Human Impacts on Hydrology and Streams

Scott Dierks, PE

JFNew

Partners for Clean Streams

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Presentation Outline

- Hydrologic Cycle
- Watersheds
- Rivers
- Recurrence Interval and Flooding
- Land Cover becomes Land Use (Human modification of hydrology)
- Urban Hydrologic Cycle
- Agricultural Hydrologic Cycle
- Case Study: Recover original land cover, recover hydrology?
- River Channels: Form and Process (Fluvial Geomorphology)
- Human Impact on fluvial geomorphology

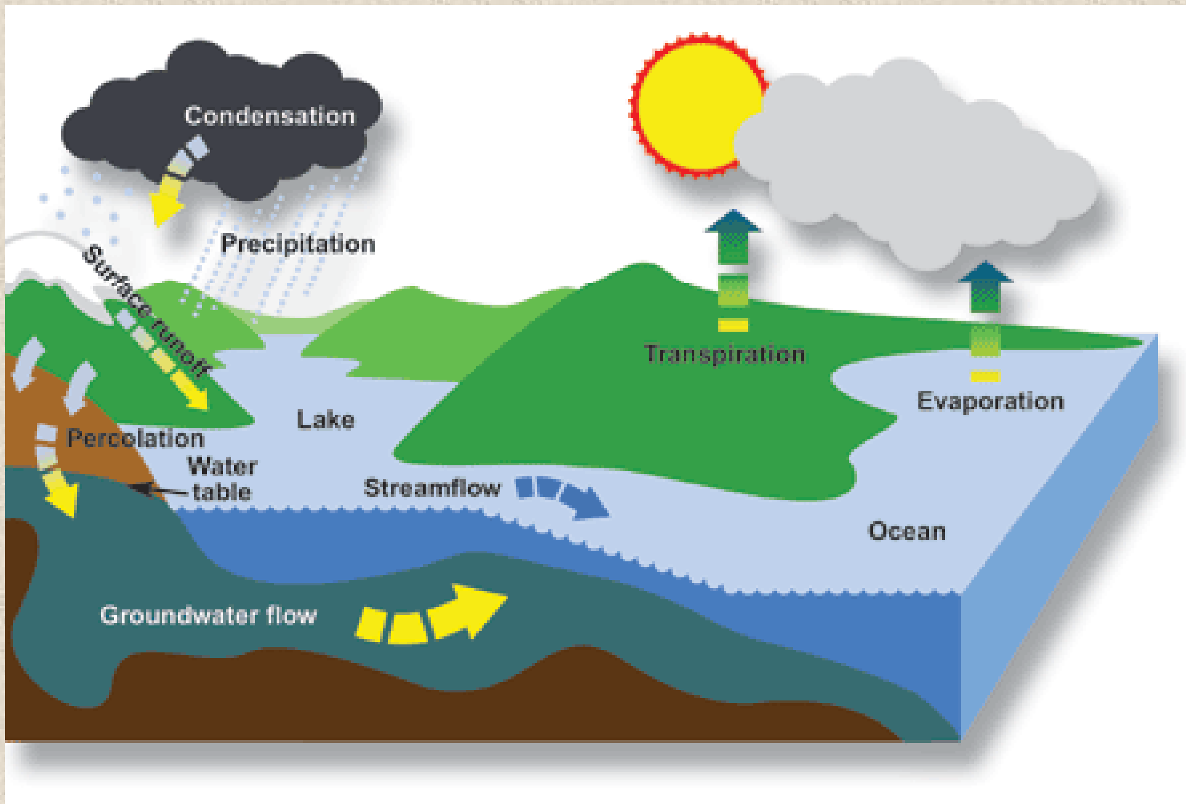
E1

The Hydrologic Cycle

Ohio's Water Balance

- P: 37.5 in/yr
- E / T: 26.0 in/yr
- I : 3.0 – 3.6 in/yr
- R: 8.4 – 9.0 in/yr

Source:

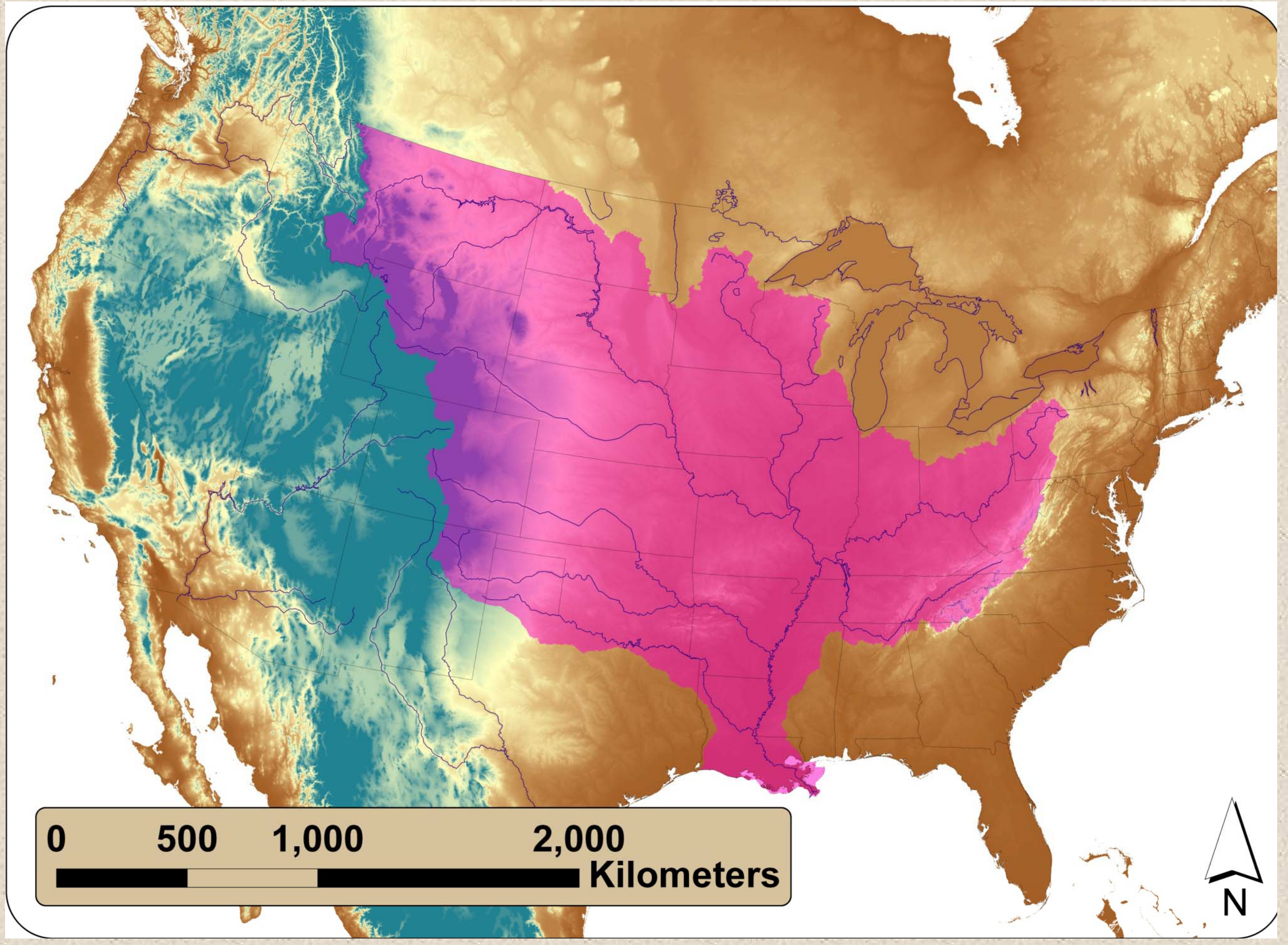


Slide 3

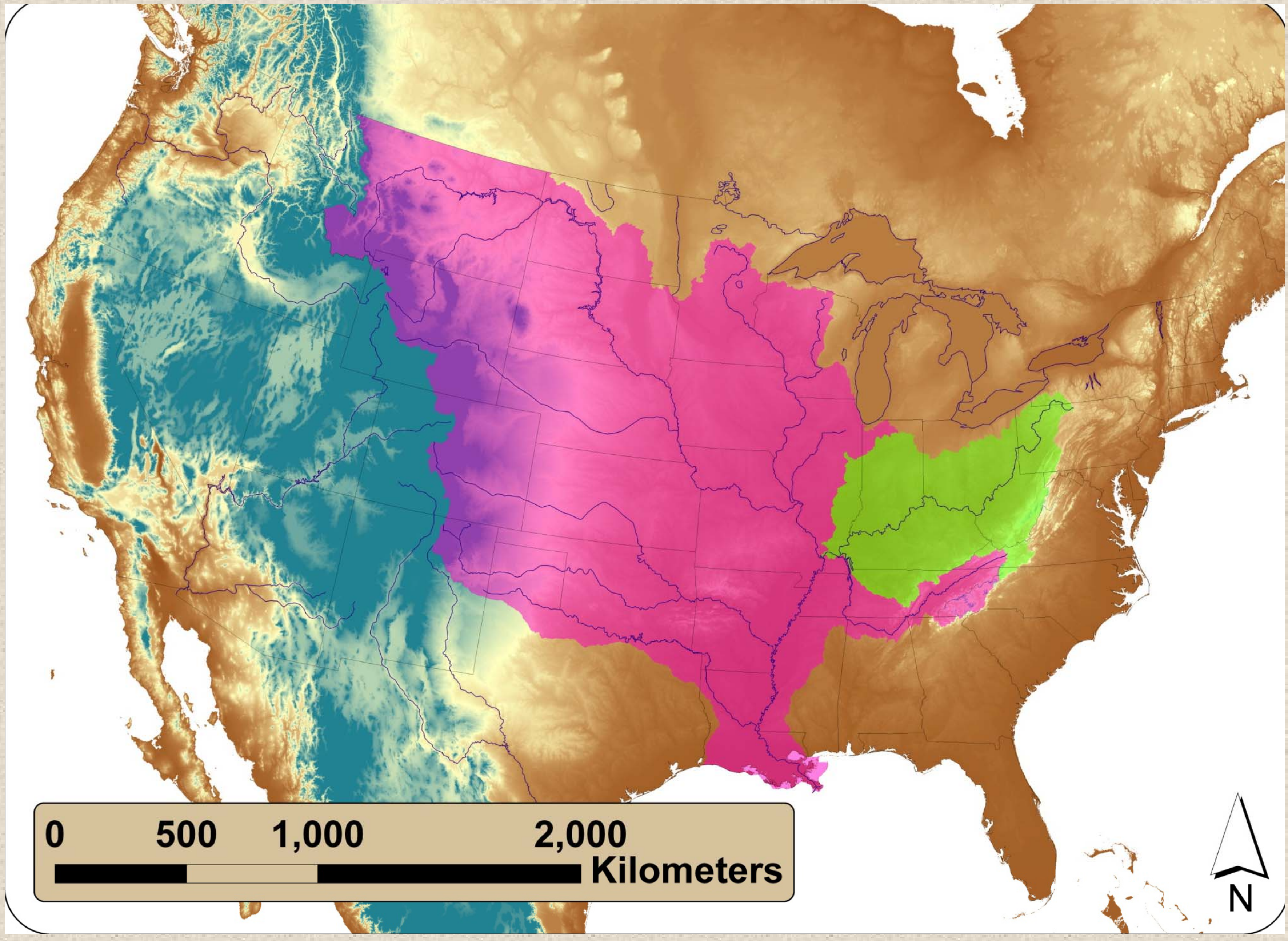
E1 these red numbers are still left over from Indiana... I can't find them for Ohio...
ESwitala, 8/22/2008

Watersheds

Watersheds are defined by natural hydrology, they represent the most logical basis for managing water resources (USEPA)



Mississippi River Watershed



Mississippi and Ohio River Watersheds

Hudson Bay
Albany
River
Albany River Basin
Ogoki River
Diversion Dam
Ogoki Project
Control Dam
Lake Nipigon
Kenogami River
Diversion Dam
Long Lake
Nipigon River
Long Lake Project Control Dam
Aguasabon River
Thunder Bay
Ontario
Minnesota
Lake Superior
Duluth
Keweenaw Peninsula
Canada
United States
Mississippi River Basin
Québec
Sault Ste. Marie
Lake Superior Control Structure
St. Marys River
Sault Ste. Marie
Ottawa River
Straits Of Mackinac
Green Bay
Lake Huron
Georgian Bay
Montreal
Ottawa
Cornwall
Massena
St. Lawrence River Control structure
Green Bay
Wisconsin
Lake Michigan
Michigan
St. Lawrence River
Kingston
Cape Vincent
Bay City
Milwaukee
Toronto
Lake Ontario
New York
Oswego
Niagara Falls
Rochester
St. Clair River
Welland Canal
Niagara River
Lake St. Clair
Buffalo
Detroit
Chicago
Detroit River
Lake Erie
Chicago Sanitary & Ship Canal
Toledo
Great
Illinois
Cleveland
Basin
Pennsylvania
Illinois Waterway
Indiana
Ohio
Lakes
Drainage

Western Lake Erie Basin Major Watersheds

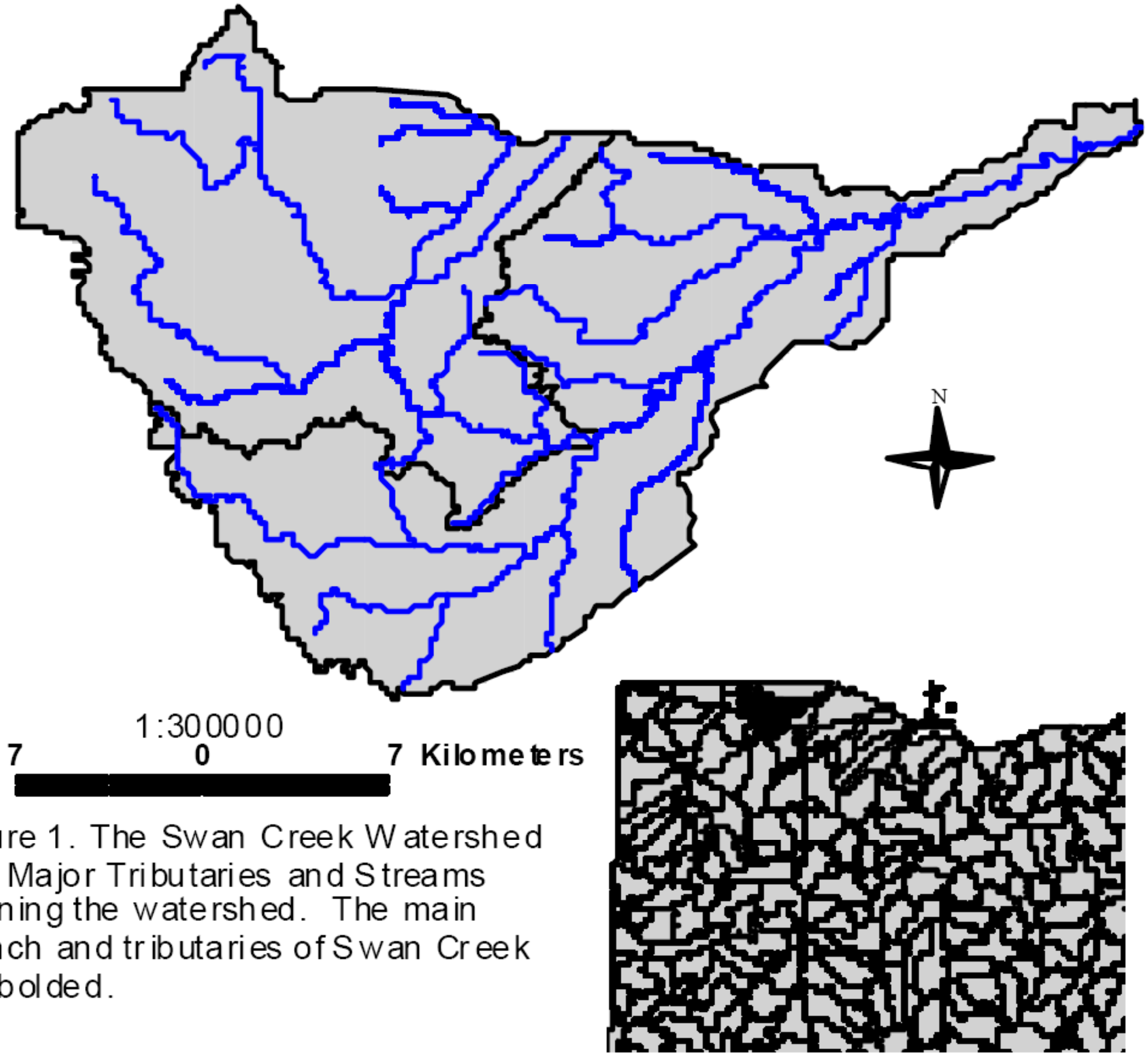
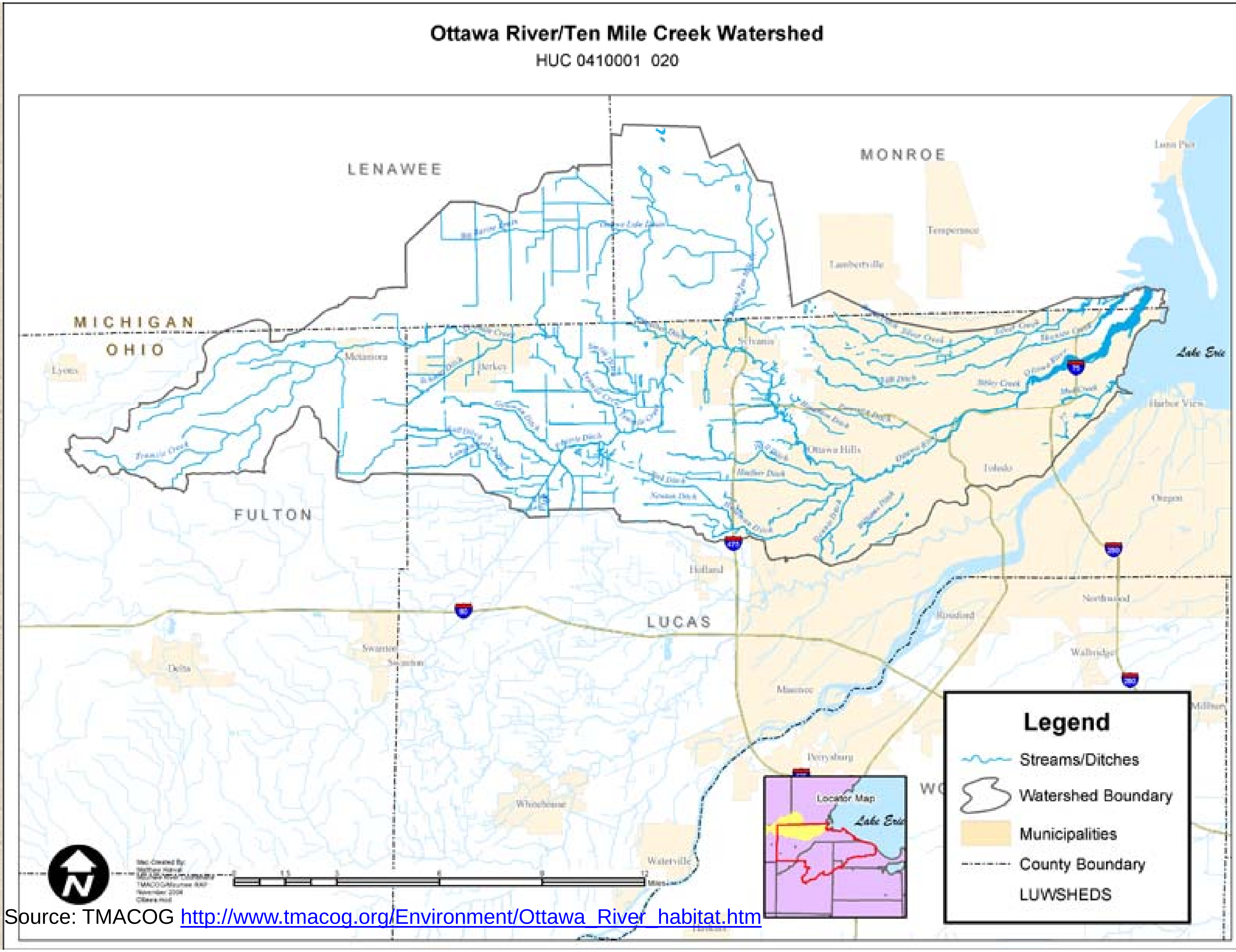


