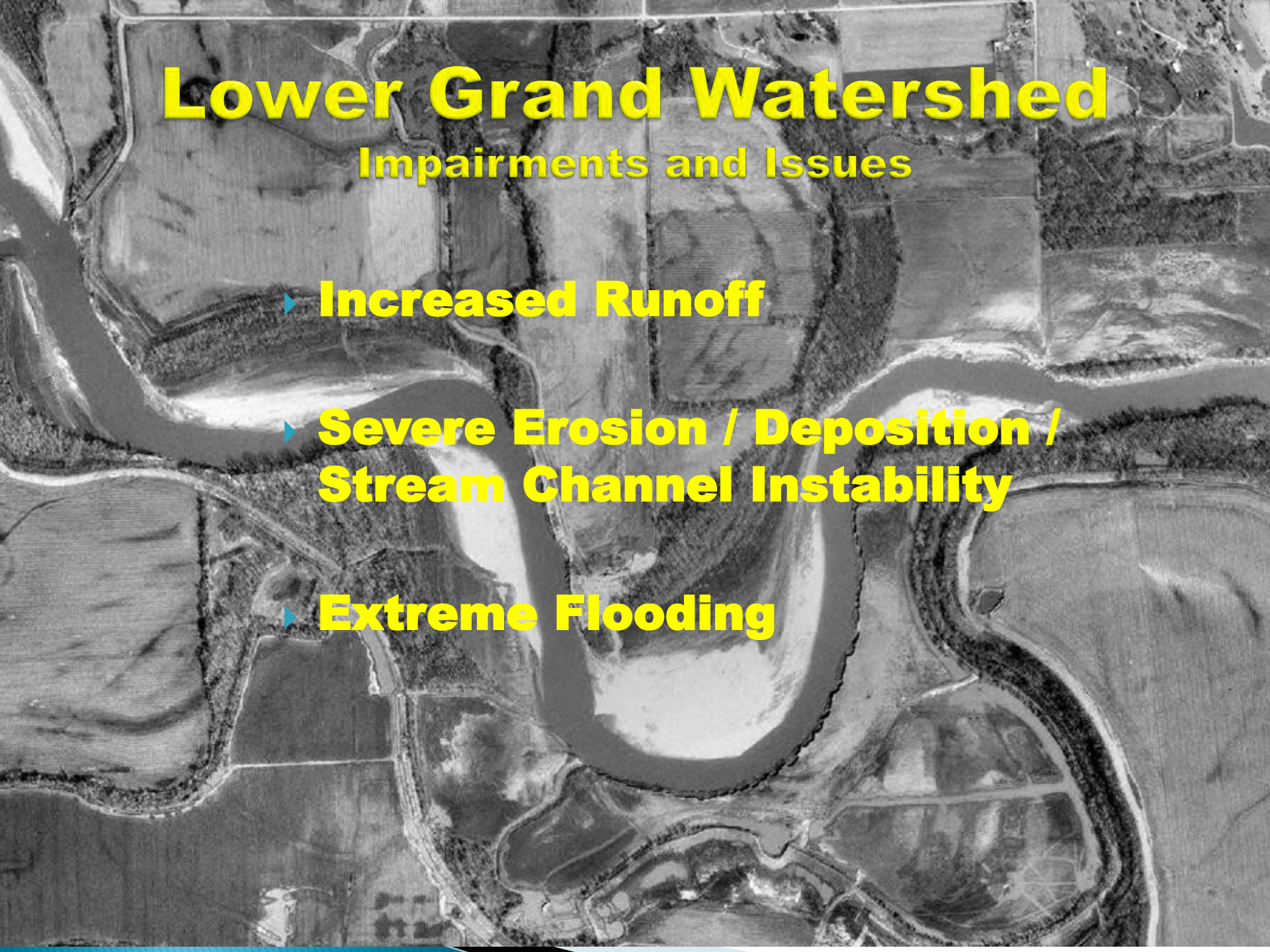
Conventional Ag Production +/-/= Urban Development????



Quicker onset of peak flow after rainfall event
Higher peak (higher flood level)
Quicker drawdown
High energy = aggressive, sediment hungry, more damaging!!!




cloud formation
rain clouds
evaporation
from vegetation
from streams
from soil
from ocean
transpiration
precipitation
lake storage
surface runoff
infiltration
soil
percolation
rock
deep percolation
ocean
ground water



Lower Grand Watershed

Impairments and Issues

- Increased Runoff
- Severe Erosion / Deposition / Stream Channel Instability
- Extreme Flooding

Multi-Agency Mitigation Efforts in the Lower Grand Basin

- Structural Practices
  - Terrace Systems and Tile Outlets
  - Pond Construction
  - PL-566 Flood Control Reservoirs
  - Wetland Restoration
  - Formerly: Levees / Channelization
- Vegetative / Management
  - CRP/Other Programs (grass, trees, forbs, wetlands)
  - No-till / Reduced Tillage
  - More recently: Cover Crops and Soil Health
  - Rotational Grazing Systems

