CHAPTER

7

Wetland Ecosystems

OUTLINE

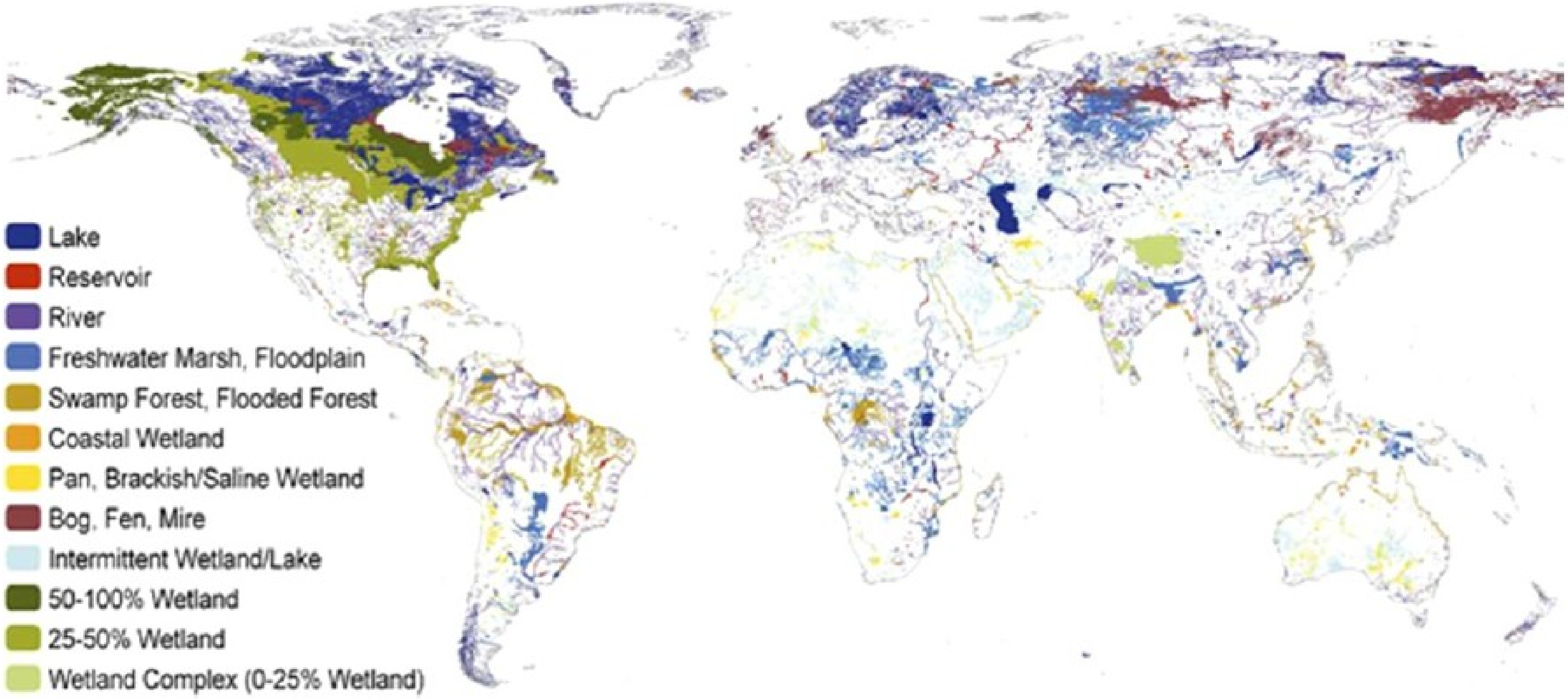


FIGURE 7.1 The distribution of global wetlands. *Source: From Lehner and Doll (2004).*

Earth’s Climate System

7.1

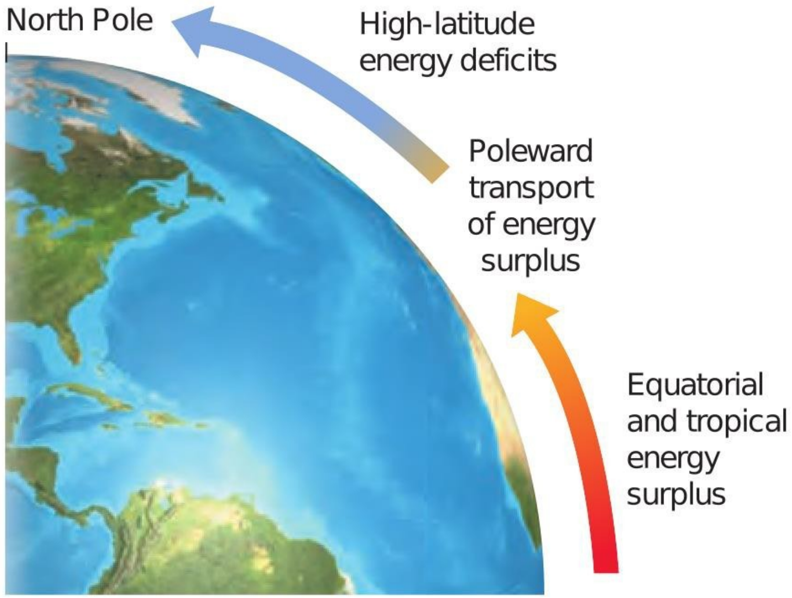
INSOLATION

Incoming solar radiation is the energy input for the climate system. Insolation varies by latitude, as well as on a daily and seasonal basis with changing day length and Sun angle. (*Chapter 2; review Figures 2.9, 2.10, and GIA 2*)

7.2

EARTH’S ENERGY BALANCE

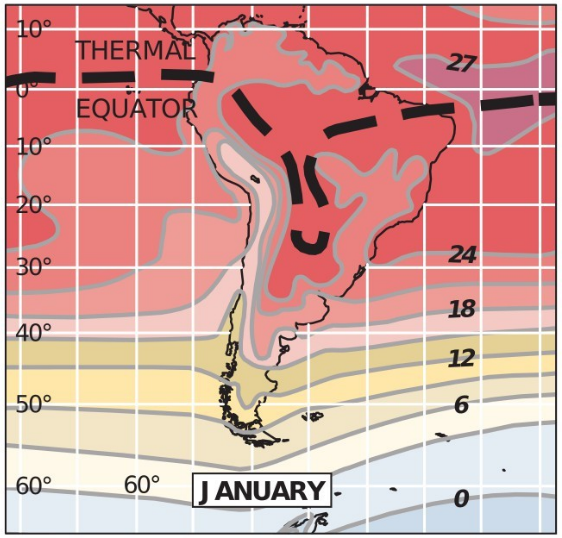
The imbalance created by energy surpluses at the equator and energy deficits at the poles causes the global circulation patterns of winds and ocean currents that drive weather systems. (*Chapter 3; review Figure 3.13*)



