Landcare Research
Manaaki Whenua

Landscape ecology and Integrated catchment management (ICM)

1. Landscape processes & flows

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And bits borrowed from many people including
Kevin Connery, Breck Bowden, Andrew Fenemor, Hans Schreier

in this lecture …..

- Landscapes and catchments
- Landform/topography
- What is a Catchment/Watershed
- Why catchments? Why an ICM approach?
- Why focus on hydrology – flows, connections
- Hydrological cycle
- Nutrients – N, C, ….
- Water quality
- Management example – buffers

Learning points

- Big picture
- Wide eyes
- Everything is connected to everything else
- No such thing as a free lunch
- Many names for the same thing
- People make the difference

The fundamental challenges of managing land/water resources

- Understanding the consequences of resource uses distributed across land
- Understanding the consequences of resource uses distributed over time

Landscapes and catchments

- Landscape – a heterogeneous land area composed of a cluster of interacting ecosystems, repeated in similar form throughout

- Catchment/watershed/basin – is the area drained by a river or stream & its tributaries

- Generally many catchments are included in a landscape and a landscape boundary may/not correspond to boundaries of catchments

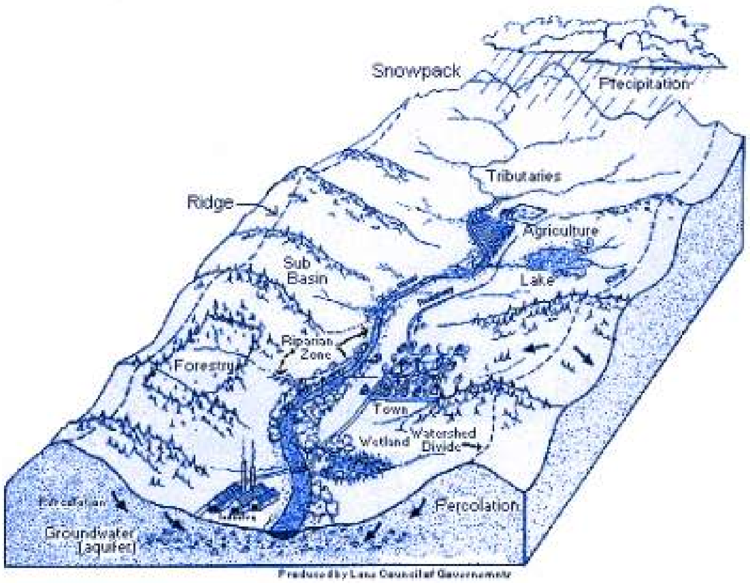
General landscape processes - topography/landform

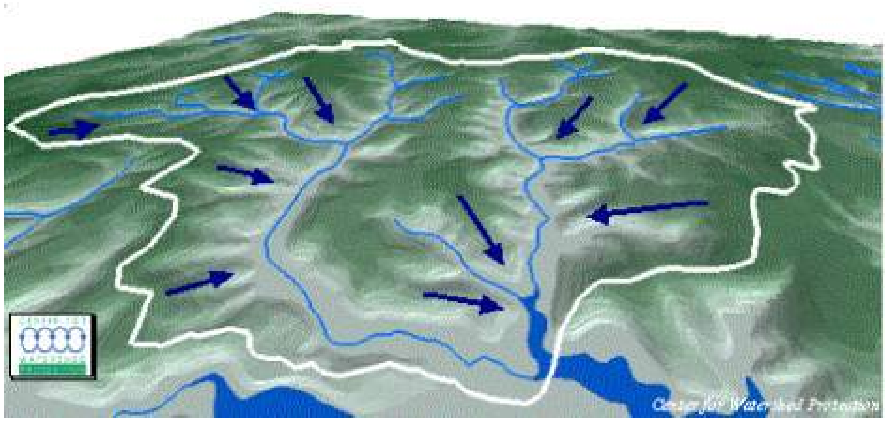
- Affect temp, nutrients, moisture/water (elevation, aspect)
- Affect flow of organisms (seeds, migration, energy)
- Influence frequency and spatial pattern of disturbance (fire, wind, grazing)
- Constrain rate &/or frequency of geomorphic processes that affect biotic features & processes (landslides, rivers)





What is a catchment or watershed?





An area of land that contributes runoff to one outlet point.

The selection of where that outlet point is, determines the size of the catchment

Has definable physiographic boundaries and internal drainage networks

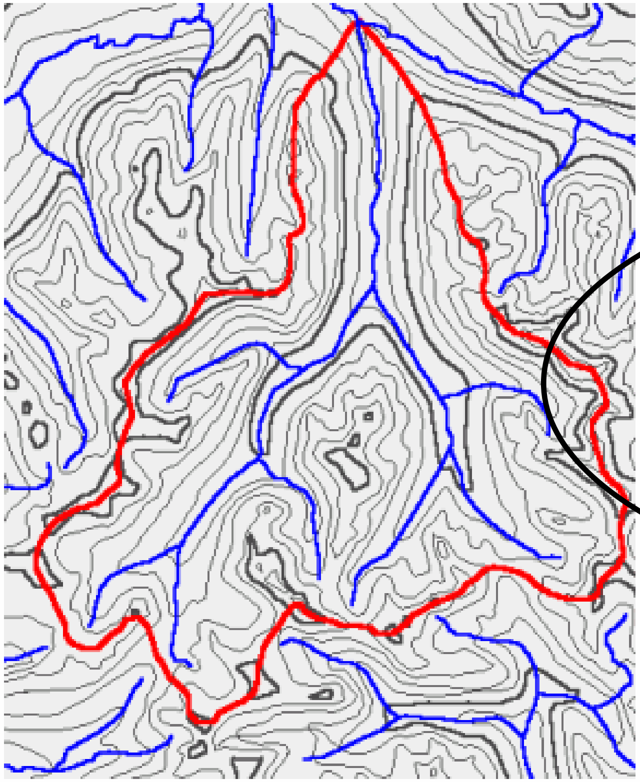
Often comprised of sub-basins, sub-watersheds, sub-catchments

Why catchments?

What is a catchment?

Catchment and watershed are used interchangeably.

Watershed is commonly used in North America and catchment in Europe and Australasia.



Text

The term catchment is broadly defined as the geographic delineation of an entire water body system and the land area that drains into it. Because of their readily identifiable boundaries, catchments provide a functional geographic unit for coordinating management efforts. Catchment planning and management is a cooperative and coordinated effort by stakeholders to develop and implement a long-term management plan for the resources within a catchment.

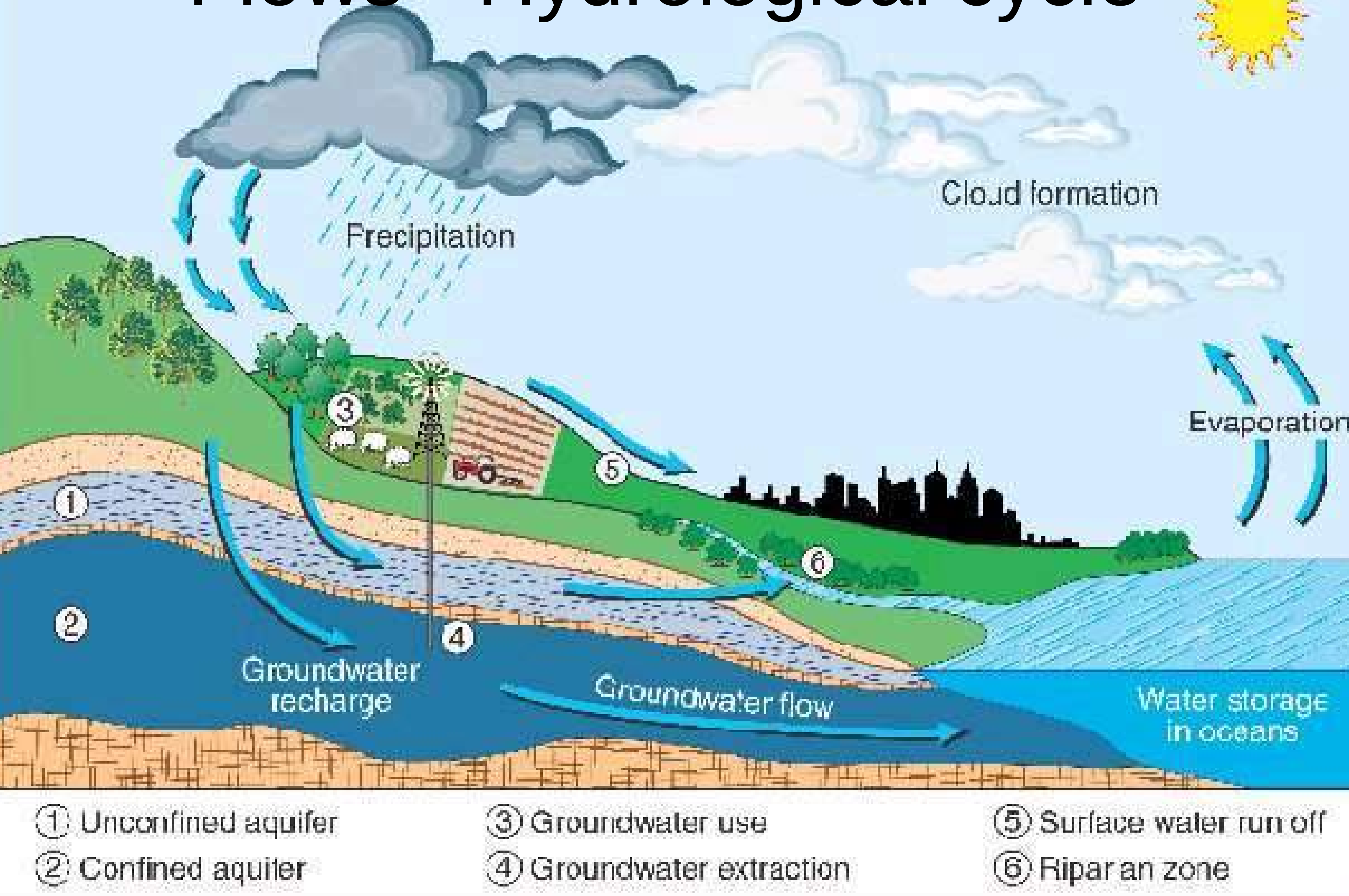
At the heart of catchment management lies the premise that "everything is connected to everything else". A catchment is an ecosystem with a complex set of interacting natural and cultural components. It includes all water bodies, land features, humans and other living things. Human activities have a direct influence on the quality and quantity of surface water, groundwater and other natural resources in the catchment. Upstream land uses affect downstream areas regardless of municipal boundaries and jurisdictions, and impacts on any one part of the catchment can have profound effects on other parts.

Catchments are used as an organizing principle based on the premise that the protection and restoration of water resources are best addressed through integrated efforts within hydrologically defined areas. Catchment management is a resource-centered approach involving several steps to achieve the overall goal of maintaining and improving environmental quality and protecting public health. Typically, emphasis is placed on the protection and restoration of specific water uses such as drinking water supply, aquatic habitat, waste assimilation and recreation.

Why focus on hydrology?

- Flows are important for landscape ecology
- Flows of water, nutrients, energy, species, $
- Water flow is a good <u>analogue</u> for others
- Flow connects things
  – Patches, corridors
- Flow transfers things – currencies
  – Nutrients, species, $

Flows - Hydrological cycle



Precipitation – P (rain)

close

- precipitation occurs when the atmosphere is saturated (airmasses cool or moisture is added)
- small particles act as nuclei for condensation
- if particles of water and ice grow large enough that their weight overcomes the uplift forces, then precipitation occurs

- water vapor forms clouds
- the vapor then coalesces into droplets too large to remain in suspension resulting in rain (or snow if temperature is below freezing)

Evaporation - E

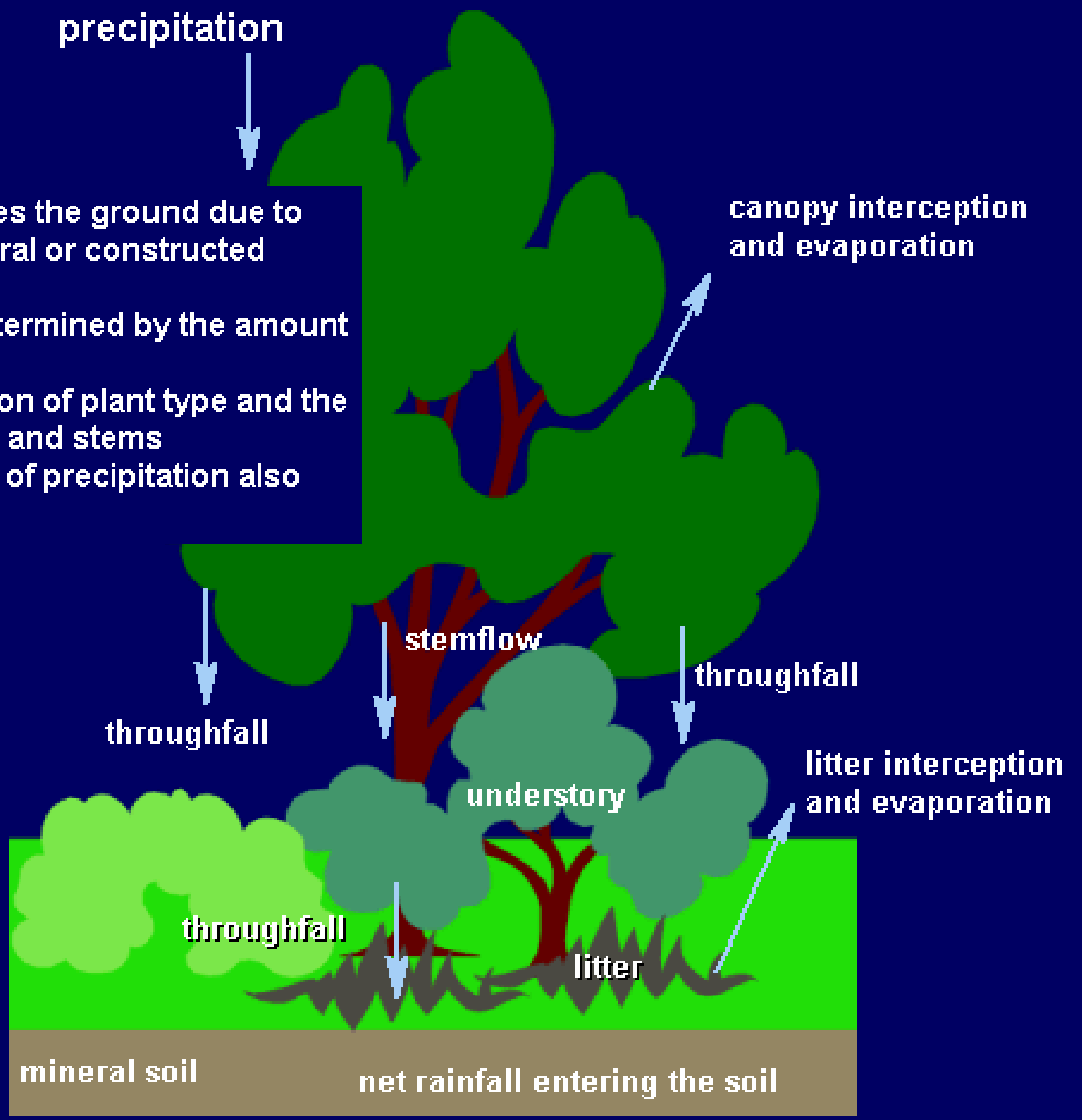
close

- transpiration = the diffusion of water vapor from plant leaves to the atmosphere
- transpired water originates from water taken in by roots
- evaporation = the movement of water from liquid state to vapor from a wet surface
- evaporated water originates from intercepted water by vegetation cover, evaporation from the soil surface and from water held by the soil
- difficult to separate water loss due to transpiration and evaporation; the two processes are commonly combined and labeled evapotranspiration