Increased Runoff

- Change from pre-settlement conditions to intensive agriculture

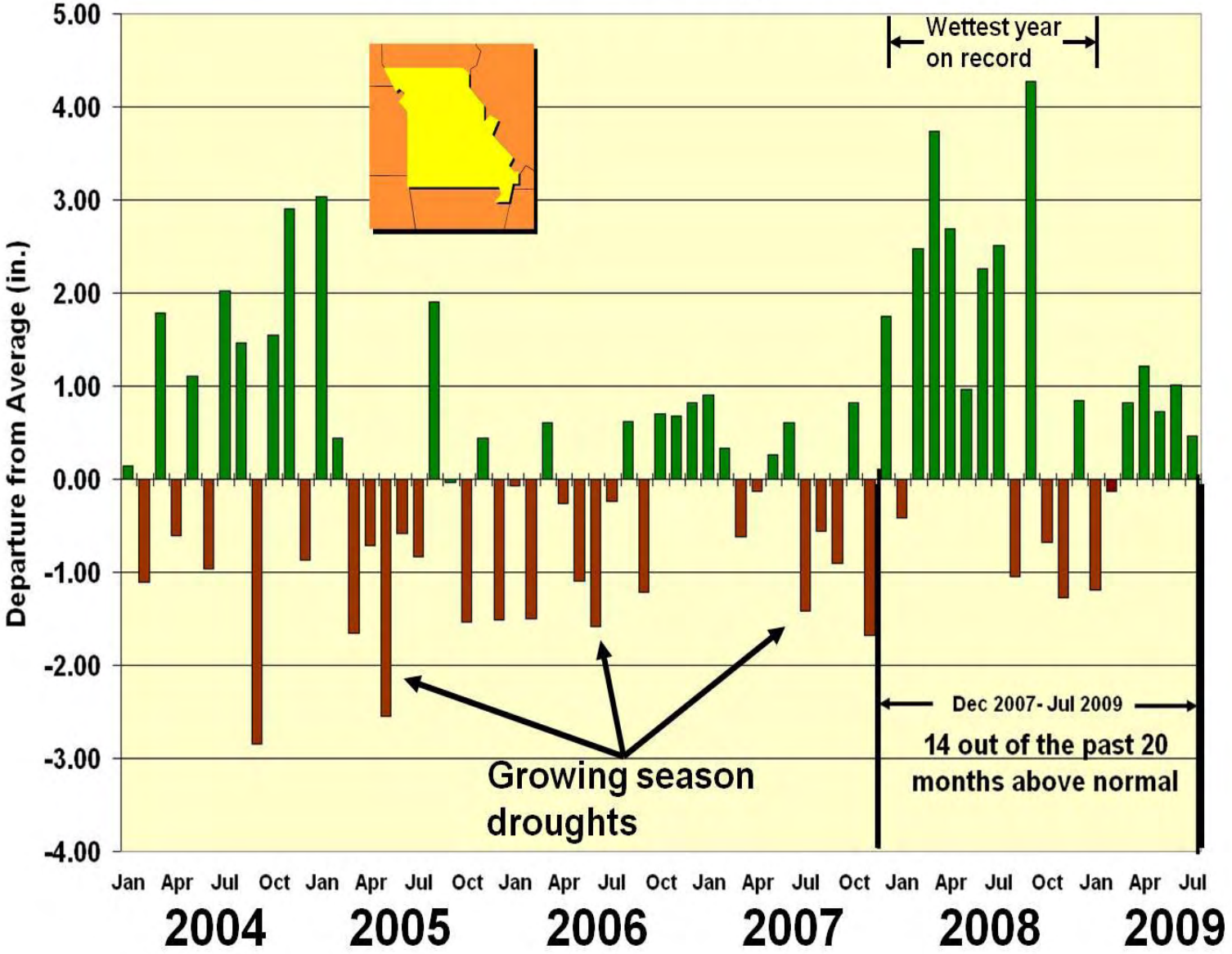
  (de-vegetation and loss of functioning prairies, wetlands, and forests).
- Loss of high native soil quality

  (O.M., structure, infiltration, percolation, water holding capacity).
- Some urbanization
- MAYBE IT'S THE WEATHER????

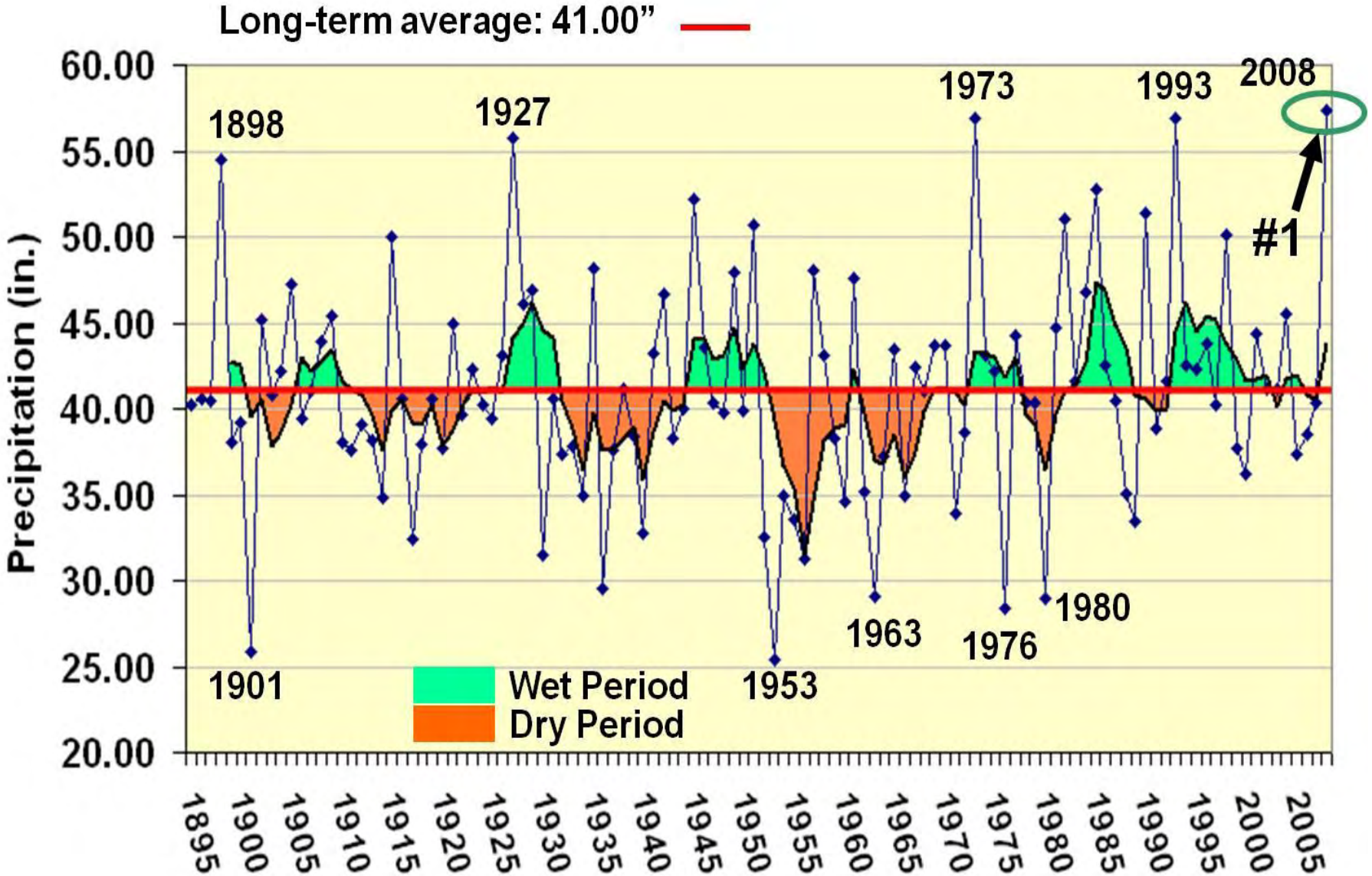
Historical and Recent Climate Trends in Missouri