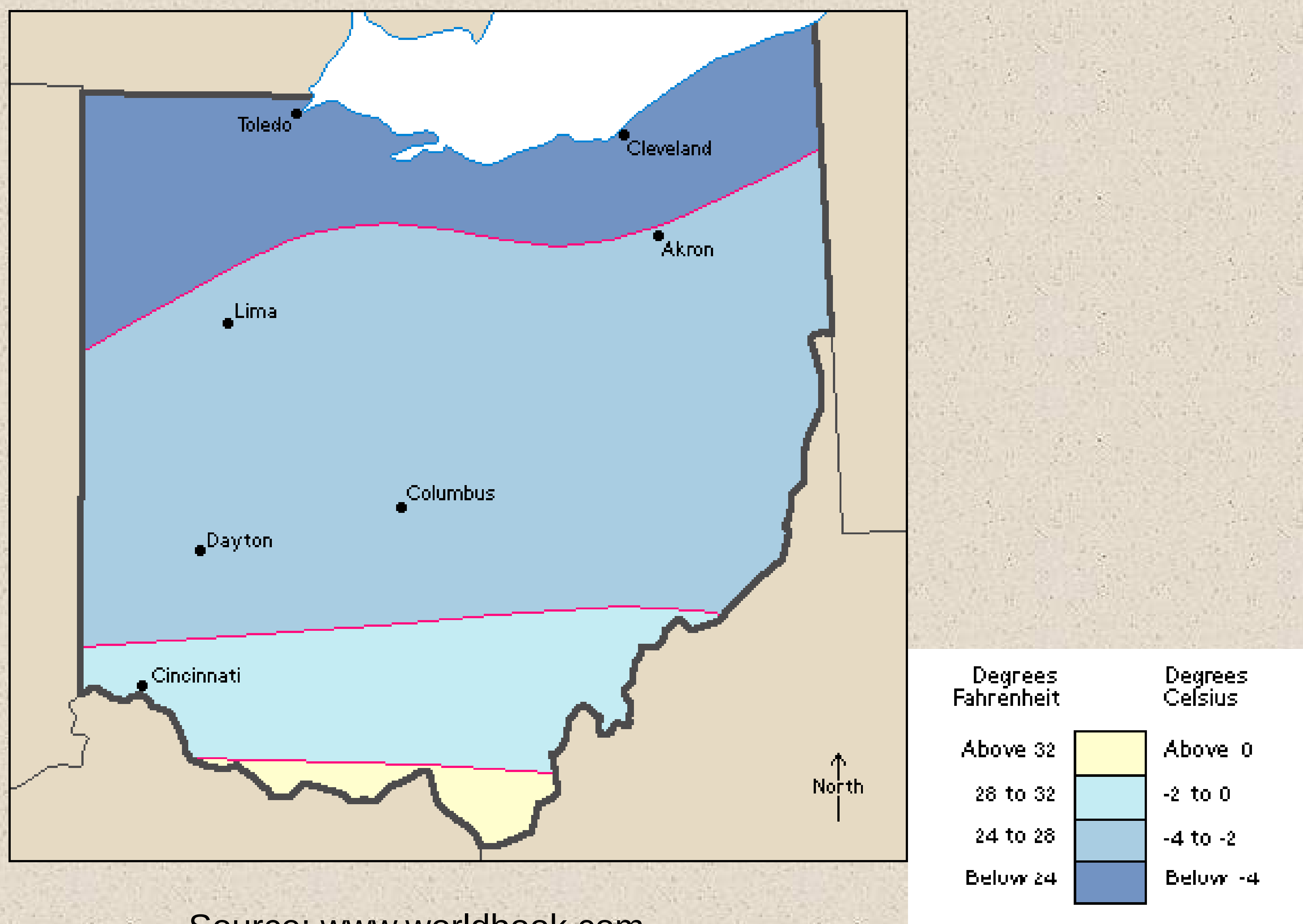
Figure 1. The Swan Creek Watershed and Major Tributaries and Streams draining the watershed. The main branch and tributaries of Swan Creek are bolded.

Swan Creek Watershed

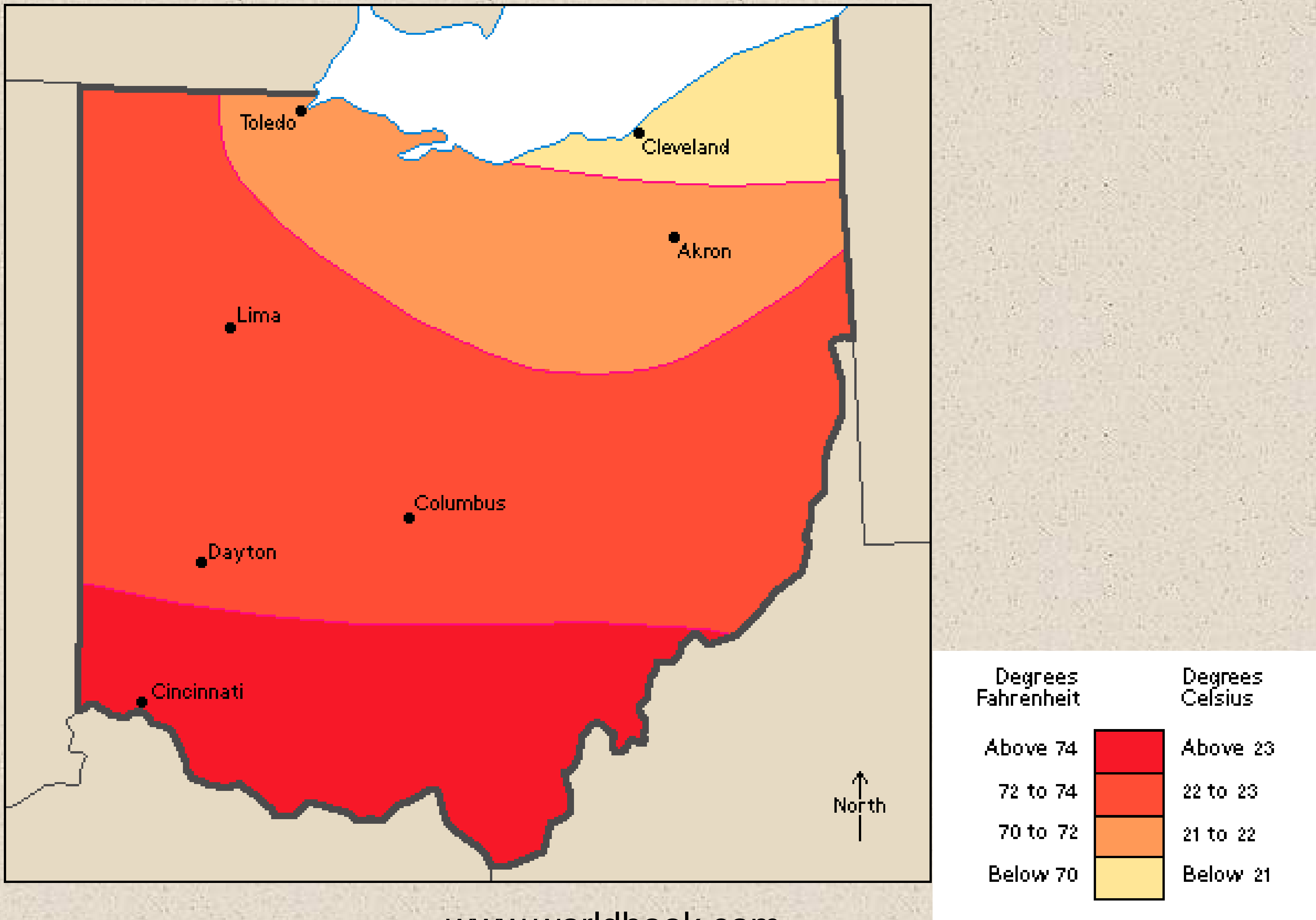
Source: Swan Creek Watershed Plan of Action 2001



Source: TMACOG http://www.tmacog.org/Environment/Ottawa_River_habitat.htm



Source: www.worldbook.com



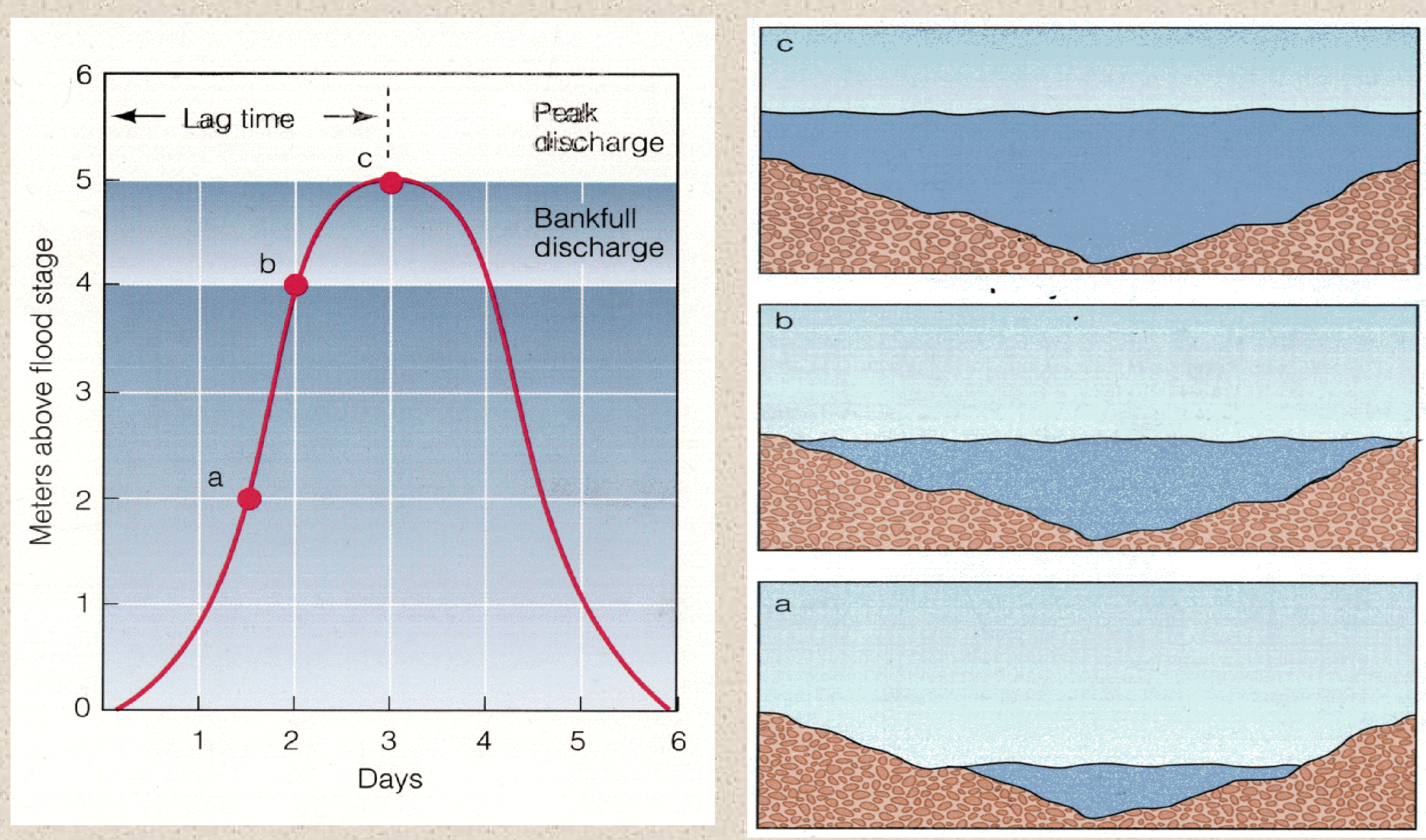
www.worldbook.com

Rivers

Basic terminology:

- stage -- refers to the height of a river above a locally defined reference surface
- bankfull (flood) stage --
  - when discharge increases the channel may fill completely
  - any further increase in discharge results in water overflowing the banks

- Stream discharge is typically displayed on a hydrograph - a graph in which stream discharge is plotted against time



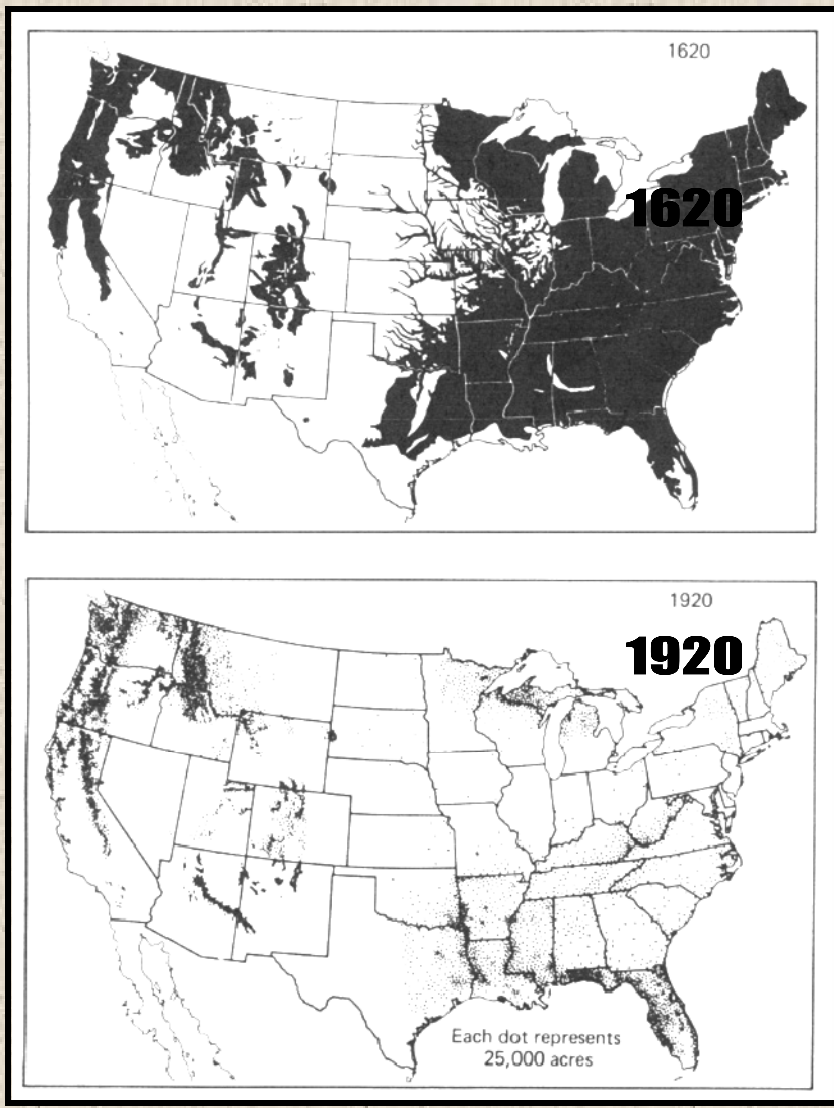
Lag time
Peak discharge
Bankfull discharge
c
b
a
Meters above flood stage
0
1
2
3
4
5
6
Days
1
2
3
4
5
6
c
b
a

Ohio's Physical Setting

Human Modification of the Hydrologic Cycle

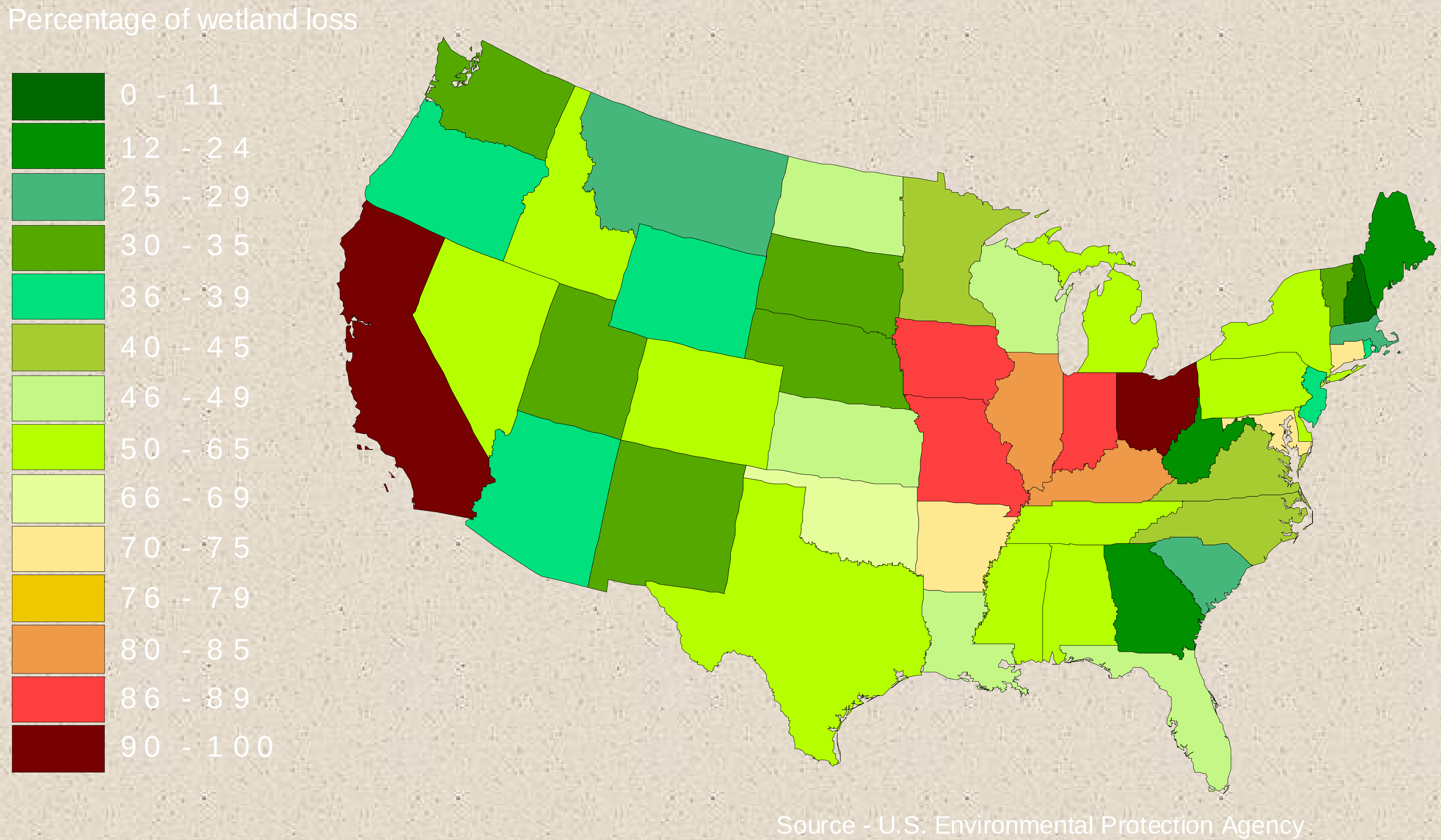
- Human modification of the landscape has altered the natural hydrologic cycle in Ohio
  - Deforestation as an initial impact (sediment loading, runoff, stream adjustment, climate change)
  - Agricultural drainage and piping (wetland loss, groundwater level modification)
  - Urbanization and residential development (continued wetland loss, increased runoff)

Deforestation



(Goudie, 1954)