Interception (special E)

close

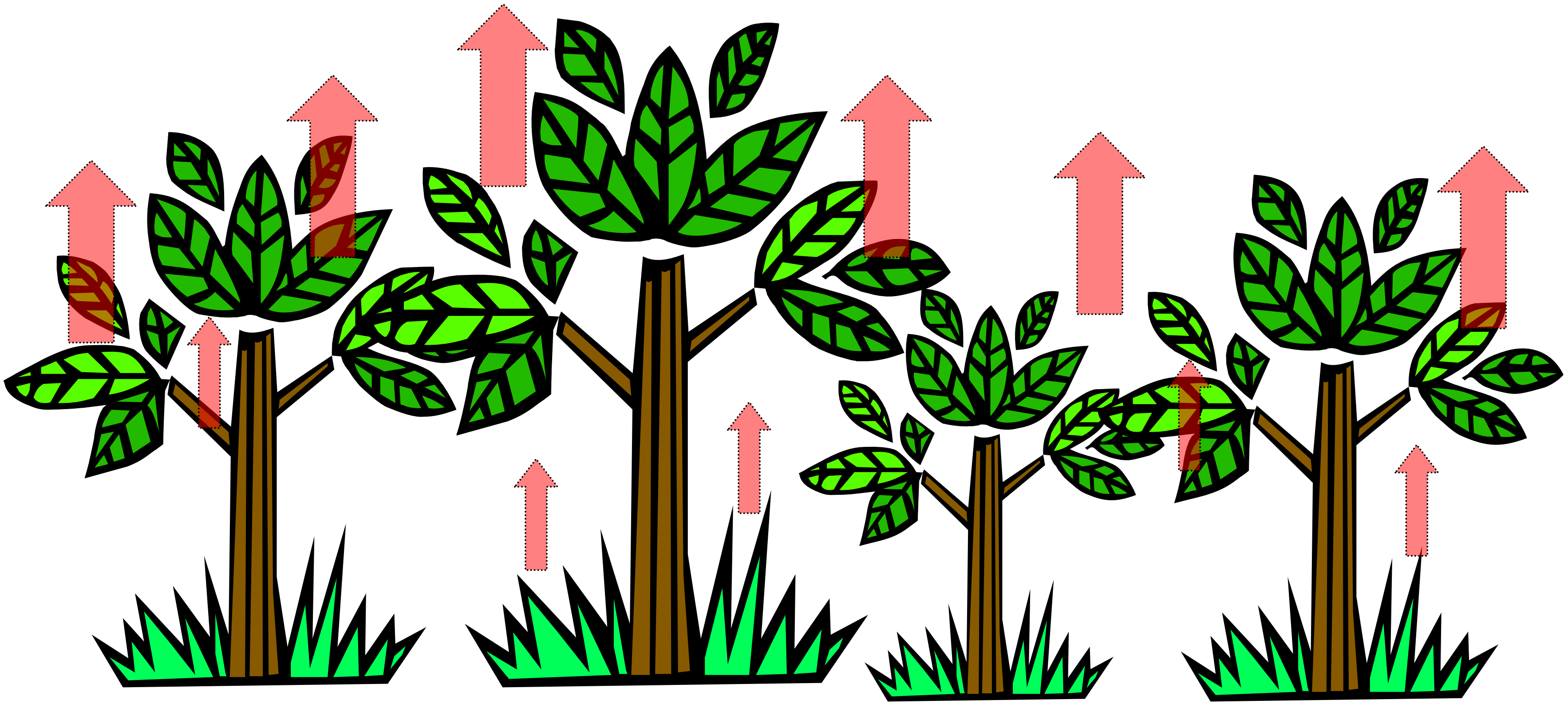
- a portion of precipitation never reaches the ground due to interception by vegetation, other natural or constructed surfaces
- the amount of water intercepted is determined by the amount of interception storage available
- in vegetated areas, storage is a function of plant type and the form and density of leaves, branches, and stems
- the intensity, duration, and frequency of precipitation also affect levels of interception



- interception diagram
- % intercepted per veg type
- description

Why are trees so good at intercepting water?

Lots of intercepting surfaces (leaves/needles)



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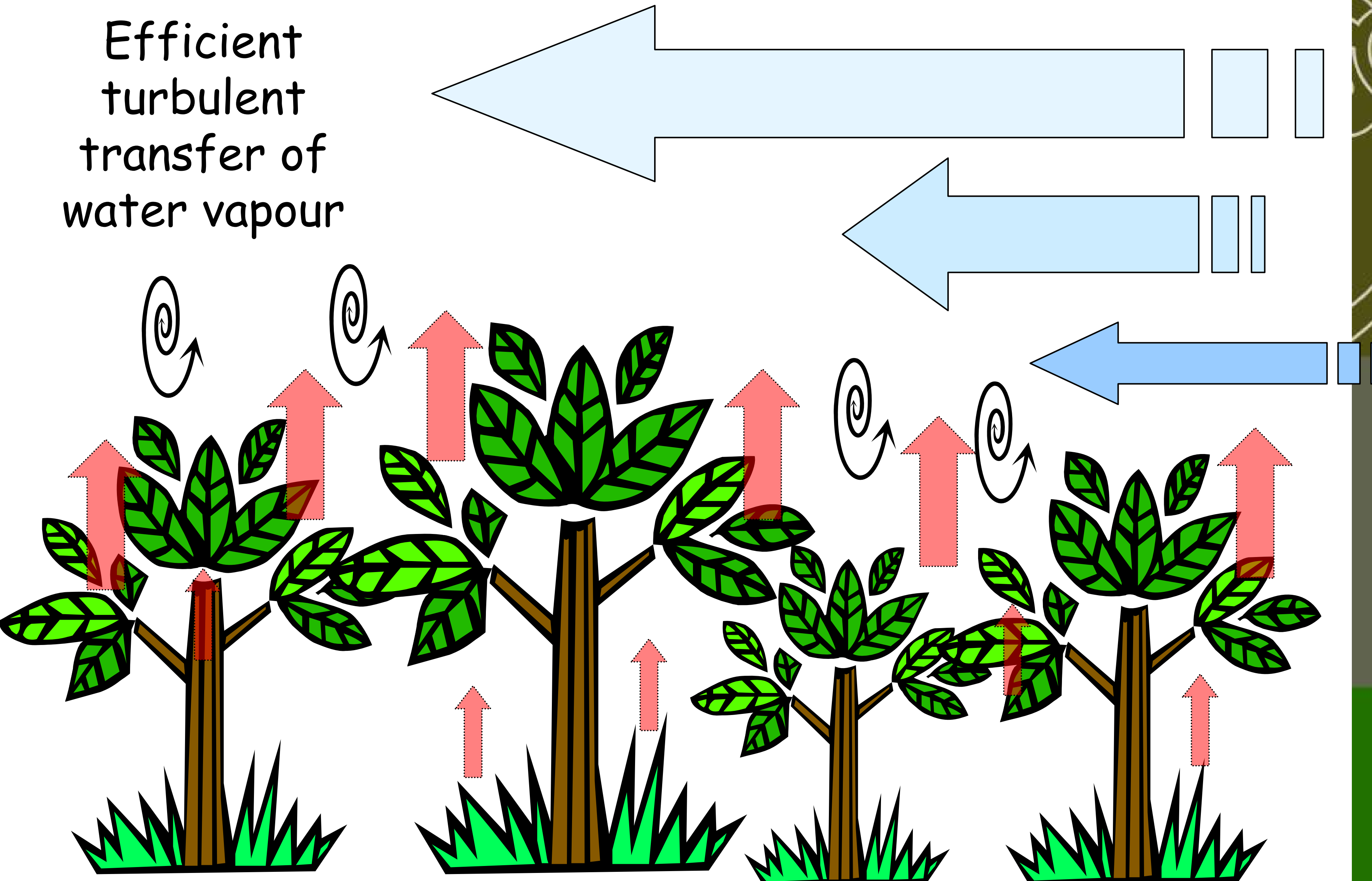
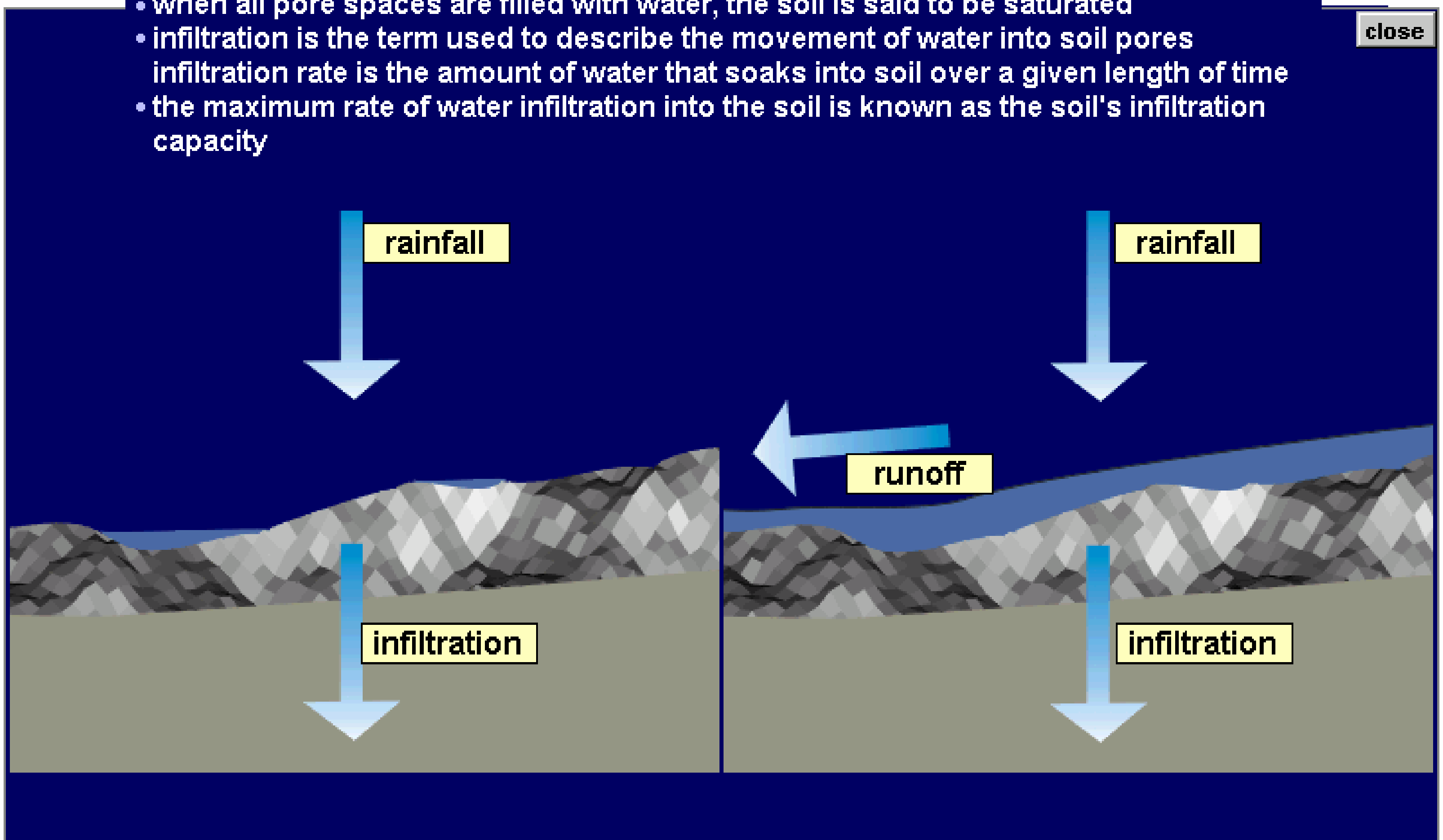


Infiltration

- precipitation that is not intercepted or flows as surface runoff moves into the soil
- water can be stored in the upper layer or move downward through the soil profile to the saturated layer
- gravity is the dominant force for water moving into the largest openings, such as worm or root holes
- capillary action is the dominant force for water moving into soils with very fine pores the size and density of pore openings determine the water's rate of entry into the soil
- porosity is the term used to describe the percentage of the total soil volume taken up by spaces between soil particles
- when all pore spaces are filled with water, the soil is said to be saturated
- infiltration is the term used to describe the movement of water into soil pores infiltration rate is the amount of water that soaks into soil over a given length of time
- the maximum rate of water infiltration into the soil is known as the soil's infiltration capacity



Runoff - Q

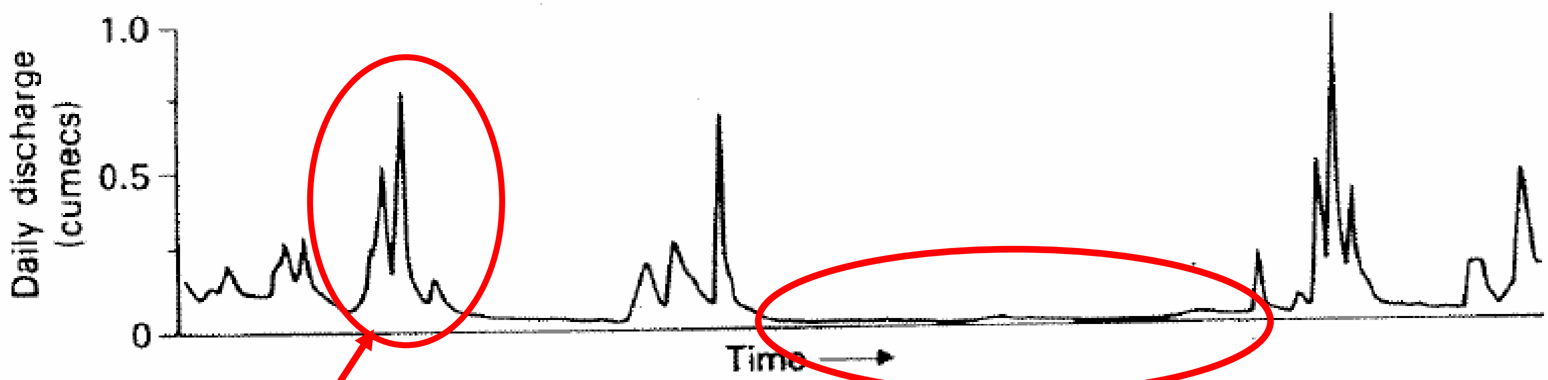
close

When the rate of rainfall or snowmelt exceeds infiltration capacity, excess water collects on the soil surface and travels downslope as runoff.