Earth’s Clima
Syste

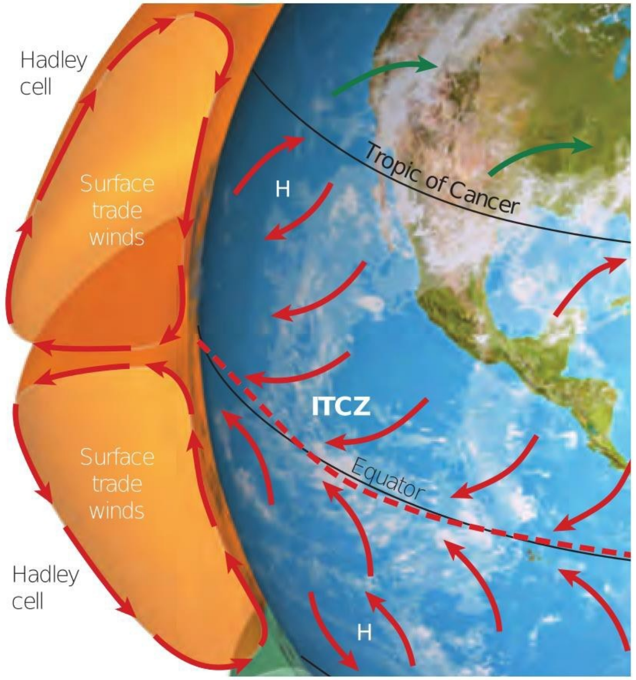
7.3 TEMPERATURE

Primary temperature controls are latitude, elevation, cloud cover, and land–water heating differences. The pattern of world temperatures is affected by global winds, ocean currents, and air masses. (*Chapter 3; review Figures 3.26 through 3.28*)

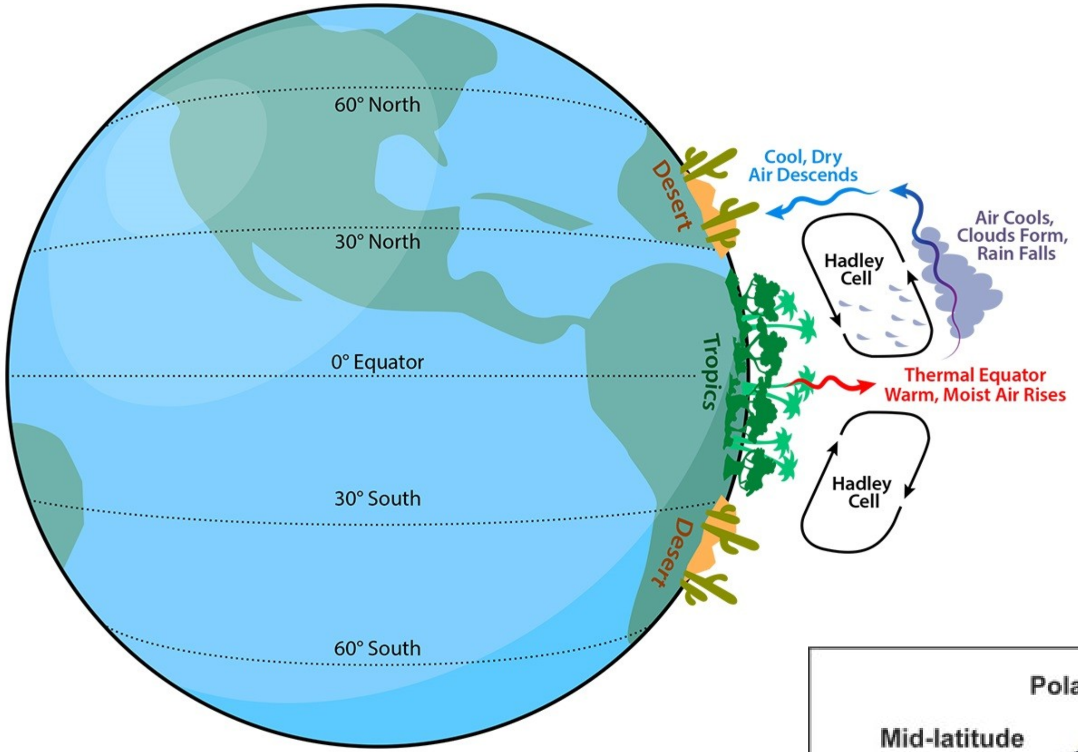


7.4 AIR PRESSURE

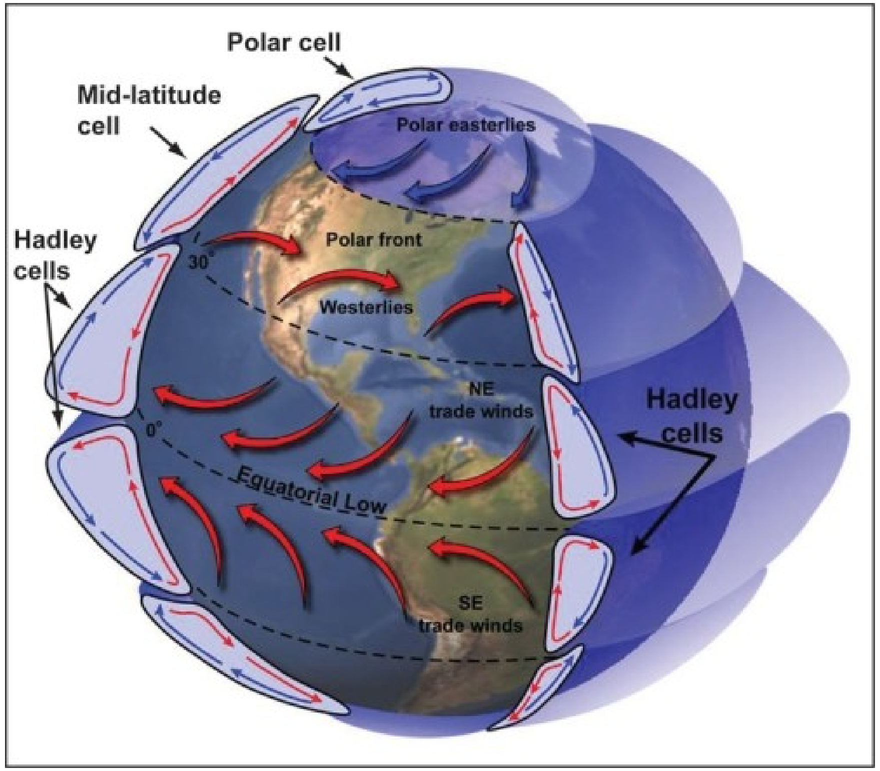
Winds flow from areas of high pressure to areas of low pressure. The equatorial low creates a belt of wet climates. Subtropical highs create areas of dry climates. Pressure patterns influence atmospheric circulation and movement of air masses. Oceanic circulation and multiyear oscillations in pressure and temperature patterns over the oceans also affect weather and climate. (*Chapter 4; review Figures 4.12 and GIA 4*)