Wetland Loss from Time of European Settlement

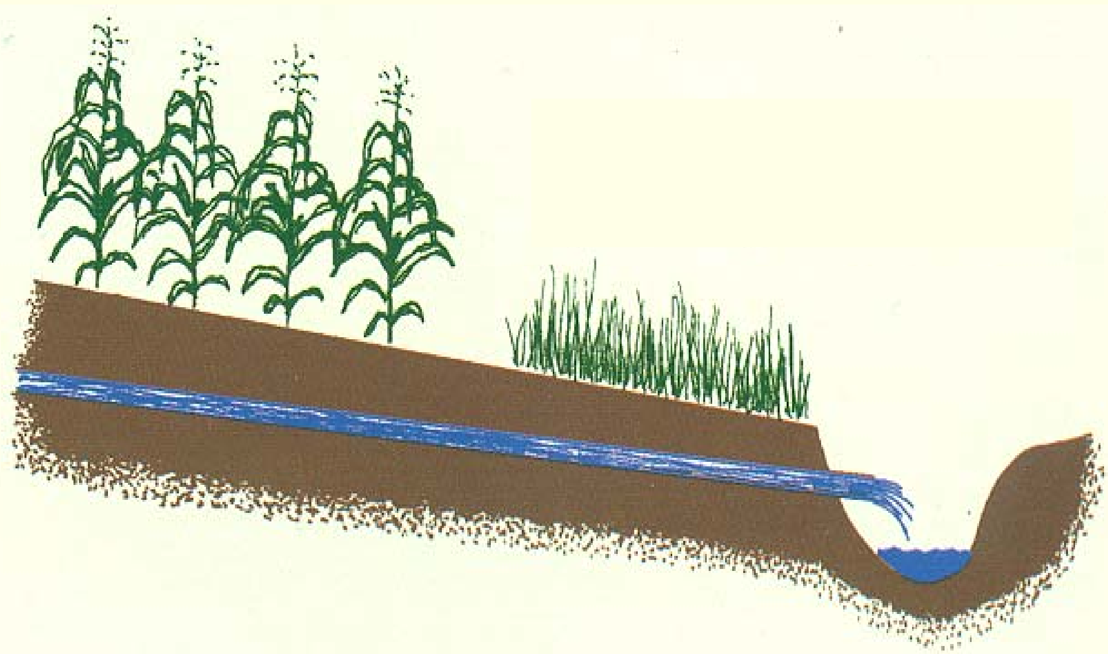


Loss of Ohio Wetlands

- Wetlands were converted to agricultural land uses during most of the 20th century
- Wetlands were drained by agricultural drainage tiles
- Wetland drainage and filling continues today largely due to urban sprawl
- Restoring wetlands in headwater areas can improve water quality and enhance wildlife habitat

Agricultural Drainage System

- 75-80% of the agricultural areas are tile drained
- In these areas, riparian buffer strips are short-circuited by tile drains



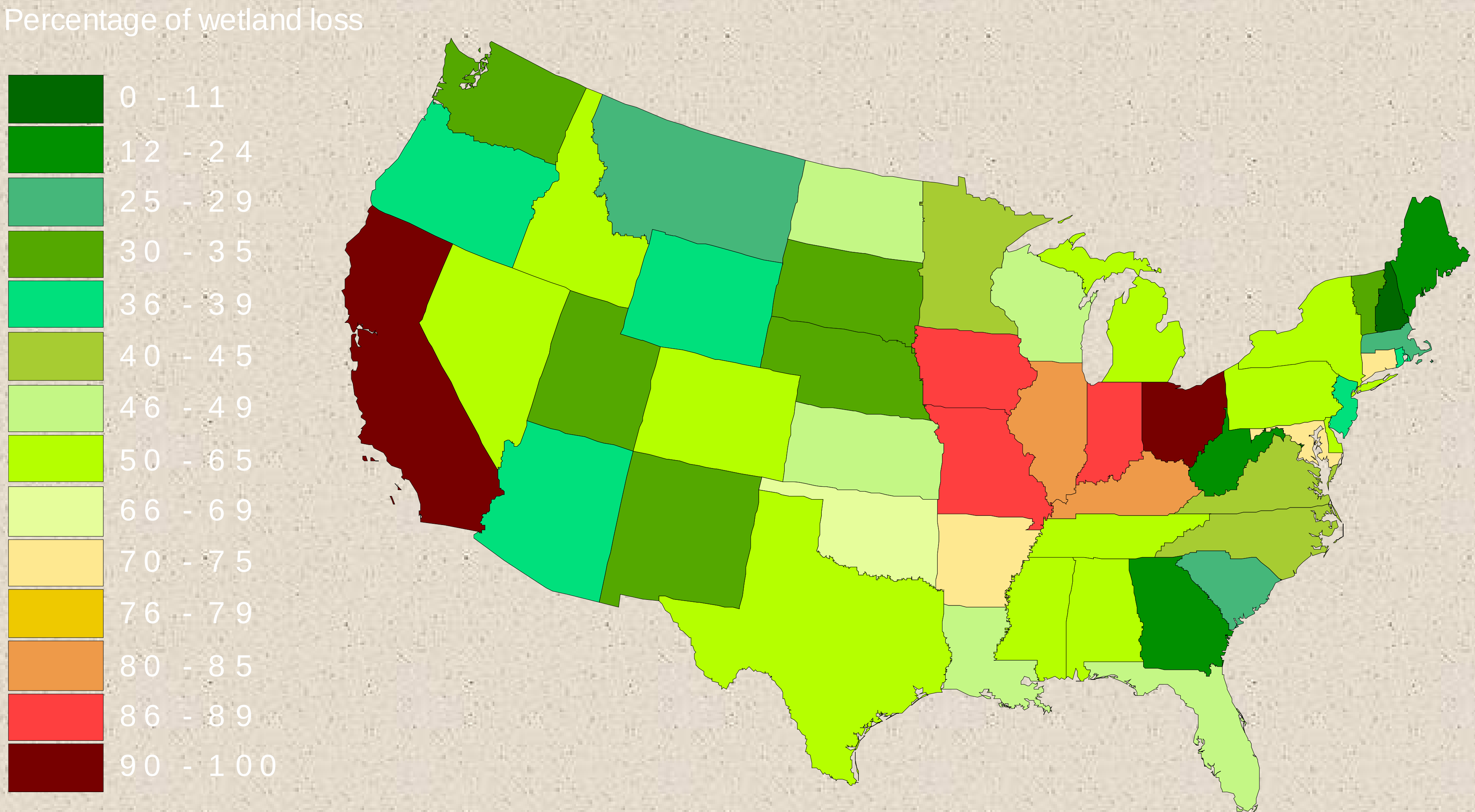
Miller, BES

Ohio Wetland Loss

HISTORIC WETLANDS	AREA IN ACRES	DATE DRAINED	SOURCE
Black Swamp	3,072,000	1859–1885	Ohio Dept. Nat. Res., 1988
Pickaway Plains	4,800	1821	Gordon, 1969
Scioto Marsh	16,000	1859, 1883	Gordon, 1969
Other marshes, Hardin County	9,000	1860's	Howe, 1900
Hog Creek Marsh	8,000	1868–1874	Gordon, 1969
Cranberry Marsh	1,000	Unknown	Gordon, 1969
Lake Erie Marshes	300,000	1936–1974	Bednarik, 1984
Dougan's Prairie	Unknown	1827	Middleton, 1917
TOTAL	**3,410,800**		

Figure 8. Location, estimated original acreage, and drainage date of Ohio's historic wetlands.

Wetland Loss from time of European Settlement



Source - U.S. Environmental Protection Agency

IUPUI
INDIANA UNIVERSITY–PURDUE UNIVERSITY INDIANAPOLIS

Ohio
Land Use/Cover

- Industrial
- Residential
- Cropland
- Forested

- Ohio is Dominated by Agricultural Land Cover
- Glaciated Landscapes (Till and Outwash) Dominant in North and Central Areas
- Southeastern Portion of State More Forested with Deeply Incised Valleys
- Geologic Setting and Land Use /Land Cover Determine Water Resources and Define Threats

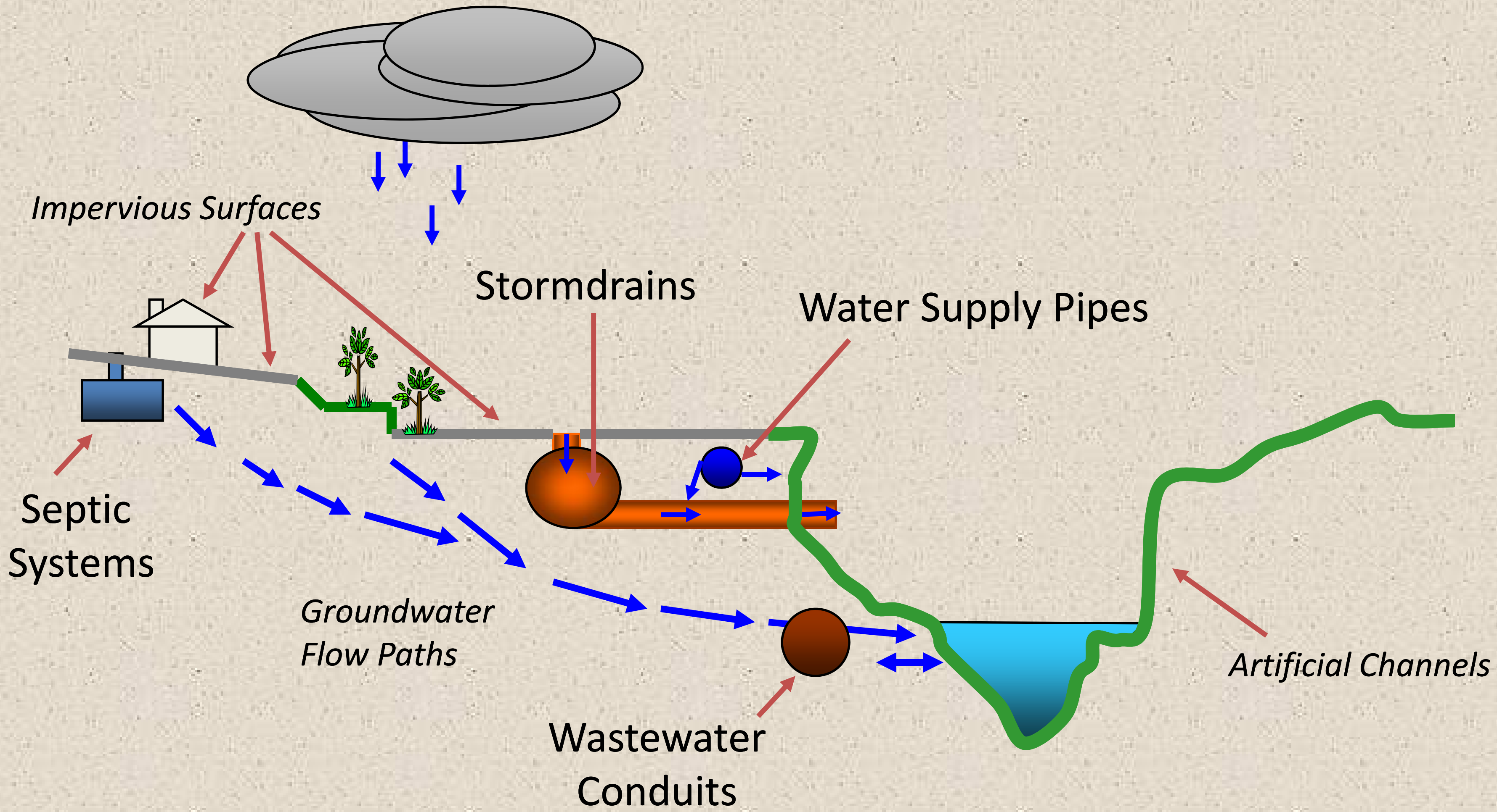
US EPA 1994

Impact of Urbanization on Stream Channels

- Stream systems are dynamic
- River channels continuously adjust to variations in discharge and load by changing their shape and orientation
- Size and shape of a channel’s cross-section reflect the river conditions prevailing at that point