Factors that affect runoff processes include:

- climate
- geology
- topography
- soil characteristics, and
- vegetation.

Hydrograph



Annual hydrograph for the Catchwater Drain, North Humberside, 1967.

Stormflow

Quickflow

Baseflow

Lowflow

Storm hydrograph

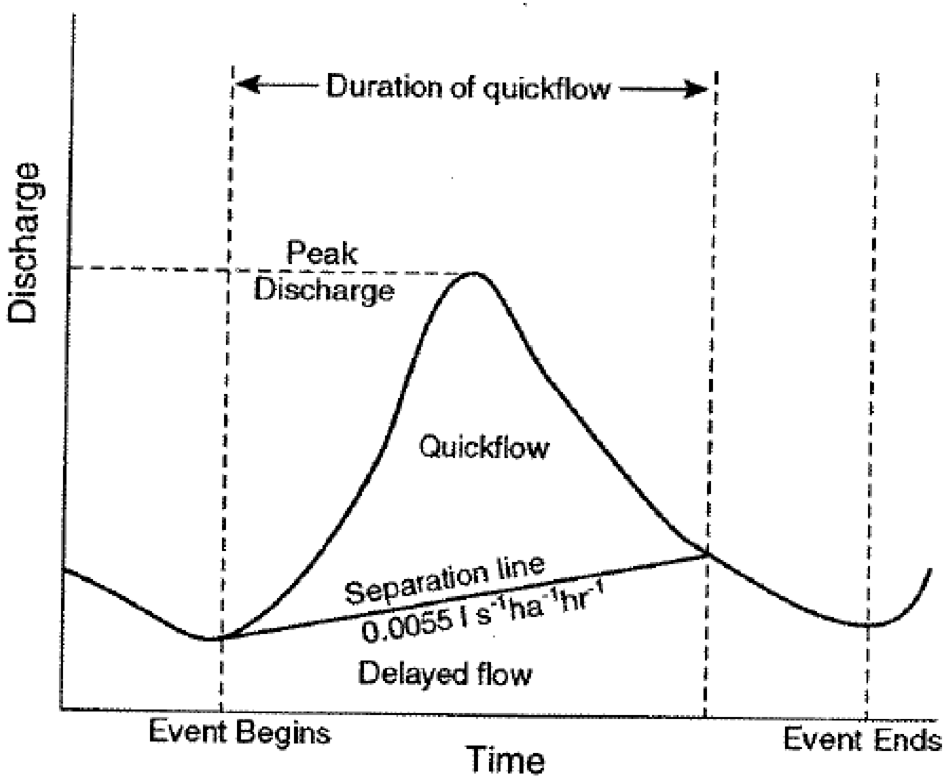
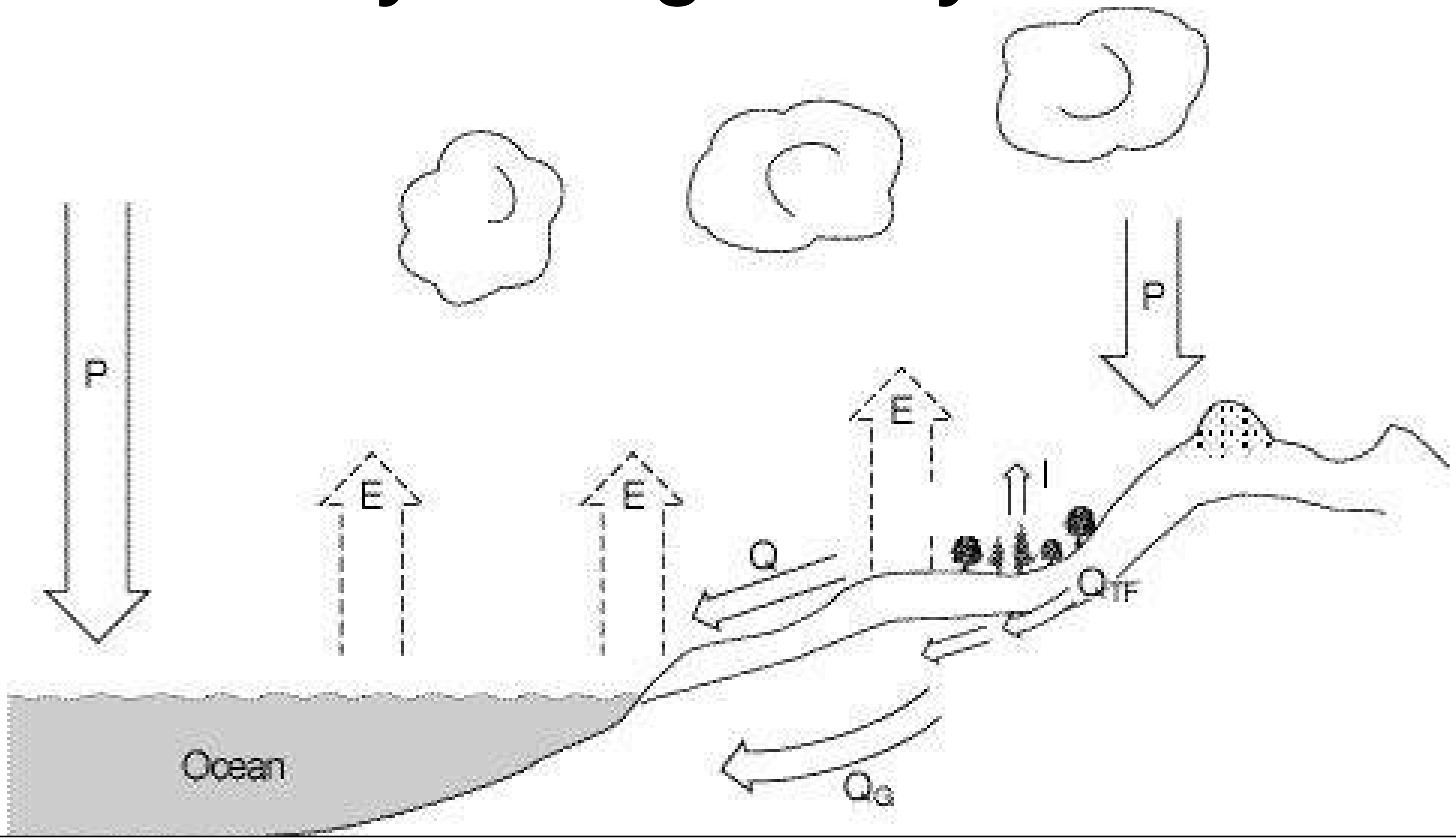


Figure 15.3 A stream hydrograph showing the hydrograph separation method of Hewlett and Hibbert (1967)

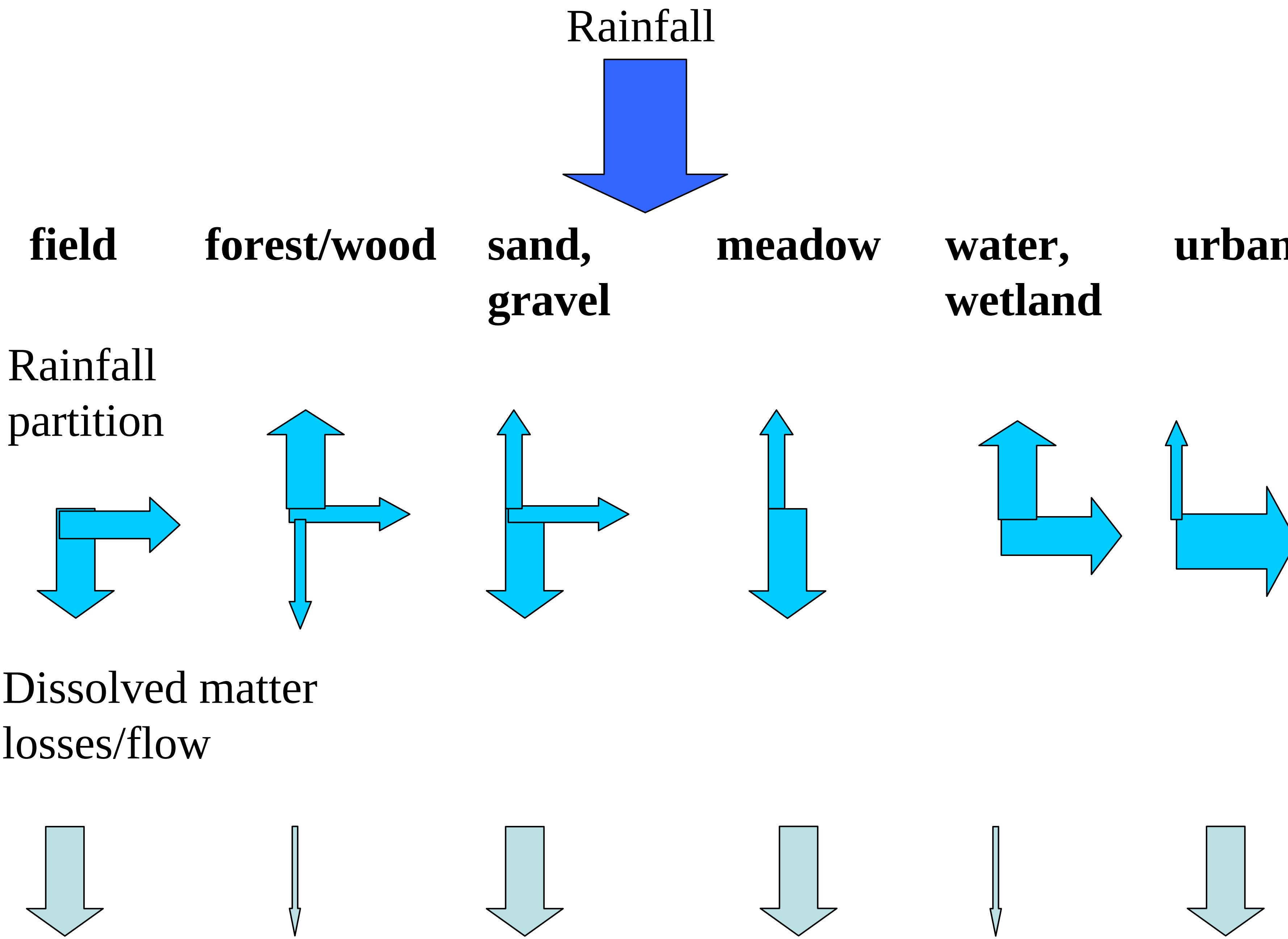
Hydrological cycle



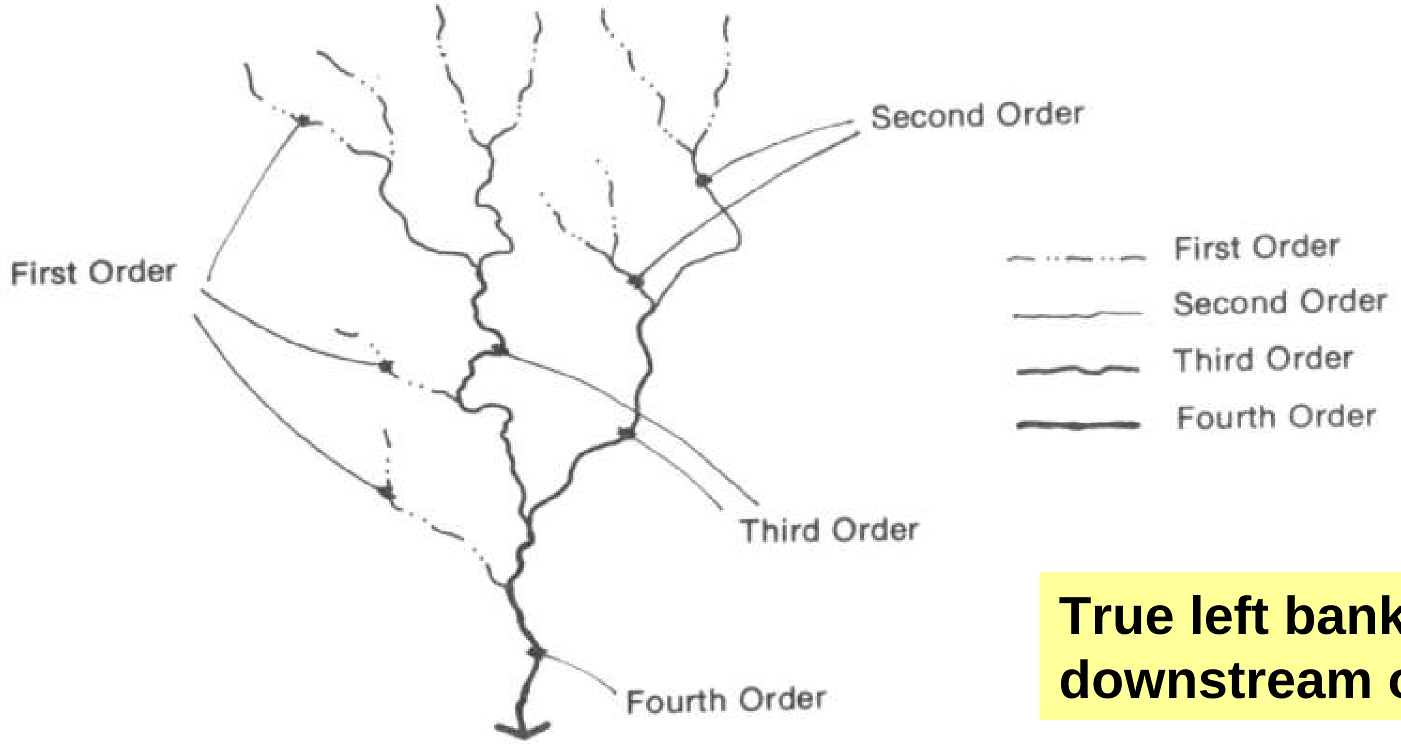
$$P \pm E \pm Q \pm \Delta S = 0$$

Over a long time period

$$E = P - Q$$


Rainfall
field
forest/wood
sand, gravel
meadow
water, wetland
urban
Rainfall partition
Dissolved matter losses/flow

Stream Order Classification



True left bank = look downstream on LHS

Fig. 9.1 Stream order classification according to rank in the drainage network. This follows the scheme originally defined by Robert Horton.

