LECTURE 8:
MAY 20, 2014

ECOSYSTEMS AND MATTER CYCLING

HUMAN ACTIVITY & IMPACTS

Text Reference: Dearden and Mitchell (2012), Ch. 4, pp. 135-149

Outline

- Upcoming:
  - **May 22 (Thursday):**
    - Field Trip (Bare Point Water Treatment Plant)
    - (To be confirmed)
  - **May 26 (Monday) CHANGE:**
    - Midterm exam

Source: Dearden and Mitchell (2012)

- Today:
  - (lecture) human activities and their impacts on the hydrological and biogeochemical cycles

Recap from last class

- Biogeochemical Cycles (gaseous and sedimentary cycles for C, N, P, S)
- Hydrological Cycle

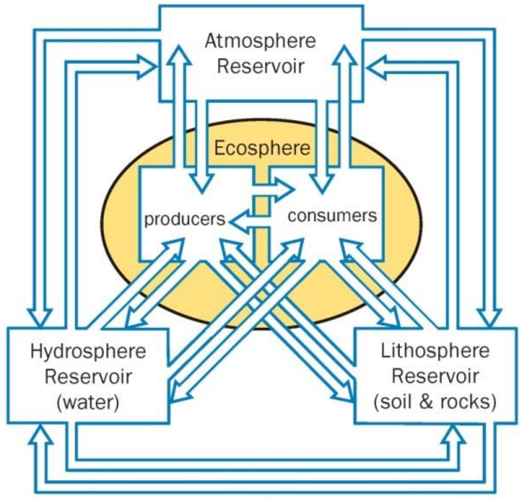


Figure 4.1 | Each nutrient is stored and released by components of the Earth's systems. Different nutrients follow slightly different paths through the systems and are stored and released at different rates.

Source: Dearden and Mitchell (2012)

Carbon Cycle – key terms / concepts

1. **<u>photosynthesis</u>**:
2. **<u>respiration</u>**:
3. C incorporated into the 'food chain';
4. residence times of C in the biosphere vary (naturally);

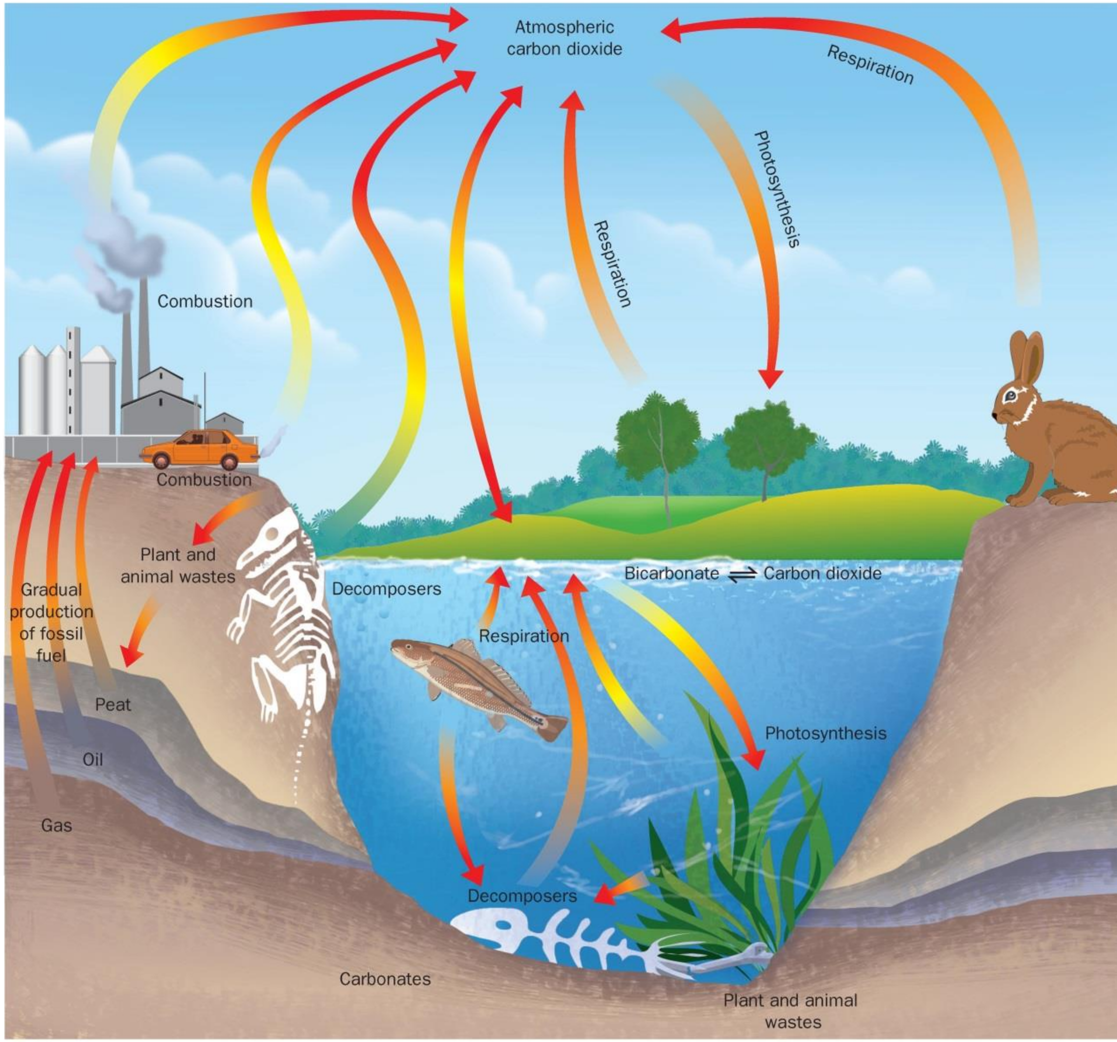


Figure 4.7 | The carbon cycle.

Source: Dearden and Mitchell (2012)

Hydrological Cycle – key terms / concepts

- precipitation
- interception
- evaporation
- evapotranspiration
- infiltration (to gdw)
- condensation (onto 'condensation nuclei') and forms clouds

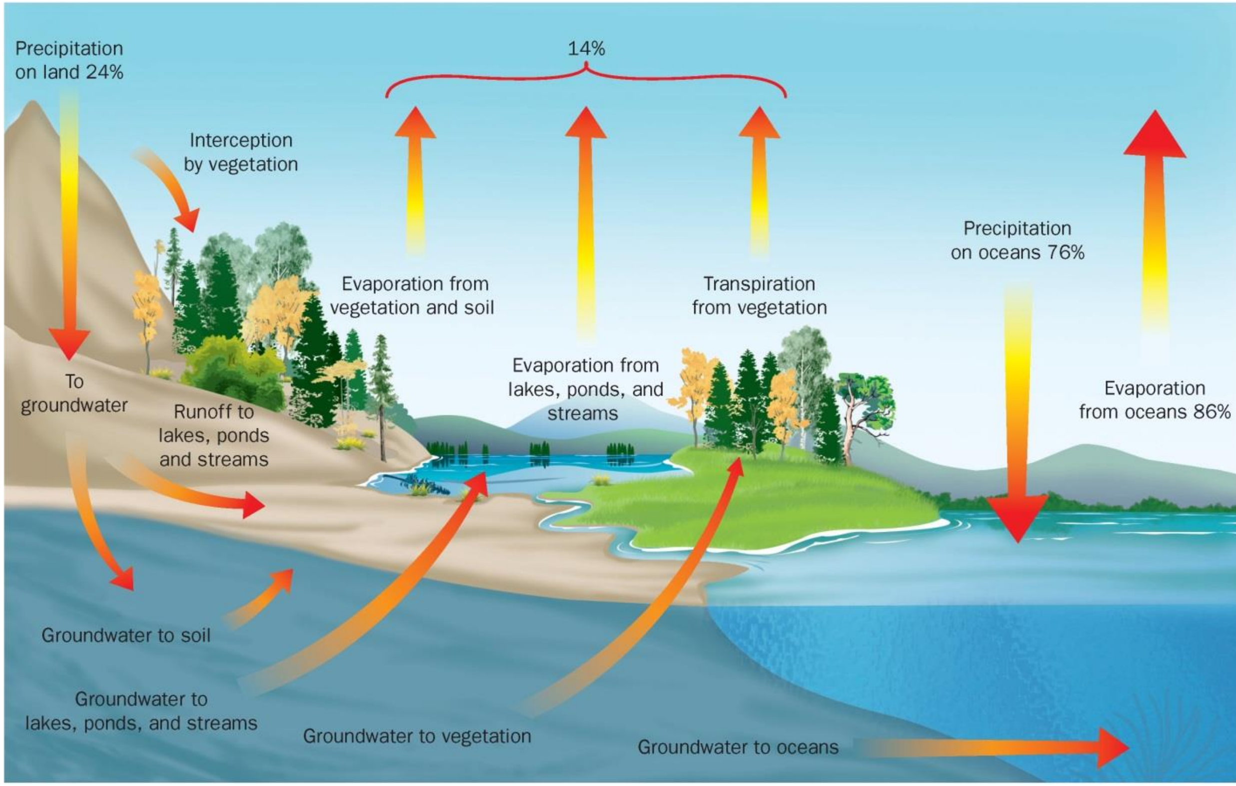


Figure 4.8 | The hydrological cycle. Water moves through the hydrological cycle as a liquid, as a vapour, and as snow.