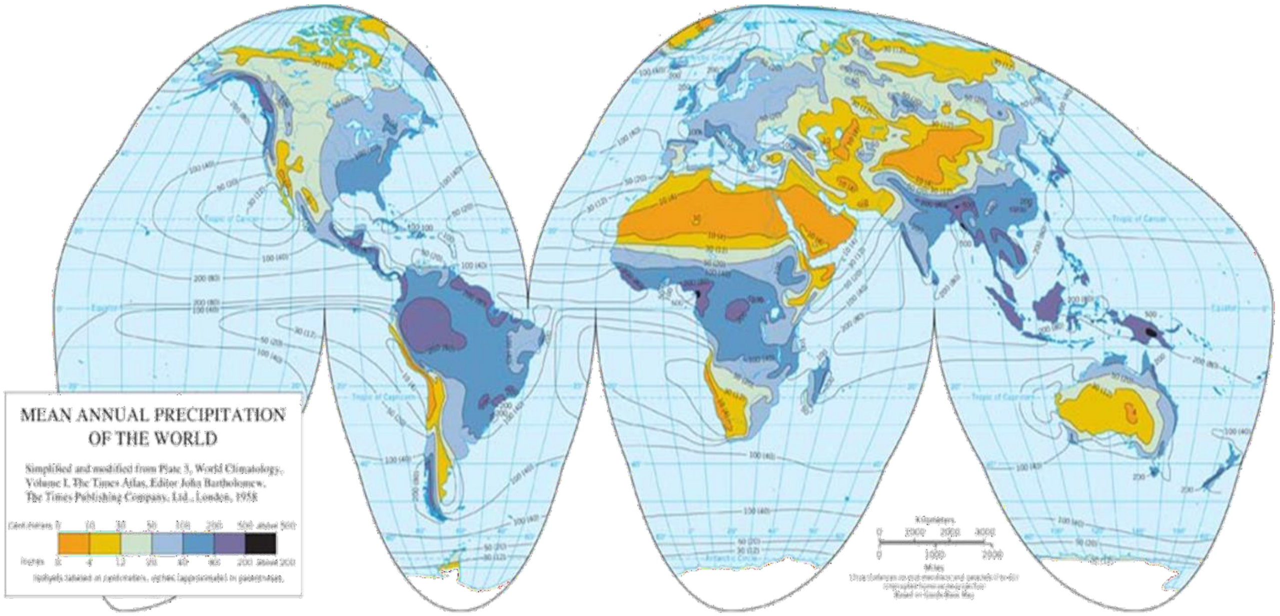
Figures GIA 7.3-7.4



60° North
30° North
0° Equator
30° South
60° South
Desert
Tropics
Desert
Cool, Dry
Air Descends
Air Cools,
Clouds Form,
Rain Falls
Hadley
Cell
Thermal Equator
Warm, Moist Air Rises
Hadley
Cell



Polar cell
Mid-latitude
cell
Polar easterlies
Hadley
cells
30°
Polar front
Westerlies
NE
trade winds
0°
Equatorial Low
Hadley
cells
SE
trade winds



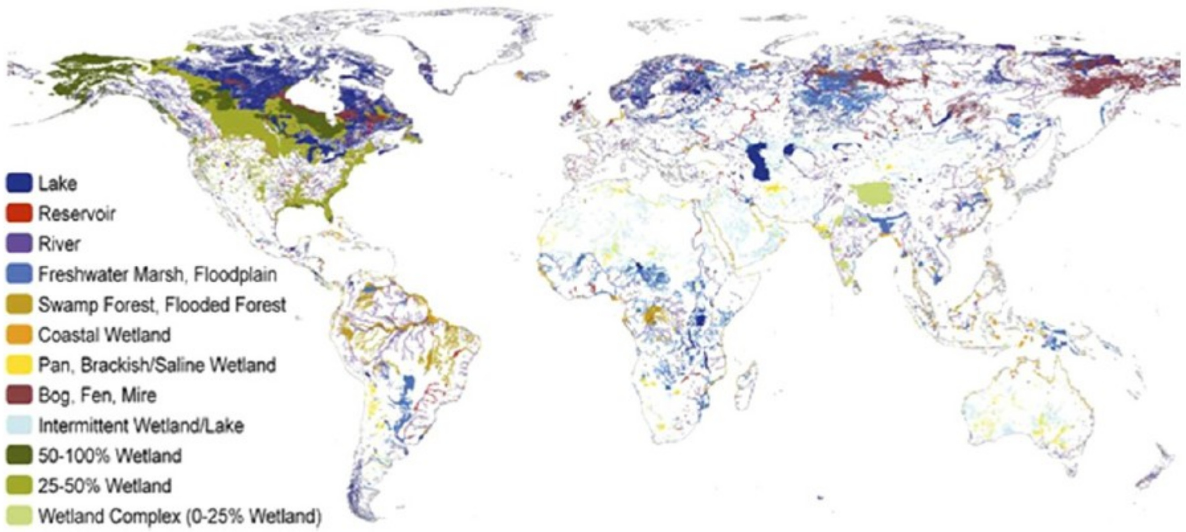


FIGURE 7.1 The distribution of global wetlands. *Source: From Lehner and Doll (2004).*

Global Precipitation regions

1. Wet equatorial belt
2. Trade-wind coasts
3. Tropical deserts
4. Mid-latitude deserts and steppes
5. Moist subtropical regions
6. Mid-latitude west coasts
7. Arctic and polar deserts

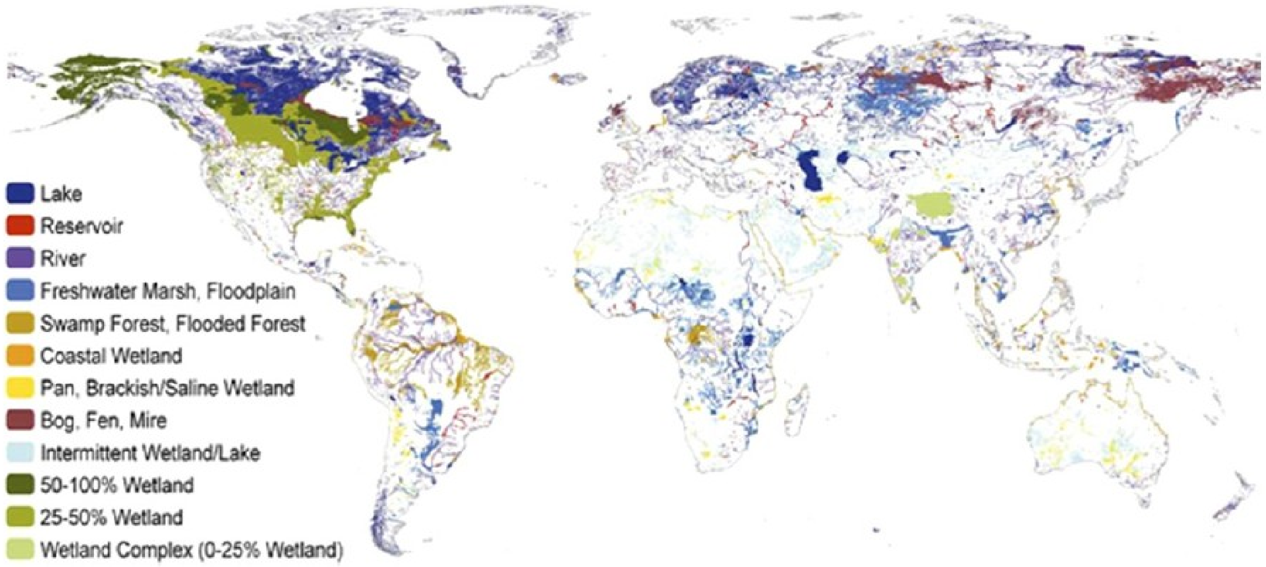


FIGURE 7.1 The distribution of global wetlands. *Source: From Lehner and Doll (2004).*