1 + 1 = 2

2 + 2 = 3

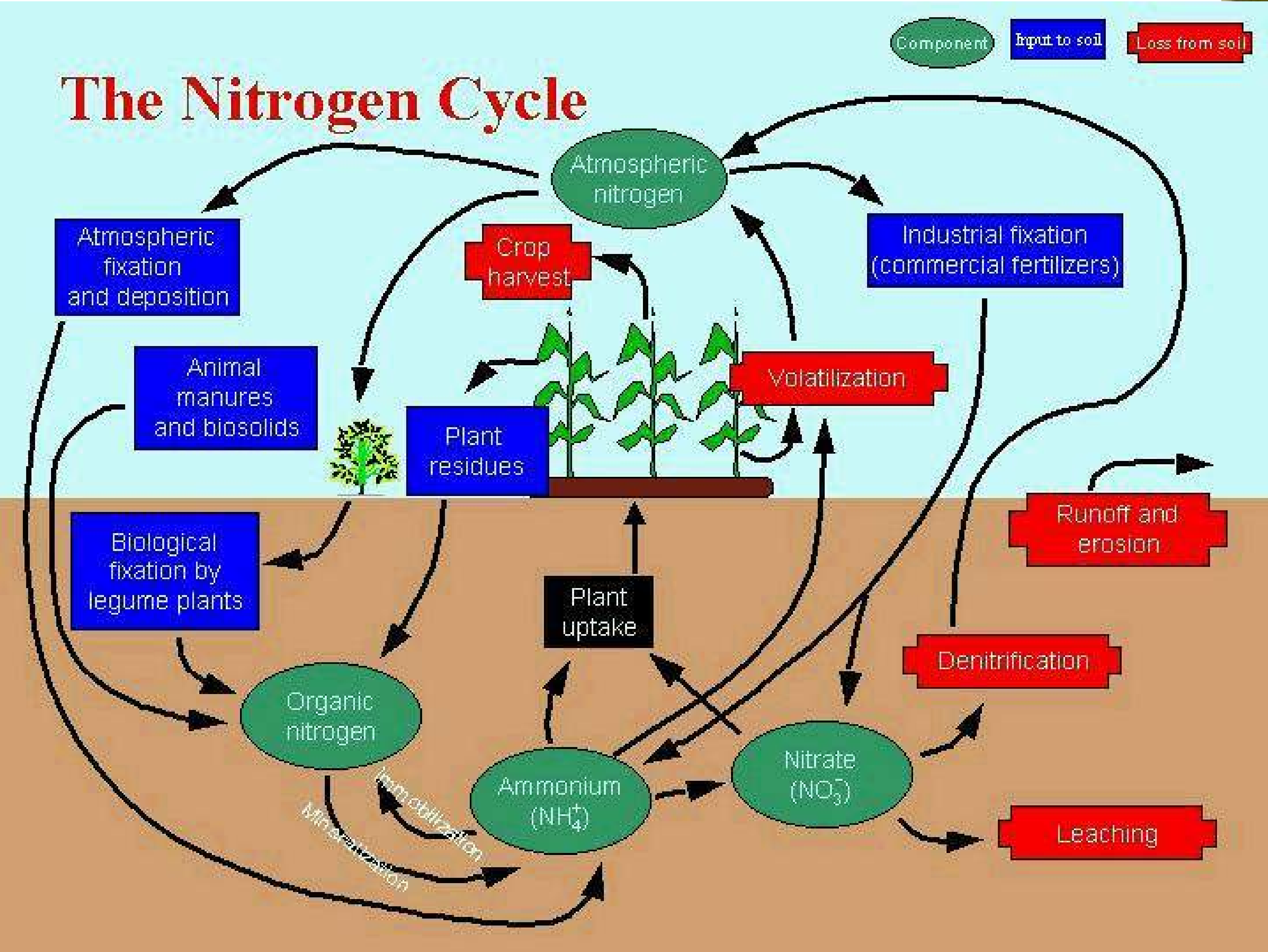
1 + 2 = 2

Small streams = low number

Big rivers = high number

Nutrient flows – Nitrogen cycle

- N - essential for all plants & animals to make protein.
- Atmospheric form most common (N_2 - 79% of air)
- Photosynthesis and soil bacteria metabolism natural process of ‘N’ assimilation as Ammonia (NH_4^+), Nitrates (NO_3^-), Nitrites (NO_2^-)
- Nitrogen in air can’t be used – needs to be fixed to make it into a usable form eg roots of plants (legumes)
- Nitrate very soluble and easily lost from soil by leaching
- Denitrification reduces nitrate to N_2 or N_20 – gas



The Nitrogen Cycle
Component
Input to soil
Loss from soil
Atmospheric nitrogen
Atmospheric fixation and deposition
Industrial fixation (commercial fertilizers)
Crop harvest
Volatilization
Animal manures and biosolids
Plant residues
Runoff and erosion
Biological fixation by legume plants
Plant uptake
Denitrification
Organic nitrogen
Immobilization
Mineralization
Ammonium (NH_4^+)
Nitrate (NO_3^-)
Leaching

Water Quality – Nitrogen

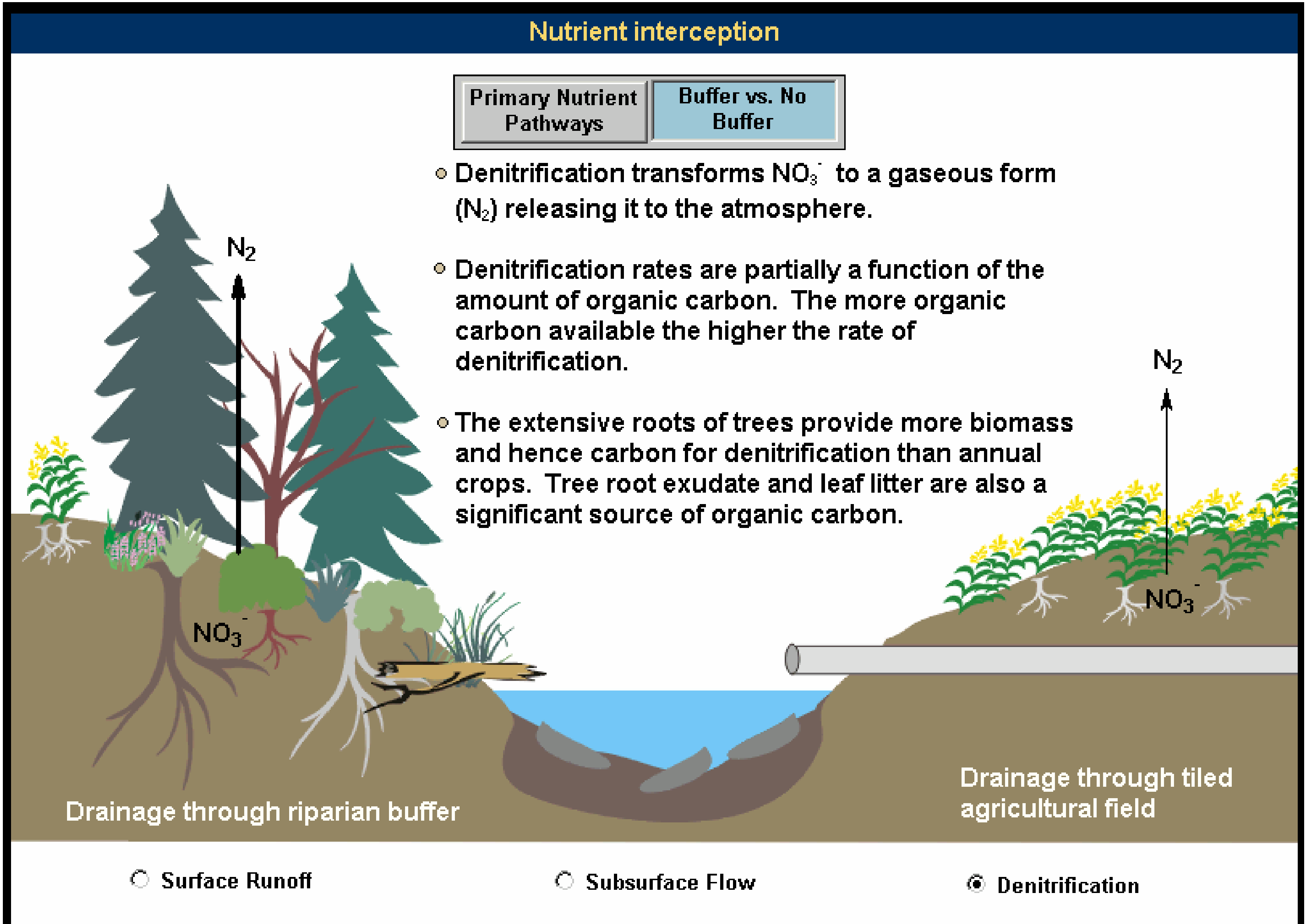
too much of a good thing?

- Natural levels: less than 1mg/L
- Main source of nitrates added by humans: wastewater + fert
  - Wastewater effluent: up to 30mg/L
- Fertilizers and runoff from agricultural operations – excessive fertilizer use, high leaching properties of ammonia nitrogen, especially in heavily irrigated areas with sandy soils.
- Inadequately treated wastewater from sewage treatment plants/poorly functioning septic systems.
- RESULT: Part of watershed can become "eutrophic"
  - Increased aquatic plant growth causes hypoxia (reduced DO levels)
  - Flora/Fauna community structure changes

http://www.esa.org/science/Issues/FileEnglish/issue1.pdf

Lots written on this subject

Denitrification



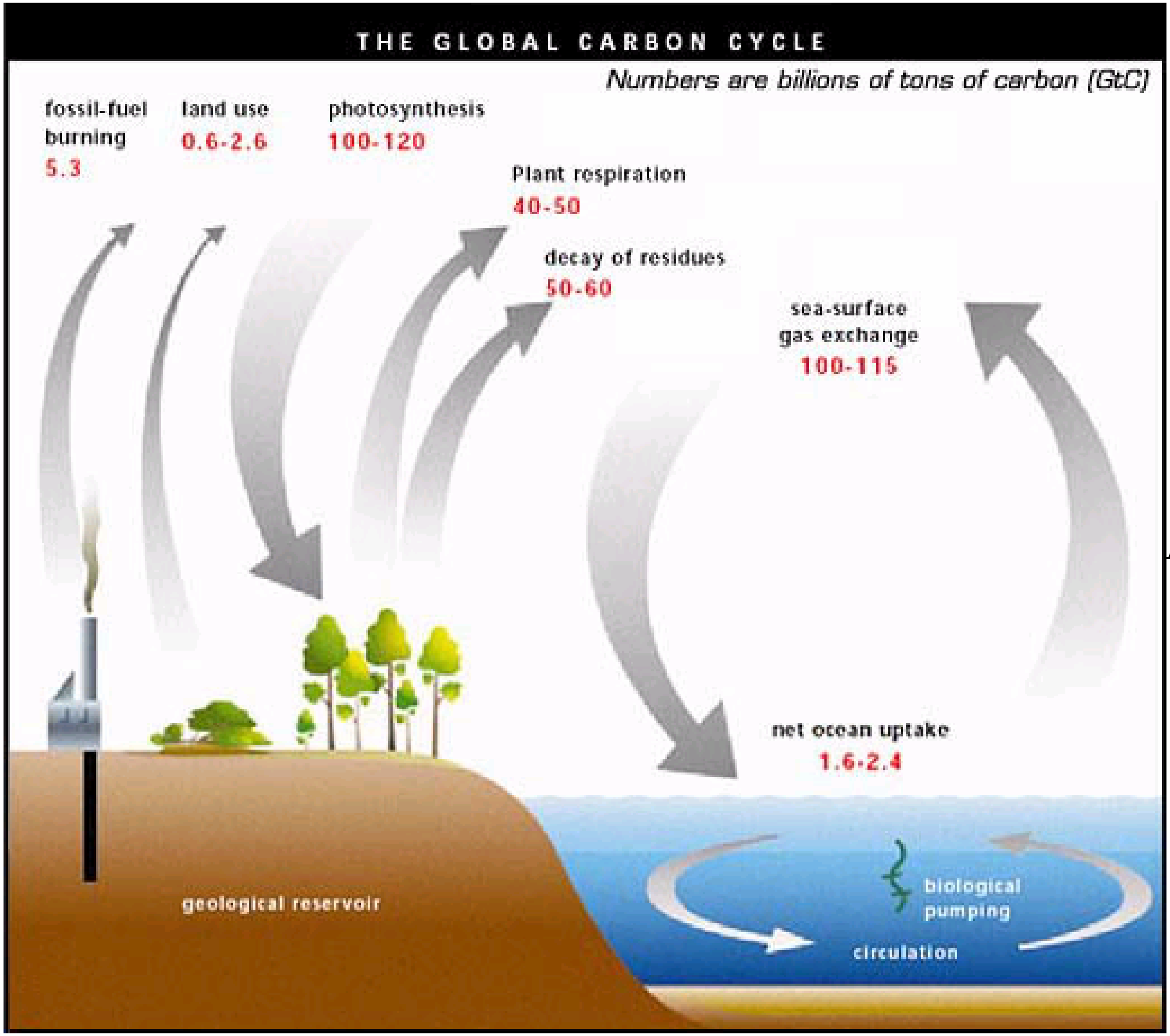
Nutrient flows – carbon cycle

- C – key building block in all living cells
- Captured by plant from $C0_2$ via photosynthesis
- Decomposition is critical link in nutrient cycling
- Changes to C cycle can affect other nutrient cycles eg N cycle
- The carbon cycle is a closed system – fixed amount in the world.