Source: Dearden and Mitchell (2012)

Groundwater Flow – key terms / concepts

** Augment with board sketch **

- water table
- aquifer
- permeability
- recharge zone
- confined vs unconfined aquifers
- piezometric surface
- artesian well

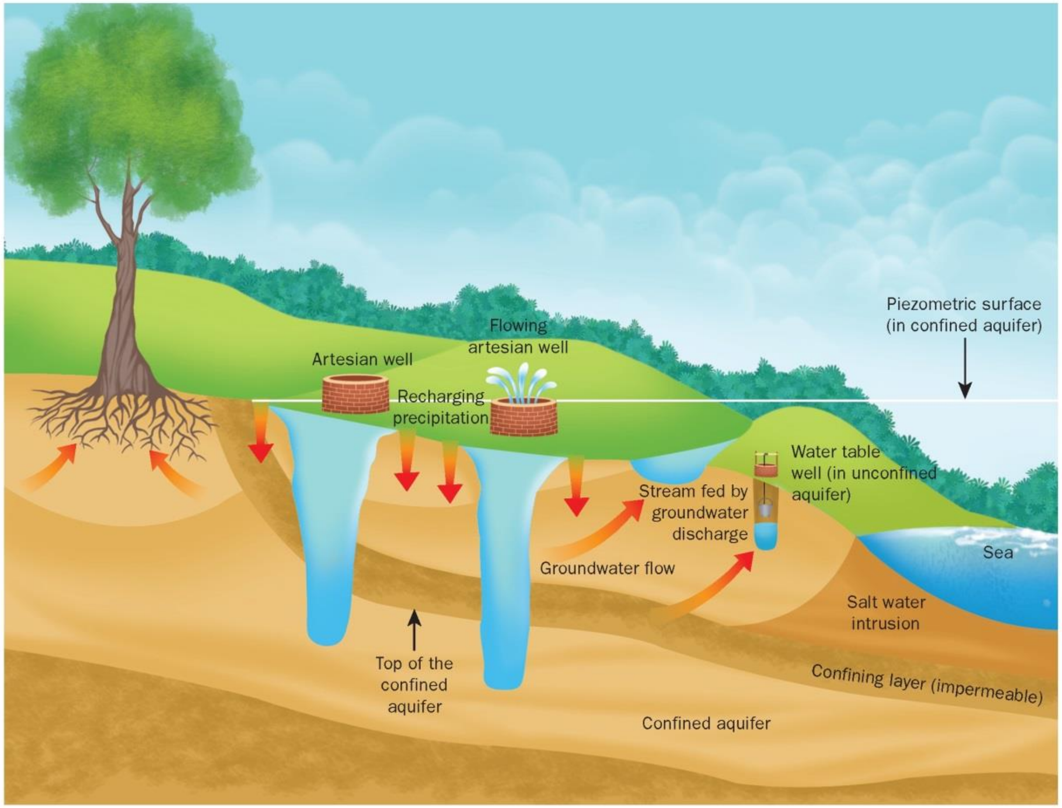


Figure 4.9 | Groundwater flow.

Source: Dearden and Mitchell (2012)

Source: Dearden and Mitchell (2012)

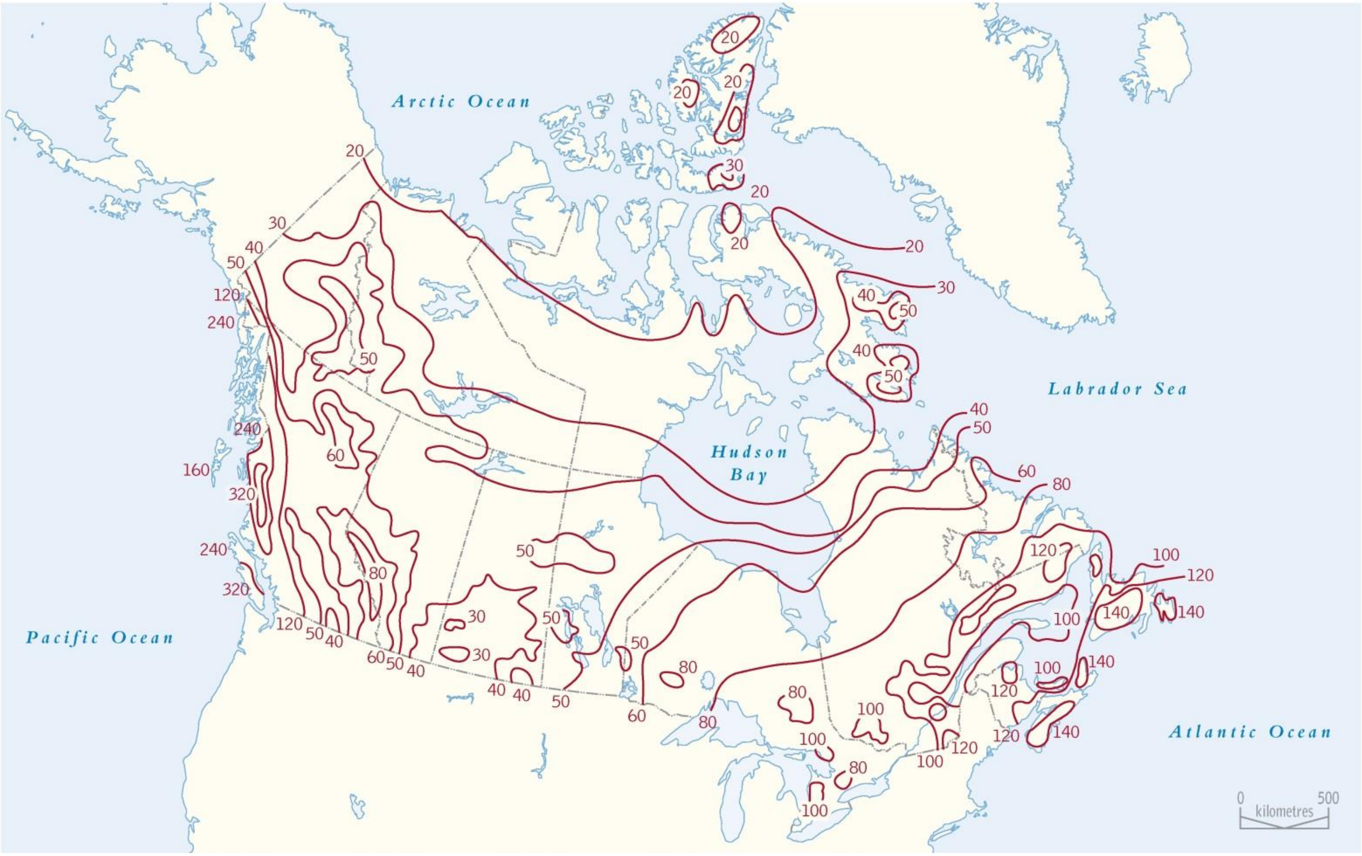
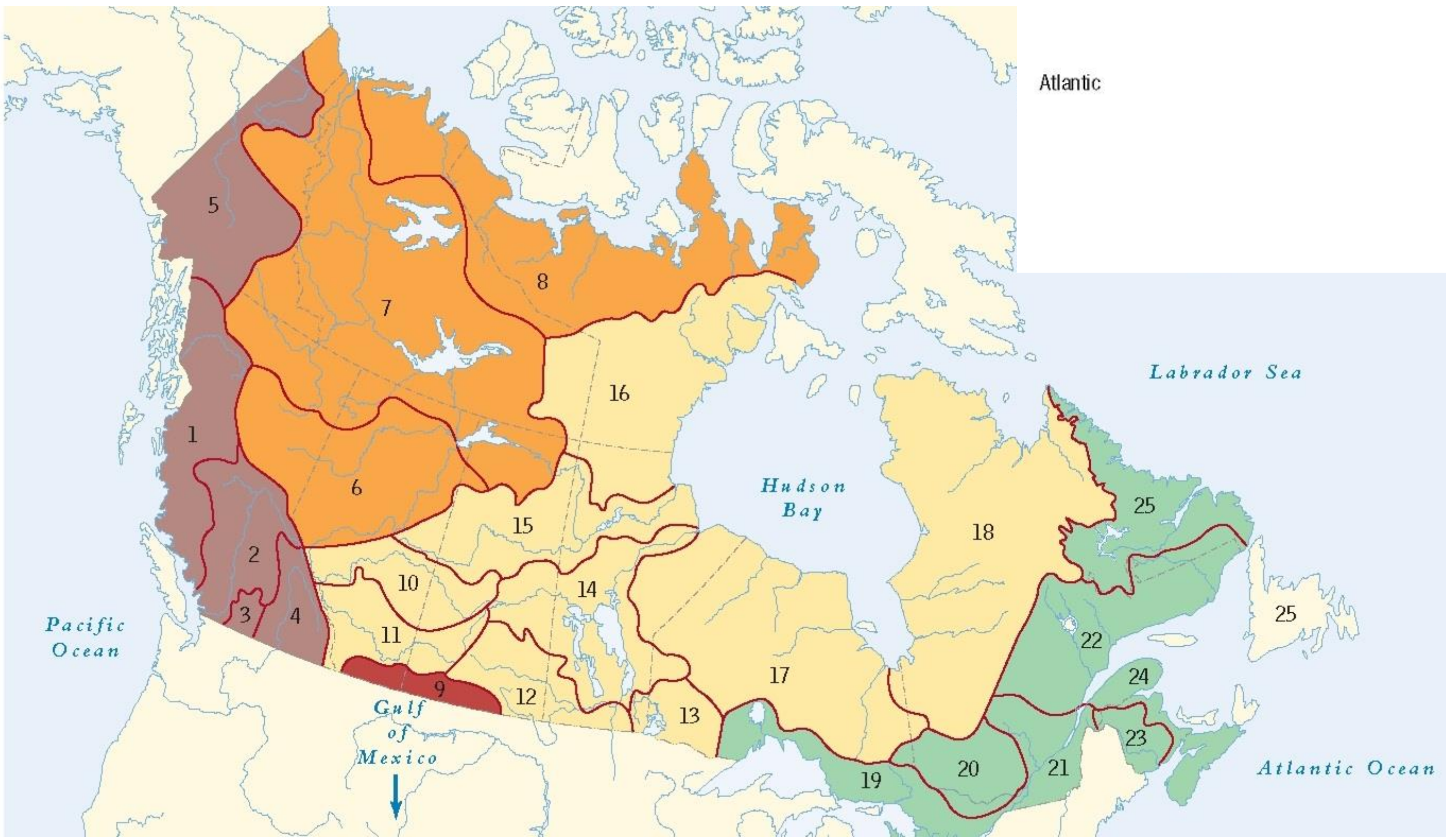


Figure 4.10 | Average annual rain and snow for Canada (cm). *Source: Phillips (1990: 210).*

- maritime areas wetter – especially West Coast
- low precipitation in Prairies
- “polar desert”

Drainage Basins
(*aka* Watersheds)

Ocean Basin Region		River Basin Region
Pacific	1	Pacific Coastal
	2	Fraser-Lower Mainland
	3	Okanagan-Similkameen[a]
	4	Columbia[a]
	5	Yukon
Arctic	6	Peace-Athabasca
	7	Lower Mackenzie
	8	Arctic Coast–Islands
Gulf of Mexico	9	Missouri[a]
Hudson Bay	10	North Saskatchewan
	11	South Saskatchewan[a]
	12	Assiniboine-Red[a]
	13	Winnipeg[a]
	14	Lower Saskatchewan–Nelson
	15	Churchill
	16	Keewatin
	17	Northern Ontario
	18	Northern Quebec
Atlantic	19	Great Lakes[a]
	20	Ottawa
	21	St Lawrence[a]
	22	North Shore–Gaspé
	23	St John–St Croix[a]
	24	Maritime Coastal
	25	Newfoundland-Labrador



Source: Dearden and Mitchell (2012)

Outline

- Impacts on hydrological cycle
- Impacts on biogeochemical cycles
  - Eutrophication
  - Acid Deposition
  - Climate Change (chapter 7 → next week).
- What has happened; what can we do (have we done to date?)