TABLE 7.1 Estimated Global Spatial Extent of Inland Waters

	Global Area	
Class	10^3 km^2	%
1. Lake	2428	1.8
2. Reservoir	251	0.2
3. River	360	0.3
4. Freshwater Marsh, Floodplain	2529	1.9
5. Swamp Forest, Flooded Forest	1165	0.9
6. Coastal Wetland	660	0.5
7. Pan, Brackish/Saline Wetland	435	0.3
8. Bog, Fen, Mire	708	0.5
9. Intermittent Wetland/Lake	690	0.5
10. Wetland Complexes		
50–100% Wetland	882–1764	0.7–1.3
35–50% Wetland	790–1580	0.6–1.2
0–25% Wetland	0–228	0–0.2
Total lakes and reservoirs (1–3)	2679	2.0
Total Wetlands (4–10)	8219–10,119	6.2–7.6

Source: Data from Lehner and Doll (2004). In these analyses, they assumed a total global land surface area (excluding Antarctica and glaciated Greenland) of 133 million km^2.

Earth’s Water Distribution

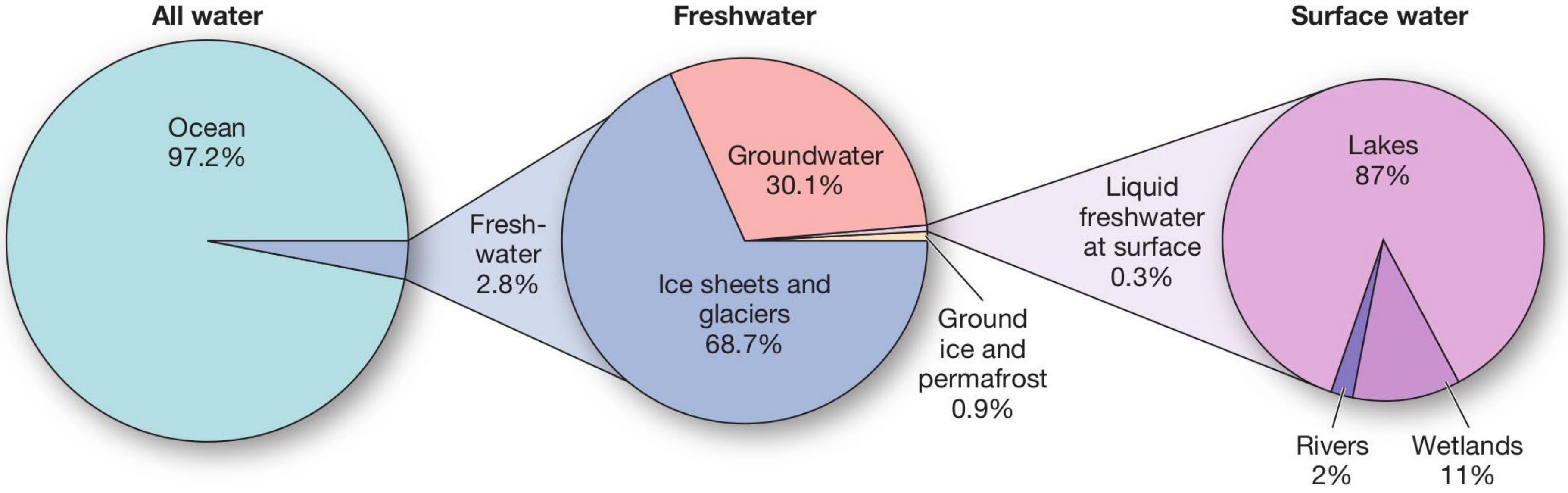
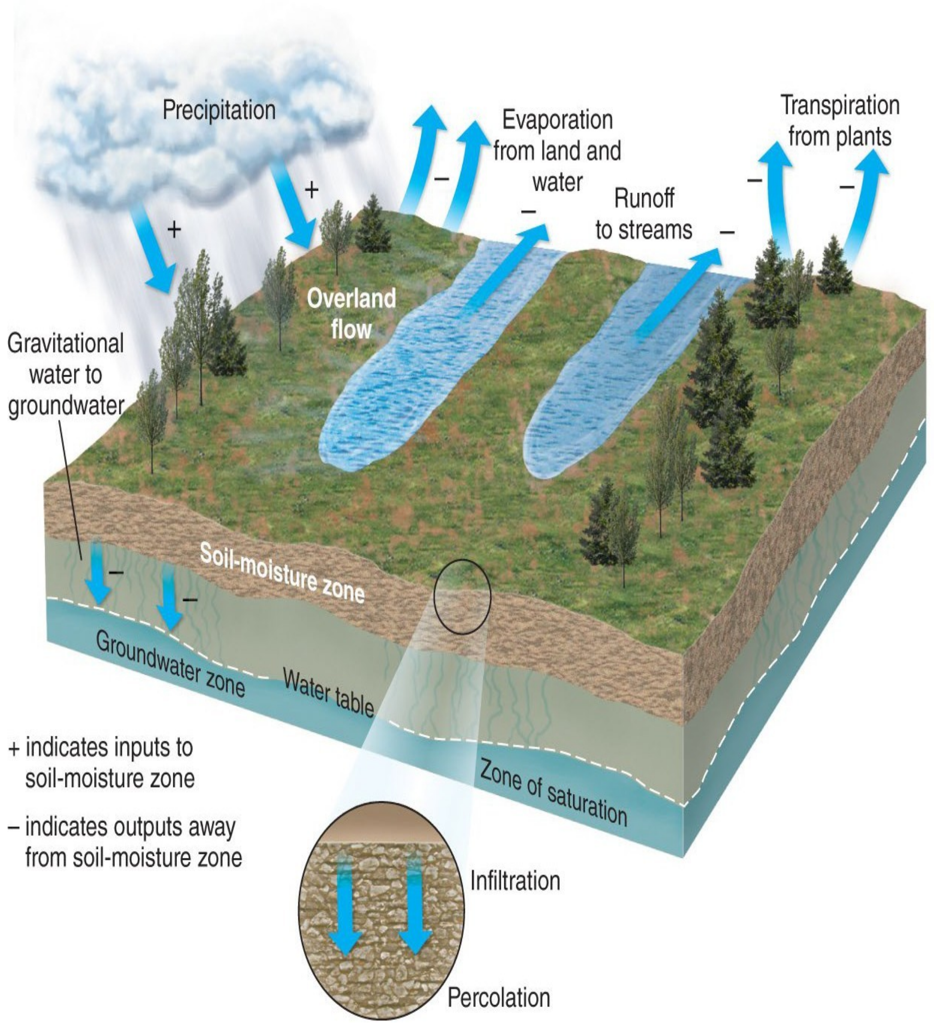