Lots written on this subject – climate change

Nutrient flows – carbon cycle

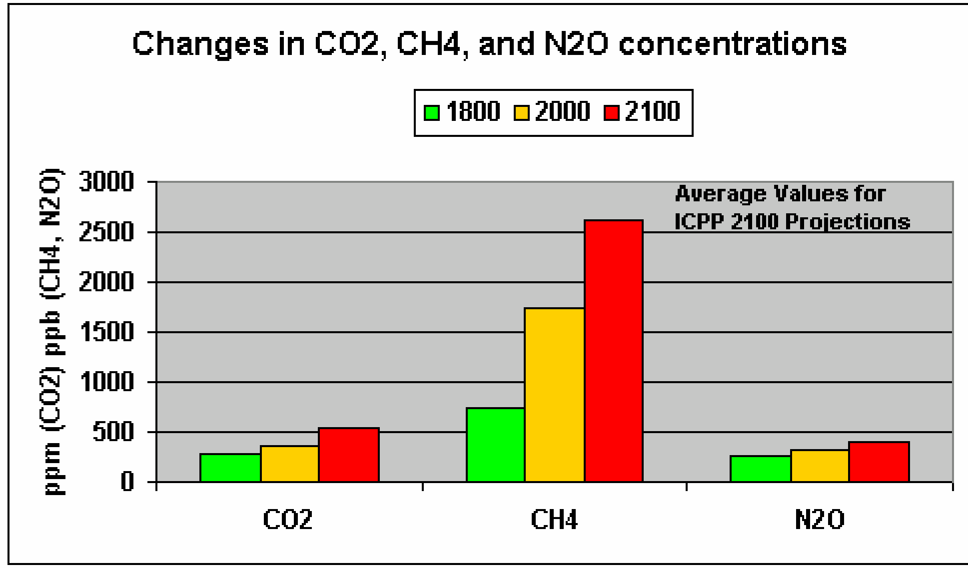
Emitted or released



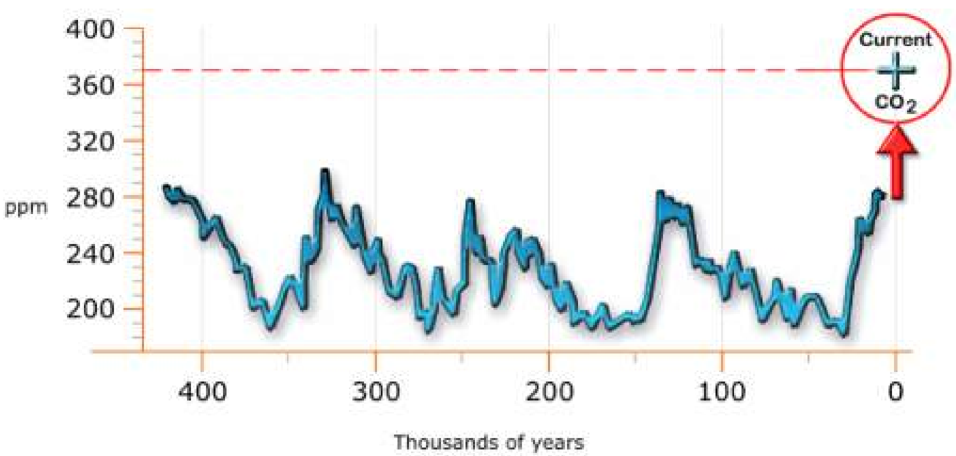
Absorbed

Global carbon cycle – climate change

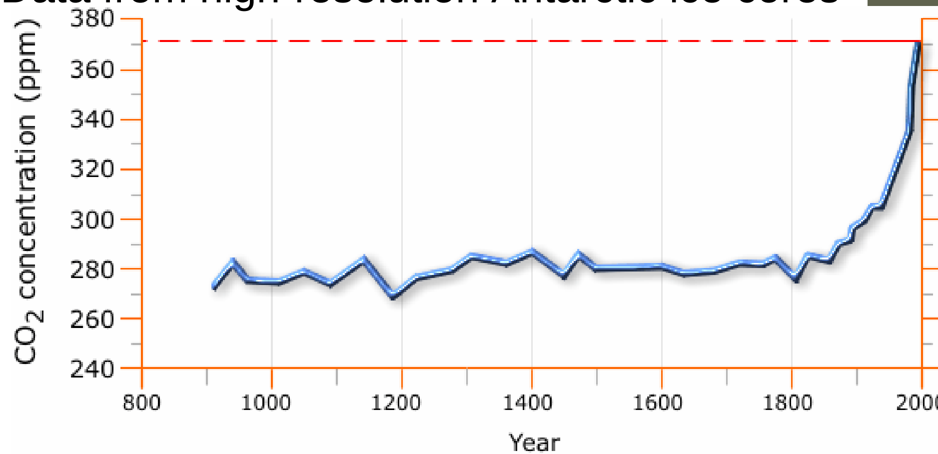
- Is out of balance – climate change likely
- Atmospheric CO_2 levels rising rapidly
- CO2 conc up from 280 ppm to 370 ppm in 100 yrs
- Many human activities release CO_2 – agriculture, clearing forests, burning fossil fuels, building infrastructure



Chemicals	Rate of Change	Atmospheric Lifetime
CO_2	1.5 ppm / year	5 -200 years
CH_4	7.0 ppb / year	12 years
N_2O	0.8 ppb / year	114 years



Data from high-resolution Antarctic ice cores



Key factors

Evidence of Climate Change

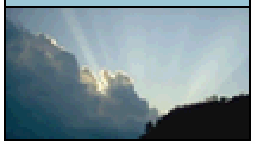
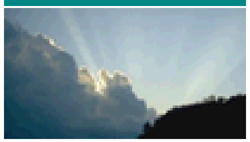
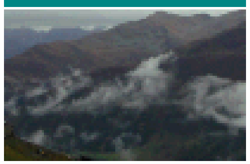
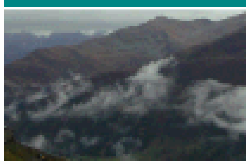
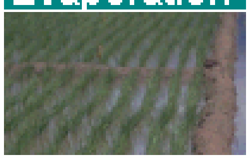
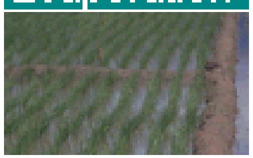
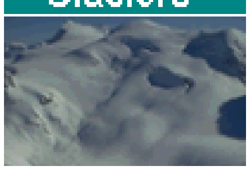
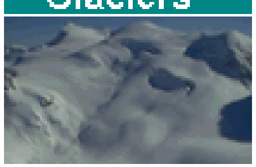
Well documented trends
Greater climatic extremes (more floods, more droughts)
Global temperature increases (clear evidence in the northern hemisphere)
Glaciers are melting at a faster rate than experts predicted
Sea-levels are increasing

No clear trends and insufficient information on:
Precipitation, moisture distribution, evaporation, and stream runoff

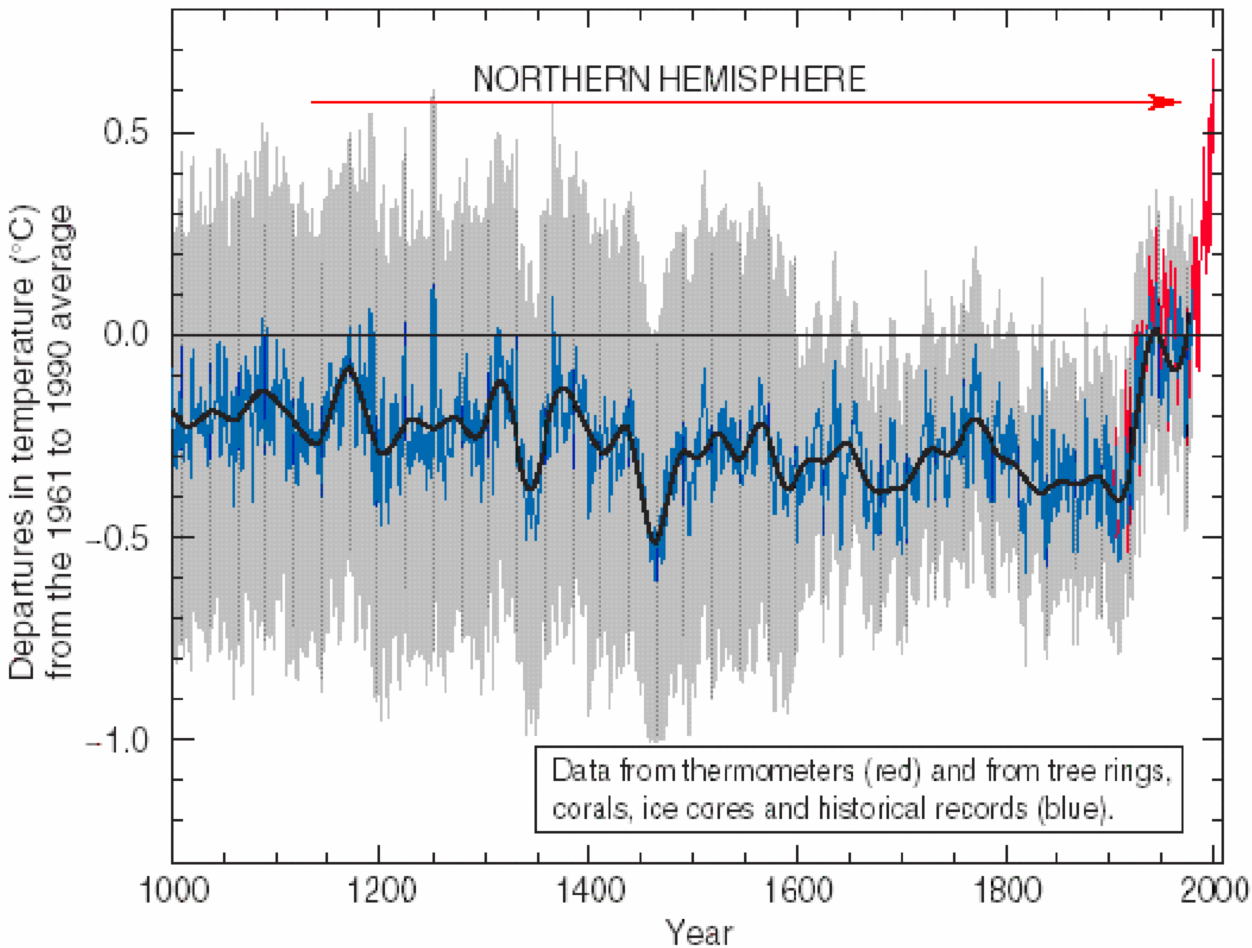
Alps, Switzerland

◉ Global Temperature ○ Canadian Example ○ Daily Minimum Temp.

Click on pictures

Global & Regional Trends	Events & Seasonal Effects
Temperature	Temperature
	
Precipitation	Precipitation
	
Evaporation	Evaporation
	
Runoff	Runoff
	
Glaciers	Glaciers
	

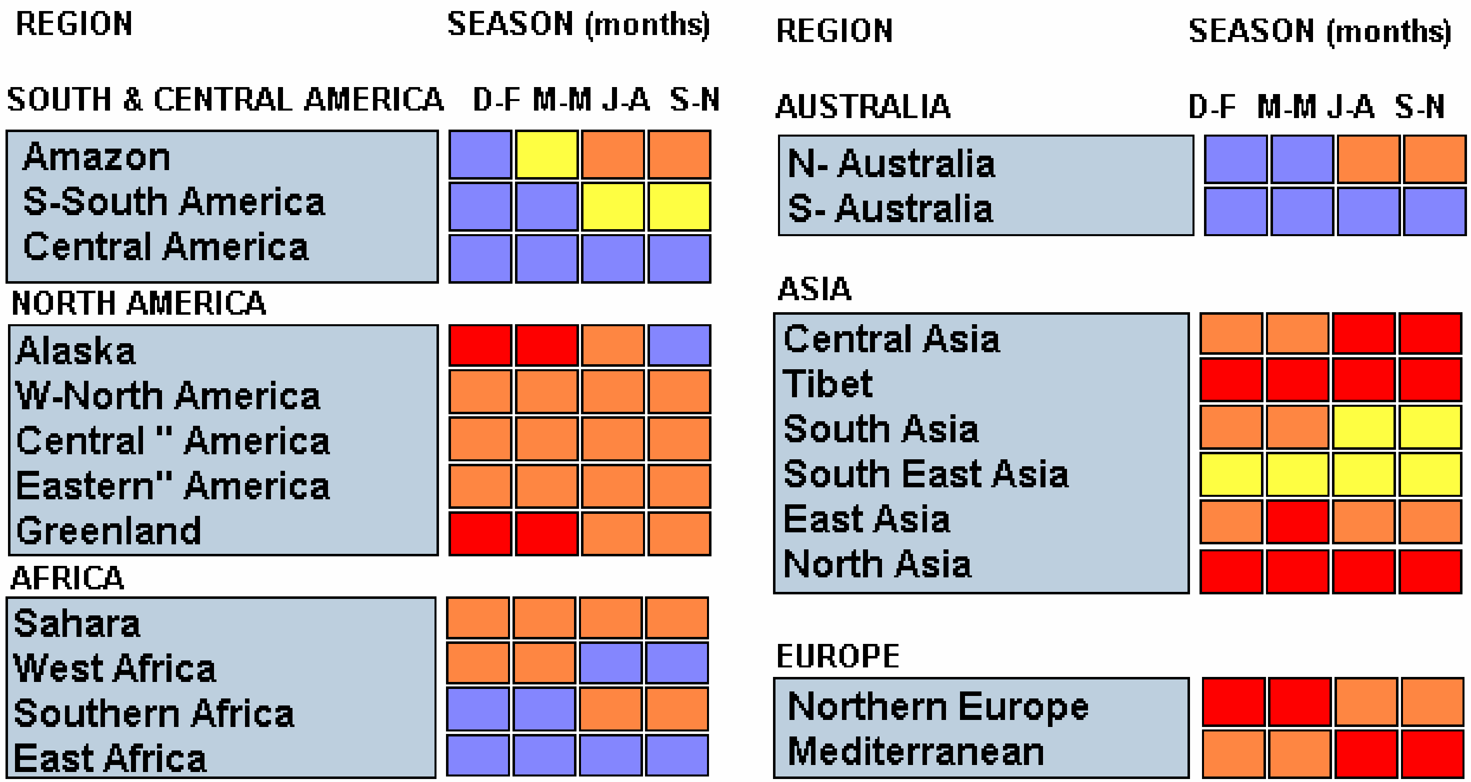
Temperature Variation 1000 - 2000 (Northern Hemisphere



Source: IPCC 2002

- Temperatures
- Precipitation
- Snow & Ice
- Sealevel Rise
- Extreme Events

Projected Temperature Changes by Regions (2100)