Human Impacts on the Hydrological Cycle

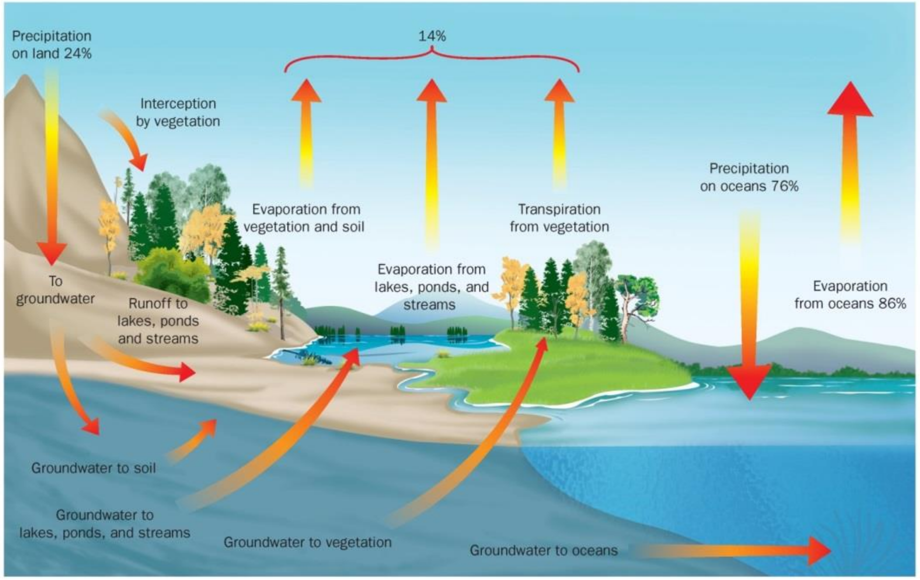


Figure 4.8 | The hydrological cycle. Water moves through the hydrological cycle as a liquid, as a vapour, and as snow.

Source: Dearden and Mitchell (2012)

1. Storage and redistribution of surface runoff for domestic, agricultural and industrial uses;
2. Storage structures to control floods (dams, floodways);
3. Drainage of wetlands;
4. Groundwater pumping;
5. Land use changes (e.g., deforestation, urbanization) that pathways alter patterns of runoff and evapotranspiration;

Impacts on biogeochemical cycles (preamble)

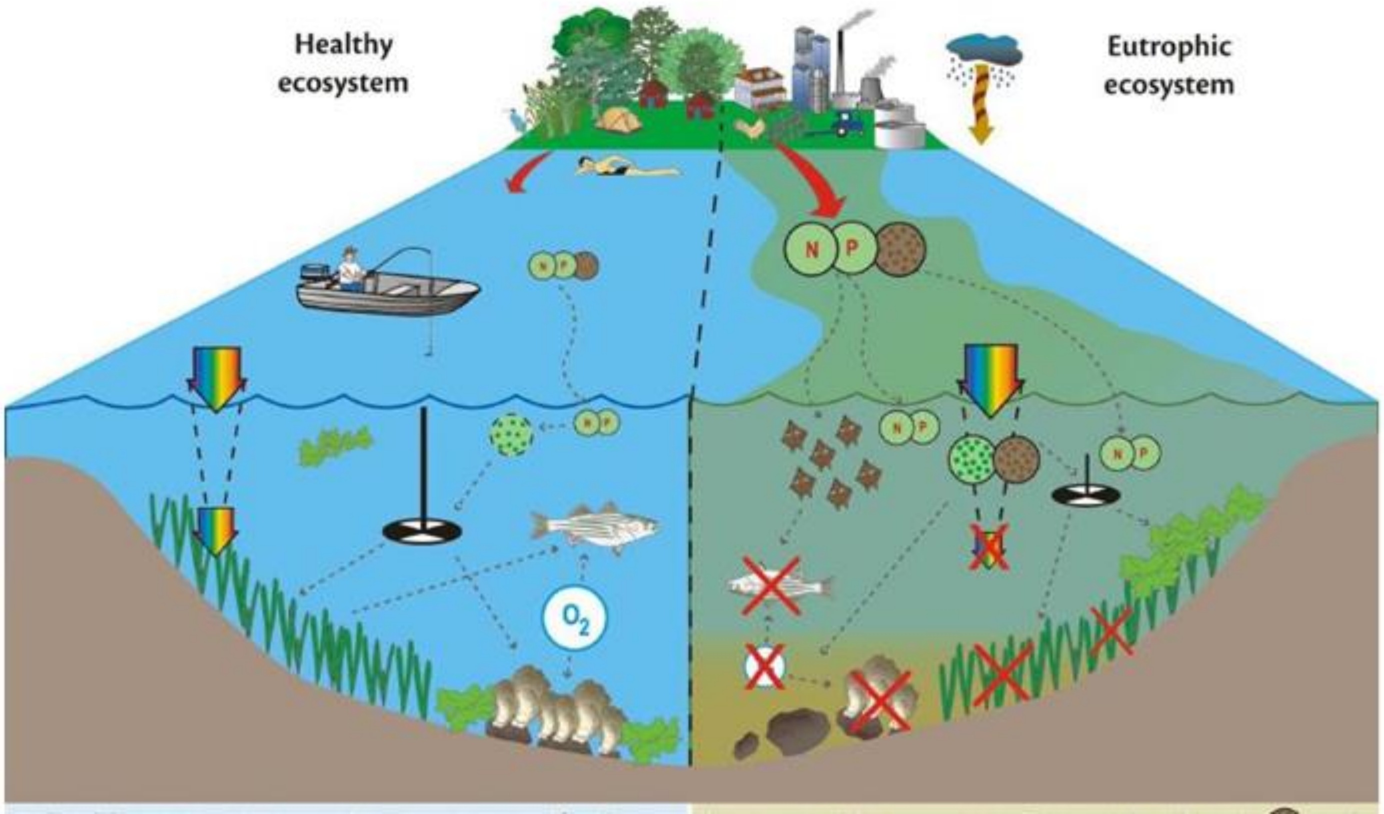
- Society could not exist without biogeochemical cycles and the bacteria that help them work
- All of the cycles are susceptible to disturbance by human activity
- Major transfers between ***some*** of the reservoirs in the cycles are human-induced
- Some of the most notable and difficult environmental challenges now faced by society derive from these transfers

Will explore 3 key impacts on biogeochemical cycles:

- Eutrophication;
- Acid Deposition;
- Climate Change

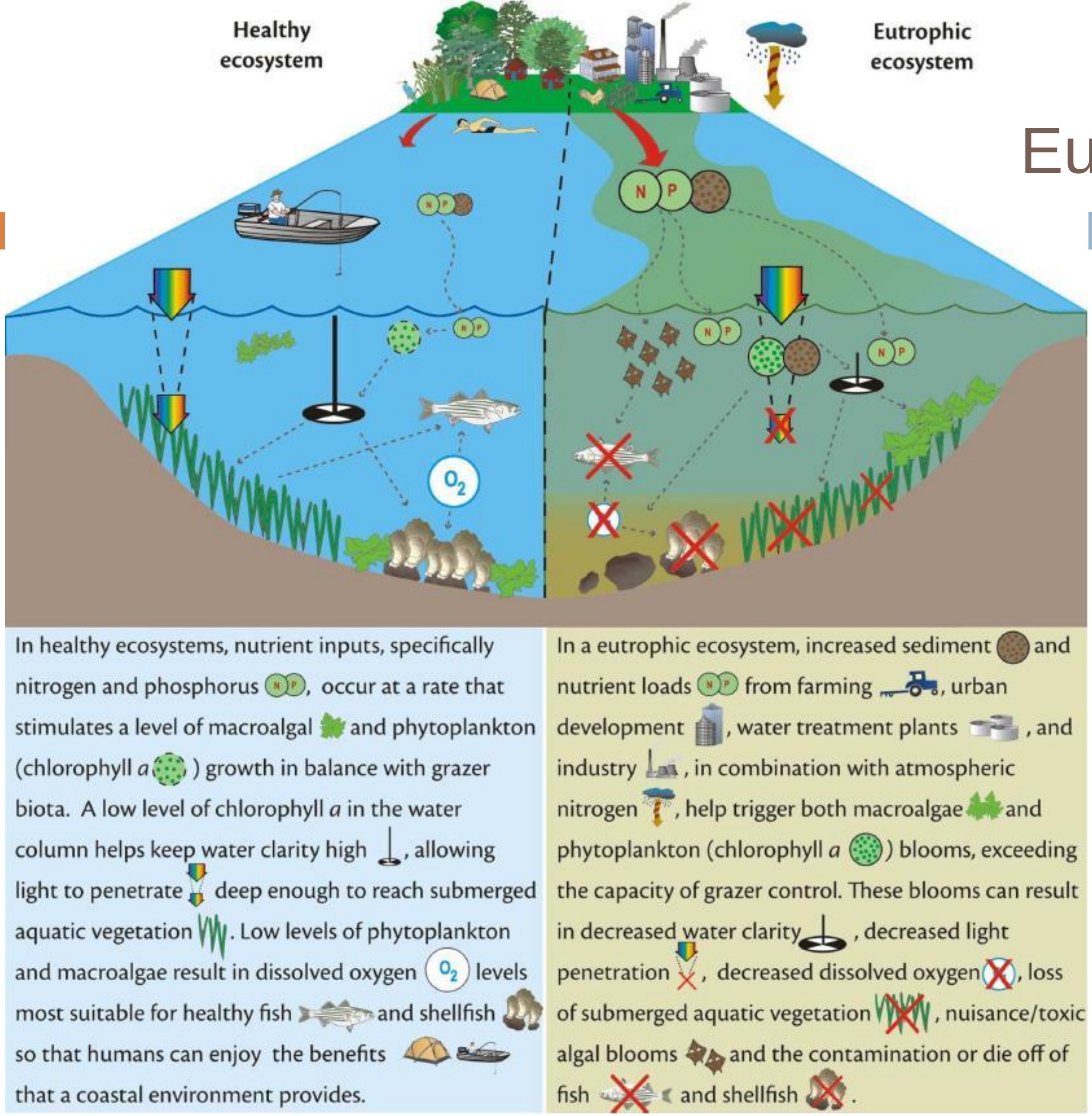
Eutrophication

- Natural process of nutrient enrichment in water bodies → greater productivity;
- P and N are often two main growth-limiting nutrients;



From Environment Canada (2011) but adapted by EC from Bricker et al. (2007)

Eutrophication



From Environment Canada (2011) but adapted by EC from Bricker et al. (2007)

Table 4.5 | Characteristics of Oligotrophic and Eutrophic Water Bodies

Characteristic	Oligotrophic	Eutrophic
Nutrient cycling	low	high
Productivity (total biomass)	low	high
Species diversity	high*	low
Relative numbers of 'undesirable' species	low	high
Water quality	high	low

*Lakes that are extremely non-productive (e.g., high mountain lakes) will have low species diversity.