Figure 6.4



Highest Average Productivity 1300 g C m^{-2} yr^{-1}

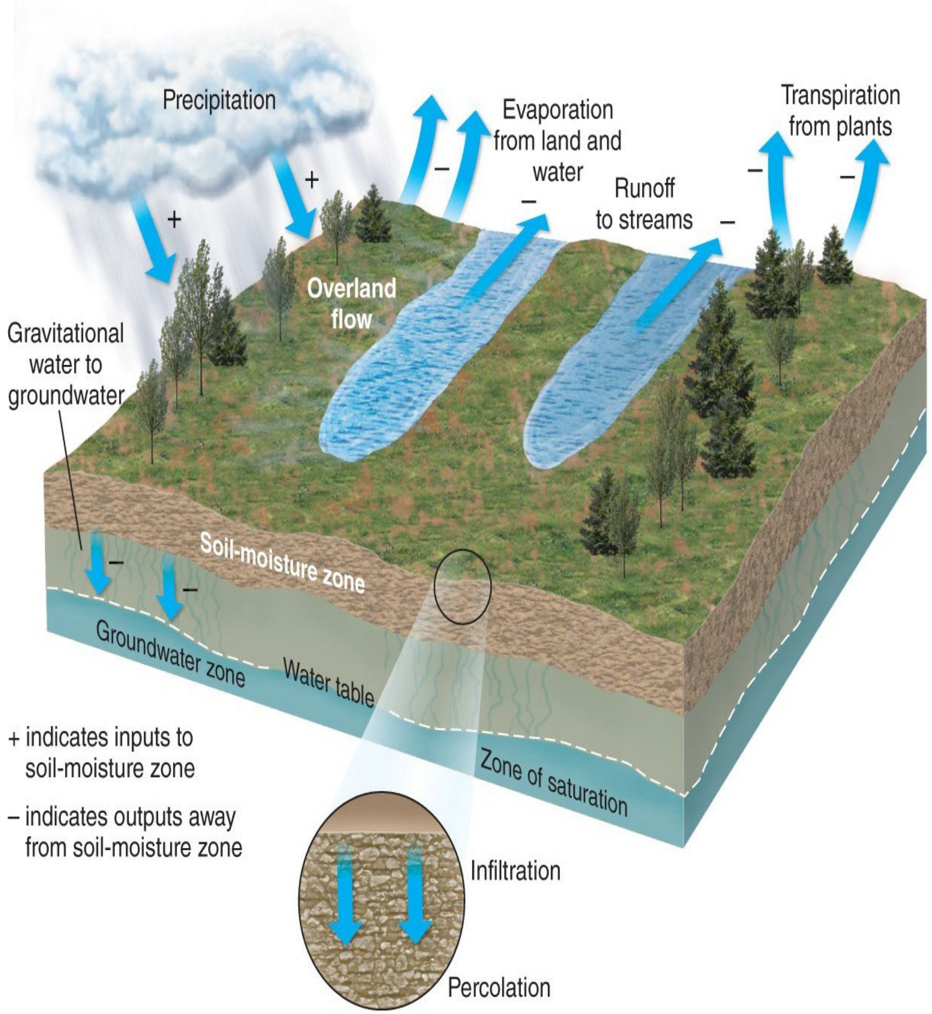
7-15% of Global Terrestrial Productivity

Store > 50% of all soil C (peatlands)

20-33 % of global CH_4 emission

High N-denitrification Potential

High Potential for N and P sequestration



Wetland Hydrology

Water may enter a wetland by precipitation, tributary inflows, near-surface seepage, and exchange with deeper groundwater; water leaves wetlands through groundwater recharge, surface outflows, and evapotranspiration (Figure 7.2).

$$\text{Wetland volume (V)} = \text{Inputs } (P_n + S_i + G_i) - \text{Outputs } (ET - G_o - S_o). \tag{7.1}$$

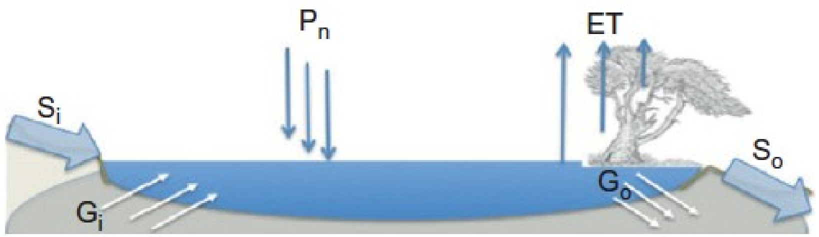


FIGURE 7.2 A wetland water budget. P_n represents precipitation inputs; ET represents evapotranspiration losses. S denotes surface water; G denotes groundwater. Subscript i indicates inputs; o indicates outputs.