Pat Guinan
Extension Climatologist
Commercial Agriculture Program

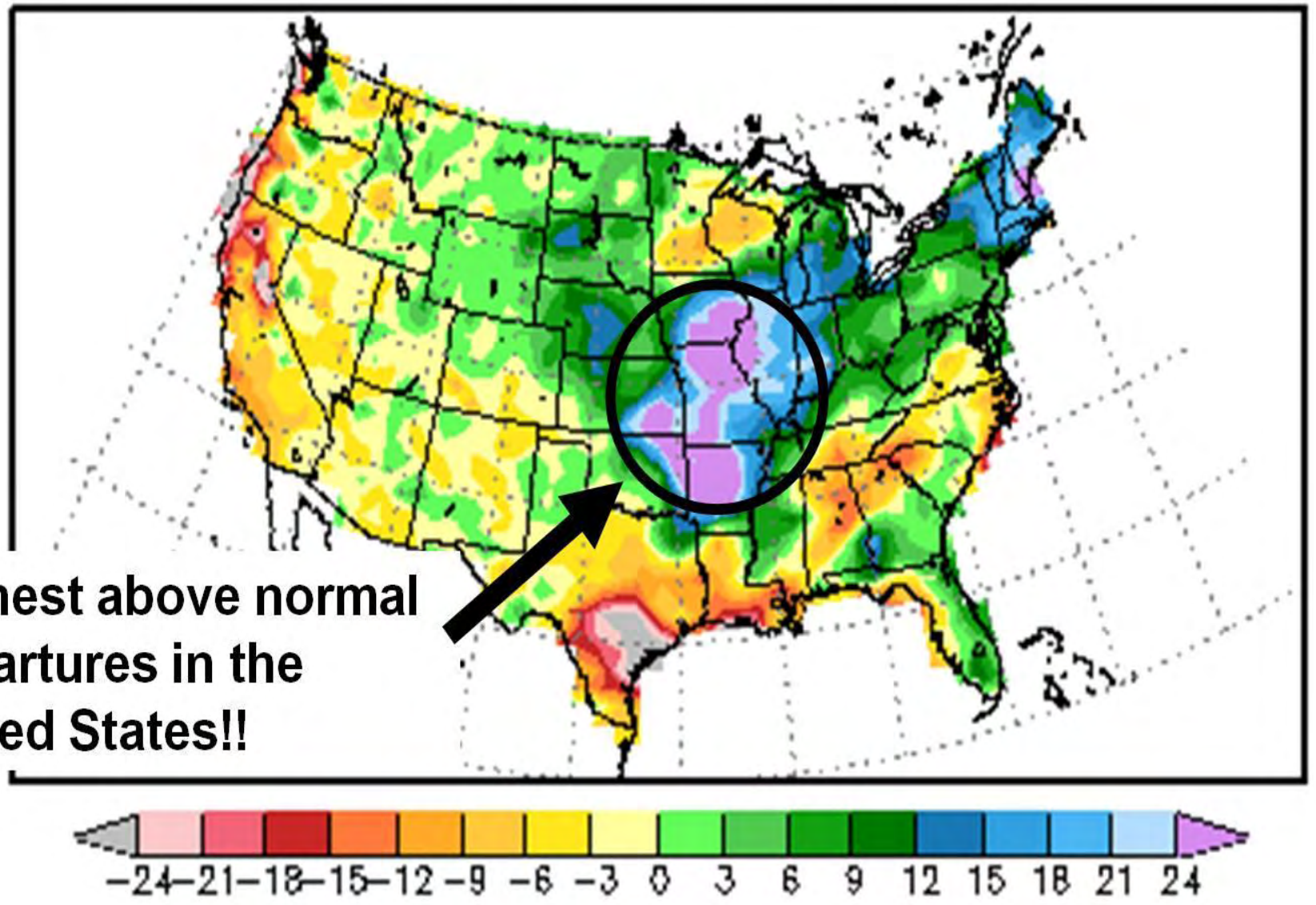
Missouri
Monthly Precipitation Departure from Long-Term Normal
January 2004-July 2009



Missouri Annual Average Precipitation (1895-2008)