Source: Dearden and Mitchell (2012)

- **Oligotrophic** systems: **low** nutrient levels
- **Eutrophic** systems: **high** nutrient levels
- **Mesotrophic** systems: **intermediate** nutrient levels

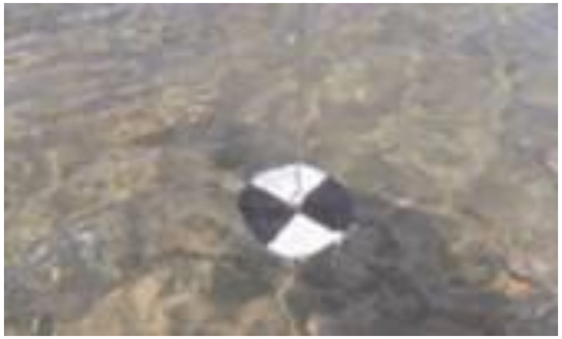
Water Quality Issues

Government of Canada Gouvernement du Canada

Environment Canada

- Nutrients (phosphorus and nitrogen)

  → Eutrophication … 3 of 5 levels shown below…

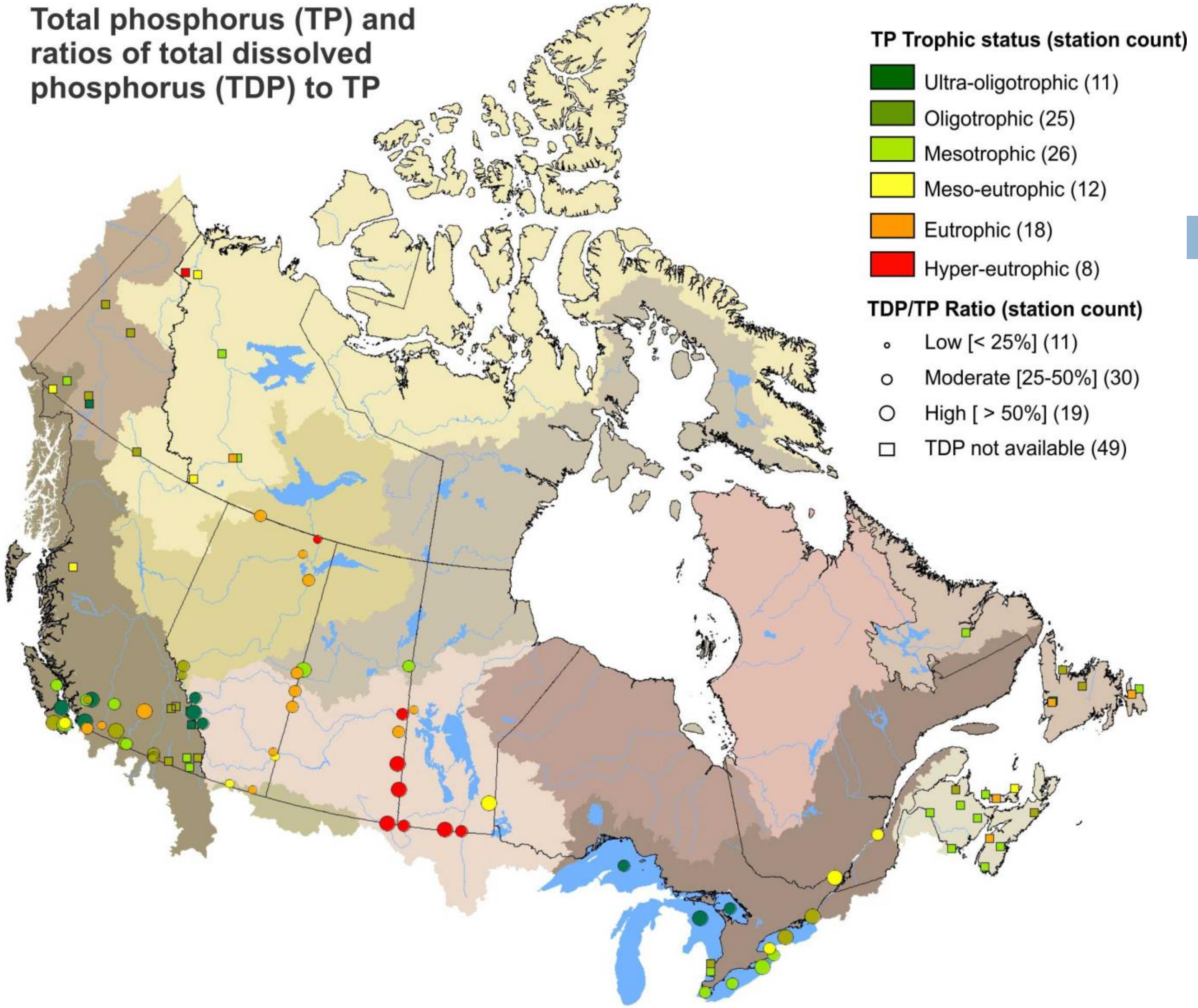


"Ultra-oligotrophic"
total phosphorus <0.004 mg/L
low nutrients, low plant growth
high water clarity

"Mesotrophic"
total phosphorus 0.01 – 0.02 mg/L
moderate nutrients/plant growth
reduced water clarity

"Eutrophic"
total phosphorus 0.035-0.100 mg/L
high nutrients/plant growth
very limited water clarity

Environment Canada "*Phosphorus in Canada's Aquatic Ecosystems*"
www.ec.gc.ca/



Concentration levels of total phosphorus (TP) and ratios of total dissolved phosphorus (TDP) to TP in rivers and the Great Lakes, Canada, 2004 to 2006. From Environment Canada. *** Note that some areas have naturally low or high levels of phosphorus.***

Causes of Eutrophication

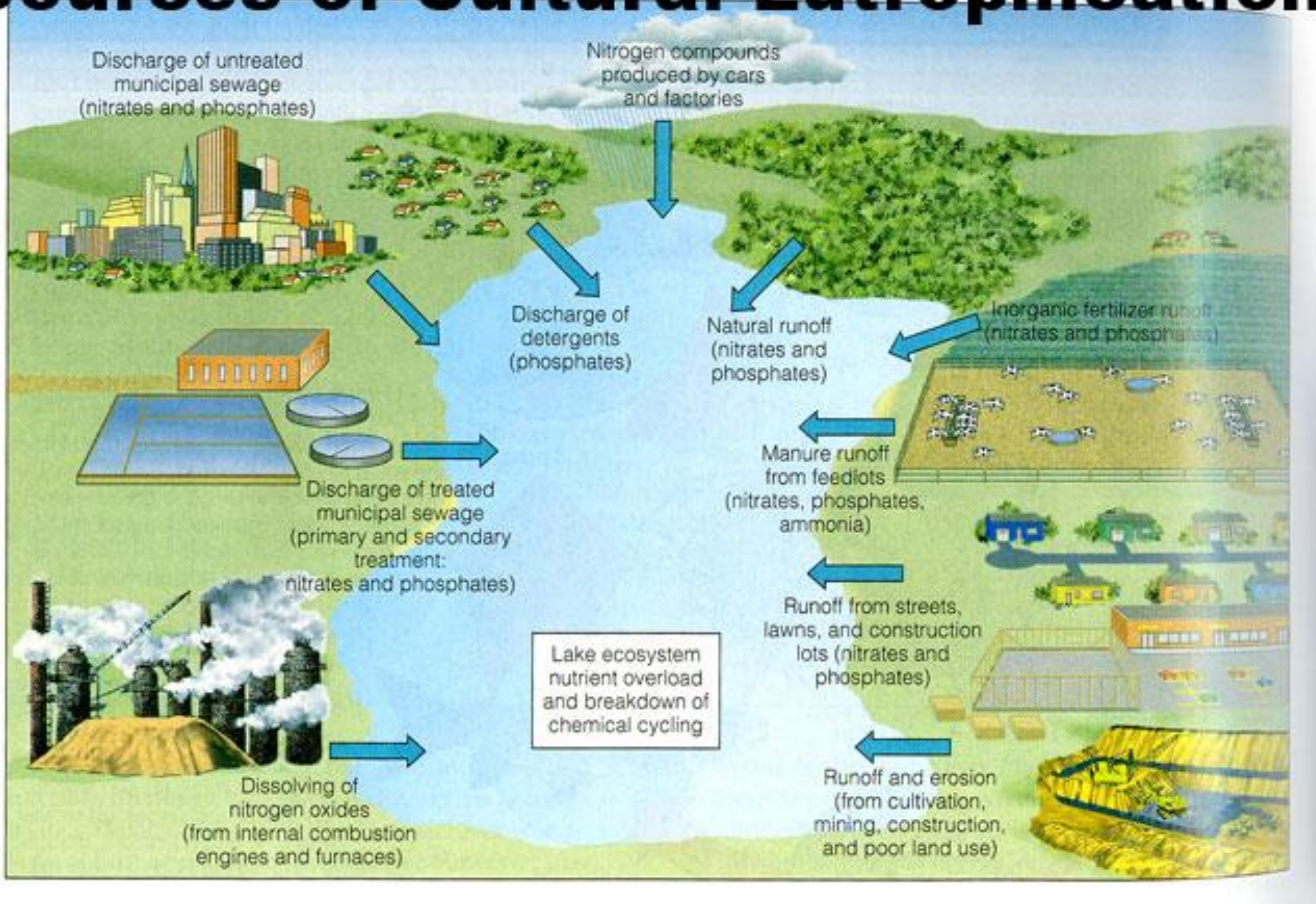
- Enhancement of a **naturally-occurring process** (cultural or human-induced eutrophication)
  - Via the addition of phosphates and nitrates to water bodies;
  - Approx. 8 times (the natural amounts) of these enter the oceans annually;

Table 4.6 | Main Nutrient Sources Contributing to Cultural Eutrophication

Runoff from	fertilizers (N and P)
	feedlots (N and P)
	land-use change, such as cultivation, construction, mining natural sources
Discharge of	detergents (P)
	untreated sewage (N and P)
	primary and secondary treated sewage (N and P)
Dissolved nitrogen oxides	(from internal combustion engines)

Source: Dearden and Mitchell (2012)

Sources of Cultural Eutrophication



Effects of Eutrophication

- Nutrient enrichment encourages increased growth of aquatic plants, favouring growth of phytoplankton over **benthic plants** rooted in the substrate
- Benthic plants get shaded out; thus less O_2 is produced at depth
- O_2 depletion is further increased by the decay of the large mass of phytoplankton produced
- Fish decline due to O_2 depletion

Algal blooms, Sept 2009 on Lake Erie

Oxygen sag curve and BOD

- Rise in bacteria to decompose organic waste gives rise to drop in oxygen;
- **BOD**: Biological Oxygen Demand: "amount of dissolved oxygen needed by aerobic decomposers to break down organic material"

Source: Dearden and Mitchell (2012)