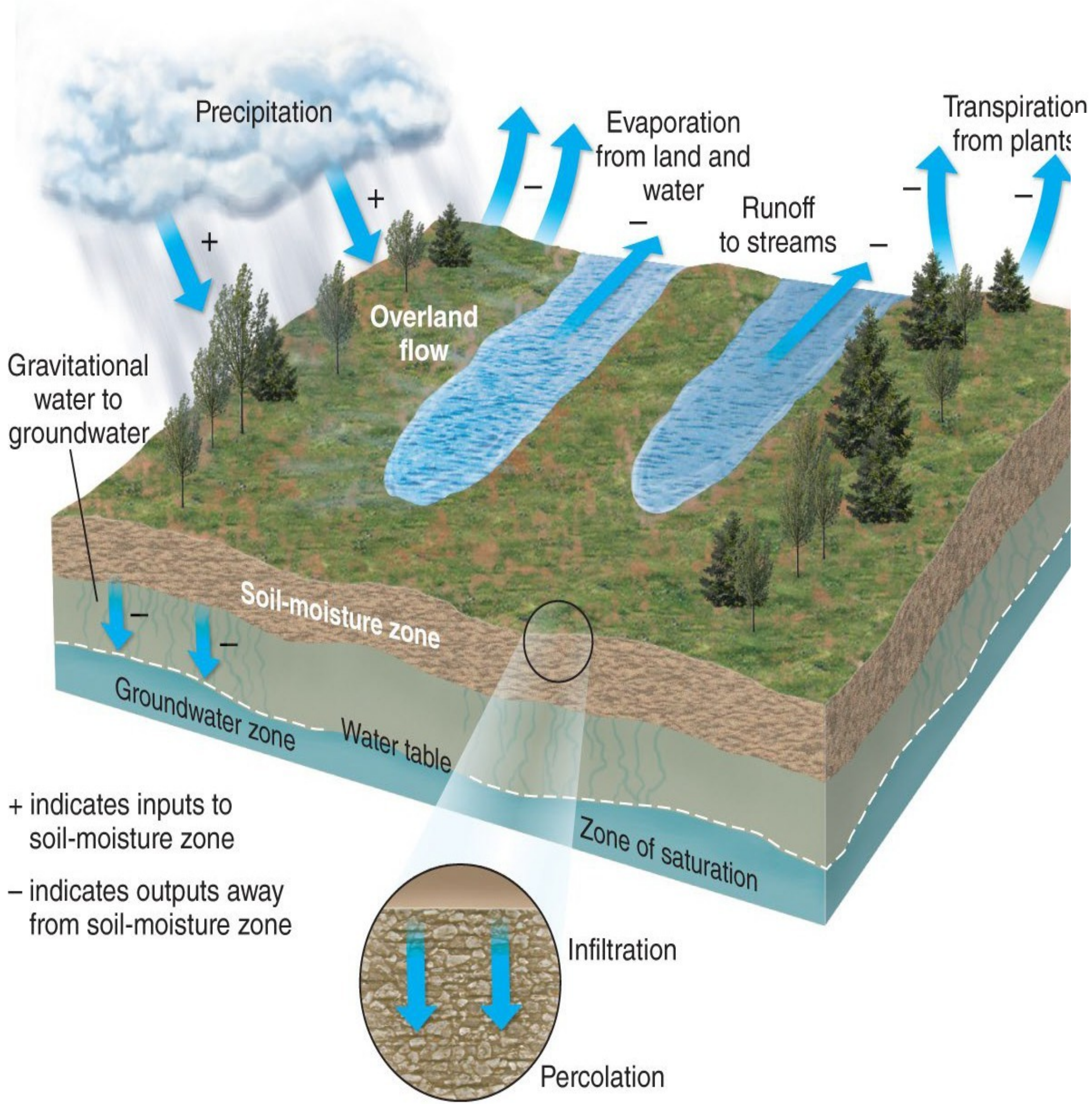
O_2 10^4 more slowly in water than air

Primary Production
(Photosynthesis)
Inorganic → Organic
Immobilization

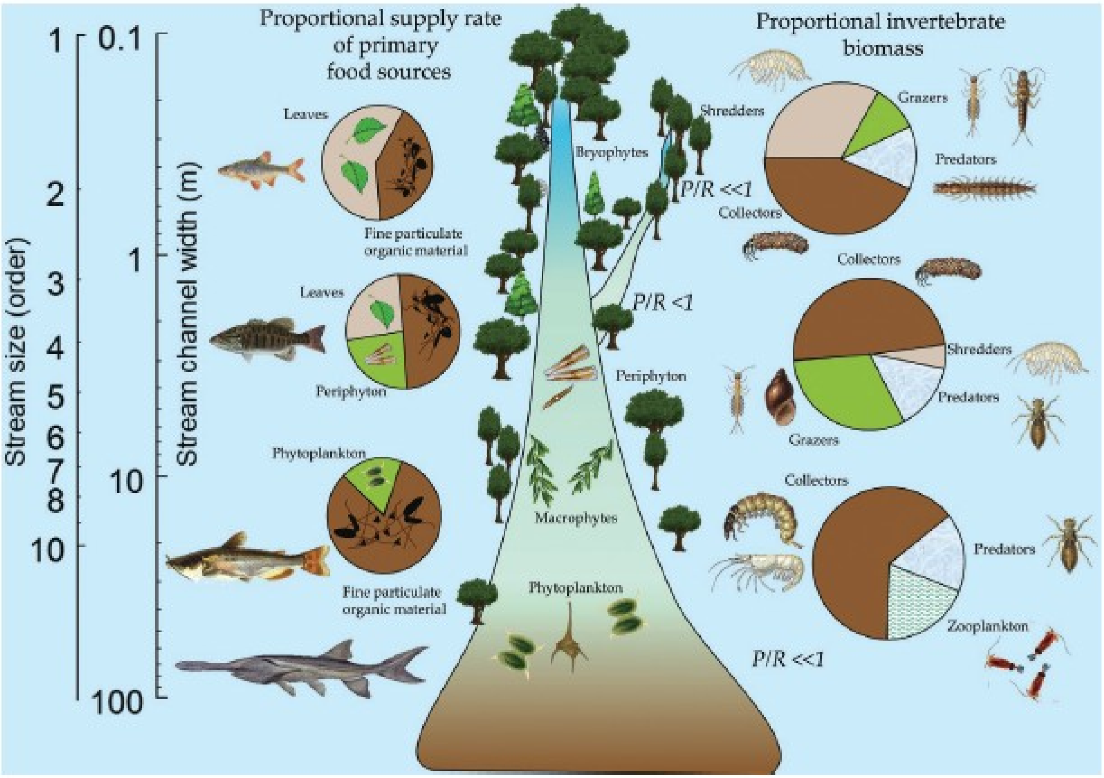
$$6CO_2 + 6H_20 \rightleftarrows C_6H_{12}0_6 + 60_2$$

Respiration
(Decomposition)
Organic → Inorgani
Mineralization

The heightened capacity for denitrification, CH_4 production, and soil carbon storage in wetlands are all a result of a lack of oxygen in wetland sediments. While aerobic oxidation ($CH_2O + O_2 \rightarrow CO_2 + H_2O$) dominates organic matter decomposition in most terrestrial ecosystems, microbes in flooded soils must use a variety of anaerobic metabolic pathways to obtain energy from organic matter. Microbial consumption of oxygen in wet soils and sediments frequently exceeds O_2 supply through diffusion. Without oxygen, microbes cannot use oxidative phosphorylation to decompose organic polymers to CO_2, and instead must rely on the alternate electron acceptors NO_3^-, Fe^{3+} and Mn^{4+}, SO_4^{2-}, or, in the most highly reducing environments, fermentation products such as acetate or CO_2 itself. Many of these primitive metabolic pathways evolved prior to the oxygenation of the Earth (Chapter 2), and continue to dominate the biogeochemistry of anoxic wetland sediments. These pathways yield less energy than aerobic respiration and the supply of alternate electron acceptors is often limiting, leading to far less efficient decomposition in wetlands and ultimately to large stores of organic matter. Over geologic time, the organic detritus accumulated in wetlands of the Carboniferous was buried and lithified to become modern coal deposits (Cross and Phillips 1990, McCabe 2009).