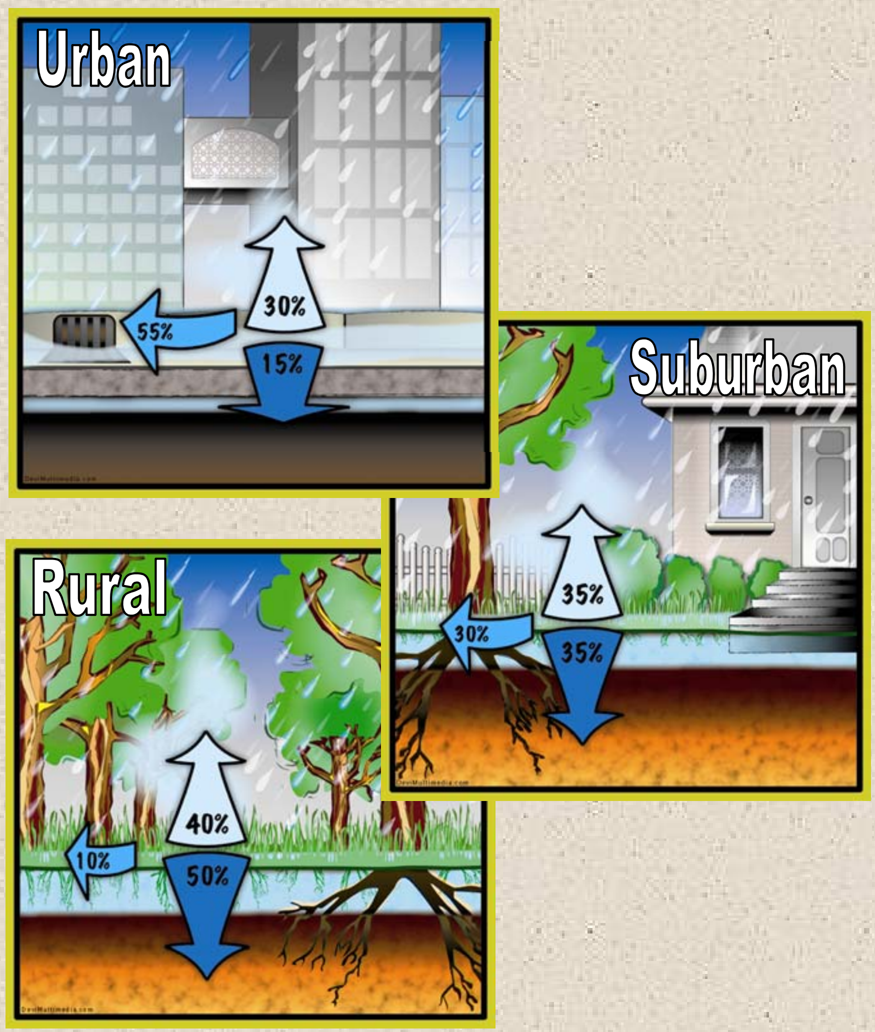
The Urban Hydrologic System

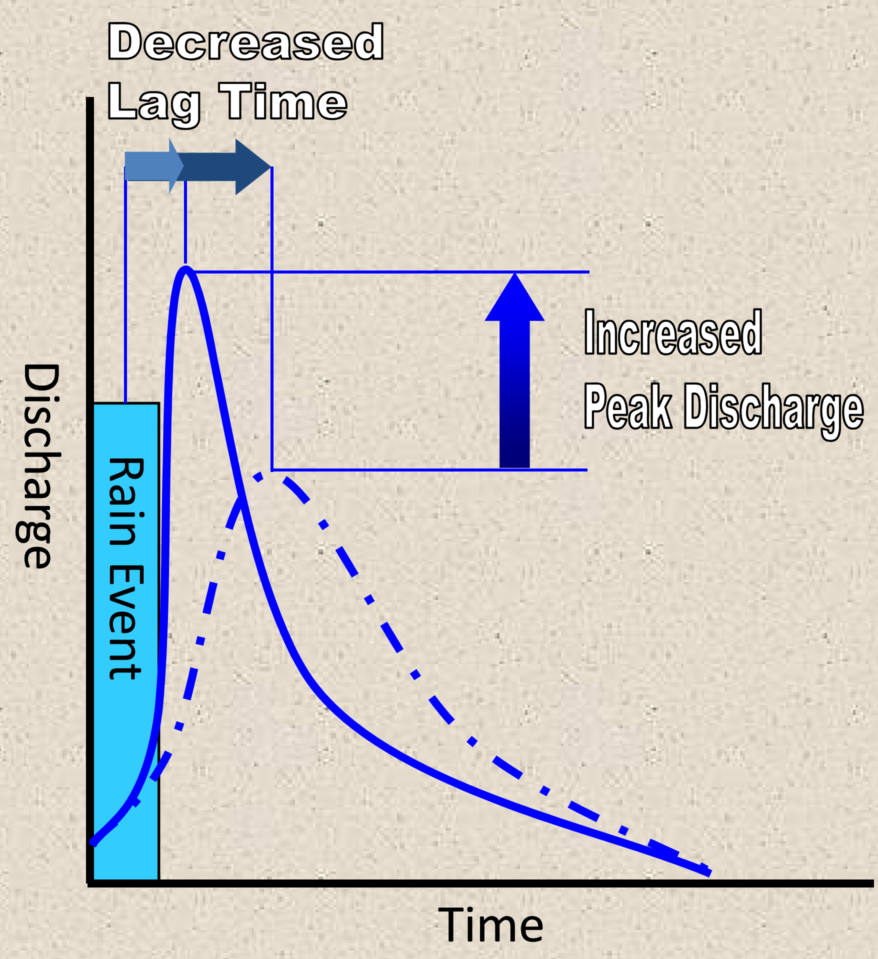
infrastructure driven pathways



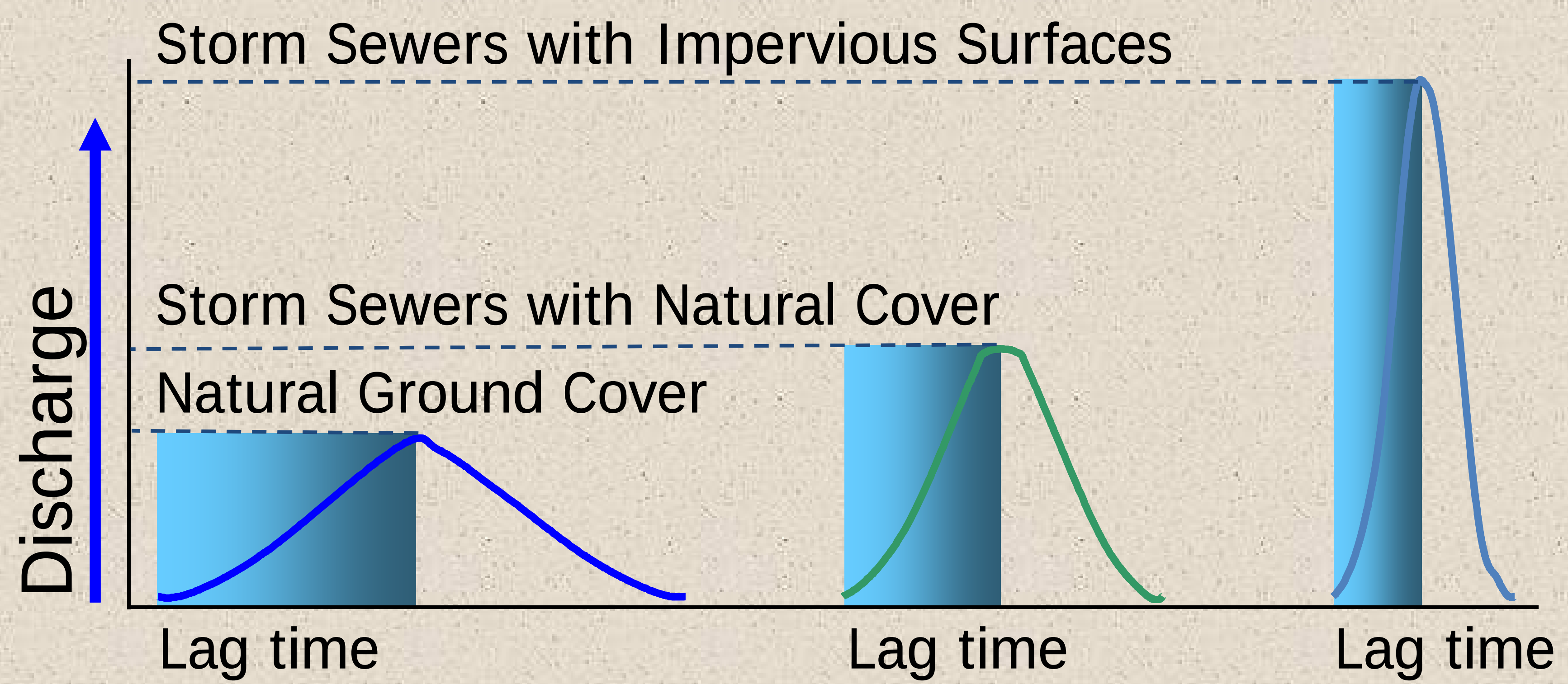
Miller, BES

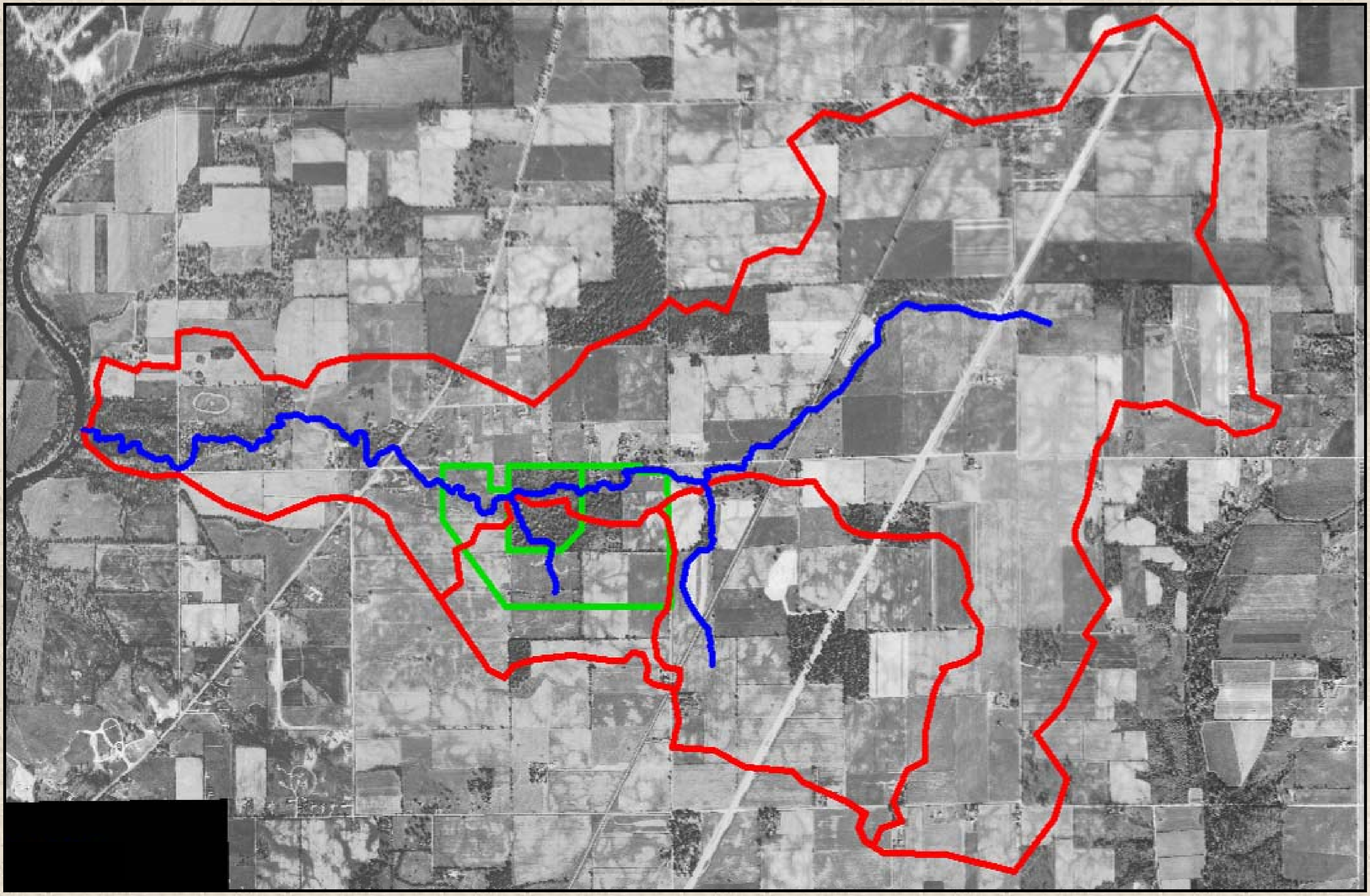
Change in Hydrology after Urbanization





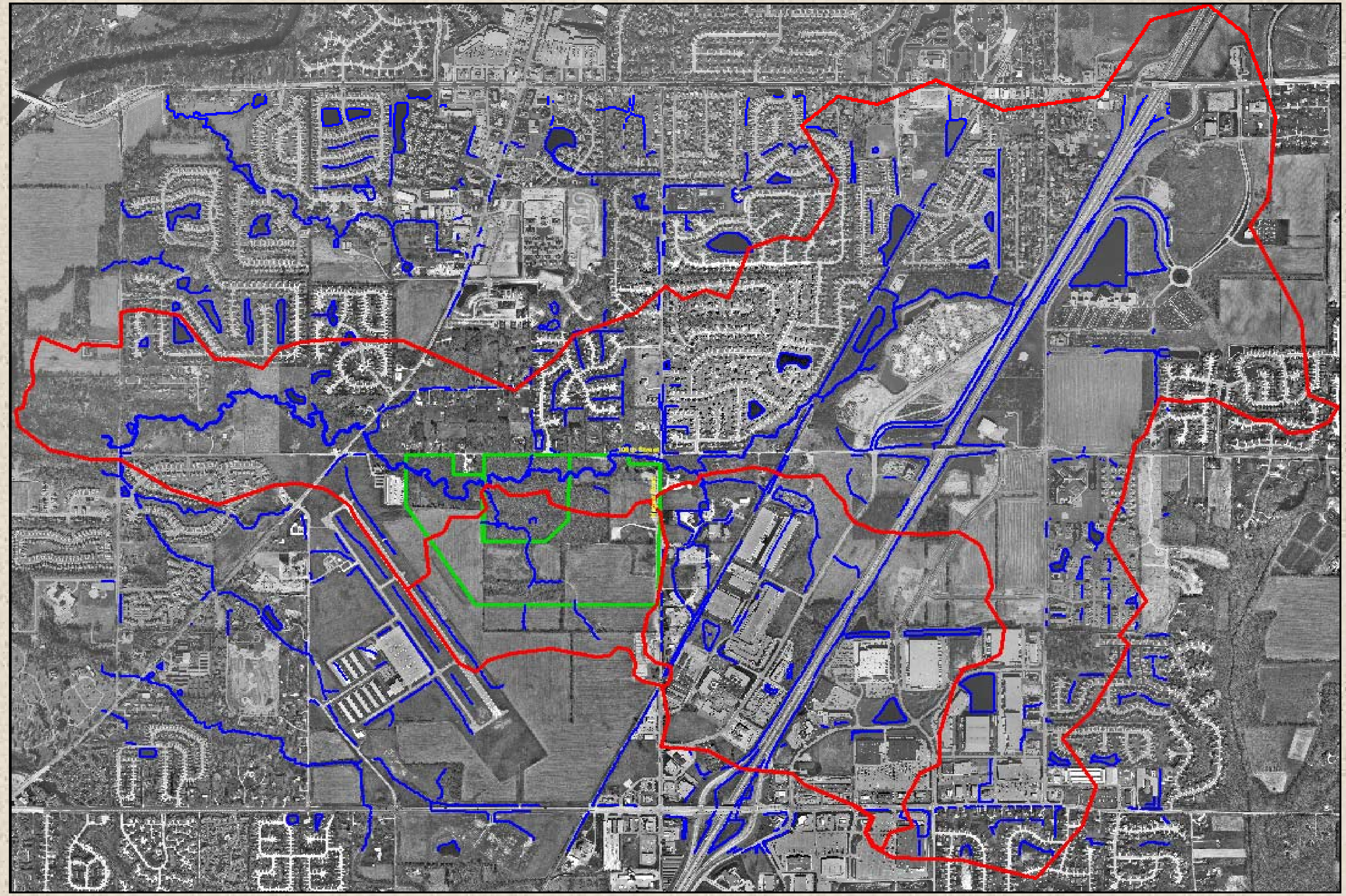
Idealized Hydrographs





NRCS, 1956

Historic Land Use, Cheeney Creek Watershed 1956



Hamilton County GIS, March 2000

Increase in First Order Streams and Drainageways

Headwaters of Cheeney Creek

Hare Creek, Ritchey Woods Nature Preserve

Impact of Agricultiural Modifications on Flow Regime

- Tile drains function much like urban storm water drains
- Effect is the same > peak flows, < base flow

Effect of Land Use Changes on Flow Regime

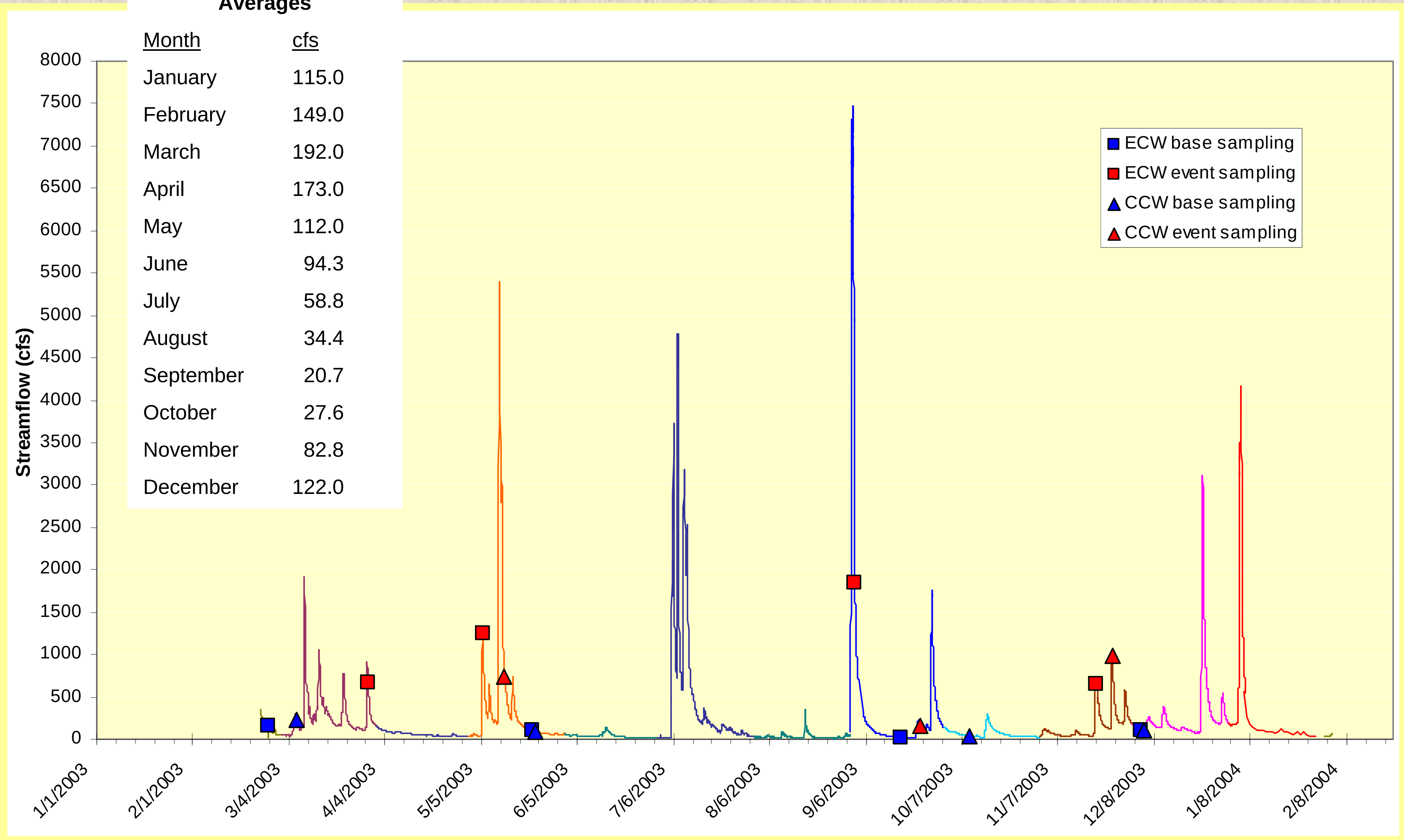
Fishback Creek Headwaters


School Branch, Eagle Creek
Watershed 8/2004

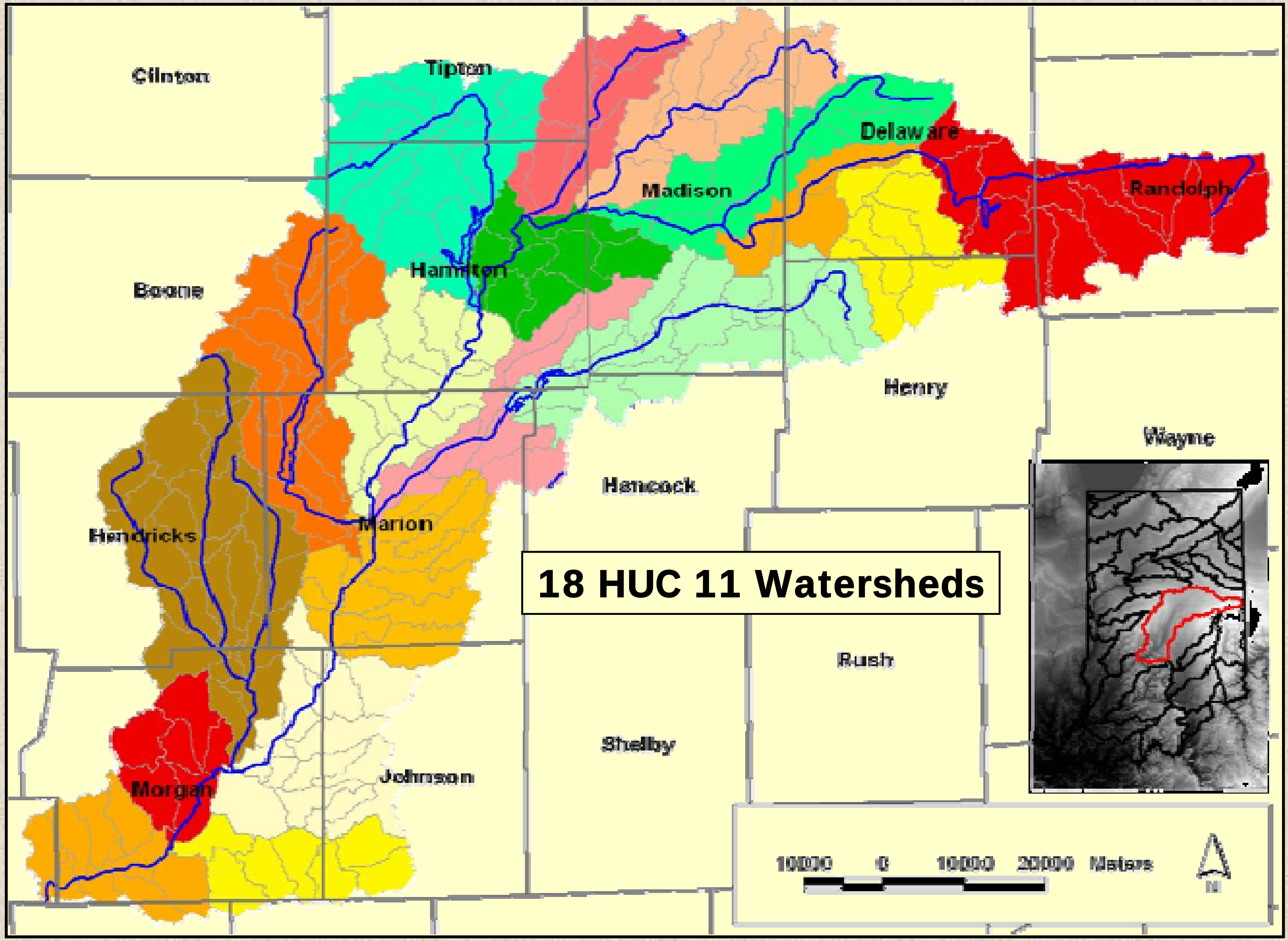
Hydrograph – Eagle Creek Watershed USGS Gauge 03353200

Monthly Streamflow Averages

Month	cfs
January	115.0
February	149.0
March	192.0
April	173.0
May	112.0
June	94.3
July	58.8
August	34.4
September	20.7
October	27.6
November	82.8
December	122.0

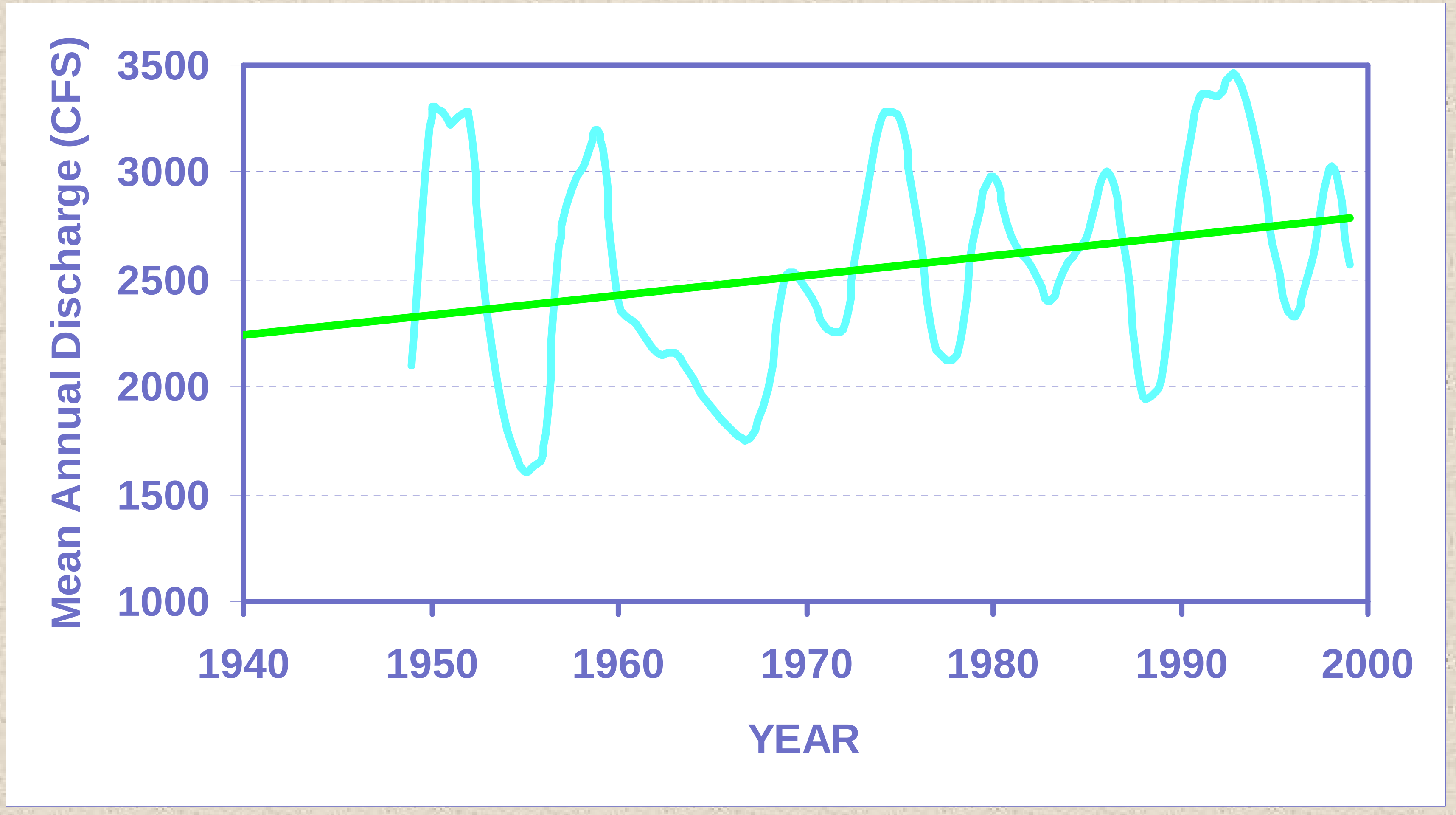


Cumulative Impacts



Upper White River Watershed

Mean Annual Discharge of the White River South of Indianapolis



Centerton Gaging Station

Data from USGS, 2000

River Flooding

January 2008, Tippecanoe River near Buffalo, IN

USGS

Flatrock River at St Paul, IN

USGS

June 2008 Floods, southern Indiana

USGS

Frequency of flooding:

- Three main approaches to flood prediction
  1. statistical techniques
  2. modeling and mapping to determine extent of flooding
  3. monitoring the progress of a storm

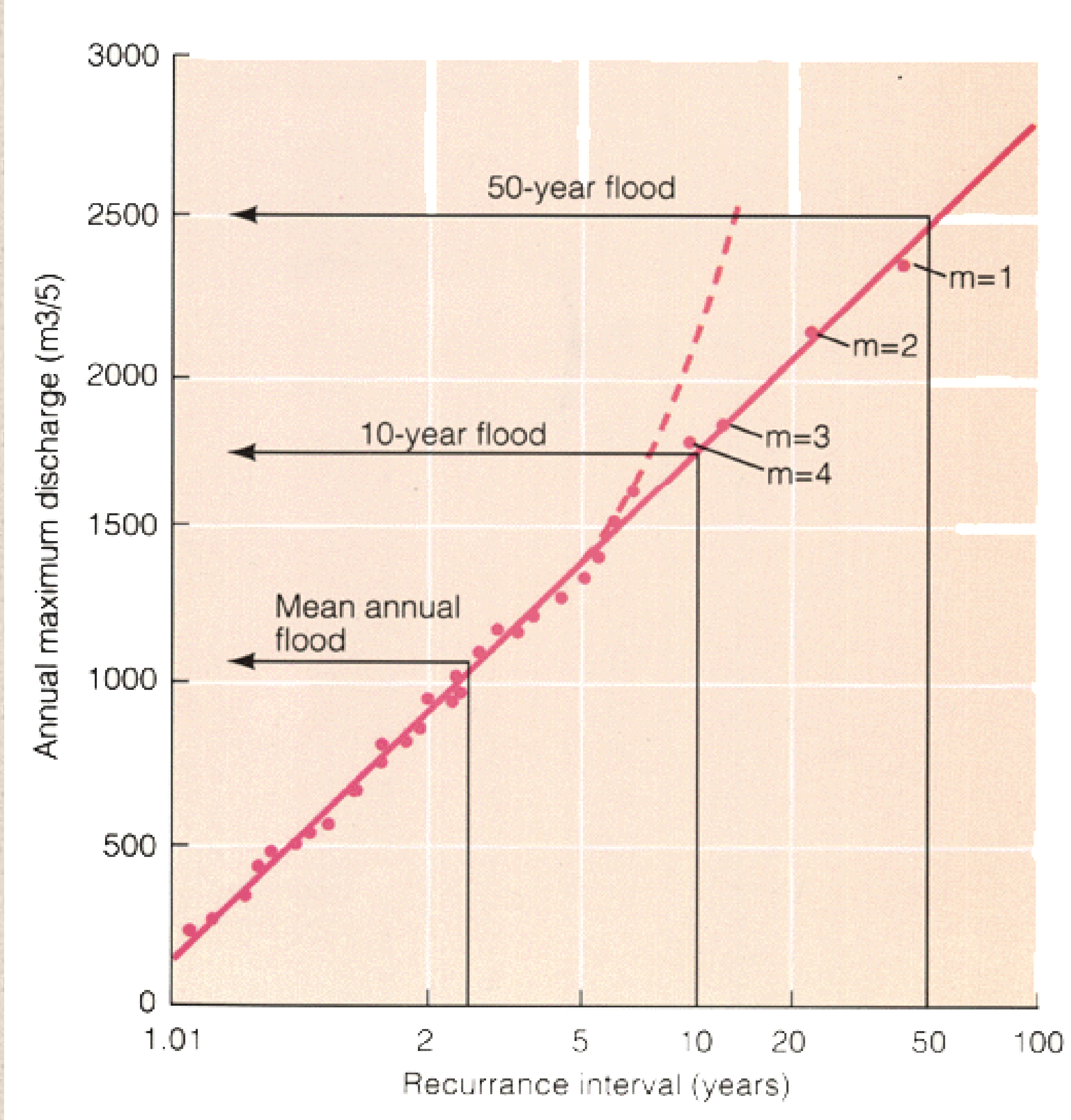
Recurrence interval:

- Predictions of the frequency of flooding are based on statistical analysis of records of hydrologic events at a station
  - one value will be the <u>annual maximum discharge</u> -- highest value measured at that station in that year
  - a record of annual maxima over a period of years is called an <u>annual maximum discharge series or array</u>

Flood Frequency Curve

- flood discharges are often plotted with respect to the calculated recurrence interval for a flood at that magnitude at a given locality
- this type of graph is called a flood frequency curve

- flood frequency curves can be used to predict the recurrence interval for events that are greater than any historically recorded events
- the longer the available data set -- the better the prediction



3000
2500
2000
1500
1000
500
0
Annual maximum discharge (m3/5)
50-year flood
10-year flood
Mean annual
flood
m=1
m=2
m=3
m=4
1.01
2
5
10
20
50
100
Recurrance interval (years)

Anticipated Changes of a warmer climate

Source: US Climate Change Science Program

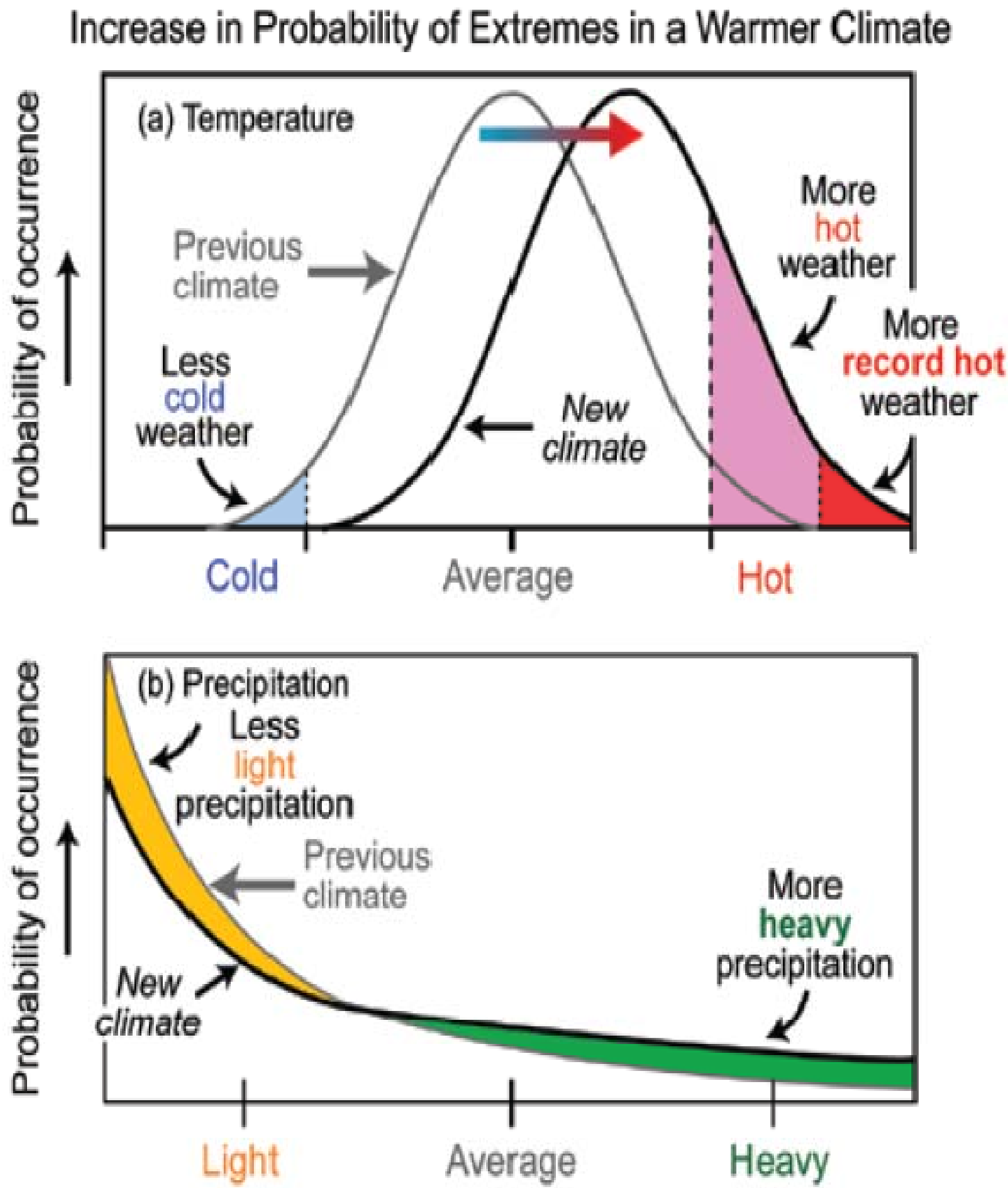
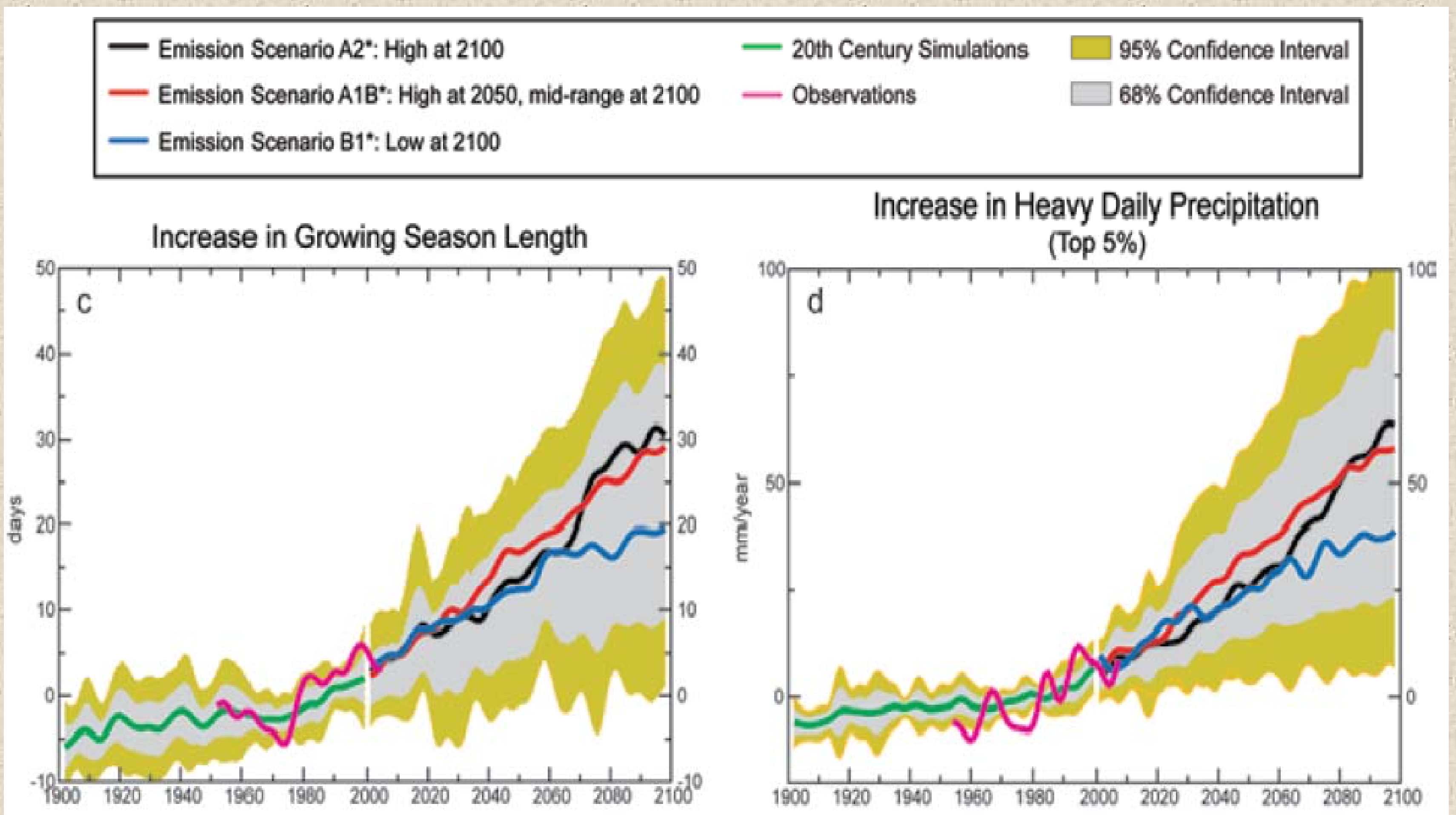


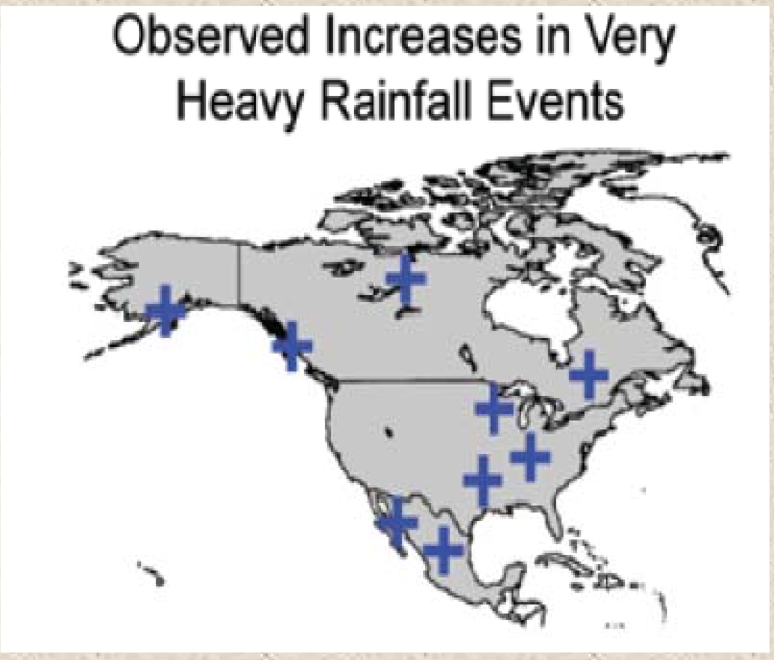
Figure 1.6 Simplified depiction of the changes in temperature and precipitation in a warming world.

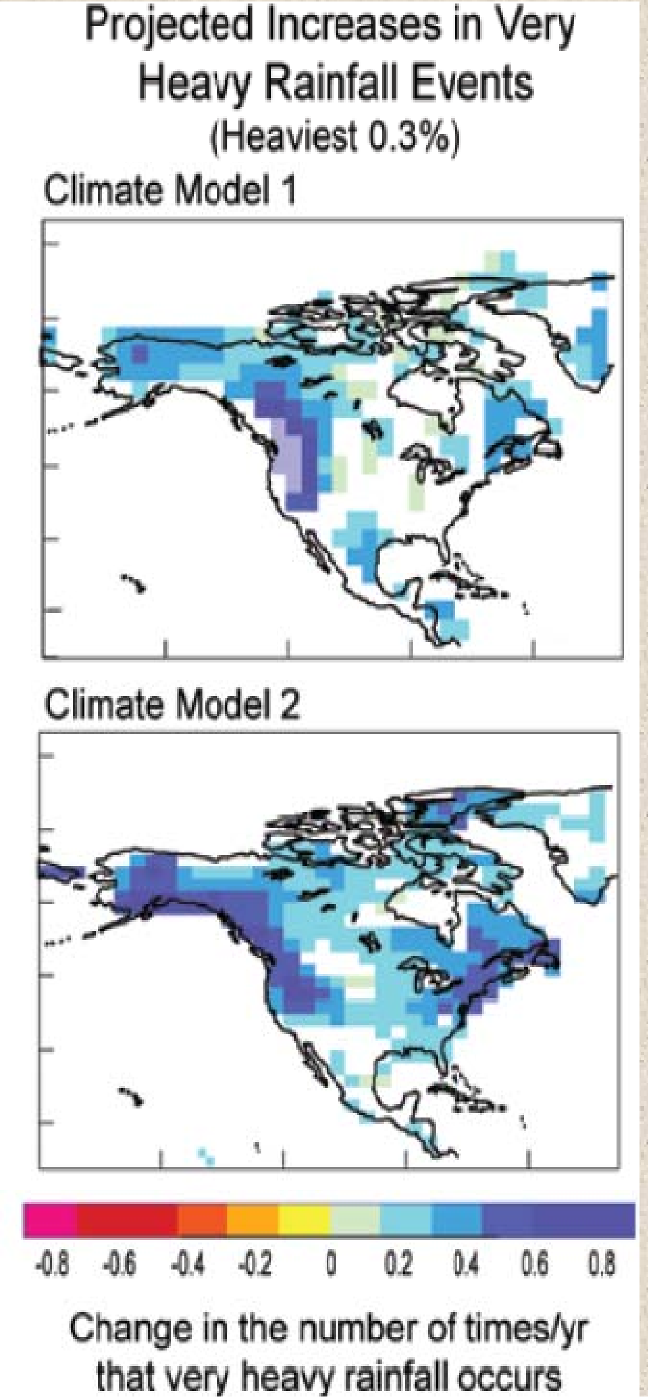
Climate Change Implications



Source: US Climate Change Science Program

Flood Frequency Increases?





Source: US Climate Change Science Program

Costs of weather-related disasters

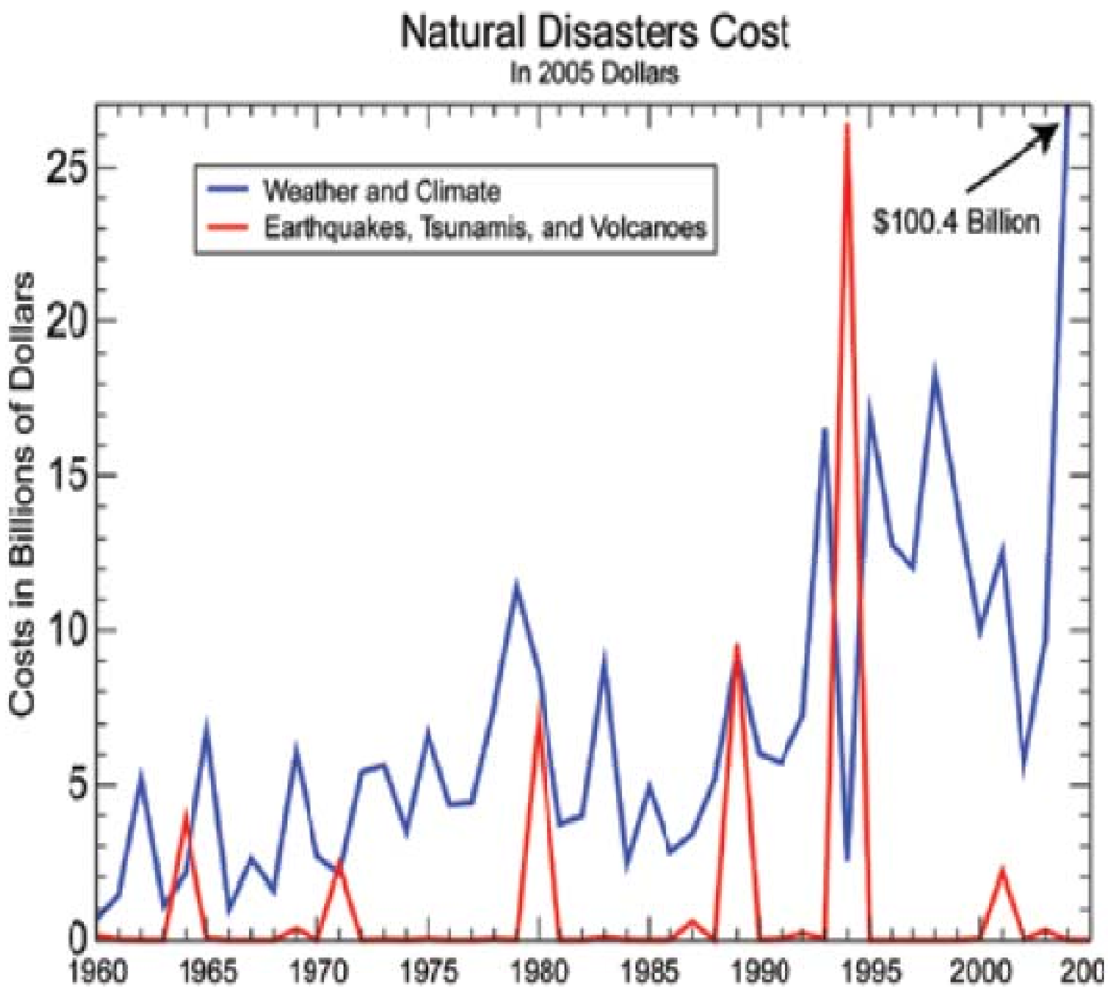


Figure 1.2 Costs from the SHELDUS database (Hazards and Vulnerability Research Institute, 2007) for weather and climate disasters and non-weather-related natural disasters in the U.S. The value for weather and climate damages in 2005 is off the graph at $100.4 billion. Weather and climate related damages have been increasing since 1960.