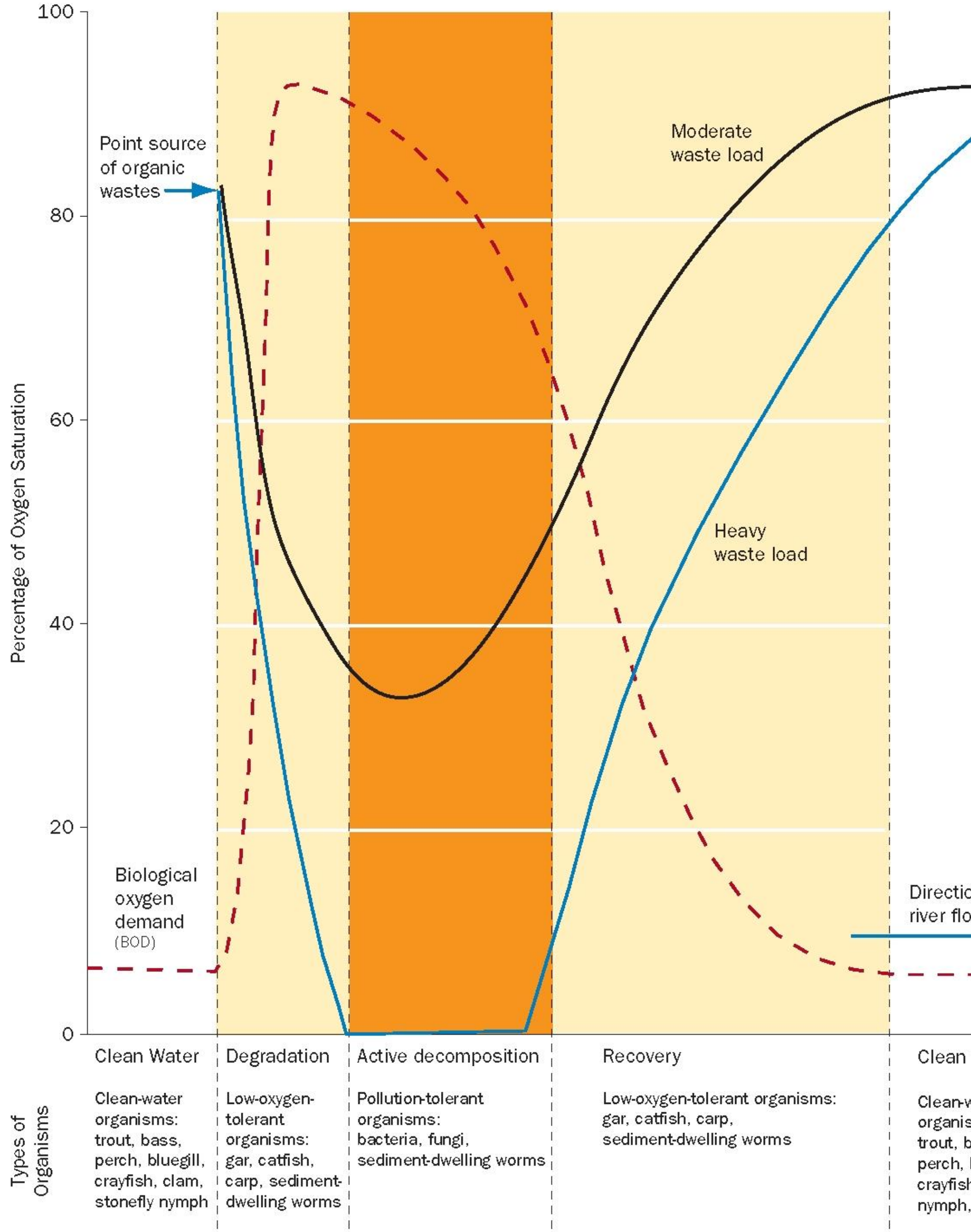


Figure 4.13 | Oxygen sag curve and biological oxygen demand (BOD).

Sources of Water Pollution

- main sources: Industrial, Urban Wastes (especially wastewater) and Agriculture
- **point sources:** e.g., manufacturing plants or sewage treatment plants
- **non-point sources:** e.g., agricultural and urban runoff; more difficult to identify since they cannot be associated with specific locations

End of pipe (point source) in Great Lakes basin from Dearden and Mitchell (2012)

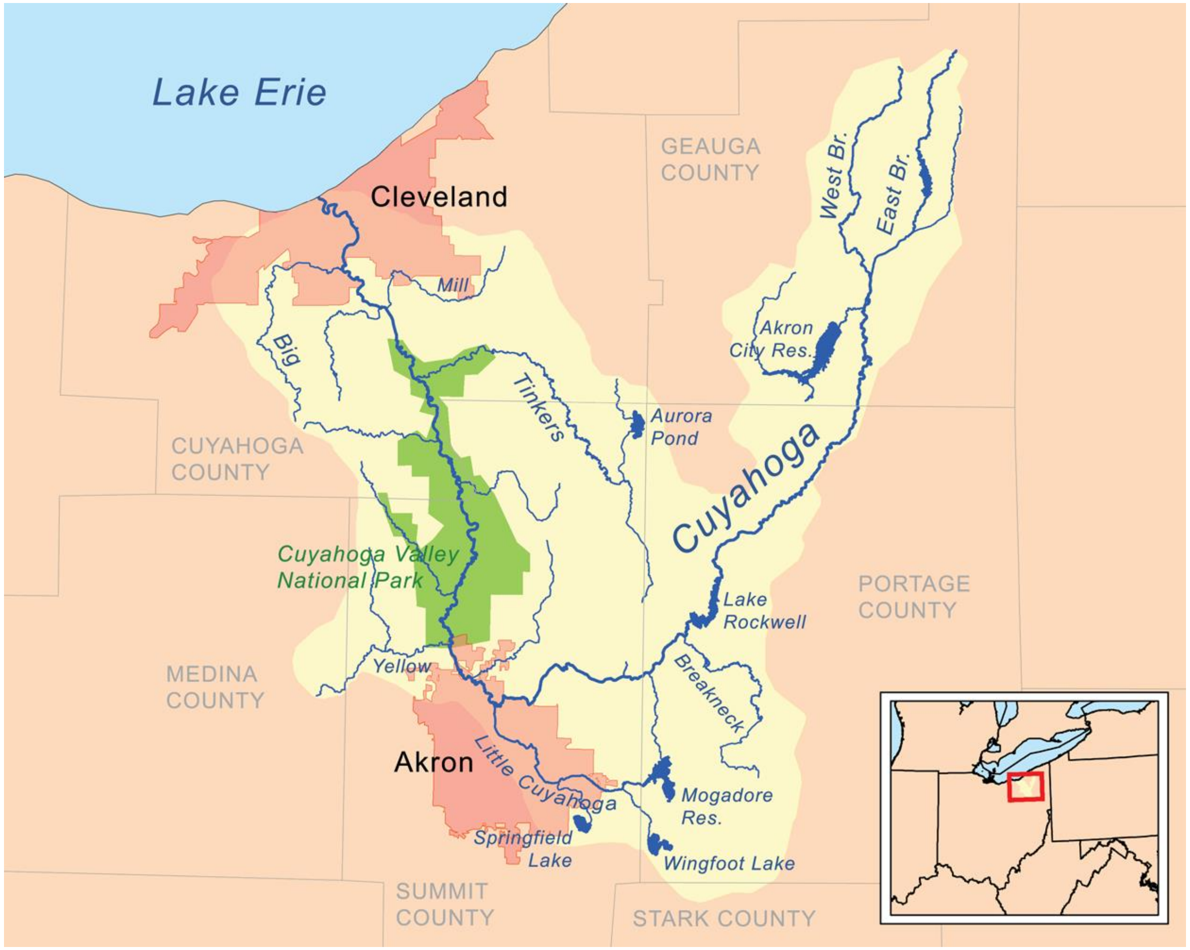
Industrial point-source on Calumet R (Chicago) from Dearden and Mitchell (2012

Non-point Sources

- Diffuse pollution has been a policy issue in the Great Lakes Basin since the 1960s – media declared that "Lake Erie was dying"….concerns arose about:
  - sedimentation from soil erosion;
  - eutrophication from nutrient loading; and
  - toxic chemicals

Courtesy of Jim Schafer … Orange-brown water from the Cuyahoga River spills out of Cleveland harbor and into Lake Erie, a regular occurrence during the late 1960s when this photo was taken by members of the city's Bureau of Industrial Wastes.

http://www.cleveland.com/science/index.ssf/2009/06/cuyahoga_river_fire_40_years_a.html



Source: en.wikipedia.org

Lake Erie: example Eutrophication Control

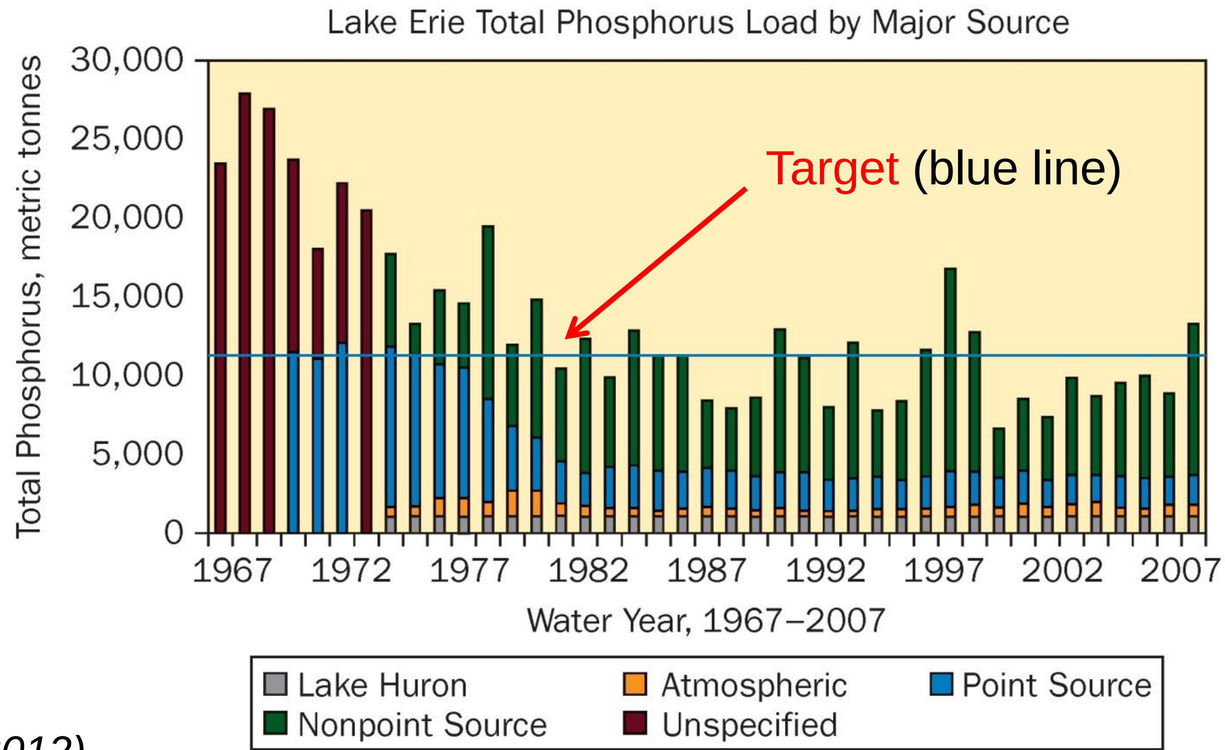
- In the past, nearly 90% of bottom layer in central portions of the lake causing huge algal blooms (mats) and beach closures

http://www.noaanews.noaa.gov/stories2013/images/

Above image from 2011 – the worst bloom in decades

Lake Erie: example Eutrophication Control

- Since the 1970s, controls on Phosphorus loading via:
  - banning of phosphate-based detergents
  - Upgrading of municipal wastewater treatment processes