- Inconsistent
- Less than average warming
- Greater than average warming
- Much greater than average (> 40% higher than global average)

Modified from IPCC, 2002. Based on Intergovernmental Panel on Climate Change Simulation modelling www.ipcc.ch/pub/wg1TARtechsum.pdf

Water Quality – other flows & stuff
(see notes at end)

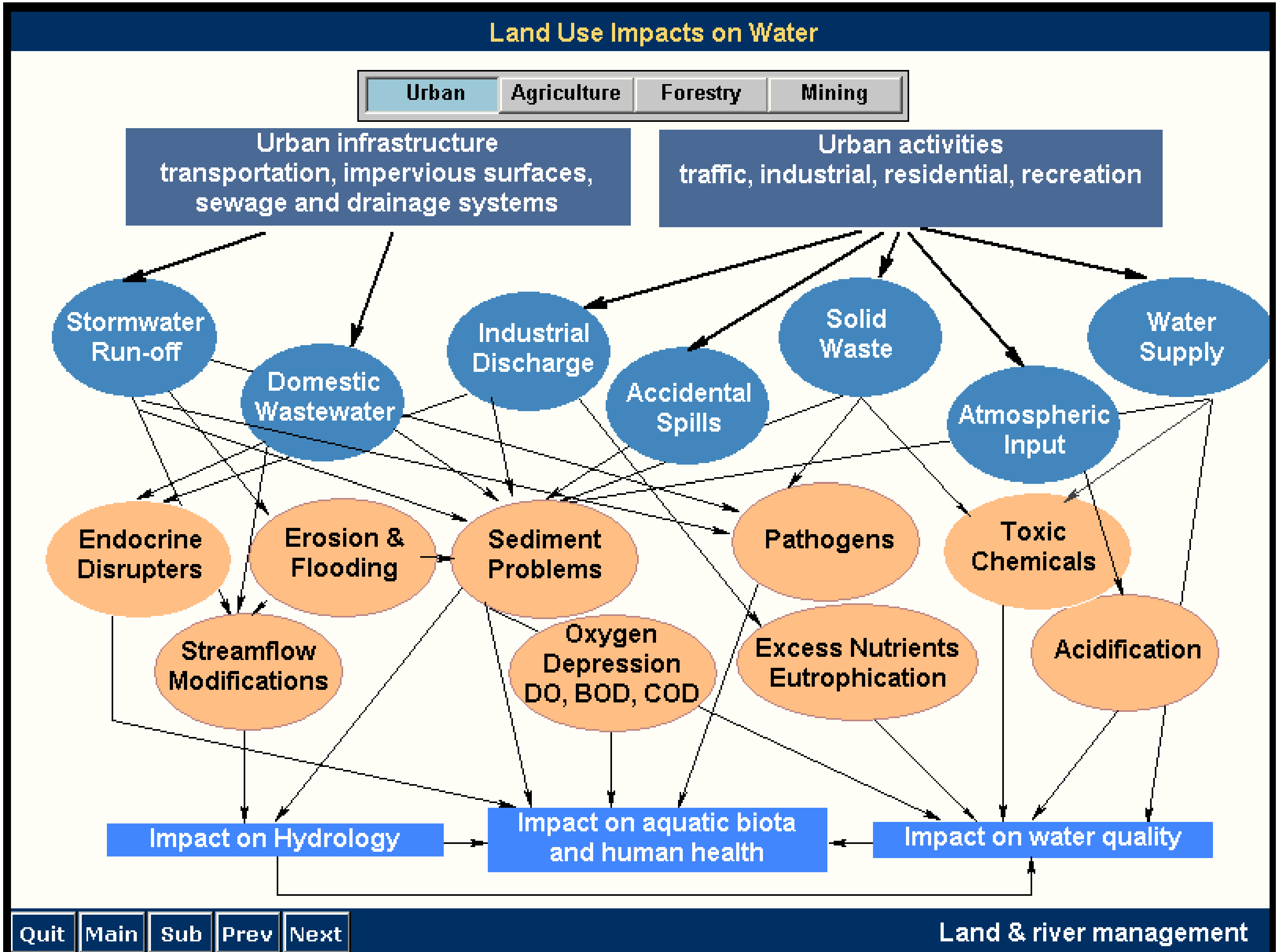
- Temperature
- Dissolved Oxygen - BOD
- Turbidity & TSS
- pH
- Phosphorous
- Faecal coliform (bugs)
- Toxic Metals
- Toxic Organic Compounds

So why do we need to know this stuff?

- Managing the environment requires a broad multi-disciplinary approach
- Everything is connected to everything else
- Push here and something happens over there
- Cumulative effects
- Environmental health & our health
- WE can stuff it up or WE can help put it right
  – buffers example coming up

Photo courtesy of USDA NRCS

Why?



Land Use Impacts on Water
Urban
Agriculture
Forestry
Mining
Urban infrastructure
transportation, impervious surfaces, sewage and drainage systems
Urban activities
traffic, industrial, residential, recreation
Stormwater Run-off
Domestic Wastewater
Industrial Discharge
Accidental Spills
Solid Waste
Atmospheric Input
Water Supply
Endocrine Disrupters
Erosion & Flooding
Sediment Problems
Pathogens
Toxic Chemicals
Streamflow Modifications
Oxygen Depression DO, BOD, COD
Excess Nutrients Eutrophication
Acidification
Impact on Hydrology
Impact on aquatic biota and human health
Impact on water quality
Quit
Main
Sub
Prev
Next
Land & river management

Why?

Water quality

Sources of water pollution
Water quality indicators
Human & ecosystem health

Human Health

Indicator	Source	Health Effect
Nitrate	Fertilizer and manure	Blue Baby Syndrome (Methemoglobinemia)
Pesticides	Direct application and leaching	Links with cancer and poisoning
Microbial	Manure	Diarrhea, Dysentery, Enteric fever

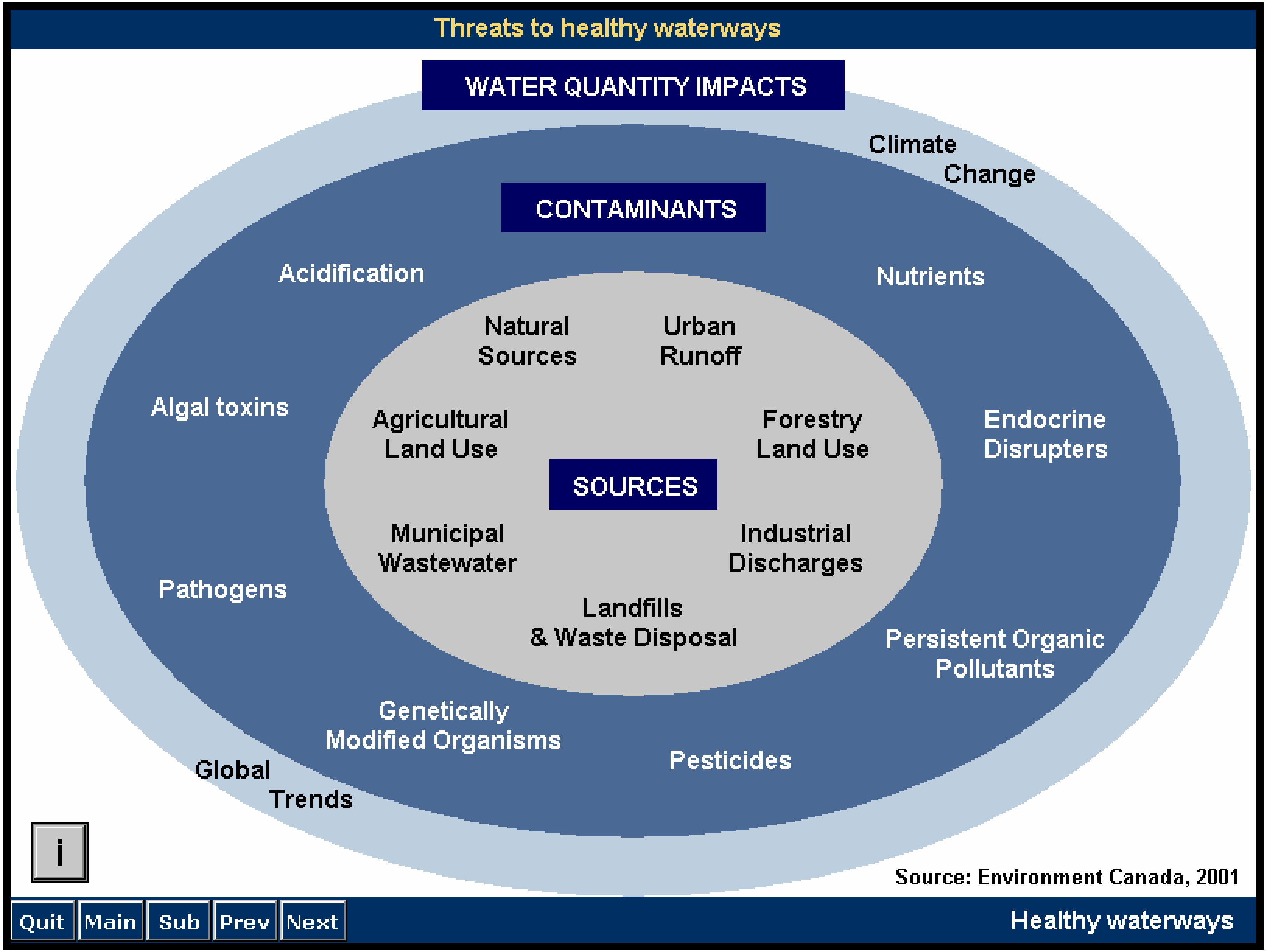
Ecosystem health

Indicator	Source	Health Effect
Nutrients	Fertilizer and manure	Eutrophication, anoxic conditions, decrease of oxygen, kills organisms, reduces food chain activities, and biodiversity
Pesticides	Direct application and leaching	Impacts food chain, reduces decomposition processes, affects aquatic life
Sediments	Soil erosion	Decreases light penetration, DO reduction (BOD)
Trace metals	In manure from feed supplements (Zn, Cu) and fertilizers (Cd)	Adsorbed to sediment released in water column

Quit | Main | Sub | Prev | Next

Land & river management

Management example - buffers



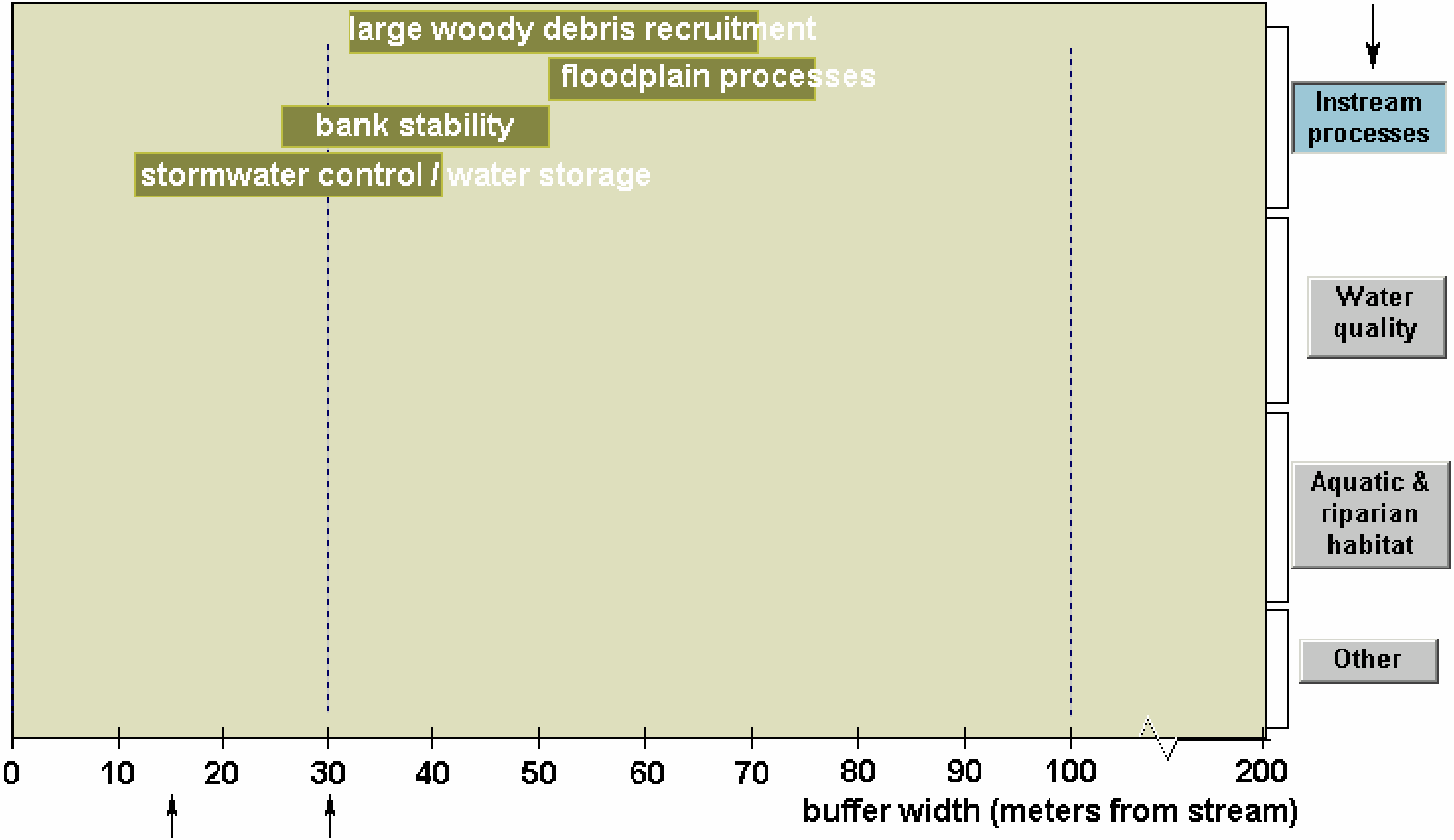
Buffers - one tool in the toolbox

Buffer design

Photos courtesy of USDA- NRCS

Green boxes represent the range of buffer widths, which studies have shown to maintain each of the associated buffer functions.