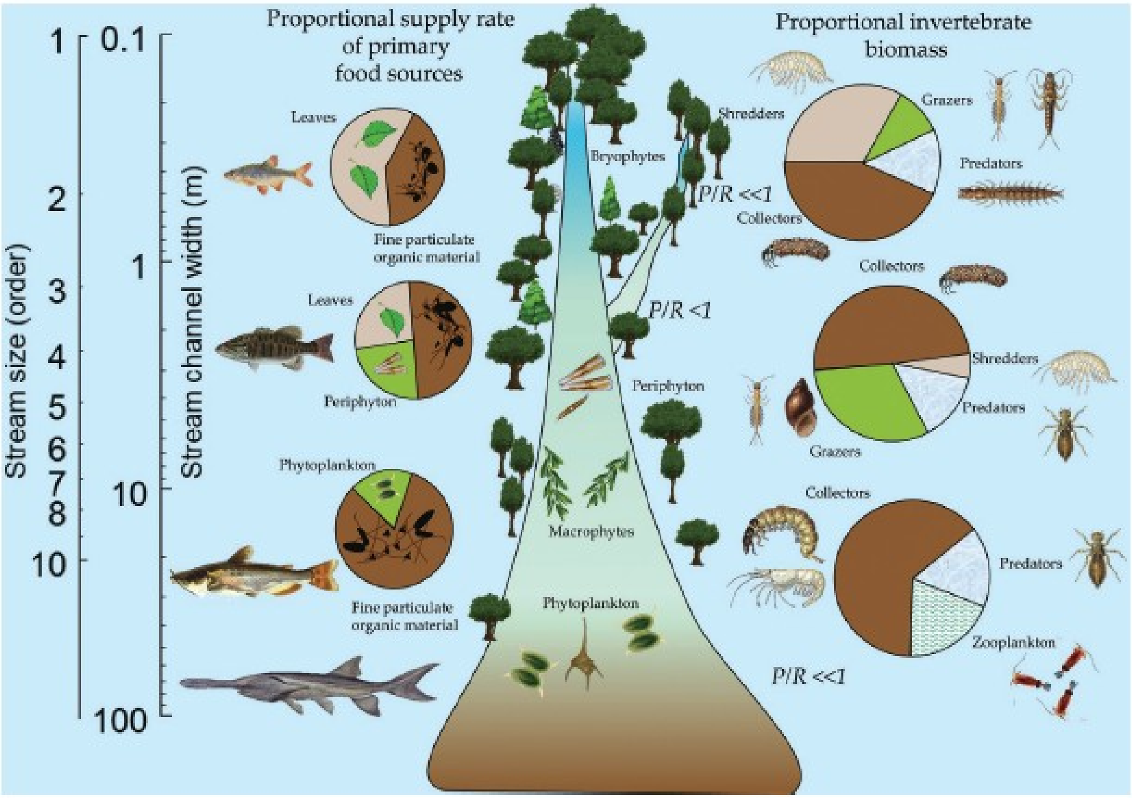


Precipitation
Evaporation from land and water
Transpiration from plants
Runoff to streams
Overland flow
Gravitational water to groundwater
Soil-moisture zone
Groundwater zone
Water table
Zone of saturation
Infiltration
Percolation
+ indicates inputs to soil-moisture zone
– indicates outputs away from soil-moisture zone



Stream size (order)
Stream channel width (m)
Proportional supply rate of primary food sources
Proportional invertebrate biomass
Leaves
Fine particulate organic material
Periphyton
Phytoplankton
Bryophytes
Macrophytes
P/R <<1
P/R <1
Shredders
Grazers
Predators
Collectors
Zooplankton

River Continuum Concept

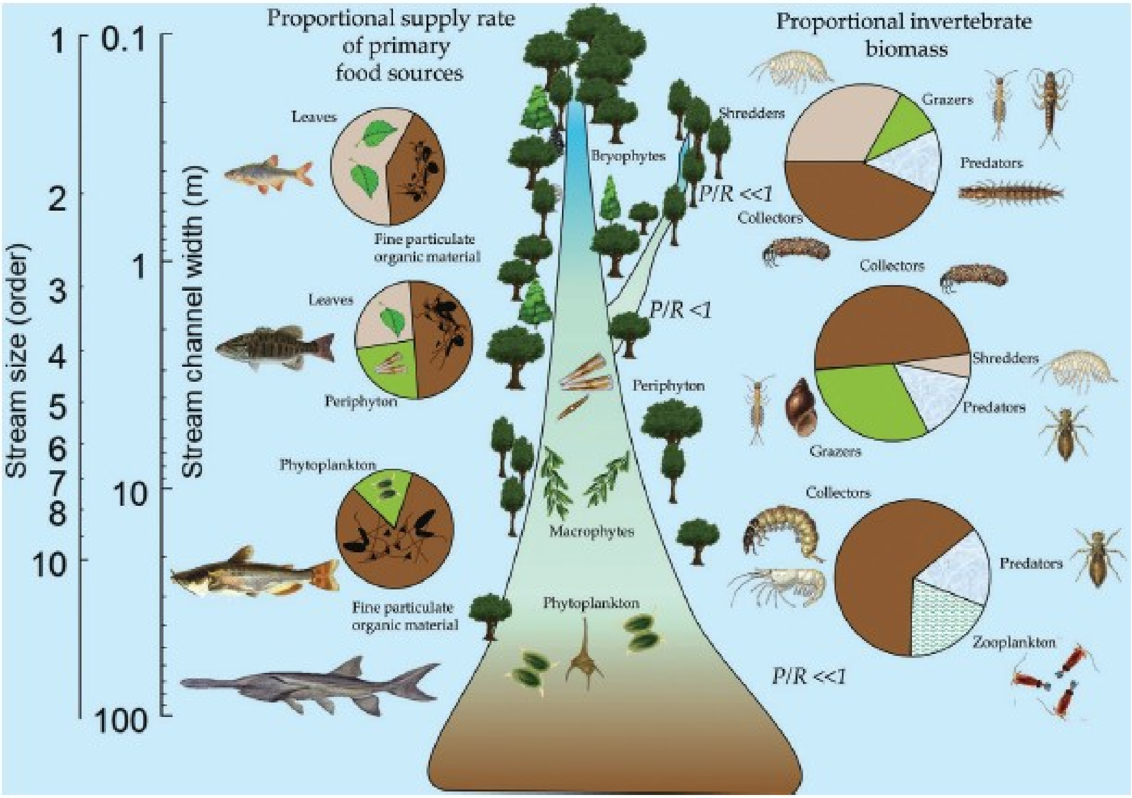


Allochthonous Inputs - Externally Derived

vs

Autochthonous Inputs – Internally Derived

River Continuum Concept



- A headwater woodland stream has steep gradient with riffles, rapids and falls.
- Sunlight is limited by overhanging trees, so photosynthesis is limited.
- Energy comes instead from leaves and woody material falling into the stream
- Aquatic insects break down and digest the terrestrial organic matter.
- Water is cooled by springs and often supports trout.

- the gradient decreases and there are fewer rapids and falls.
- The stream is wider, sunlight reaches the water allowing growth of aquatic plants.
- Insects feed on algae and living plants.
- Proportion of groundwater to runoff is lower so stream temperatures are warmer.
- The larger stream supports a greater diversity of invertebrates and fish.

- Terrestrial organic matter is insignificant in comparison to the volume of water
- Energy is supplied by dissolved organic material from upstream reaches.
- Drifting phytoplankton and zooplankton contribute to the food base as does organic matter from the floodplain during flood pulses.
- Increasing turbidity reduces sunlight to the streambed causing a reduction in rooted aquatic plants.
- Backwaters may exist where turbidity has settled and aquatic plants are abundant.
- Fish species are omnivores and plankton feeders such as carp, buffalo, suckers, and paddlefish.
- Sight feeders are limited due to the turbidity (MN DNR, Healthy Rivers).