Source: Dearden and Mitchell (2012)

Figure 4.14 | Lake Erie total phosphorus load by major source, 1967–

Total Phosphorus Loadings (1976 → 1991) Lake Erie

- initial plans of International Joint Commission (IJC) for Great Lakes in 1970s to reduce municipal loading of nutrients

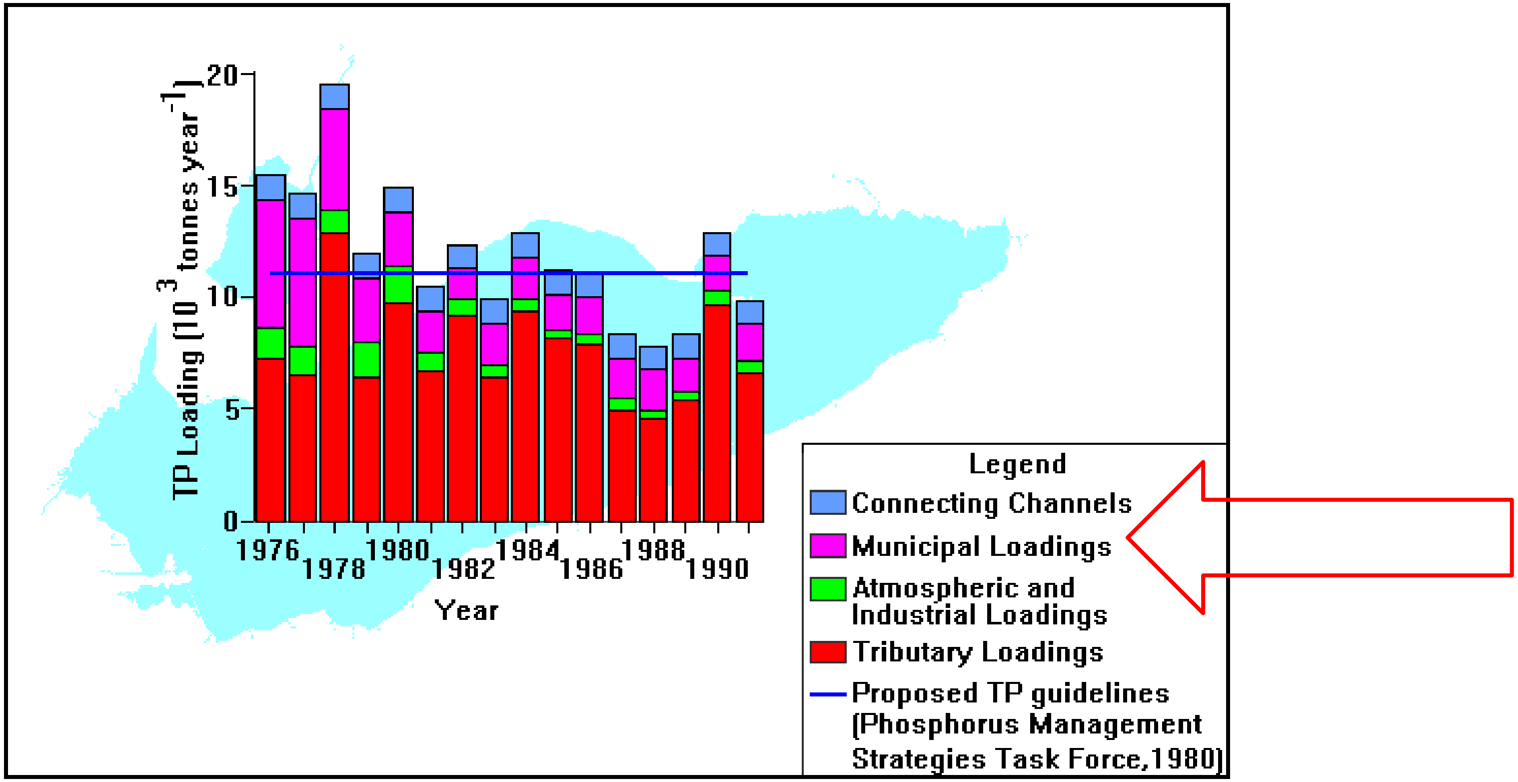


Figure 42 Lake Erie total phosphorus loads (Ref. 22). (Reproduced by permission)

The algae blooms persist …

Algal blooms, Sept 2009 on Lake Erie

http://www.noaanews.noaa.gov/stories2013/images/

Above image from 2011 – the worst bloom in decades

- Swathes of blue-green algae (form due to high phosphorus inputs) … big news in 2013 on Lake Erie
- Potential tourism and shipping impacts?

Acid Deposition

What is Acid Deposition?

- Acidity is a measure of the concentration of hydrogen ions (H+) in a solution and is measured using the pH scale (low values are 'acidic' vs 'alkaline')
- Acidic deposition is a term that includes rainfall, snow, fog, and dry deposition from dust with a pH lower <5.6

Source: Dearden and Mitchell (2012)

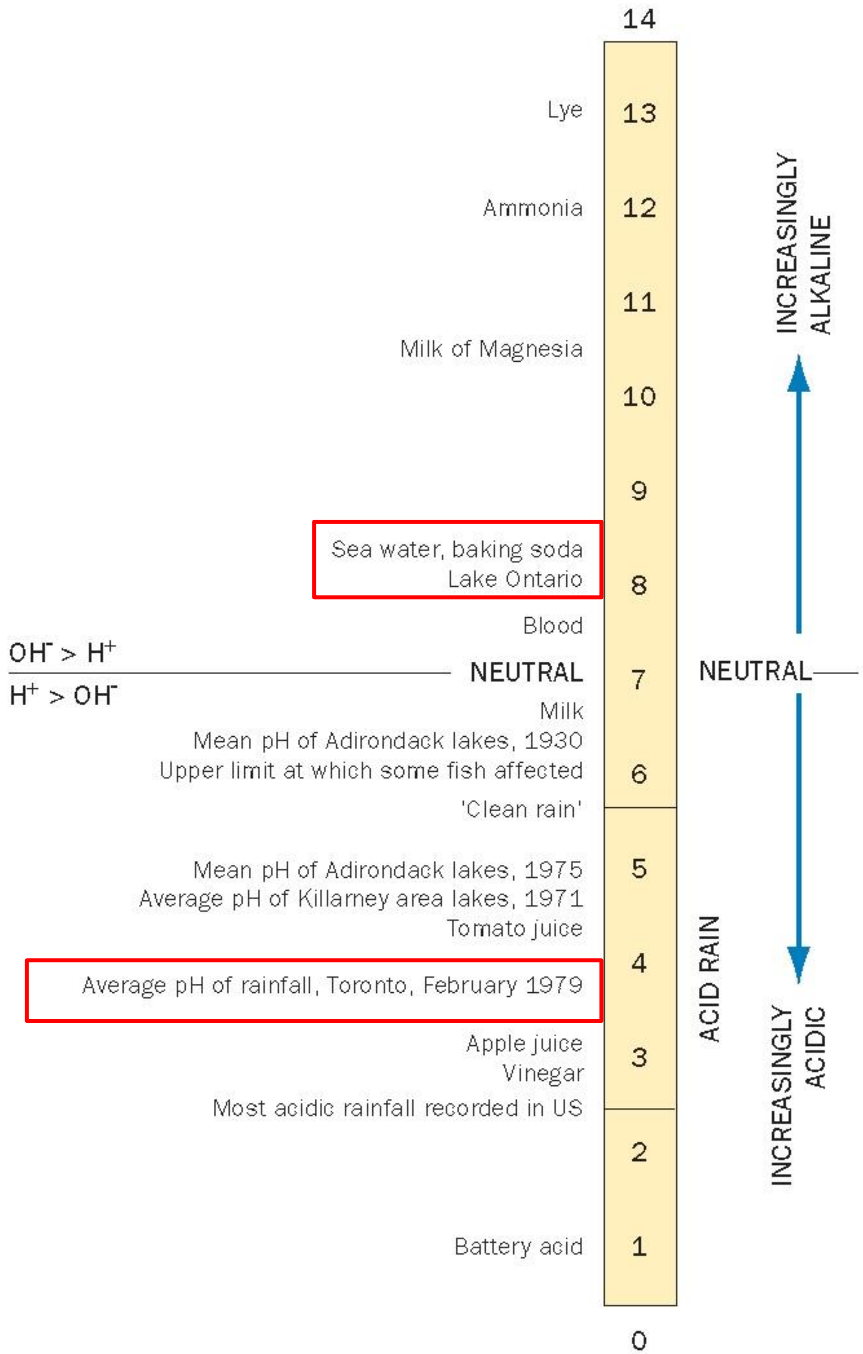
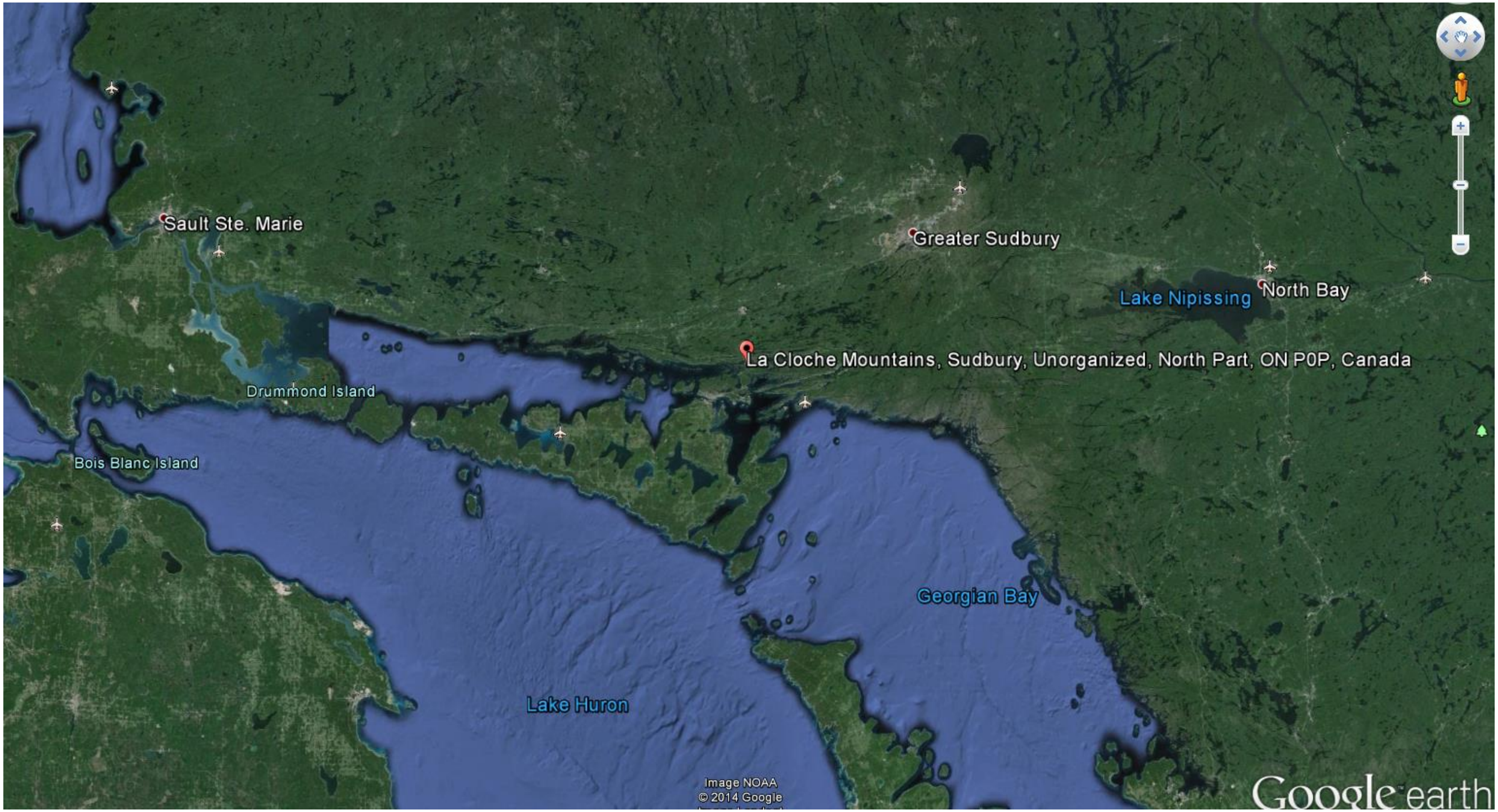