Total Precipitation Departure from Mean in inches
Dec 2007 to Aug 2009



Organic Matter of U.S. Soils

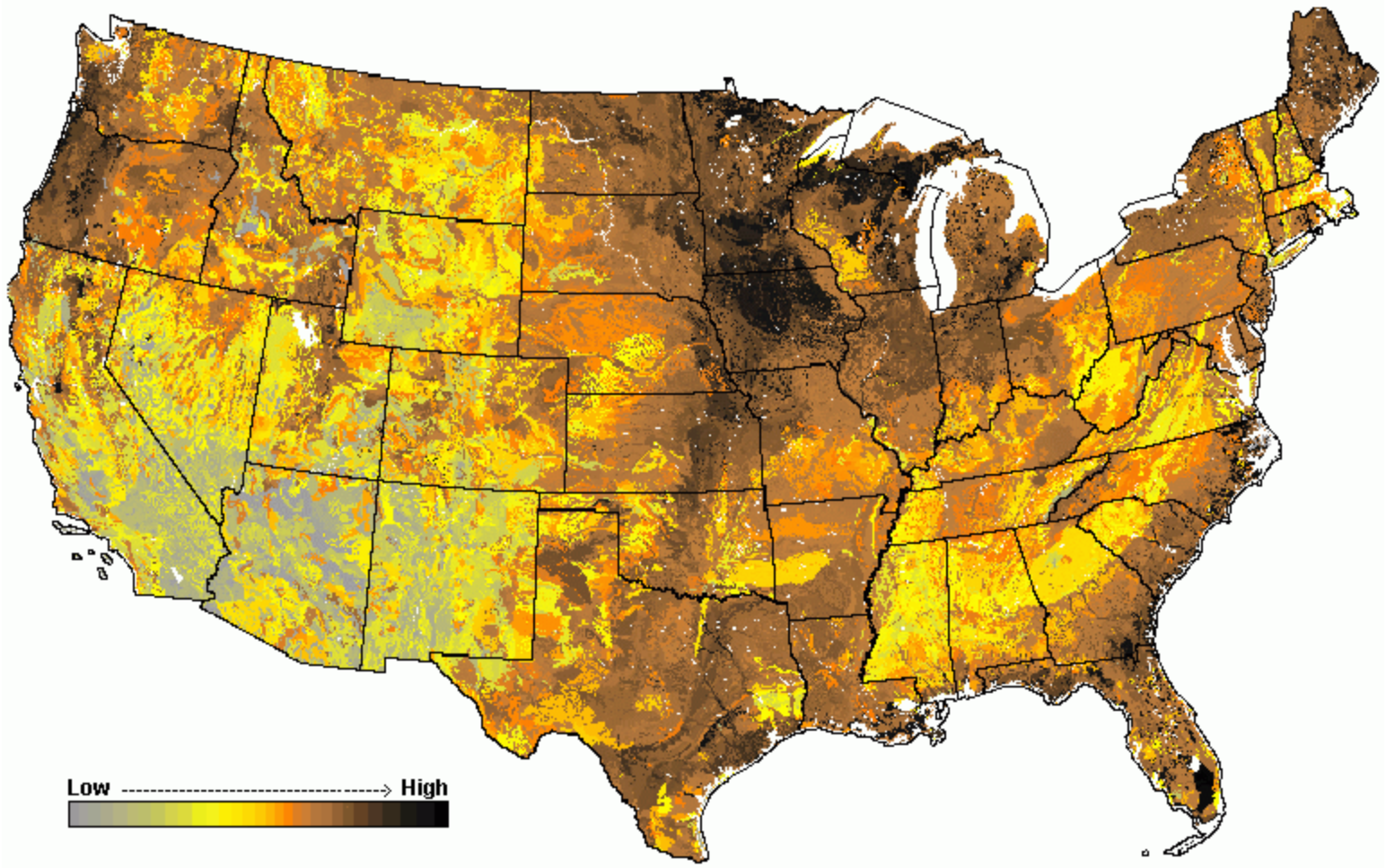


Figure 1. Soil organic matter content across the United States. Image: Hargrove and Luxmore (1988).

healthy soil has amazing water-retention capacity.

Every **1%** increase in organic matter results in as much as

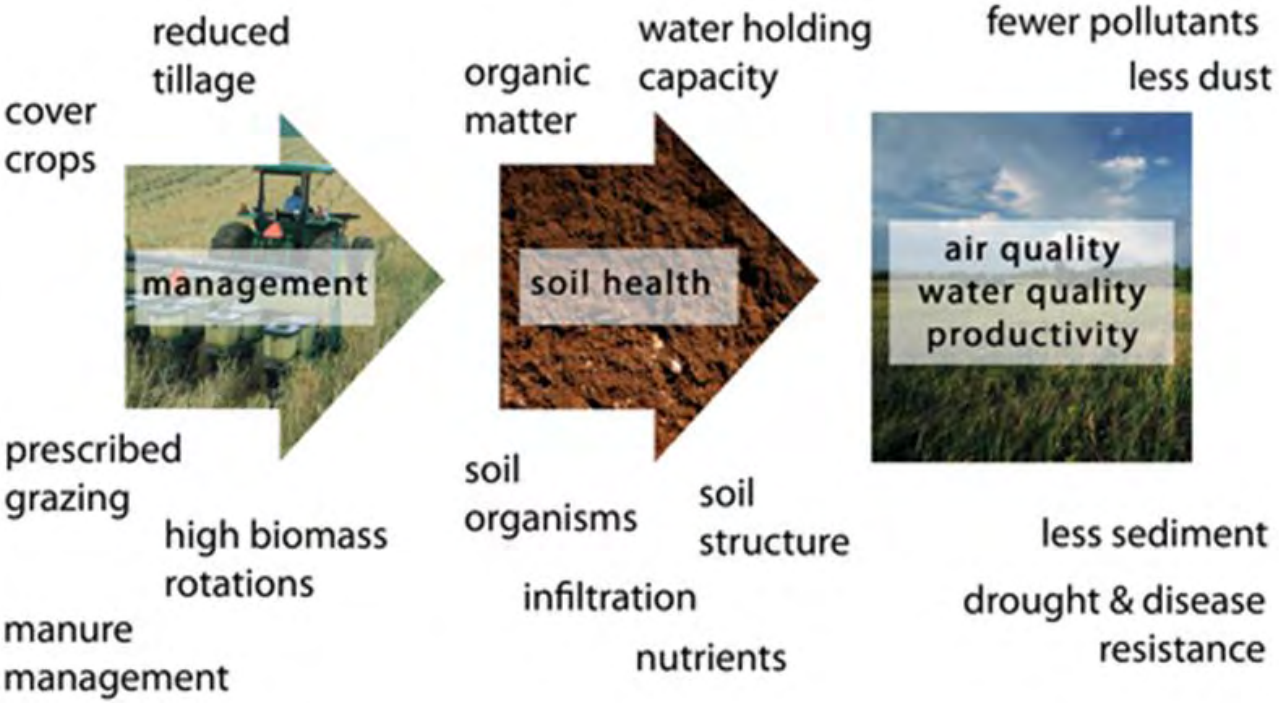
25,000 gal of available soil water per acre.

Source: Kansas State Extension Agronomy e-Updates, Number 357, July 6, 2012

USDA United States Department of Agriculture

Want more soil secrets?
Check out **www.nrcs.usda.gov**

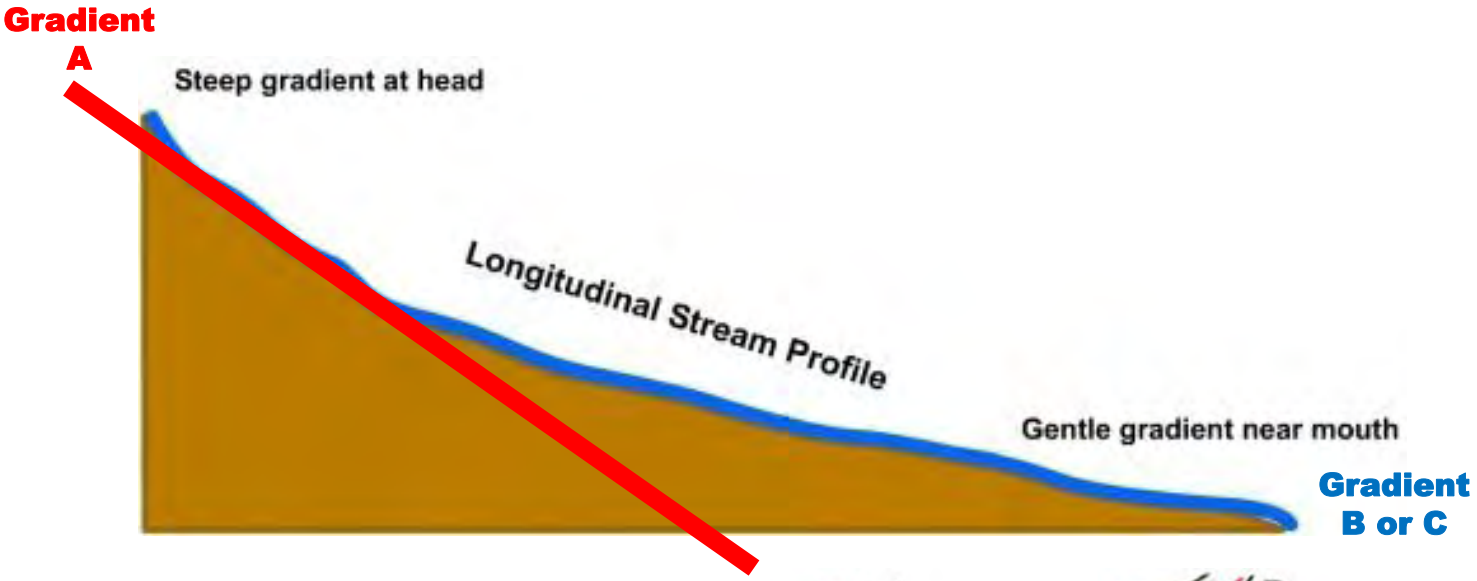
Managing soil organic matter is the key to air and water quality.