click to show functions



Common Standards

North American

New Zealand – no real standards

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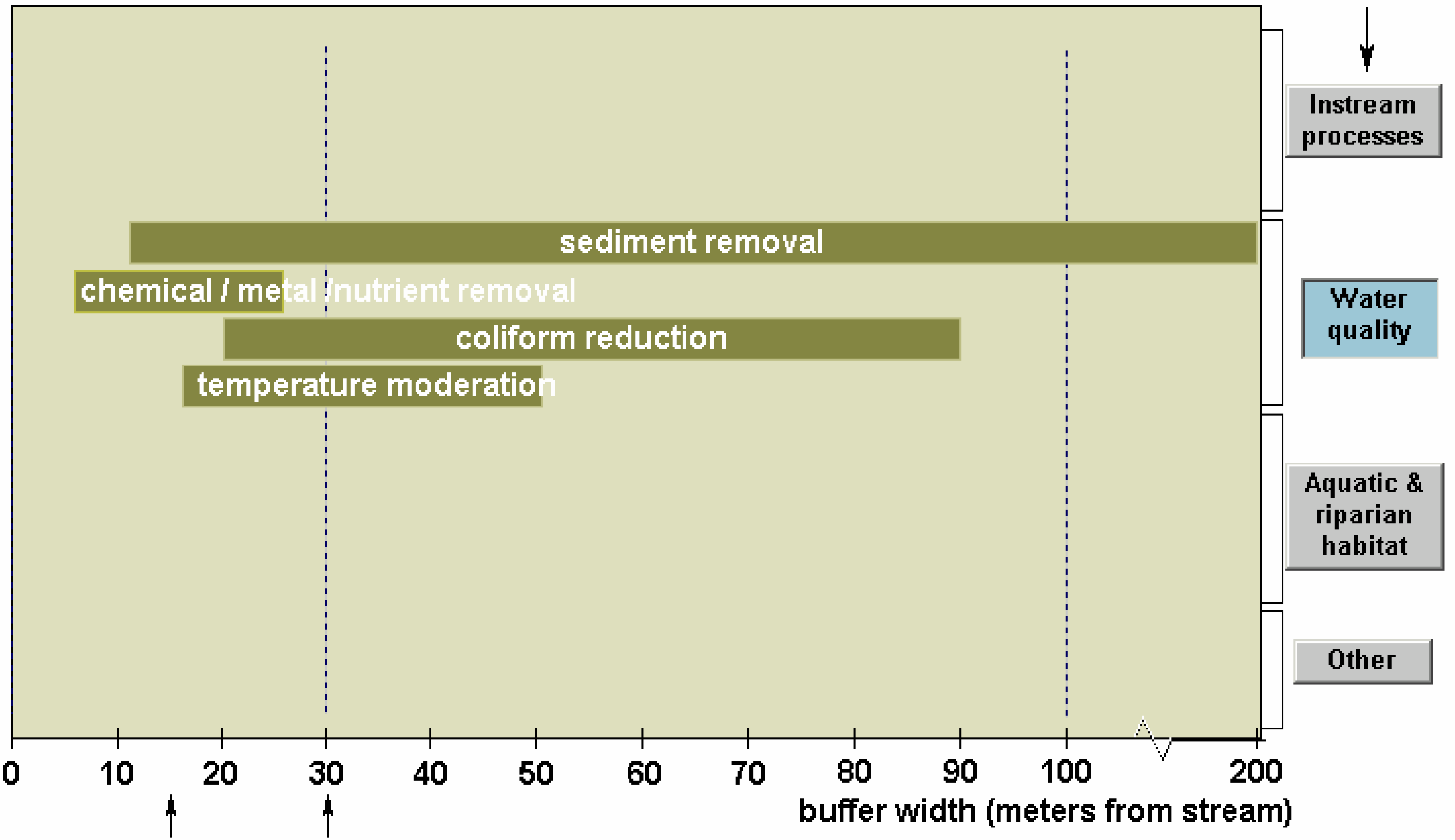

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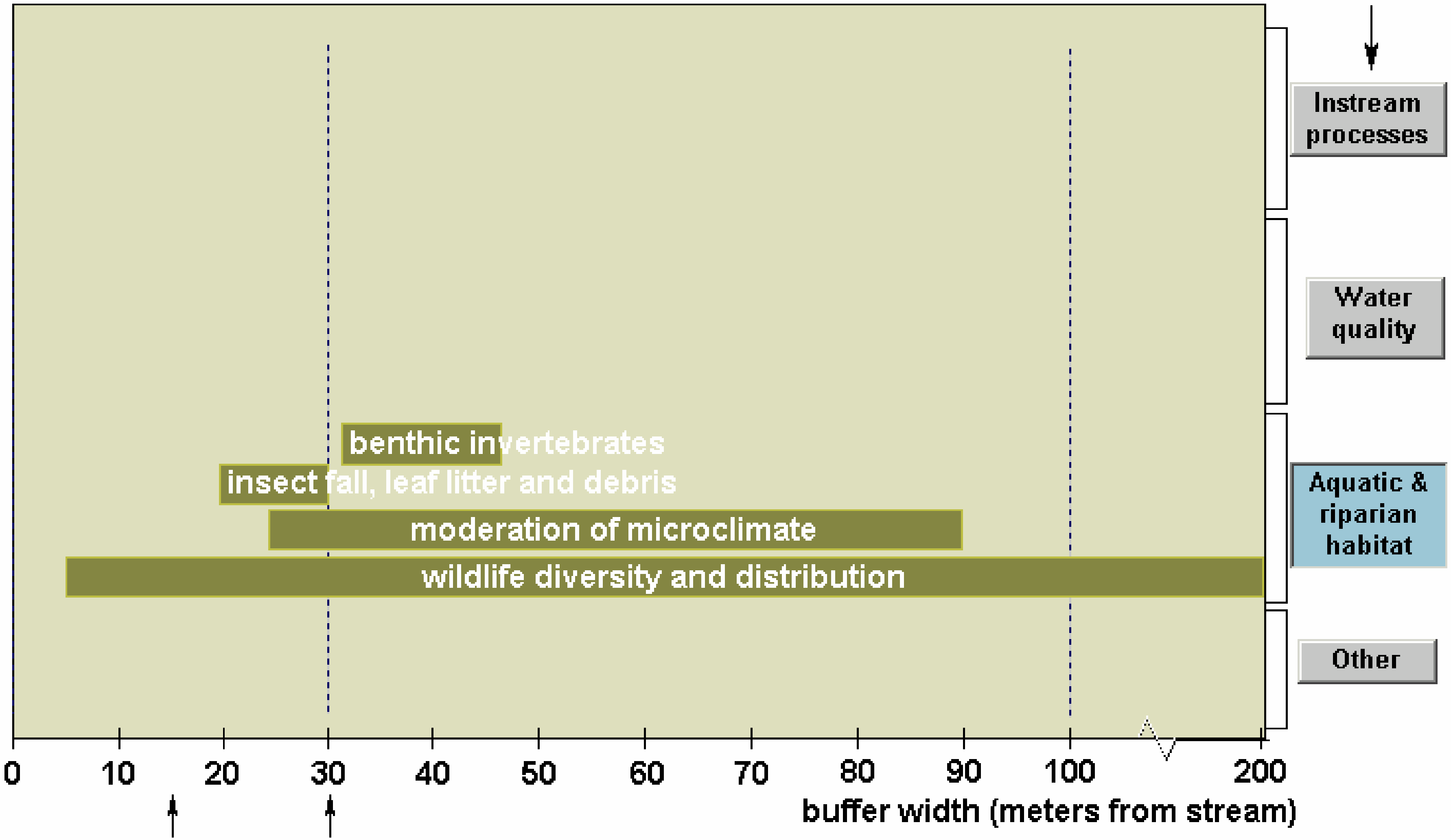

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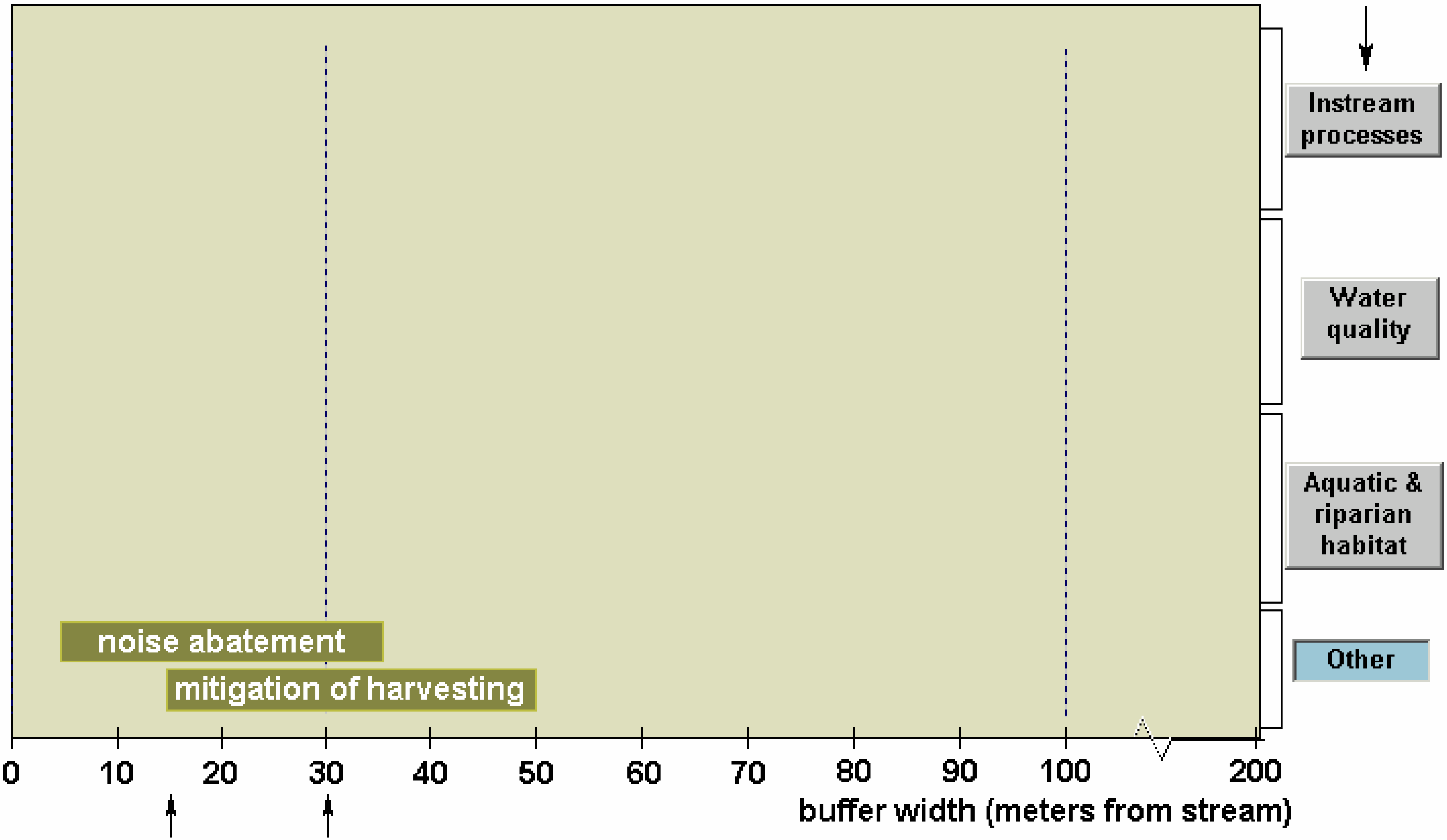


Common Standards

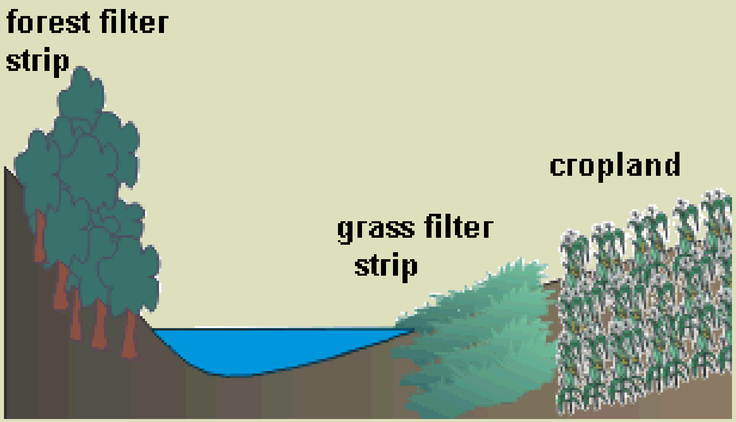
North American

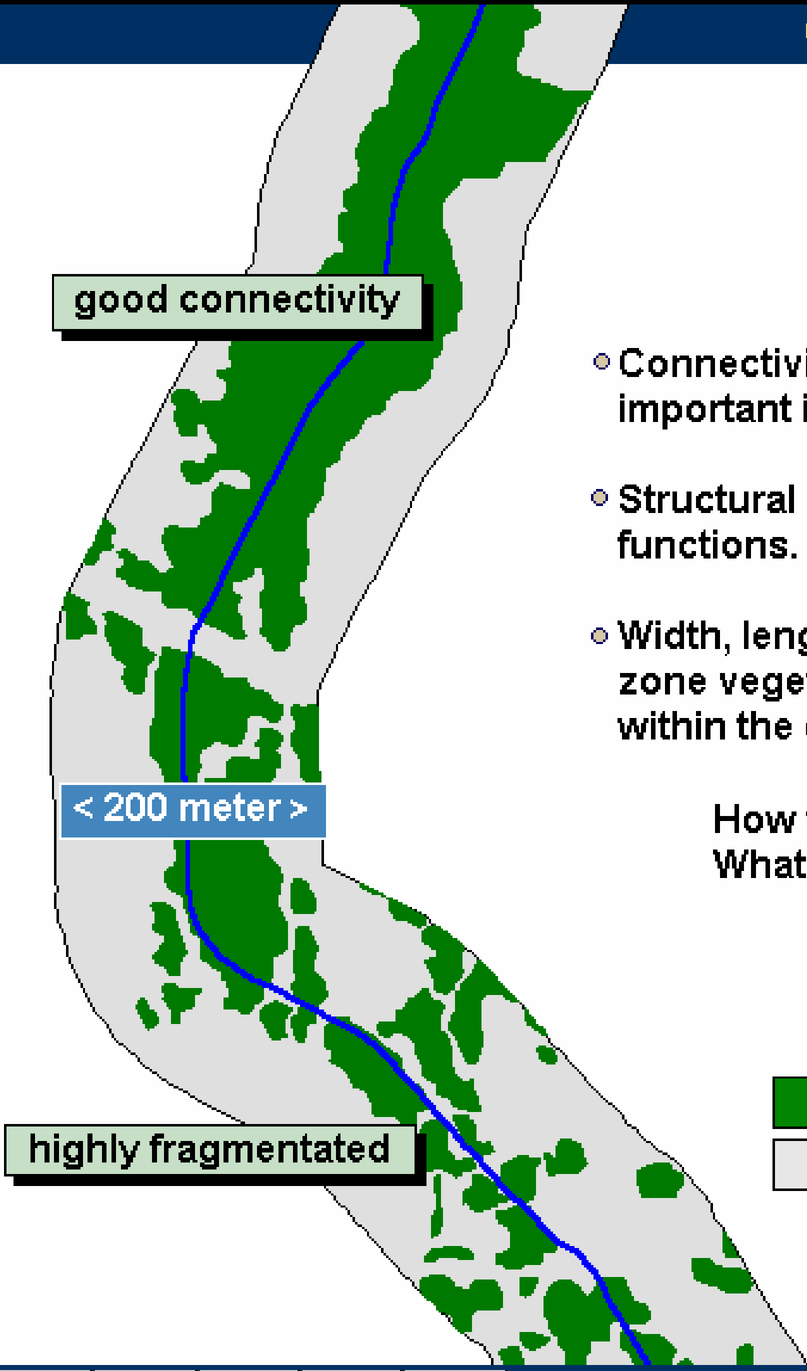
New Zealand – no real standards

Riparian buffers

areas of trees, shrubs and/or grass adjacent to streams, ponds, lakes and wetlands that provide multiple functions, from intercepting nutrients to providing wildlife habitat

Functions and Benefits	Limitations
Reduce sediment, organic material, nutrient and pesticide loads in surface runoff	Reduce area available for cropland
Reduce excess nutrients and pollutants that may seep into shallow groundwater flow	Trees shade adjacent crops
Provide food and habitat for terrestrial and aquatic wildlife	Falling branches and leaves can damage adjacent crops
Contribute structural and nutritional material to the stream	May harbour pests
Reduce the quantity of stormwater	
Moderate stream temperature	
Stabilize stream banks	
Provide recreational and educational areas	





- Connectivity and dimensions of the riparian buffer zone are important in designing effective buffer zones.
- Structural characteristics have a significant impact on corridor functions.
- Width, length, and connectivity of existing or potential buffer zone vegetation, for example, are critical to habitat functions within the corridor and adjacent ecosystems.