Figure 4.15 | The acid (pH) scale.

Lumsden Lake (in La Cloche Mts, SW of Sudbury) – re: work on fisheries research H. Harvey (mid 1960s)



Effects first noted by fisheries researcher H. Harvey in the 1960s

Table 4.7 | Disappearance of Fish from Lumsden Lake

1950s	Eight species present
1960	Last report of yellow perch
1960	Last report of burbot
1960–5	Sport fishery fails
1967	Last capture of lake trout
1967	Last capture of slimy sculpin
1968	White sucker suddenly rare
1969	Last capture of trout and perch
1969	Last capture of lake herring
1969	Last capture of white sucker
1970	One fish species present
1971	Lake chub very rare

Source: H. Harvey, unpublished speech, based on Beamish and Harvey (1972). Reprinted with the author's permission.

Table 4.8 | Lake Acidification in the La Cloche Mountains, 1961–71

Lake	pH 1961	pH 1971
Broker	6.8	4.7
David	5.2	4.3
George	6.5	4.7
Johnnie	6.8	4.8
Lumsden	6.8	4.4
Mahzenazing	6.8	5.3
O.A.S.	5.5	4.3
Spoon	6.8	5.6
Sunfish	6.8	5.6
Grey (1959)	5.6	4.1
Tyson (1955)	7.4	4.9

Source: H. Harvey, unpublished speech, based on Beamish and Ha
(1972). Reprinted with the author's permission.

Causes of Acid Deposition

- Increases in acidity to due human interferences in the S and N cycles;
- Largest sources: smelting of sulphur-rich ores (for copper, nickel production) and fossil fuel burning
- Point sources (industrial plants) much easier to control than non-point (e.g., nitrogen emissions from combustion --- transportation)

TRAIL SMOKE EATERS

Trail, BC …Home of Cominco (zinc-smelter); and the Trail Smoke-Eaters hockey club

USA

Canada

SO_2 Emissions

NO_x Emissions

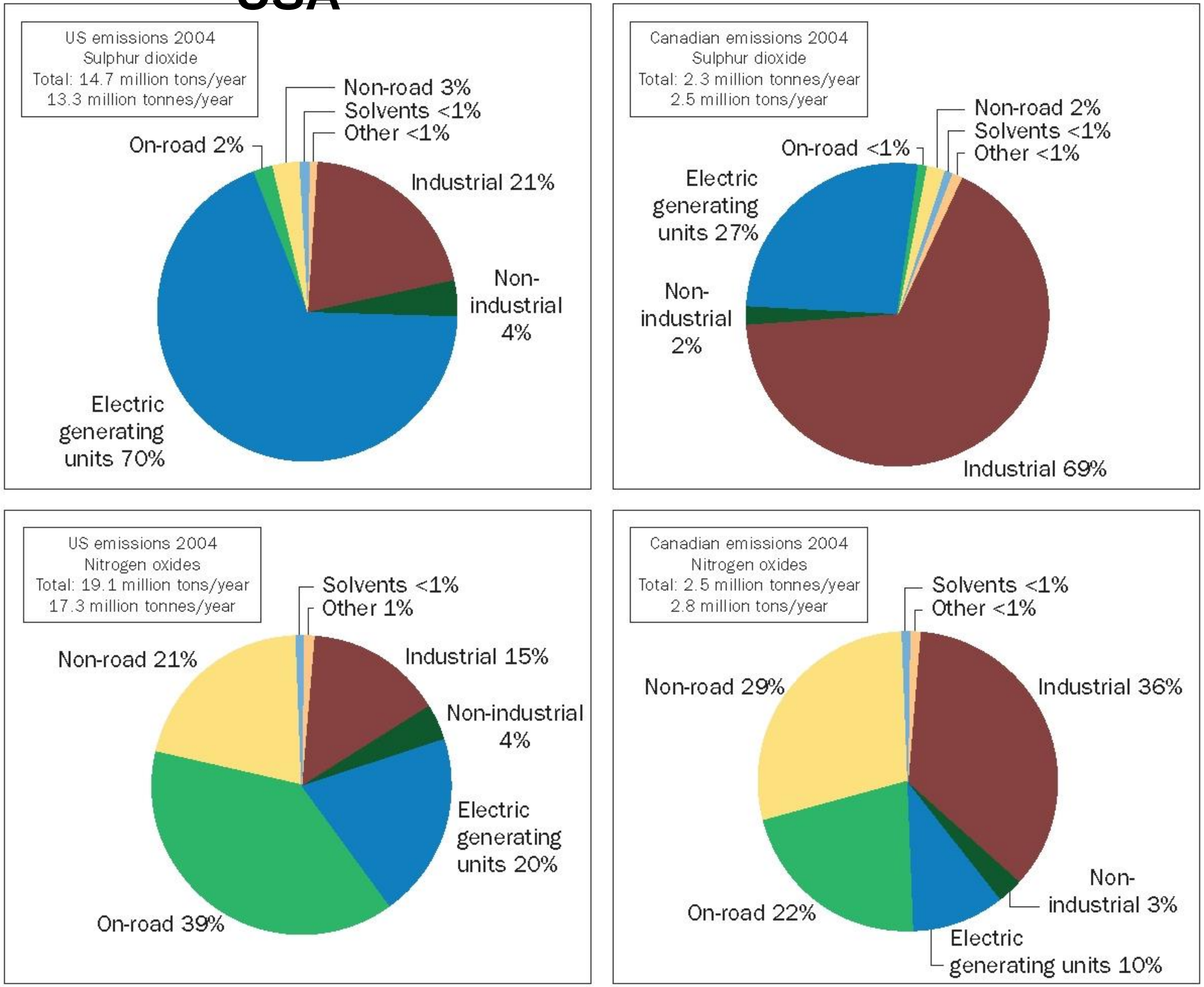


Figure 4.16 | Main sources of sulphur dioxide and nitrogen oxide emissions in Canada and US in 2004. *Source: Environment Canada (2006a).*

Effects of Acid Deposition

(Aquatic)

- Disfigurement, death and extirpation of insects and fish, food chain effects through depletion of food sources
- **<u>Acid shock</u>**: pulse of acidity in spring with snow melt