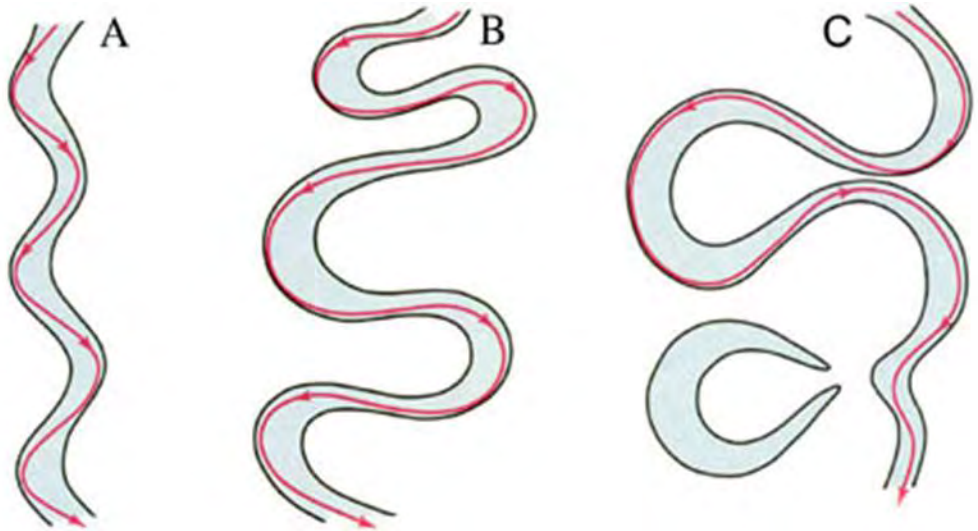


Severe Erosion/Deposition/Channel Instability

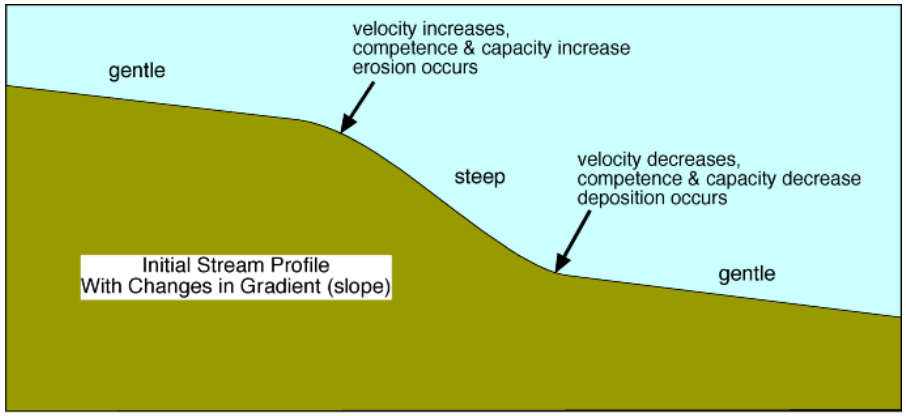
- Increased Field Runoff
  - Shift from pre-settlement conditions to intensive agriculture
    (de-vegetation and loss of functioning prairies, wetlands, and forests).
  - Loss of high native soil quality
    (O.M., structure, infiltration, percolation, water holding capacity).
  - Some urbanization
  - Wet Weather Cycle
- Collective effect of decreased vegetative cover throughout watershed (bare much of the year)
- Change in stream gradient or stream length
  due to straitening or channelization, head-cutting, etc.

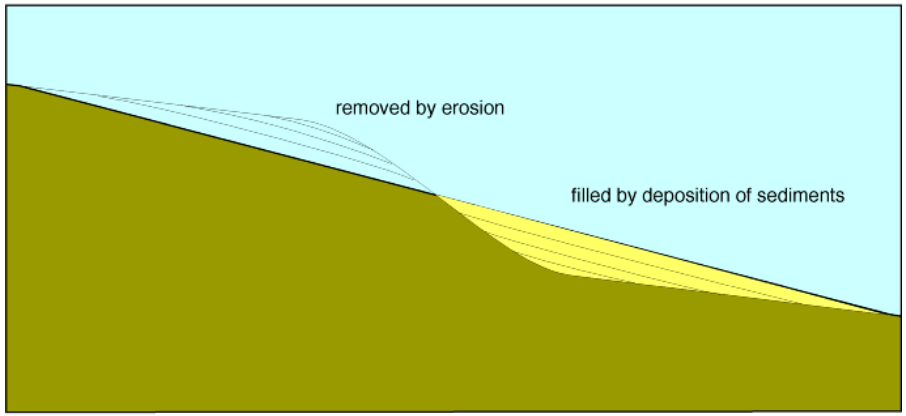
Channelizing a Stream
changes the slope of a stream