Source: US Climate Change Science Program

River Channel Patterns: Form and Process

- Channels classified as:
  - Straight
  - Meandering
  - Braided
- Boundaries are arbitrary and indistinct
  - For example, the distinction between straight and meandering is based on sinuosity (a ratio of stream length to valley length)

Channel Pattern is a function of:

1. **<u>Discharge</u>**
   - the volume of water that passes a given location within a given period of time. Usually expressed in cubic feet per second.
2. **<u>Load</u>**
   - The sediments and dissolved ions carried by the stream are the called the stream's load. Stream load is divided into three parts:
     1. Suspended load
     2. Bed load
     3. Dissolved load

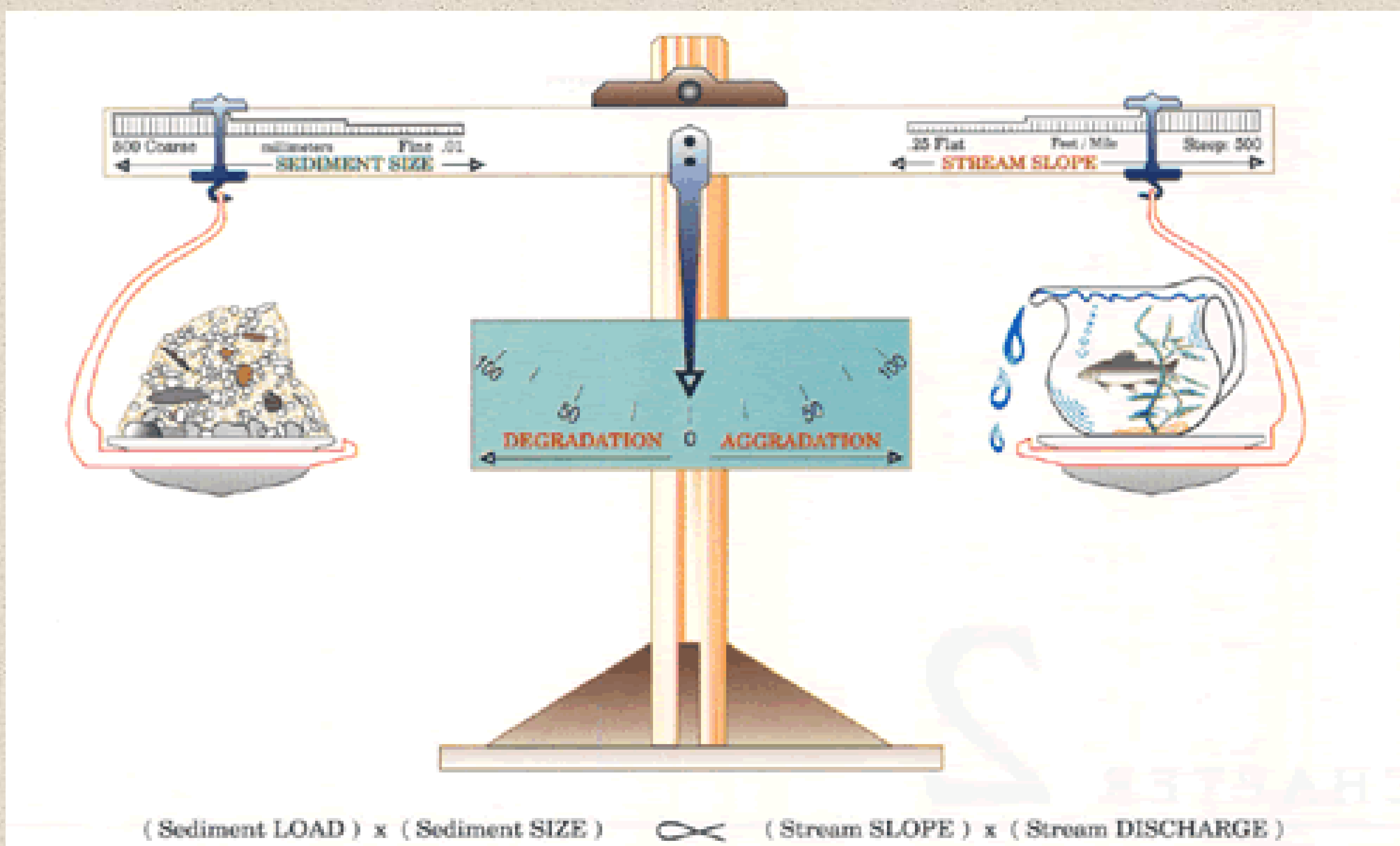
Stream Capacity

- The maximum load of sediment a stream can carry for a given discharge.
- Stream capacity increases with increasing flow velocity.
- Increased water velocity imparts a greater frictional drag on bed to erode it.
- Turbulent flow occurs under higher velocity thus increasing the water's ability to dislodge material from the bed or sides of the stream.

Stream Competence

- The largest size material the stream can move under a given discharge.

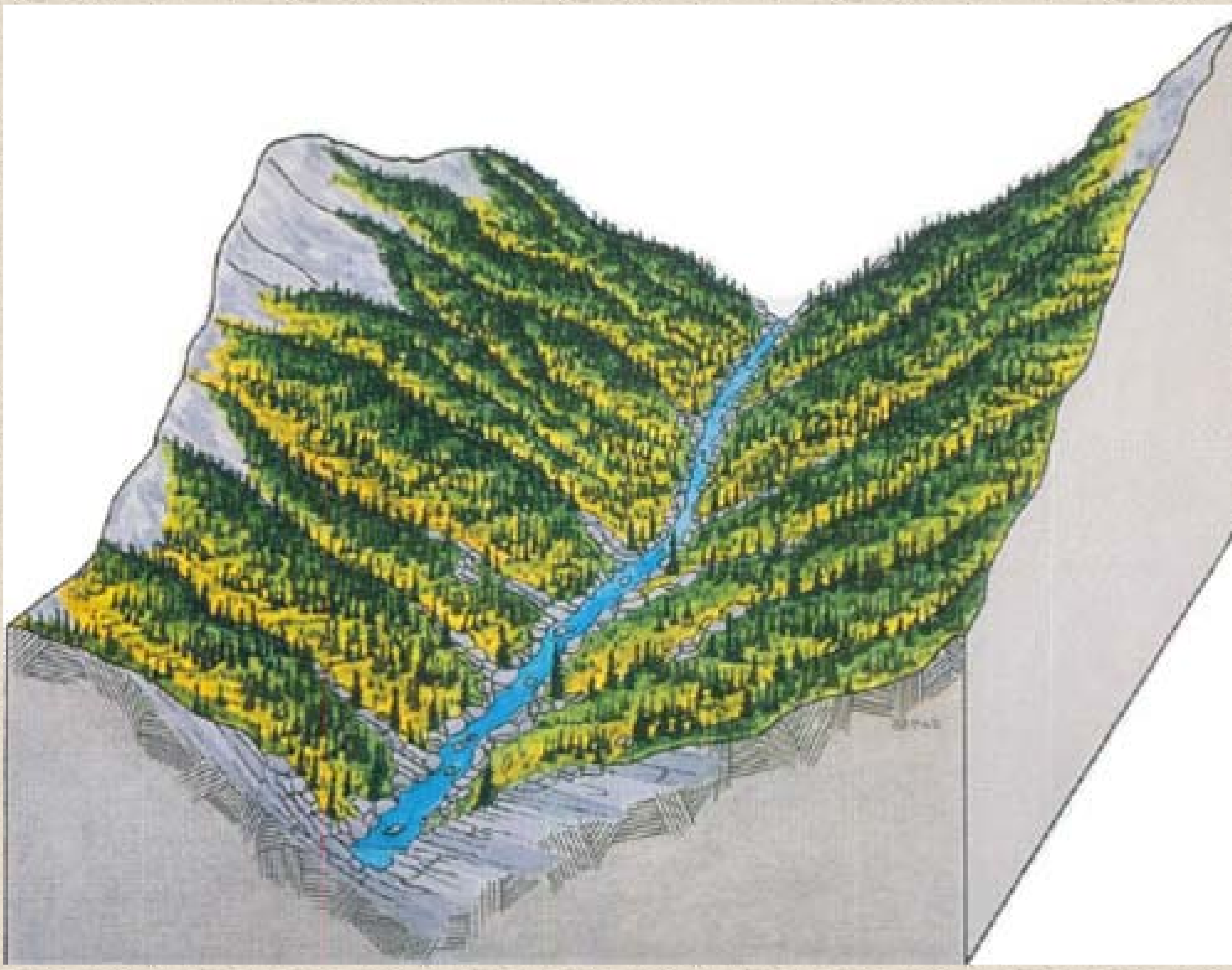
Lane's Channel Stability Model



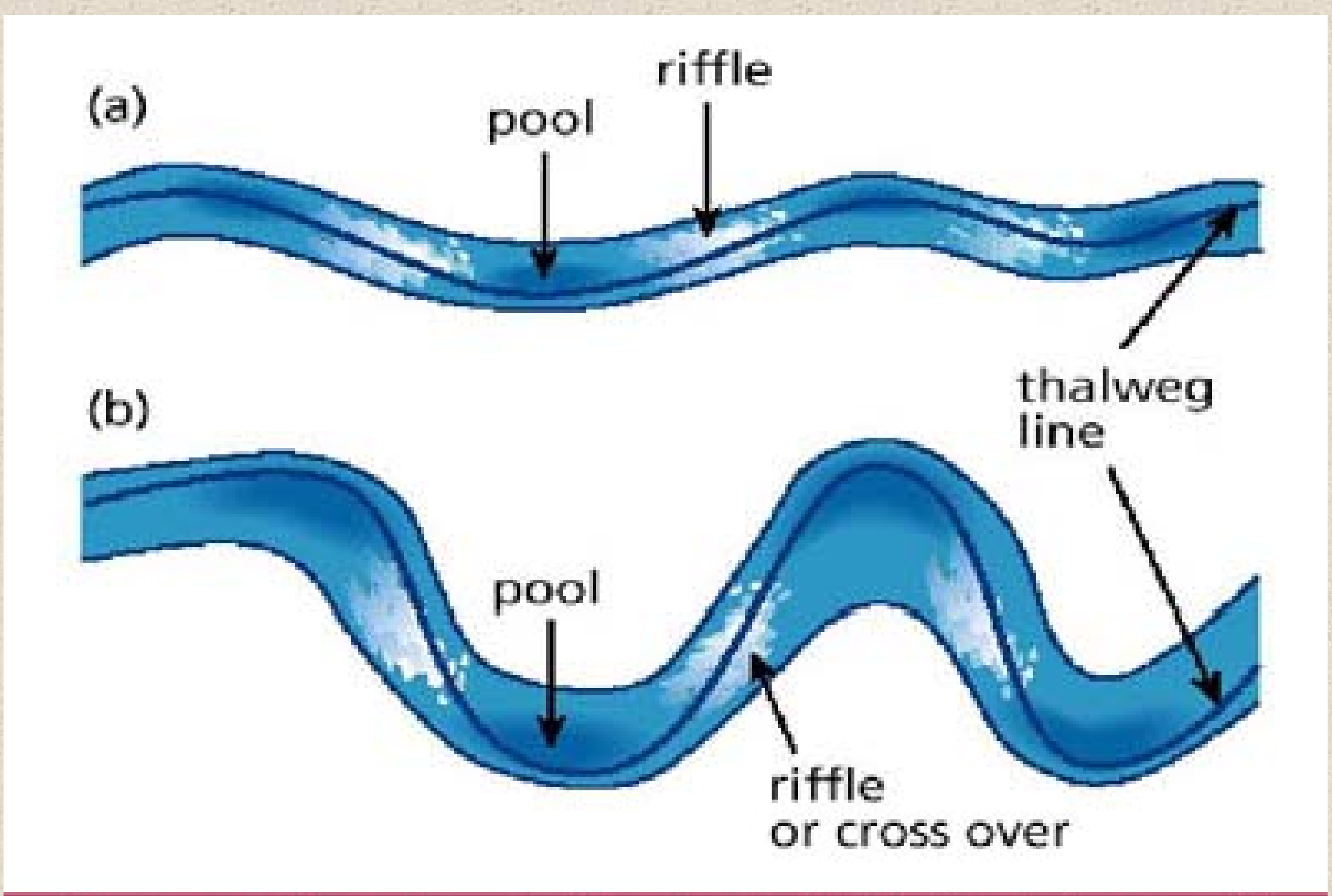
FISRWG, 1998;
Lane, 1955

Straight Channels

- Uncommon in natural systems, where found tend to be short reaches with steep slope, or bedrock controlled
- In “straight” reaches bed material frequently has features associated with meandering channels



Rosgen



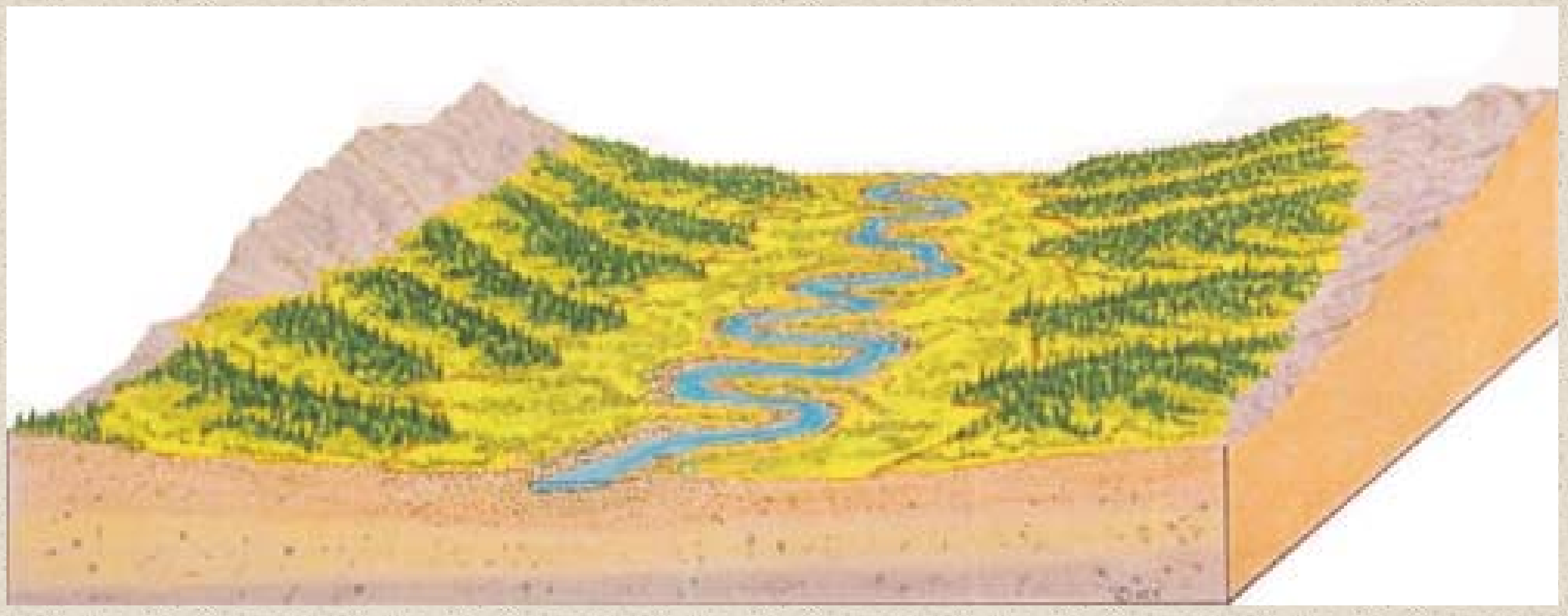
Sequence of pools and riffles in straight (a) and sinuous (b) stream channels.

USEPA

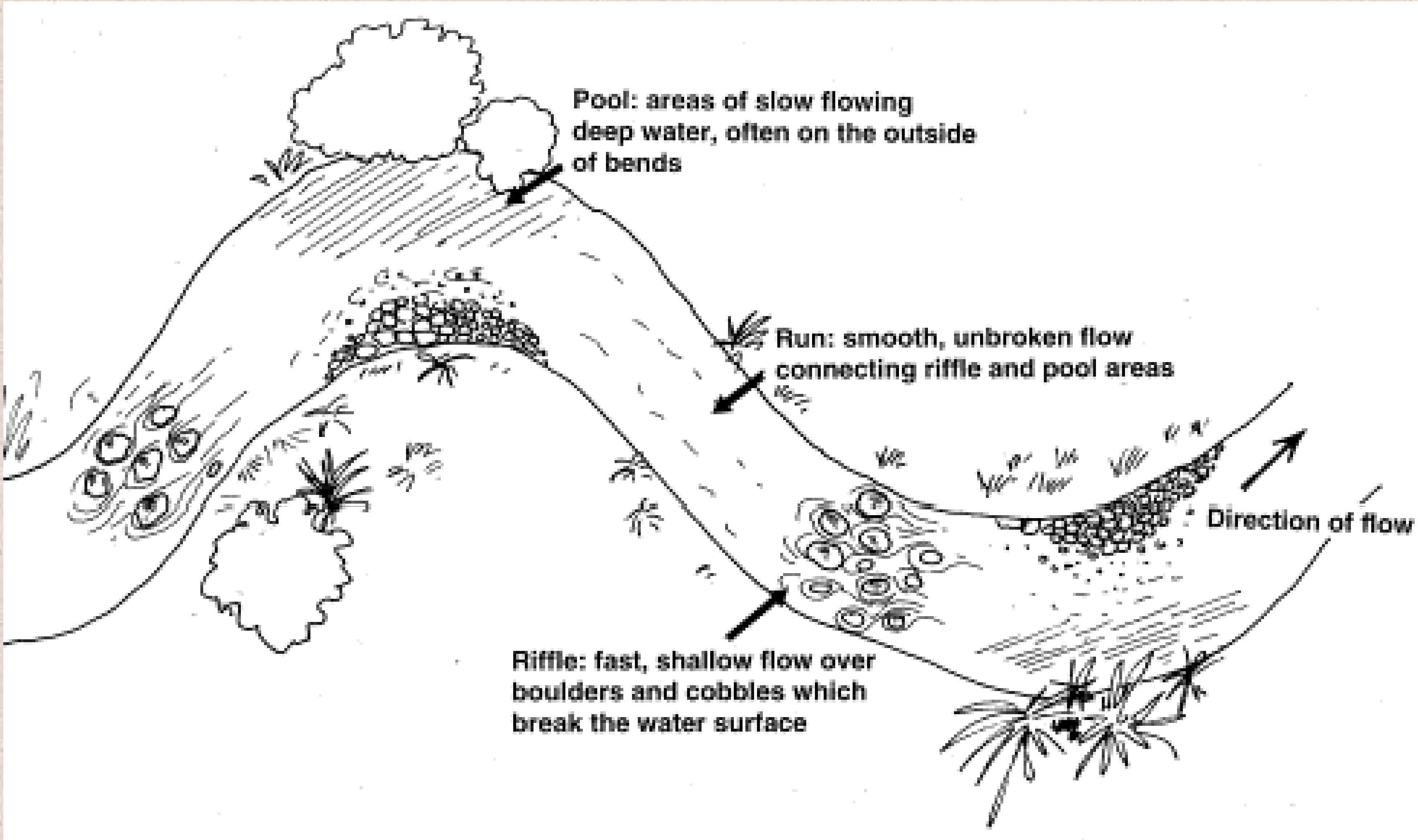
Fishback
headwaters

Meandering Channels

- Most common river form
- Meandering rivers shift their positions across the valley bottom by eroding on the outer banks of meander bends and simultaneously depositing point bars on the inside of meander bends
- Pool and riffle sequences