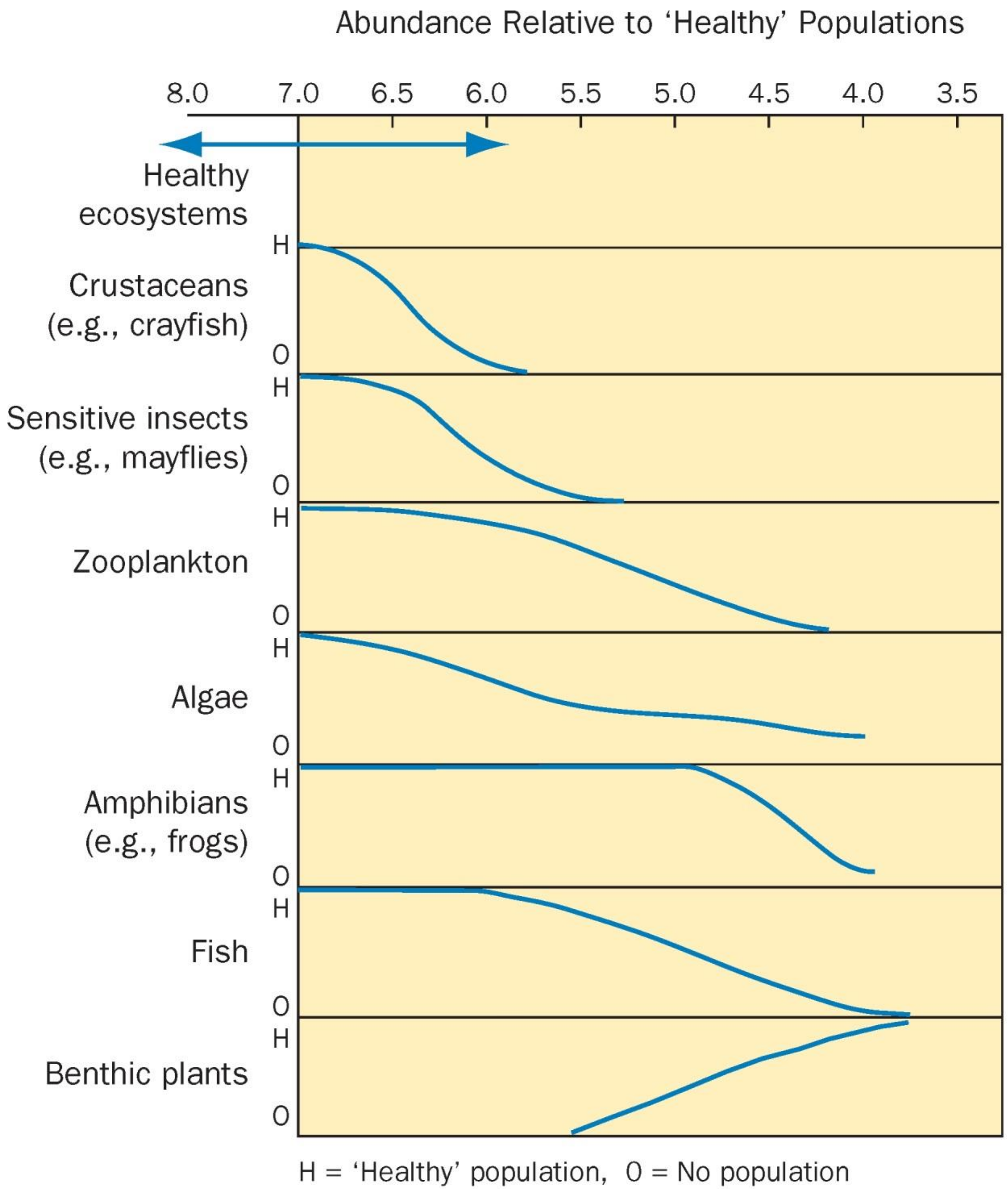


Figure 4.17 | Sensitivity of various aquatic organisms to pH level.
Source: Environment Canada (1991).

Effects of Acid Deposition (Terrestrial)

- Tissue death in plant leaves
- Acids leach away nutrients (from soils) required for plant growth → nutrient deficiencies
- Metals dissolved in soil water inhibit plant nutrient uptake → effects on food chains
- Inhibition of:
  - Microbial activity
  - crop growth

Trail, BC …Home of Cominco (zinc-smelter)

Ecosystem Sensitivity

- **Critical load:** the maximum level of acid deposition that can be sustained in an area without compromising ecological integrity
- Areas with deep soils and carbonate rock have a high **buffering capacity** (e.g., Southern Ontario, Prairies) and are not as sensitive to acid deposition, while areas with thin soils and non-carbonate rock are more susceptible (e.g. Canadian Shield, Atlantic Canada)

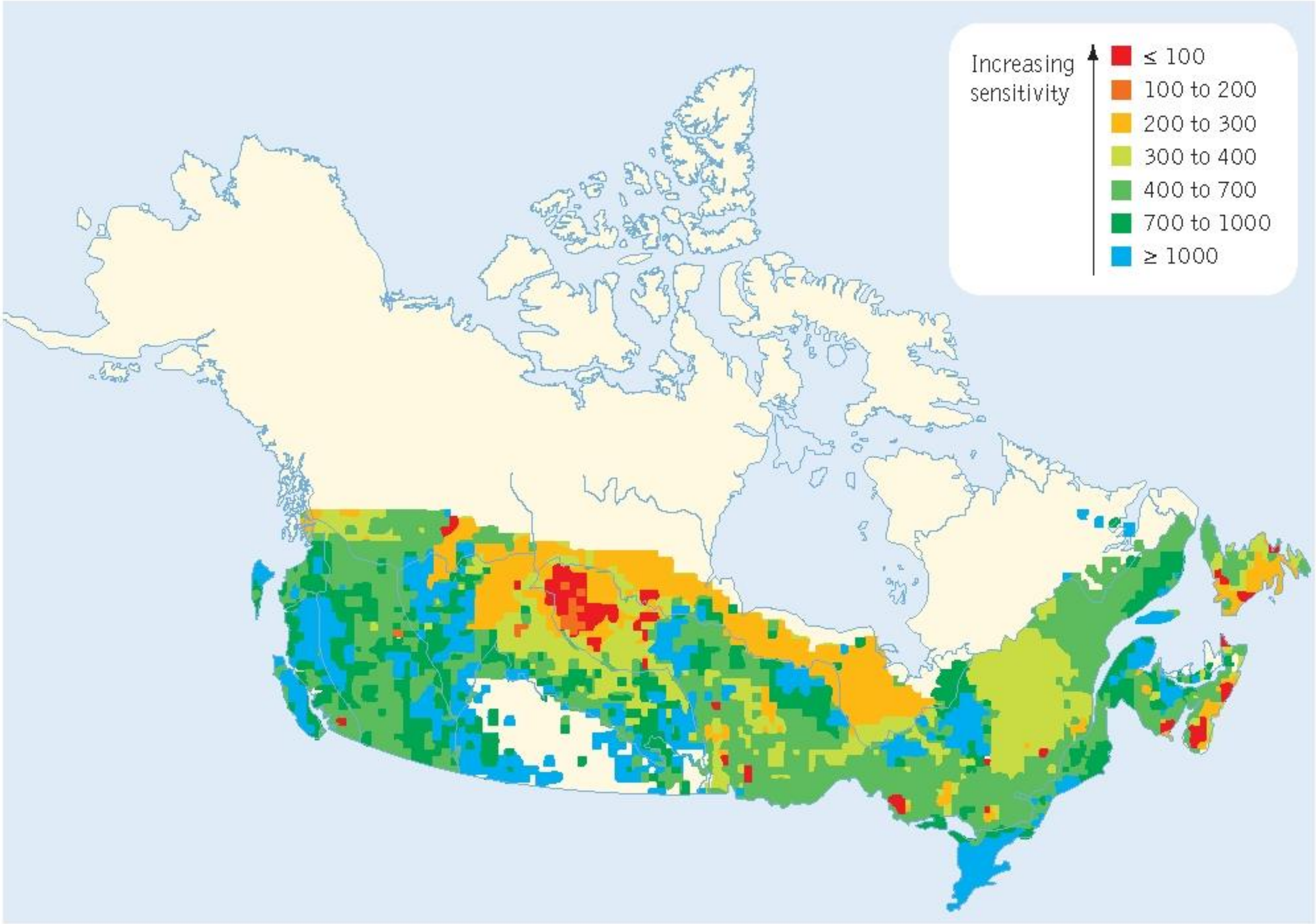
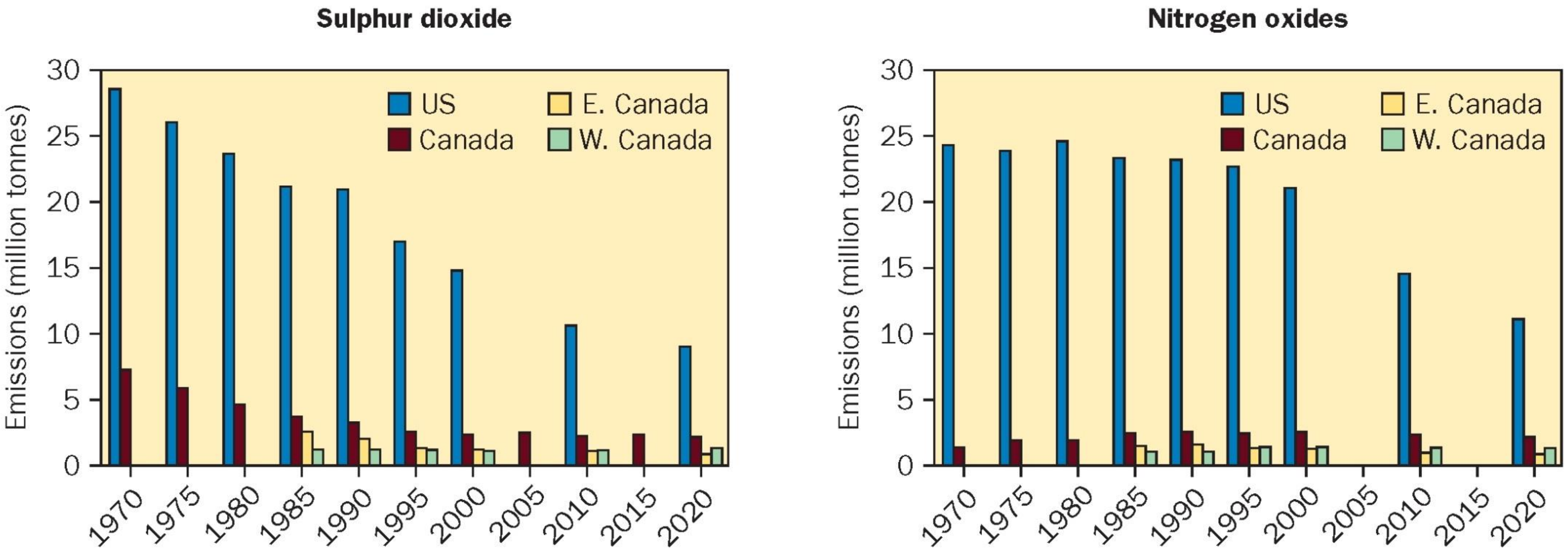


Figure 4.18 | Sensitivity of terrain to acidity. Critical load index, 2008; yellow through red categories are considered acid sensitive terrain. *Source: Federal, Provincial, and Territorial Governments of Canada (2010: 68).*

Acid Deposition: what to do about it?

- A key challenge is its international dimension:
  - over half of acid deposition in Canada originates in USA
- International efforts are required:
- Canada has reduced SO_2 emissions to 50% of 1980 levels;
- Encouraging trends in NOx as well, but some increases in Western Canada due to Oil Sands development;



gure 4.20 and 4.21 | Estimated emissions of sulphur dioxide in the US and Canada and estimated emissions of nitrogen oxides in
e US and Canada. *Source: Environment Canada (2006a).*

- Canada has met all its goals and commitments for acid deposition reductions, yet acid deposition remains a significant problem in Canada

- Sulphur has been easier to control than nitrogen

Looking Ahead to the next lectures

May 21 & 27: Planning and Management: Adaptive Management and Impact & Risk Assessment

** Case Study: Skagit Valley Landslide*

Read ahead (Chpt. 6, pp. 172 →197)

May 22:(Field trip, **to be confirmed**): ***Bare Point Water Treatment Plant***

May 26: Mid-term exam (**covers to end of Chapter 4**)

May 28: Climate Change: def'ns and scientific evidence of
Read ahead (Chpt. 7, pp. 201 →)

References

- Dearden, P and Mitchell, B. 2012. *Environmental Change and Challenge*, Fourth Edition, Don Mills, Ontario: Oxford University Press {Chapter 4: 'Ecosytems and Matter Cycling'}