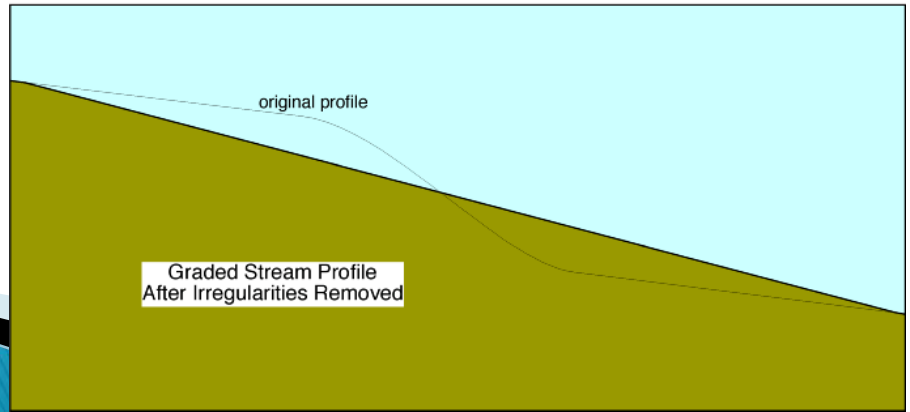




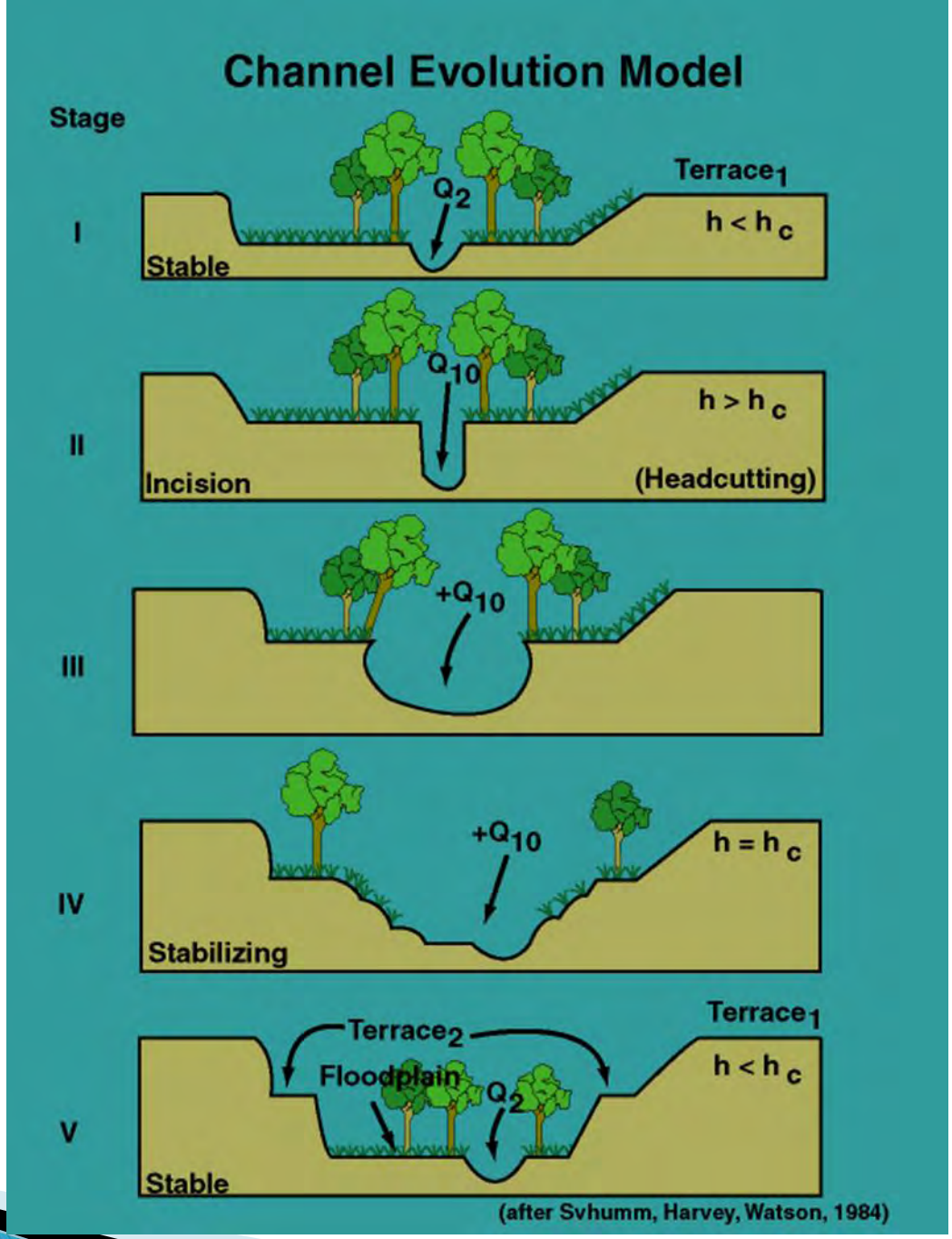
Greater slope = higher energy!!!







Severe Headcutting


Channel Evolution Model
Stage
I
Stable
Q2
Terrace1
h < hc
II
Incision
Q10
h > hc
(Headcutting)
III
+Q10
IV
Stabilizing
+Q10
h = hc
V
Stable
Terrace2
Floodplain
Q2
Terrace1
h < hc
(after Svhumm, Harvey, Watson, 1984)

Re-meander of Channelized Streams

Lower Grand Channelization Factoids:

- Grand River – decreased from 92 miles to 26 miles after channelization in the early 1900's. Slope increased from 0.6 ft/mi to 1.6 ft/mi.
- Locust Creek – decreased by 16 miles and slope increased from 2.2 ft/mi to 3.7 ft/mi.
- Result – accelerated and increased peak flows from upper watershed, increasing out of bank flows, flooding, and sedimentation in lower watershed.

Lower Grand Sedimentation Factoids:

- Sedimentation surveys on Fountain Grove CA and Swan Lake NWR in the1970-80's showed sediment accumulation up to 2 feet, along with 52-72% loss of water storage volume from filling of the floodplains/wetlands.
- Since 1983, the volume of Silver Lake and Swan Lake NWR has decreased 25% due to sediment deposition from Turkey and Elk Creeks.