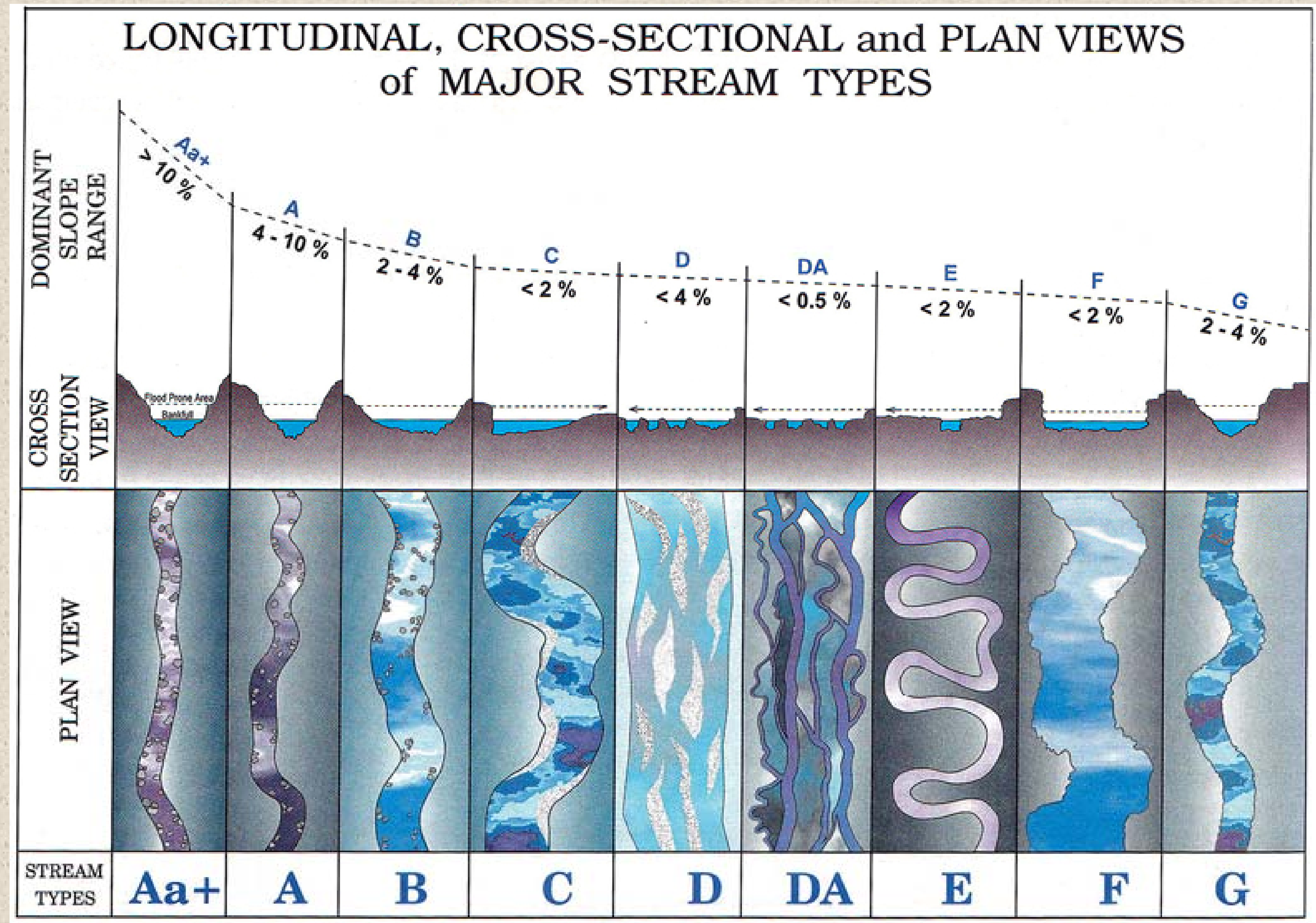
Rosgen


Pool: areas of slow flowing deep water, often on the outside of bends
Run: smooth, unbroken flow connecting riffle and pool areas
Direction of flow
Riffle: fast, shallow flow over boulders and cobbles which break the water surface

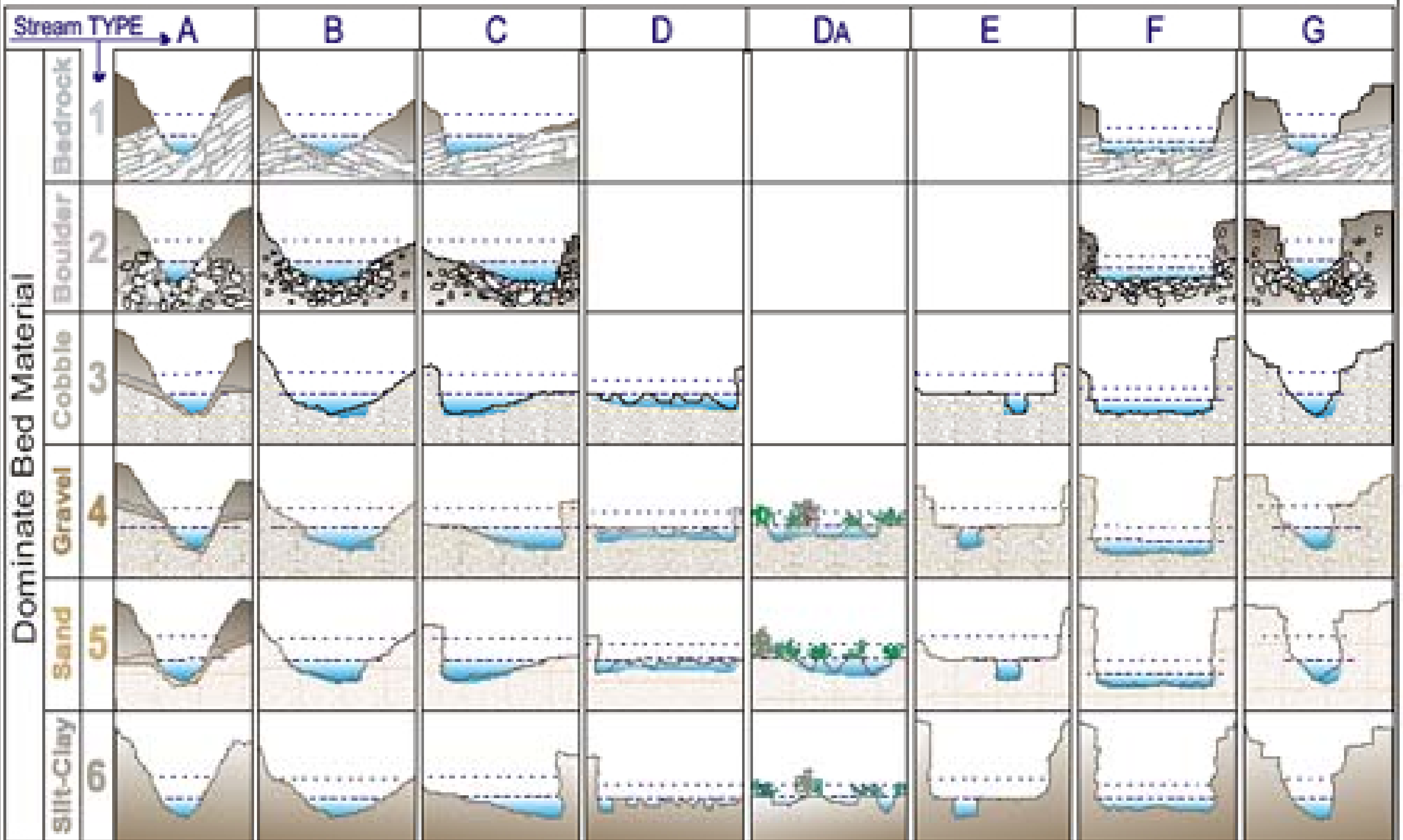
Braided

- Division of a single trunk channel into a network of channels
- Development of braid bars
- Differences between divided reaches and single channels include:
  - Braided zones usually steeper and shallower
  - Total width usually greater
  - Changes in channel position can occur quickly

Rosgen


LONGITUDINAL, CROSS-SECTIONAL and PLAN VIEWS of MAJOR STREAM TYPES
DOMINANT SLOPE RANGE
Aa+ > 10 %
A 4 - 10 %
B 2 - 4 %
C < 2 %
D < 4 %
DA < 0.5 %
E < 2 %
F < 2 %
G 2 - 4 %
CROSS SECTION VIEW
Flood Prone Area
Bankfull
PLAN VIEW
STREAM TYPES
Aa+
A
B
C
D
DA
E
F
G

Rosgen, 1996



Stream TYPE	A	B	C	D	DA	E	F	G
Entrchmnt.	< 1.4	1.4 - 2.2	> 2.2	n/a	> 4.0	> 2.2	< 1.4	< 1.4
W/D Ratio	< 12	> 12	> 12	> 40	< 40	< 12	> 12	< 12
Sinuosity	1 - 1.2	> 1.2	> 1.2	n/a	variable	> 1.5	> 1.2	> 1.2
H_20 Slope	.04-.099	.02-.039	< .02	< .04	<.005	< .02	< .02	.02-.039

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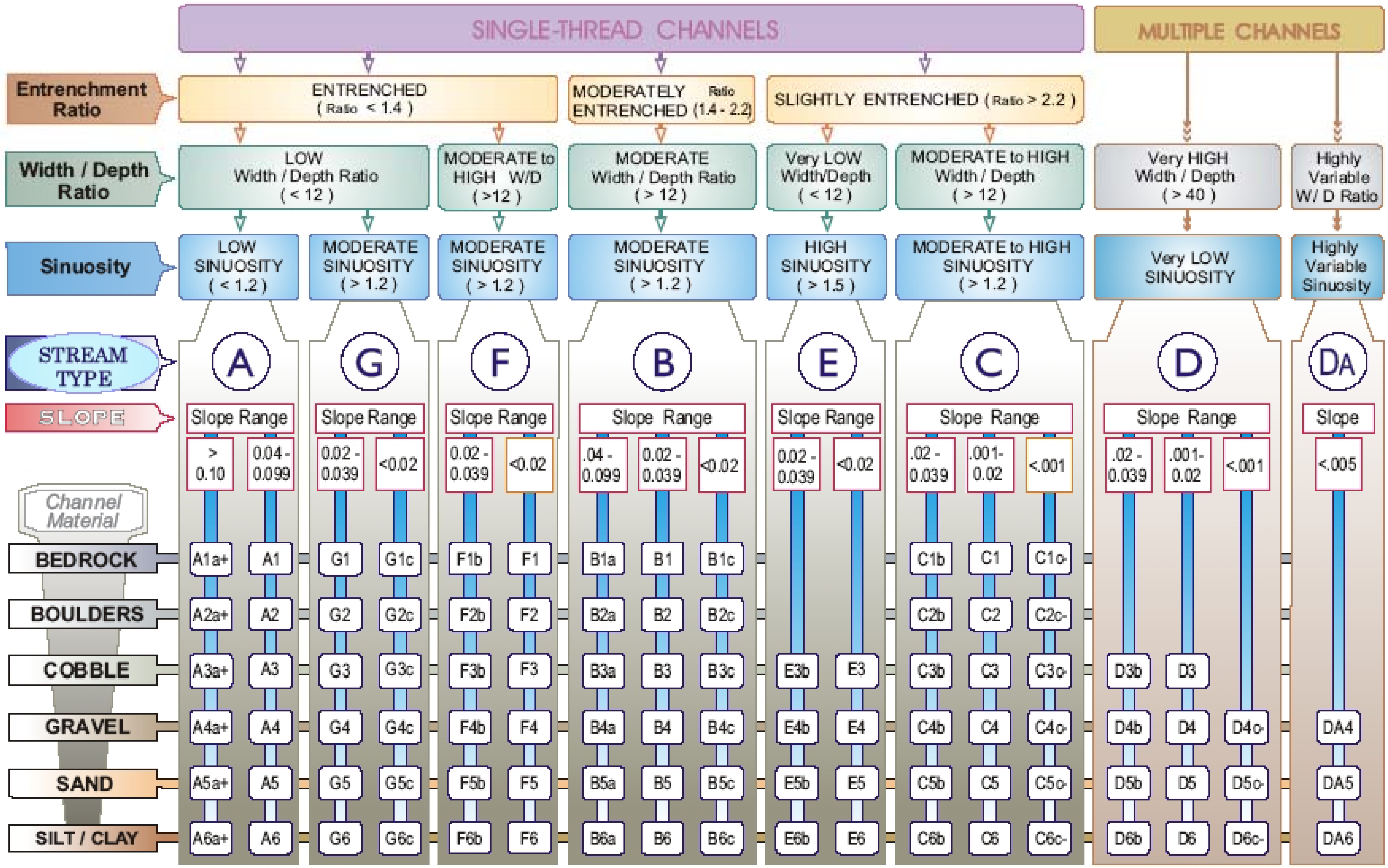
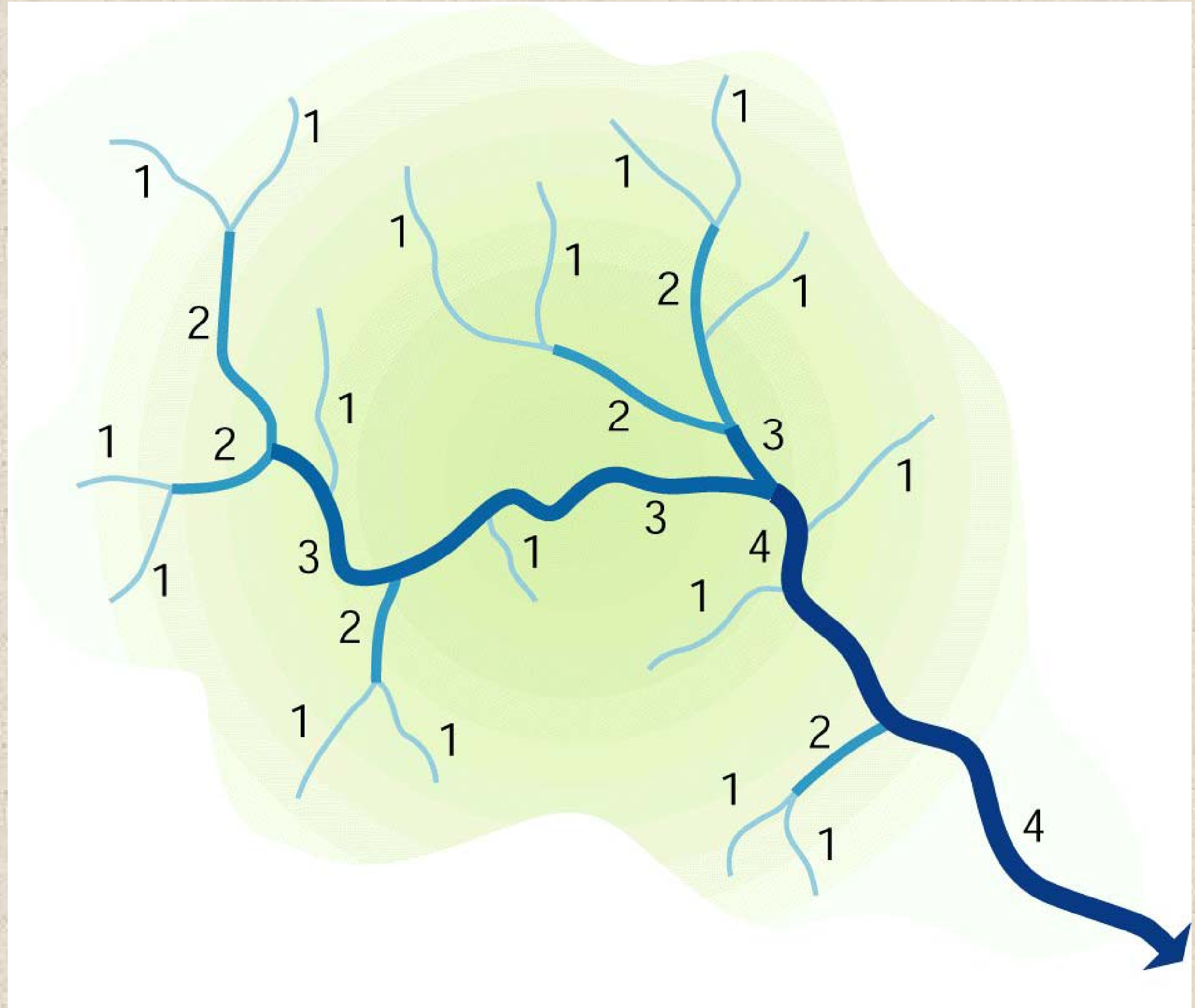
The Key to the Rosgen Classification of Natural Rivers



KEY to the *ROSGEN* CLASSIFICATION of NATURAL RIVERS. As a function of the *"continuum of physical variables"* within stream reaches, values of ***Entrenchment*** and ***Sinuosity*** ratios can vary by +/- 0.2 units; while values for ***Width / Depth*** ratios can vary by +/- 2.0 units.

Strahler Stream Order



FISRWG, 1998

Mounts Run, Eagle Creek Watershed

Mounts Run, Eagle Creek Watershed

Floodplains

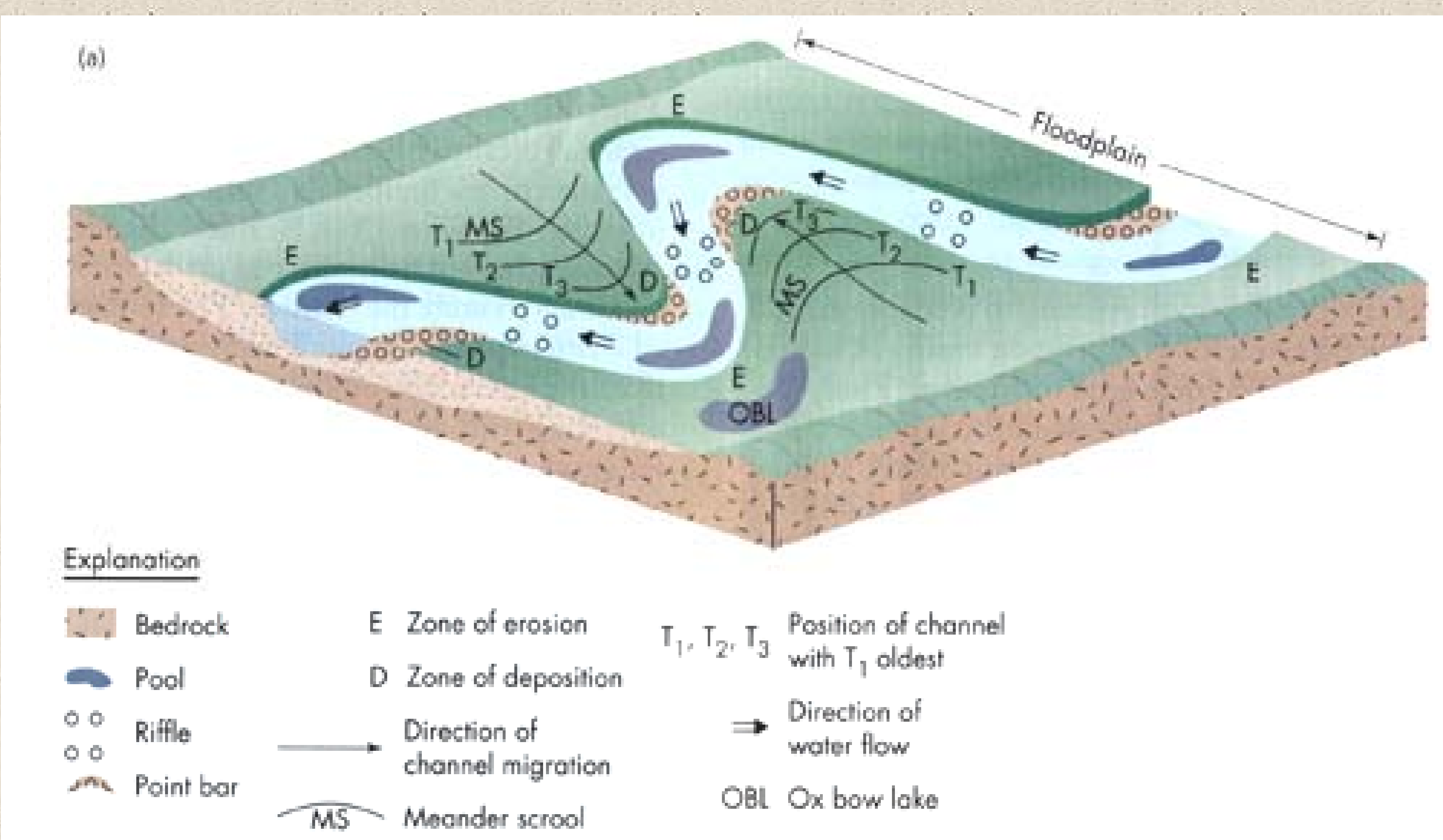
A floodplain is a level area near a river channel, constructed by the river in the present climate and overflowed during moderate flow events (Leopold)

Primary Processes Involved In Floodplain Formation

- **Lateral migration**: lateral movement of the channel across the floodplain; consists of erosion of outer bank and deposition on the point bar. Produces fining upward deposits of semi-uniform thickness.