How wide and how long should the buffer zone be?
What if there are gaps in the buffer zone?

forest
non-forest

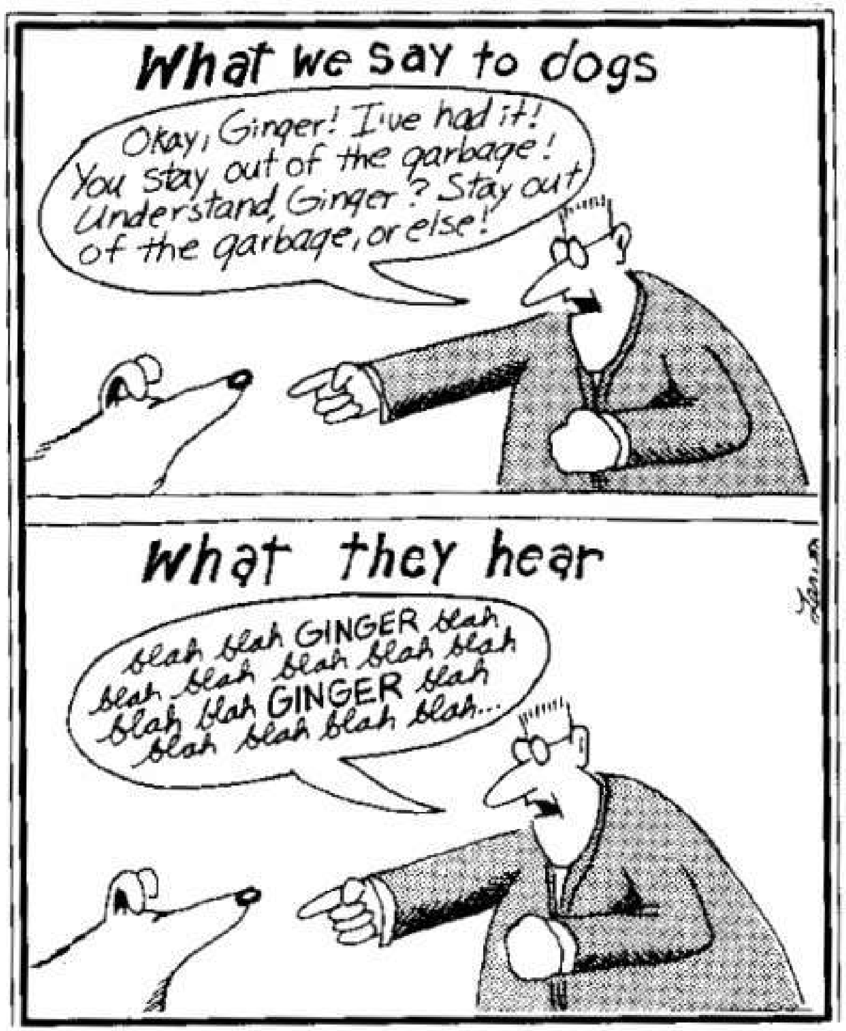
☐ design considerations

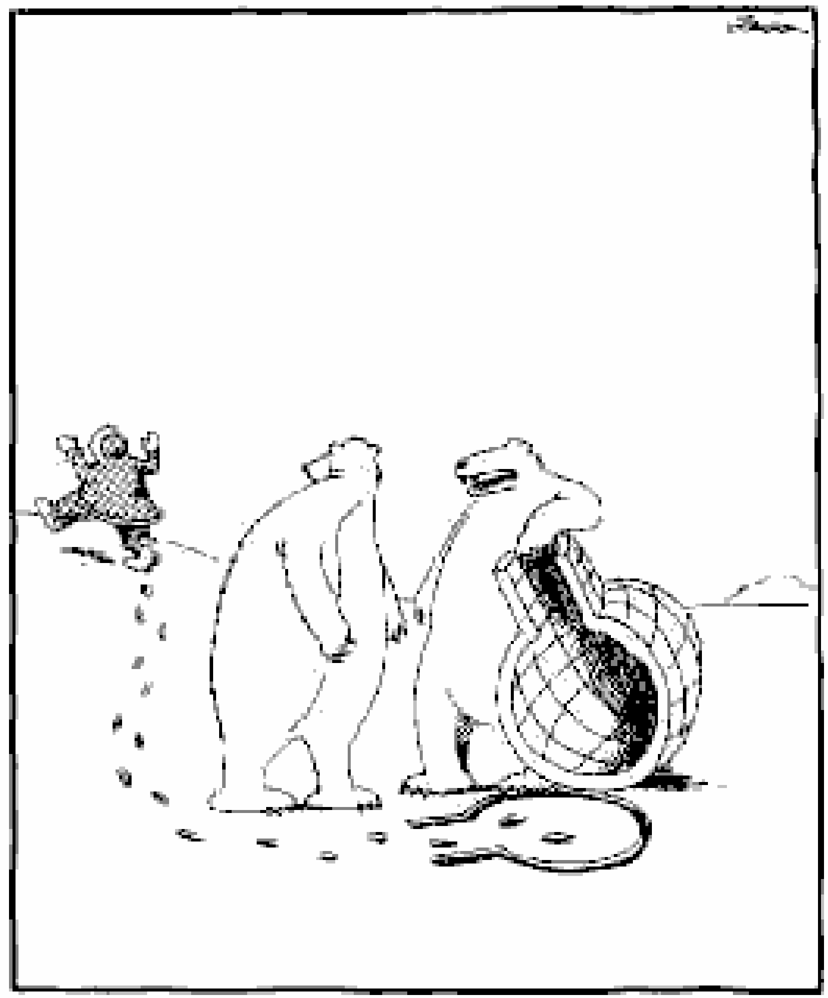
Design considerations for buffer width

- minimum width necessary to obtain desired functions
- amount and type of human activity allowed
- desired vegetative type, density and composition
- protection from adjacent high-intensity land uses
- expansion of the buffer to protect adjacent wetlands, flood plains, erodible soils or other sensitive land features
- water bodies to provide with buffers (size, class, and type of water body)
- variances allowed from buffer requirements
- allowances for reduced buffer widths in exchange for other amenities
- allowances for buffer averaging
- site conditions: buffer slope, vegetation, soils and other features
- nature of stormwater flow from adjacent land uses. (sheet flow desired)
- cost versus benefits: land put into a buffer is land lost to crop production - the costs of various width requirements should be carefully weighed against the anticipated benefits including the cost of administering and maintaining the buffer program

☑ design considerations

Until next time….





"I lift, you grab. ... Was that concept just a little too complex, Carl?"


"One good conversation can shift the direction of change forever"
- Linda Lambert
(Author & founder of Center for Educational Leadership
at California State University)

Water Quality - *Phosphorus*

- Essential nutrient for growth/metabolic reactions of plants and animals
- Common aquatic form - phosphate (PO4-P).
- Typically limit availability
- Artificially introduced through detergents, human, animal & industrial wastes, fertilizers
- Rapidly absorbed by algae and aquatic plants.
- Small increase can have big effects
  - Algae blooms
  - Low DO
  - Fish death

- Excess phosphorus causes extensive algal growth called "blooms." - ***cultural eutrophication-*** human-caused enrichment of water with nutrients (usually phosphorus
- Primary cause of most eutrophication today.

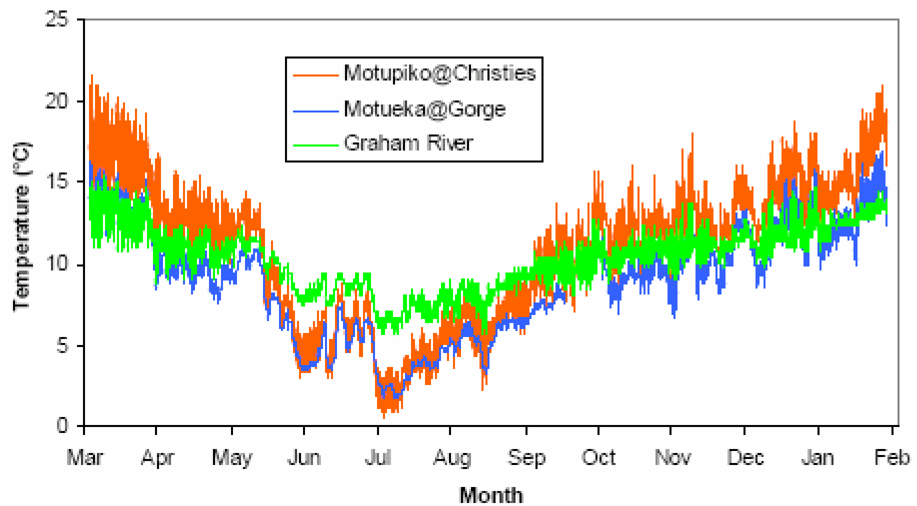
- Shallow lakes and impounded river reaches, where the water is shallow and slow-moving, are the most vulnerable to cultural eutrophication

Water Quality - *Temperature*

The main concerns with water temperature are the effects of high temperatures on aquatic life.

Some species will only tolerate relatively cool water and may become stressed or die if temperatures become too high.

Trout will cease feeding once temperatures climb above 19°C and they will begin to die once temperatures climb above 25°C for a sustained period. Trout cannot tolerate temperatures above 30°C for even a short period.



Yearly changes in water temperature at three contrasting sites in the Motueka River catchment. Temperature recorded every hour March 2001 to February 2002.

Thermal Pollution

- Increases in photosynthesis and plant growth

  leads to:
- Additional plants which eventually die and are decomposed by oxygen-consuming bacteria.

  which leads to:
- Increased need for oxygen in the water (biochemical oxygen demand) which reduces oxygen available for other species.

  which leads to:
- warm-water organisms begin to replace cool-water species

Water Quality - *Dissolved Oxygen*

- Essential for the maintenance of healthy streams and rivers.
- High DO considered an indicator of healthy, stable ecosystems.
- Primary comes from the atmosphere through physical mixing at the air—surface water interface.
- Algae and rooted aquatic plants also release oxygen into streams and lakes through photosynthesis

- Physical influences, such as volume of discharge and water temperature, directly affect oxygen concentration.
- DO levels rise with increased mixing rates as well as with decreasing temperature.
- Main factor contributing to significant changes is the build-up of organic wastes from sewage discharges, urban and agricultural runoff, and other industrial sources.
- Fertilizer residue in urban and agricultural runoff stimulates the growth of algae and other aquatic plants.

Dissolved Oxygen cont.

- As plants die, aerobic bacteria consume oxygen as process of decomposition.
- Depletions in DO causes major shifts in the kinds of aquatic organisms found in water bodies.
- Low DO tolerant organisms begin to dominate
- Algae and anaerobic organisms might also become abundant in waters with low levels of DO.

Biochemical Oxygen Demand (BOD)

- BOD - measure of the quantity of oxygen used by macro-invertebrates and bacteria in the aerobic oxidation of organic matter in streams.

- Increasing BOD levels, associated with increases in aerobic bacteria results in increased consumption of DO & little DO is then available for other aquatic organisms.

Human activities that increase BOD:

- **Point sources** contaminants are industrial/manufacturing discharges, food-processing industries, and wastewater treatment plants.

- **Nonpoint sources** include urban runoff that carries animal wastes from streets and sidewalks, nutrients from lawn fertilizers, leaves, grass clippings from residential areas.

Water Quality - *Turbidity & TSS*

- Turbidity - measure of the relative clarity of water.
- The result of suspended solids in water that reduce the transmission of light.
- The nature of total suspended solids (TSS) varies, depending upon the source of the material – erosion, urban stormwater runoff, industrial waste,sewage.

Higher levels of turbidity =

- Decreased diversity of aquatic organisms.
- Higher temperatures as TSS absorb heat from sunlight.
- Decreases in Photosynthesis as less light penetrates the water,
- Decreases in oxygen content.

- Combination of warmer water, less light, and oxygen depletion makes it impossible for some forms of aquatic life to survive.

- TSS can clog fish gills, reduce growth rates, decrease resistance to disease, and prevent egg and larvae development.

- Particles of silt, clay, and organic materials can settle on bottom, especially in slower-moving rivers and streams and smother the eggs of fish and aquatic insects/suffocate newly hatched larvae.

Water Quality - *Fecal Coliform*

- Bacteria found in the faeces of humans and other warm-blooded animals.
- Enter rivers through direct discharge of agricultural and storm runoff carrying animal waste, and from human sewage discharged into the water.
- Faecal coliform bacteria by themselves are not pathogenic.
- Pathogenic organisms that cause diseases and illnesses – bacteria, viruses and parasites - are found attached to/along with faecal coliform bacteria.