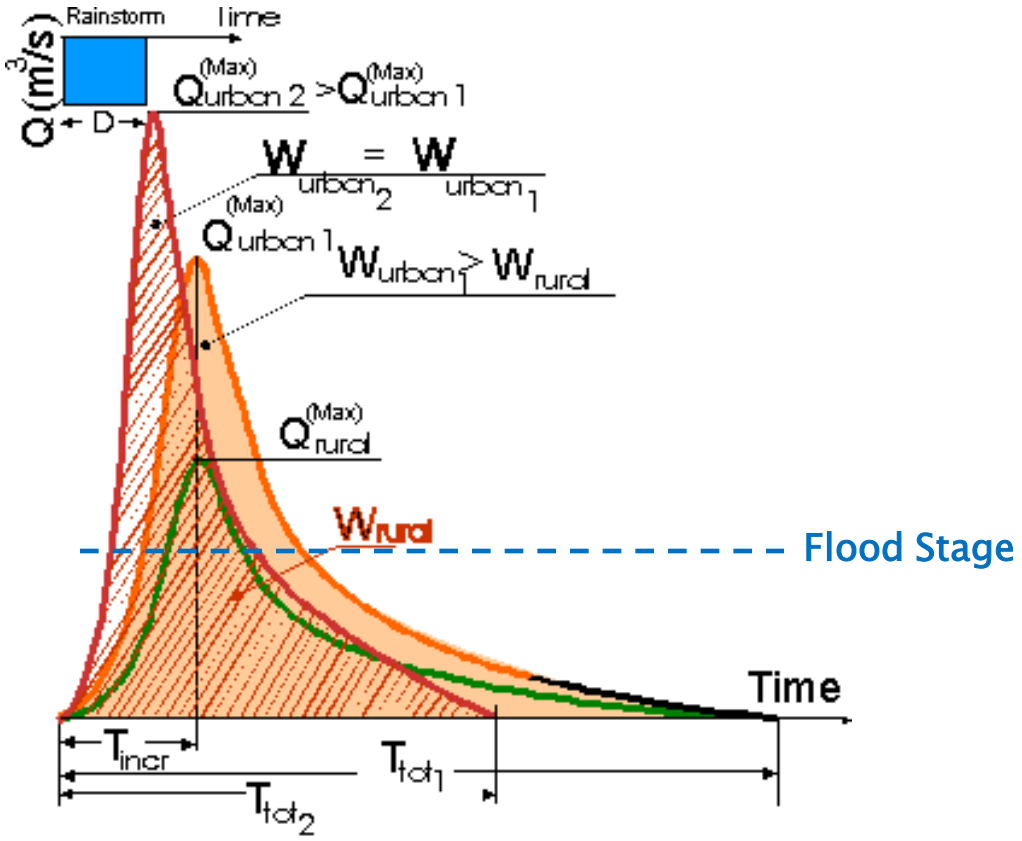
Extreme Flooding

- Increased Field Runoff
  - Shift from pre-settlement conditions to intensive agriculture
    (de-vegetation and loss of functioning prairies, wetlands, and forests).
  - Loss of high native soil quality
    (O.M., structure, infiltration, percolation, water holding capacity).
  - Some urbanization
  - Wet Weather Cycle
- Collective effect of decreased vegetative cover throughout watershed (bare much of the year)
- Change in stream gradient or stream length
  due to straitening or channelization, head-cutting, etc.
- Extensive network of Levees and Dikes???
- Extensive network of engineered structures in upper watershed (ponds, reservoirs, terraces, WASCOBs)???

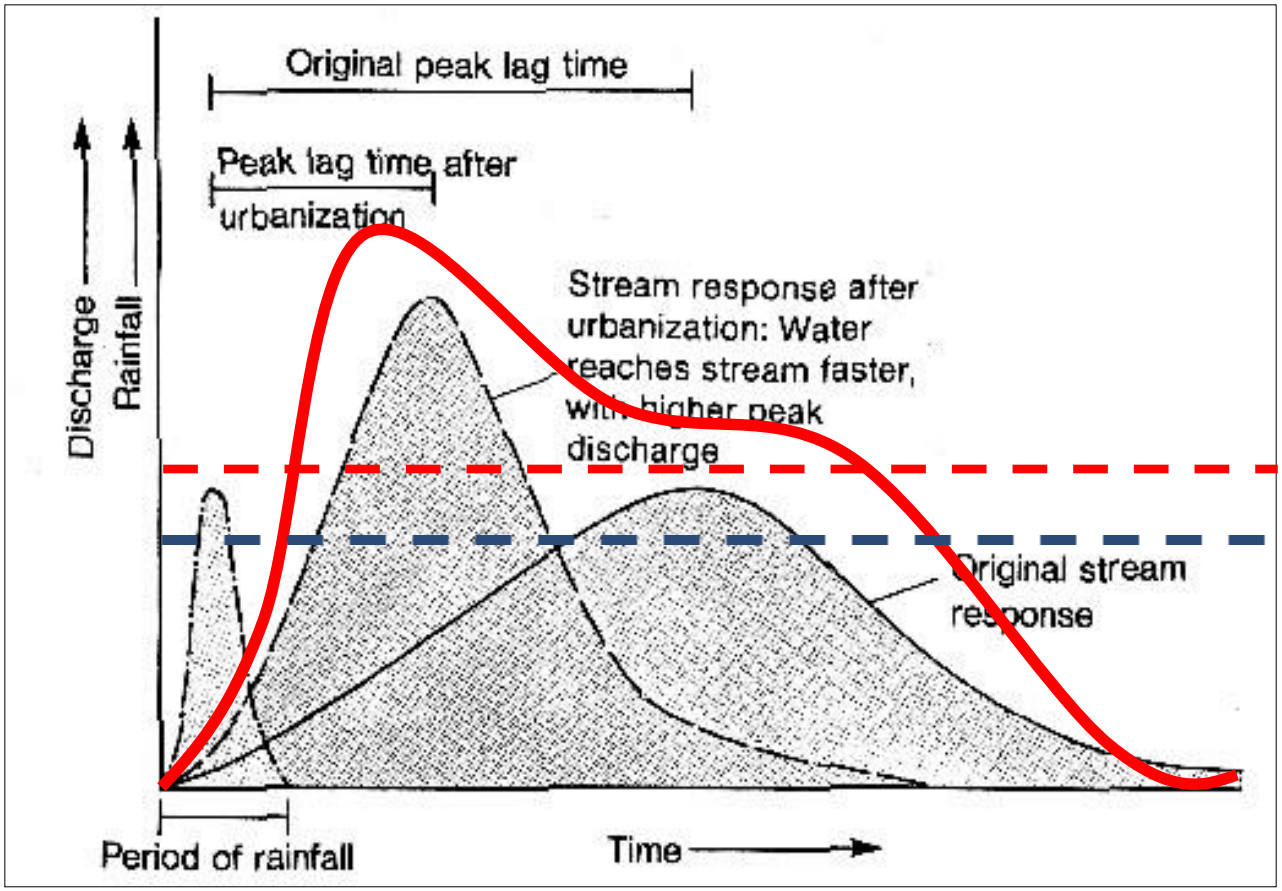
Flow Changes in an Altered System

Is this similar to:

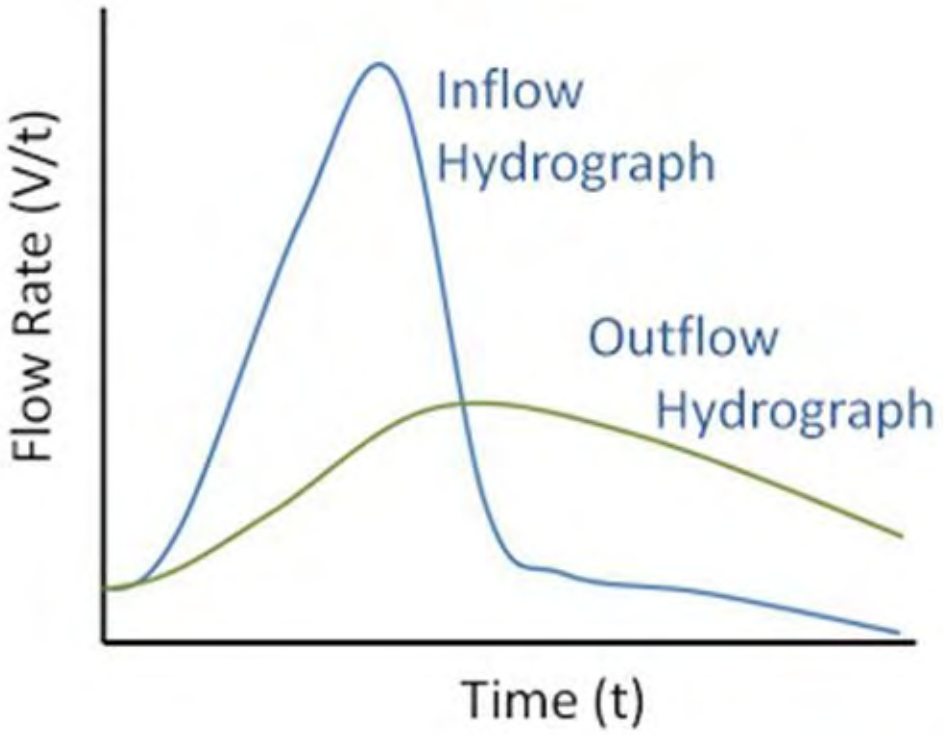
Natural → Intensive Ag → Channelization???



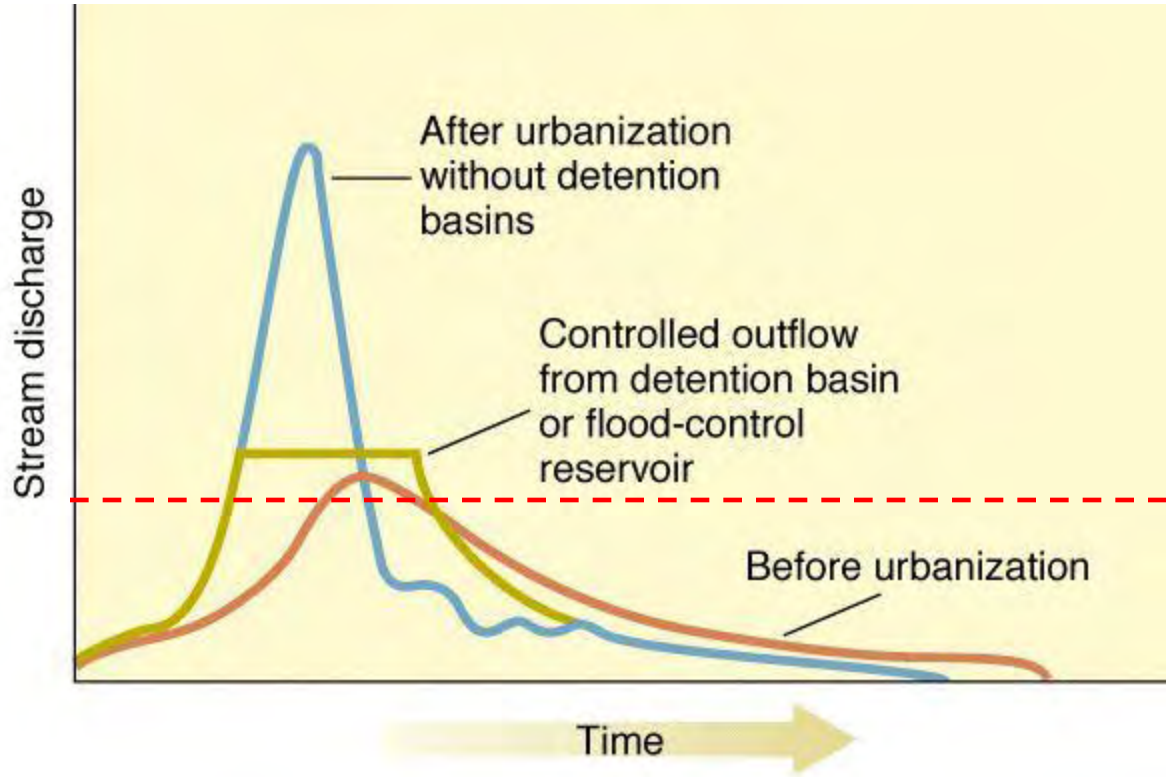
North Missouri Channelized / Leveed Streams???



Pond or Lake Function in a Watershed



Pond / Lake function in a Watershed… Ooops!



What about Terrace Systems???
Tile Outlets directly into the stream???

Lower Grand Flood Control Effort Factoids:

- Channelization – early 1900's, followed by a network of Levees.
- Grand River Basin has approximately 30 lakes over 50 acres in size.
- In the 1960's, (7) large flood control reservoirs were planned for the Grand River Basin by USACE. It was later determined that reservoirs and associated channel modifications were not feasible, and were subsequently de-authorized in 1989.
- Hundreds of PL-566 flood control structures have been constructed in north Missouri since 1970's(??).

Multi-Agency Mitigation Efforts in the Lower Grand Basin

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  - Terrace Systems and Tile Outlets
  - Pond Construction
  - PL-566 Flood Control Reservoirs
  - Wetland Restoration
  - Formerly: Levees / Channelization
- Vegetative / Management
  - CRP/Other Programs (grass, trees, forbs, wetlands)
  - No-till / Reduced Tillage
  - More recently: Cover Crops and Soil Health
  - Rotational Grazing Systems

Closing Messages

- Every soil, vegetation, mechanical, and drainage manipulation that takes place in the watershed has an impact – above and below!
- Conservation practices to address critical resource concerns at the field scale may add to watershed impairment.
- In an Ag intensive watershed, improving soil health and function may be the most cost-effective, impactful, and beneficial improvement for restoring watershed function.

Thank You!


1996
Grand River below Chillicothe (near the mouth of Shoal Creek)
Channel length increased from 15,300' (blue-topo) to 18,300' (red)
2012
1500 750 0 1500 3000