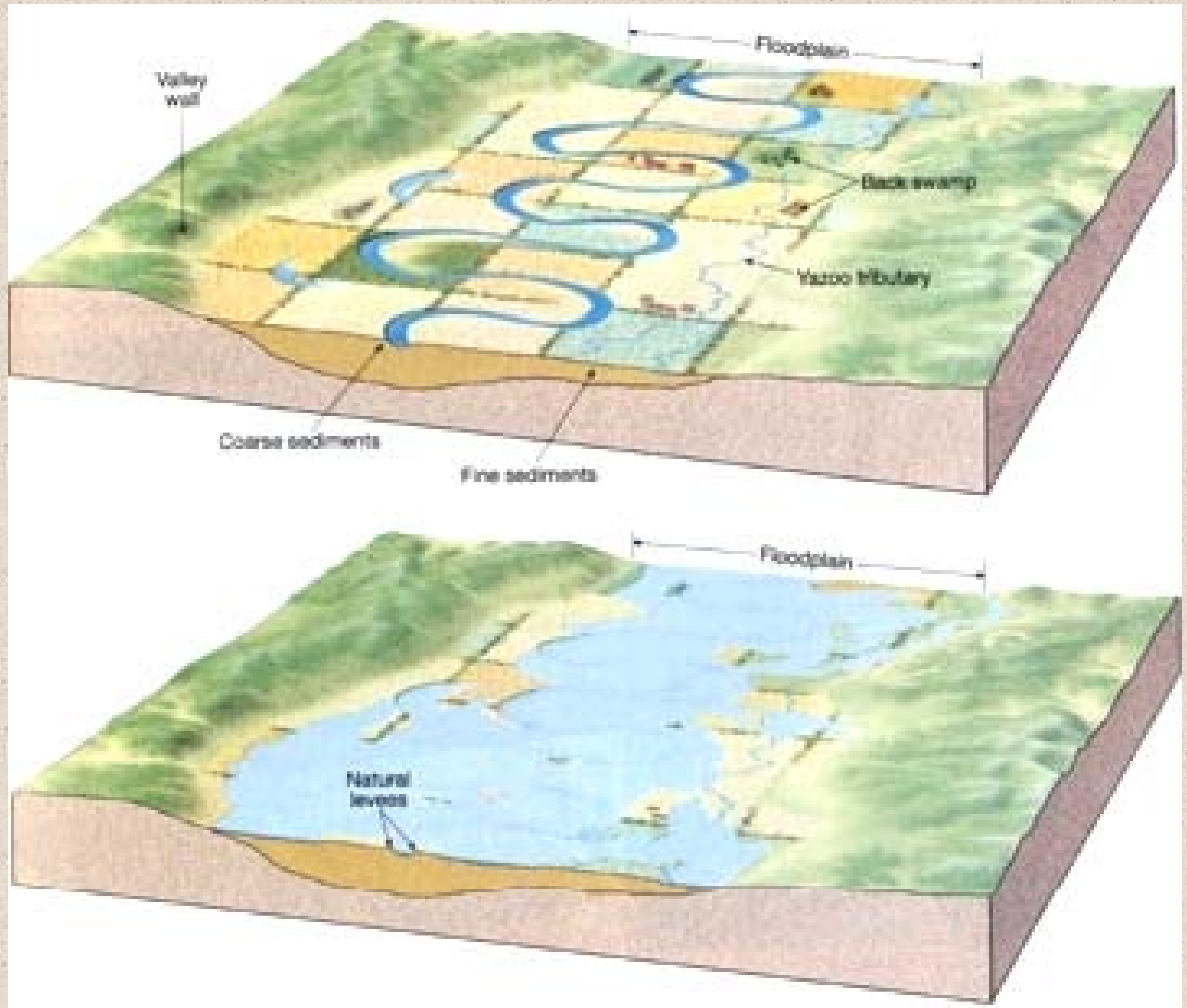
- **Vertical accretion**: deposition of sediment over the top of the floodplain during flood events; Produces horizontally bedded layers with varying degrees of lateral continuity.

Lateral Accretion of Floodplain Deposits by a Meandering Channel

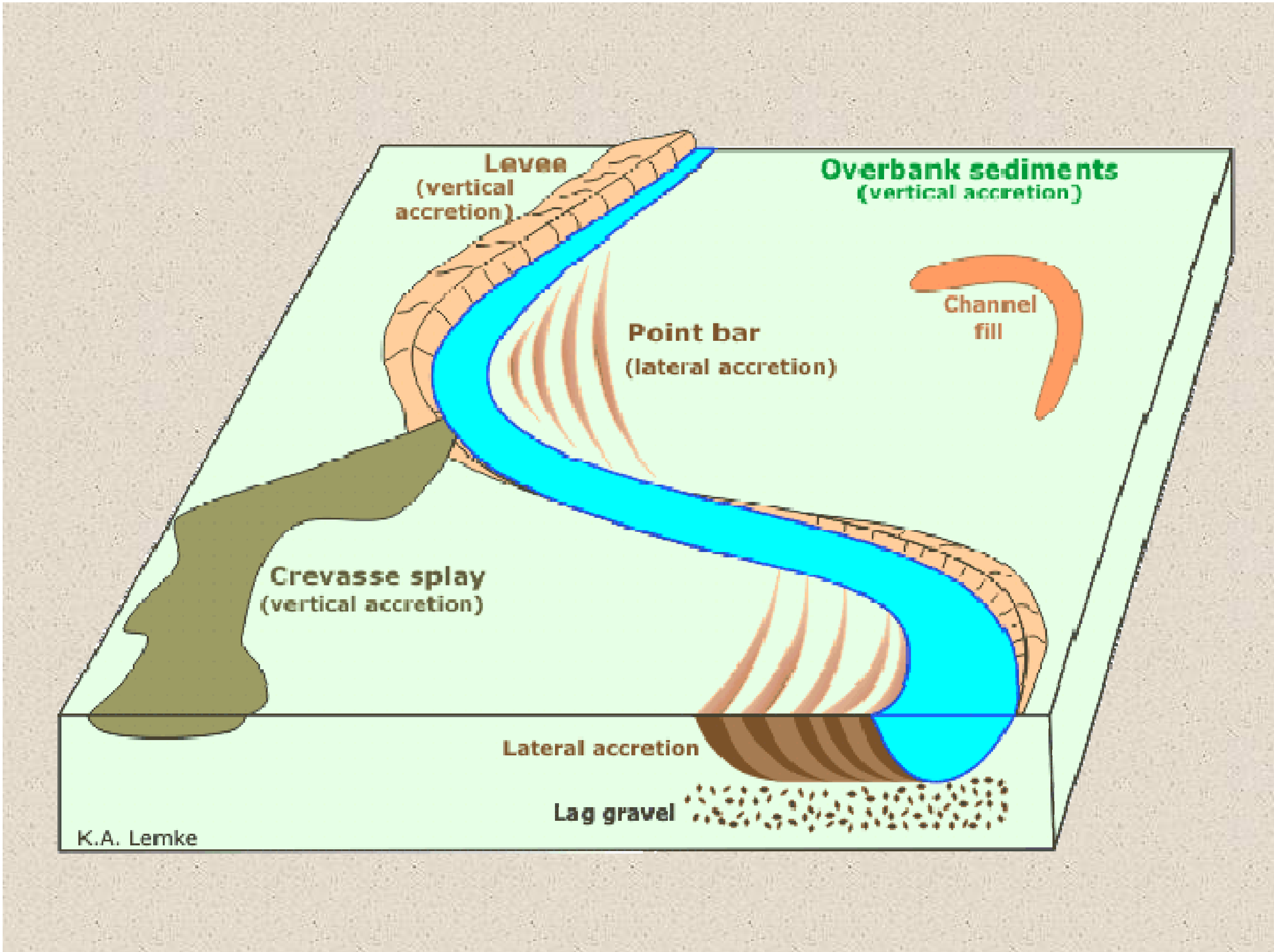



William’s Creek, Webber, 2007

Vertical Accretion

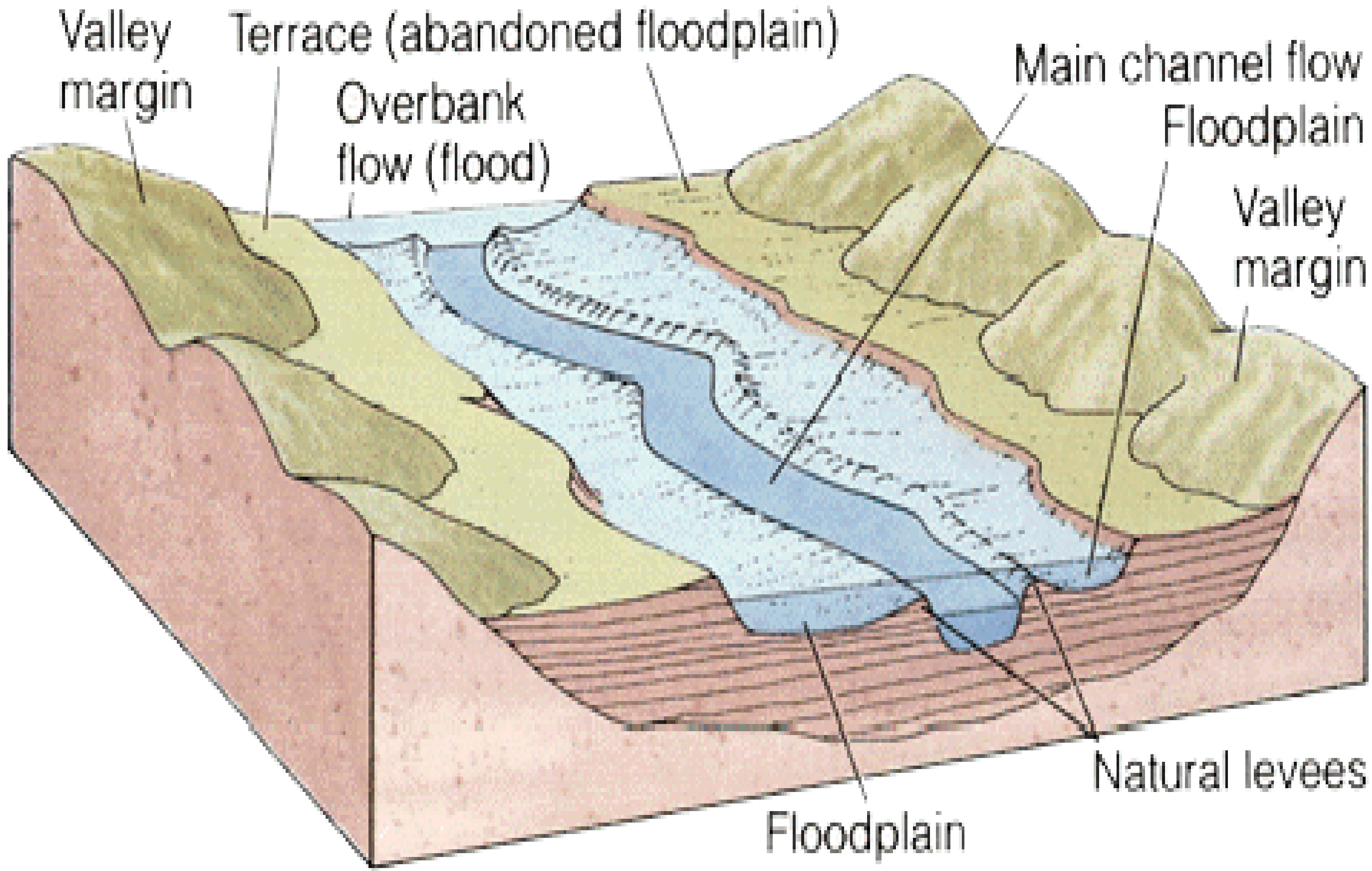


Overbank Flood Deposits, Carson River


Levee
(vertical
accretion)
Overbank sediments
(vertical accretion)
Channel
fill
Point bar
(lateral accretion)
Crevasse splay
(vertical accretion)
Lateral accretion
Lag gravel
K.A. Lemke

Floodplains and levees:

- floodplain --
  - water that overflows a river’s banks is stored on a floodplain
  - size of a floodplain is a function of the size of the river
  - boundary between a channel and its floodplain is often marked by a natural levee
    - levee is created by floods high enough to submerge the river’s banks


Valley
margin
Terrace (abandoned floodplain)
Overbank
flow (flood)
Main channel flow
Floodplain
Valley
margin
Natural levees
Floodplain

Precipitation and infiltration:

- runoff = precipitation - infiltration - interception - evaporation
  - during a storm flooding will occur when the ground's infiltration capacity is exceeded
- nature, magnitude, and likelihood of flooding will depend not only on the amount and distribution of rainfall --but also on the infiltration capacity of the ground

How rainfall distribution affects upstream and downstream flooding

- upstream flooding
  - intense, localized storms of short duration
  - short lag time
  - flooding can be severe, but is usually local in extent
  - effects of storm runoff do not usually extend to larger streams downstream
  - flash flood -- flood in which lag time is exceptionally short

- downstream flooding
  - caused by storms that continue for a long time and extend over an entire region
  - total discharge increases downstream as a result of increased flows in tributaries
  - often intensified by spring snowmelt
  - 1993 Mississippi River flood

Factors affecting infiltration:

- physical characteristics of the underlying soil and rock formation
  - particle size and type
  - porosity
  - permeability
- amount and type of vegetation
- the amount of moisture in the soil

- climatic factors
  - soils in arid regions can develop thick highly impermeable crust primarily composed of calcium carbonate
    - duricrust
    - hardpan
    - caliche
  - permanently or seasonally flooded frozen ground
- of all the factors influencing infiltration -- soil moisture is probably the most important

Human impact on infiltration :

- The primary effect of development is to increase runoff by increasing the amount of impervious cover
  - roads
  - buildings
  - parking lots

Alternatives

Utilizing Natural Storage

- 80-day flood of 1993 on the Mississippi River generated 39 million acre-feet of floodwaters (at St Louis)
- conservative estimate of available flood storage in the watershed indicates that approximately 40 million acre-feet of water could be stored within the existing levees and outside the levees on existing or drained wetlands.

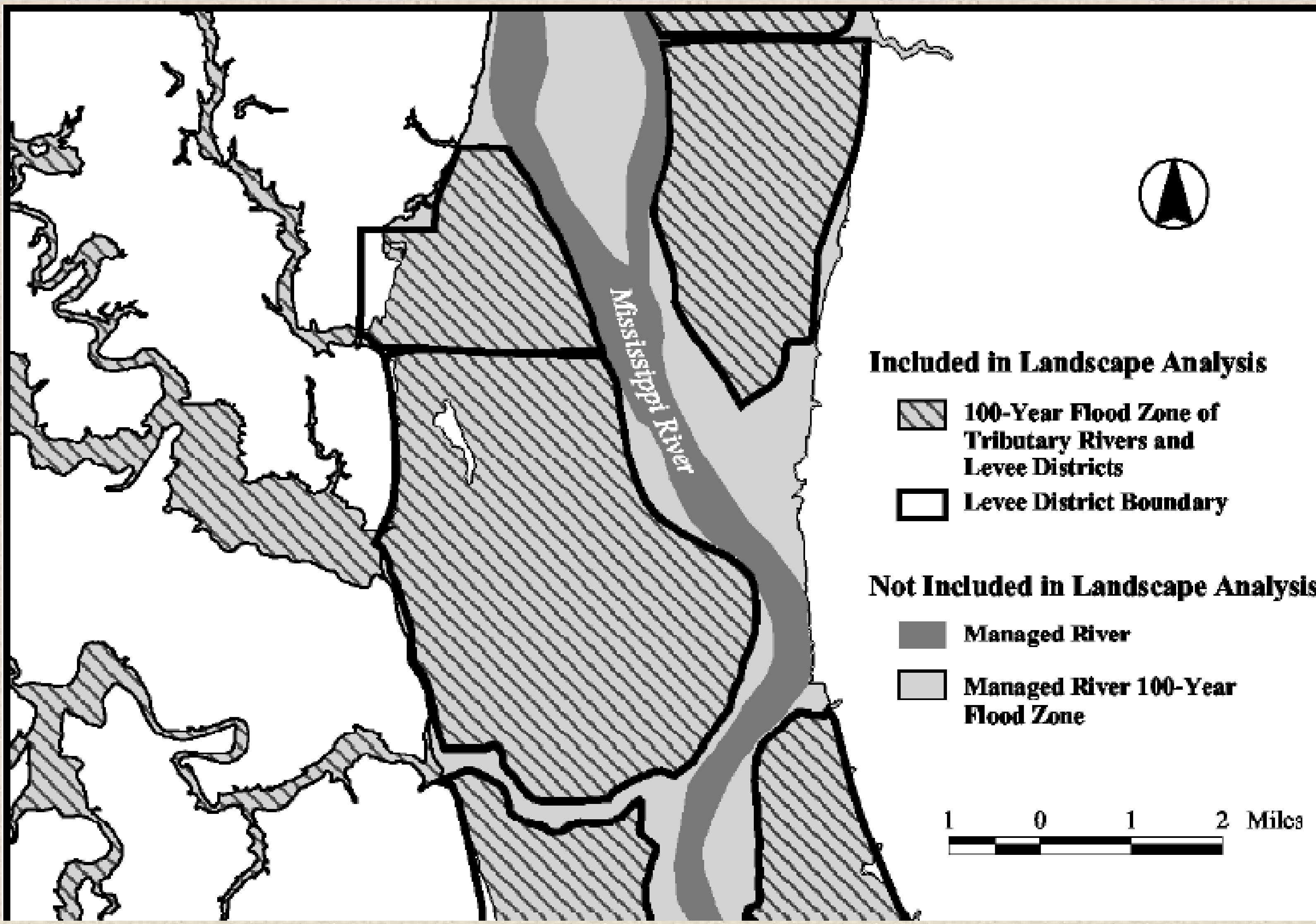


Illustration of the 100-Year Flood Zone Used

State	Number of Levees Flooded	Acres Flooded	Levees Repaired	Cost of Repairs
Iowa	36	35,291	6	$275,040
Illinois	33	226,600	0	
Missouri	145	436,000	37	$55,397,900
Total	**214**	**697,891**	**43**	**$55,672,900**

Upper Mississippi River Basin Levee Districts Damage from the 1993 Flood (Source: U.S. Army Corps of Engineers)

Hey and others, 2004

White River at 146th Street, Hamilton County, IN   February 2008

For additional information please contact:

Scott Dierks, PE
JFNew
(734)222-9690
sdierks@jfnew.com