River Continuum Concept

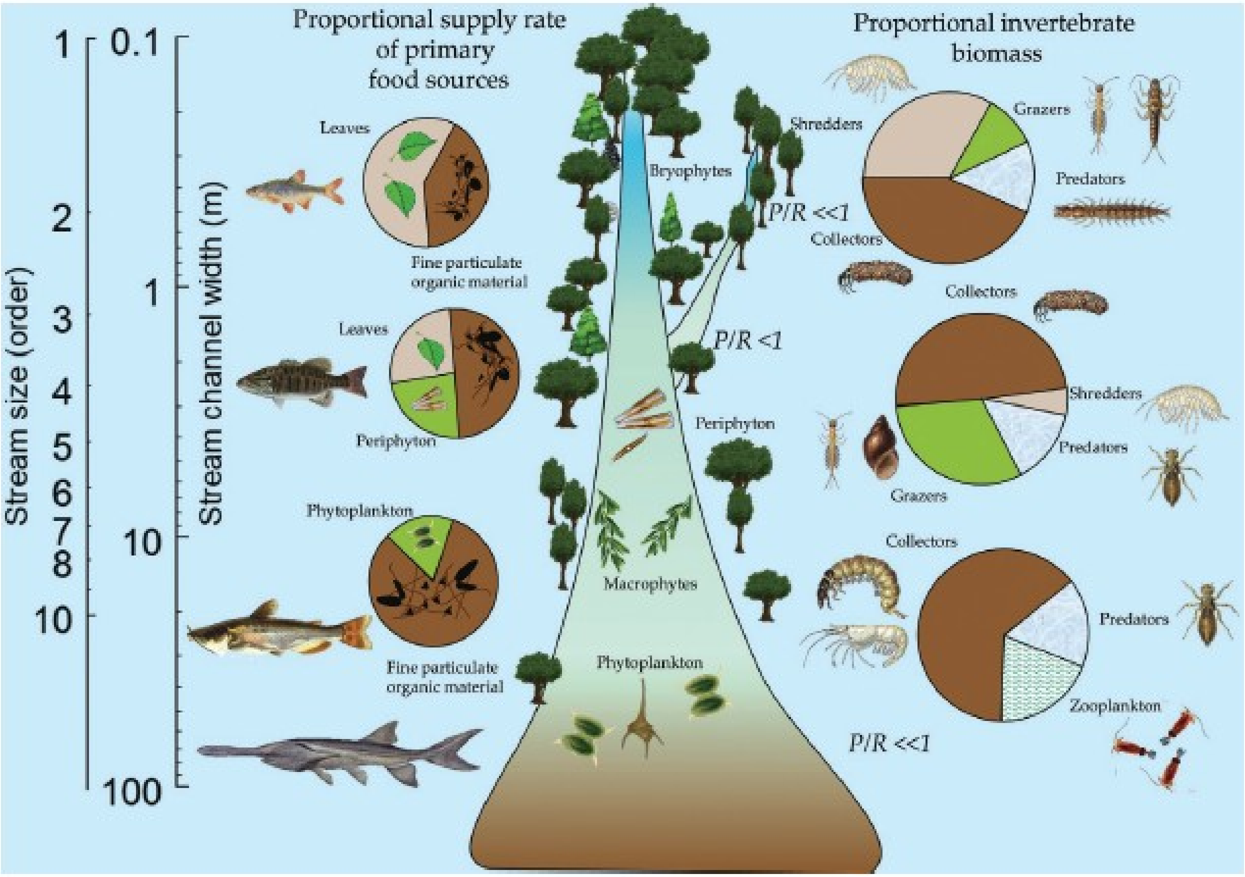


Table 1. A tabular model of ecological succession: trends to be expected in the development of ecosystems.

Ecosystem attributes	Developmental stages	Mature stages
Community energetics		
1. Gross production/community respiration (*P/R* ratio)	Greater or less than 1	Approaches 1
2. Gross production/standing crop biomass (*P/B* ratio)	High	Low
3. Biomass supported/unit energy flow (*B/E* ratio)	Low	High
4. Net community production (yield)	High	Low
5. Food chains	Linear, predominantly grazing	Weblike, predominantly detritus
Community structure		
6. Total organic matter	Small	Large
7. Inorganic nutrients	Extrabiotic	Intrabiotic
8. Species diversity—variety component	Low	High
9. Species diversity—equitability component	Low	High
10. Biochemical diversity	Low	High
11. Stratification and spatial heterogeneity (pattern diversity)	Poorly organized	Well-organized
Life history		
12. Niche specialization	Broad	Narrow
13. Size of organism	Small	Large
14. Life cycles	Short, simple	Long, complex
Nutrient cycling		
15. Mineral cycles	Open	Closed
16. Nutrient exchange rate, between organisms and environment	Rapid	Slow
17. Role of detritus in nutrient regeneration	Unimportant	Important
Selection pressure		
18. Growth form	For rapid growth ("*r*-selection")	For feedback control ("*K*-selection")
19. Production	Quantity	Quality
Overall homeostasis		
20. Internal symbiosis	Undeveloped	Developed
21. Nutrient conservation	Poor	Good
22. Stability (resistance to external perturbations)	Poor	Good
23. Entropy	High	Low
24. Information	Low	High

Wetland Soils

Generally, wetland soils can be classified into three categories:

1. Soils permanently inundated with water above the soil surface
2. Saturated soils with the water table at or just below the soil surface
3. Soils where the water table depth is always below the surface

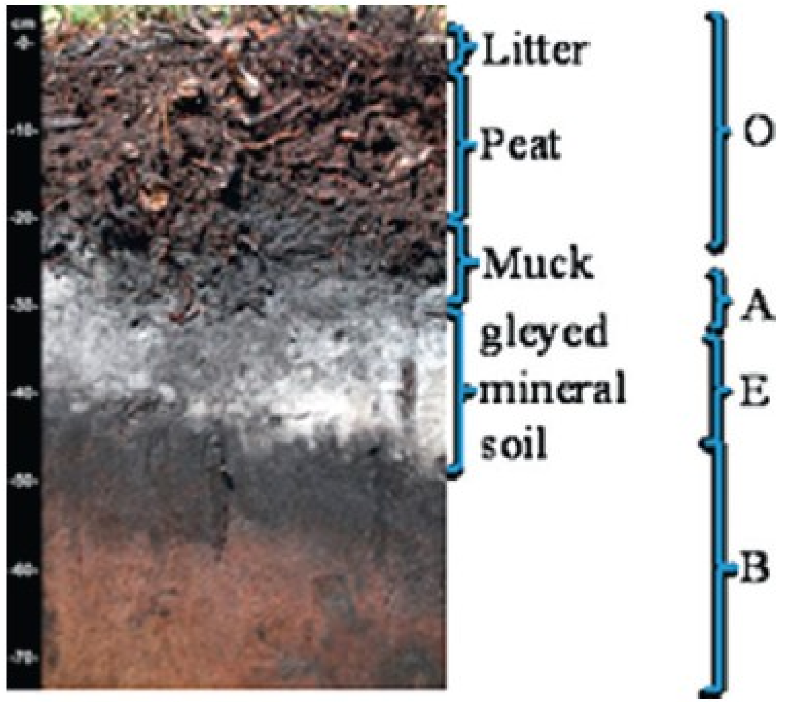


FIGURE 7.4 A hydric soil profile, with a thick dark layer of organic soil overlying a grey mineral soil characteristic of reduced iron. The traditional soil horizons for this Spodosol are indicated on the right. The organic (O) horizon overlies a mineral (A) horizon enriched in humic materials. The zone of eluviation (E) is characterized by a loss of silicate clays, iron, or aluminum and overlies the B horizon, or zone of illuviation. *Source: Image from NRCS 2010 Field Indicators of Hydric Soils in the United States; see* www.nwo.usace.army.mil/html/od-rwy/hydricsoils.pdf.

- Mosses
- Sedges
- Reeds
- Grasses
- Shrubs
- Trees

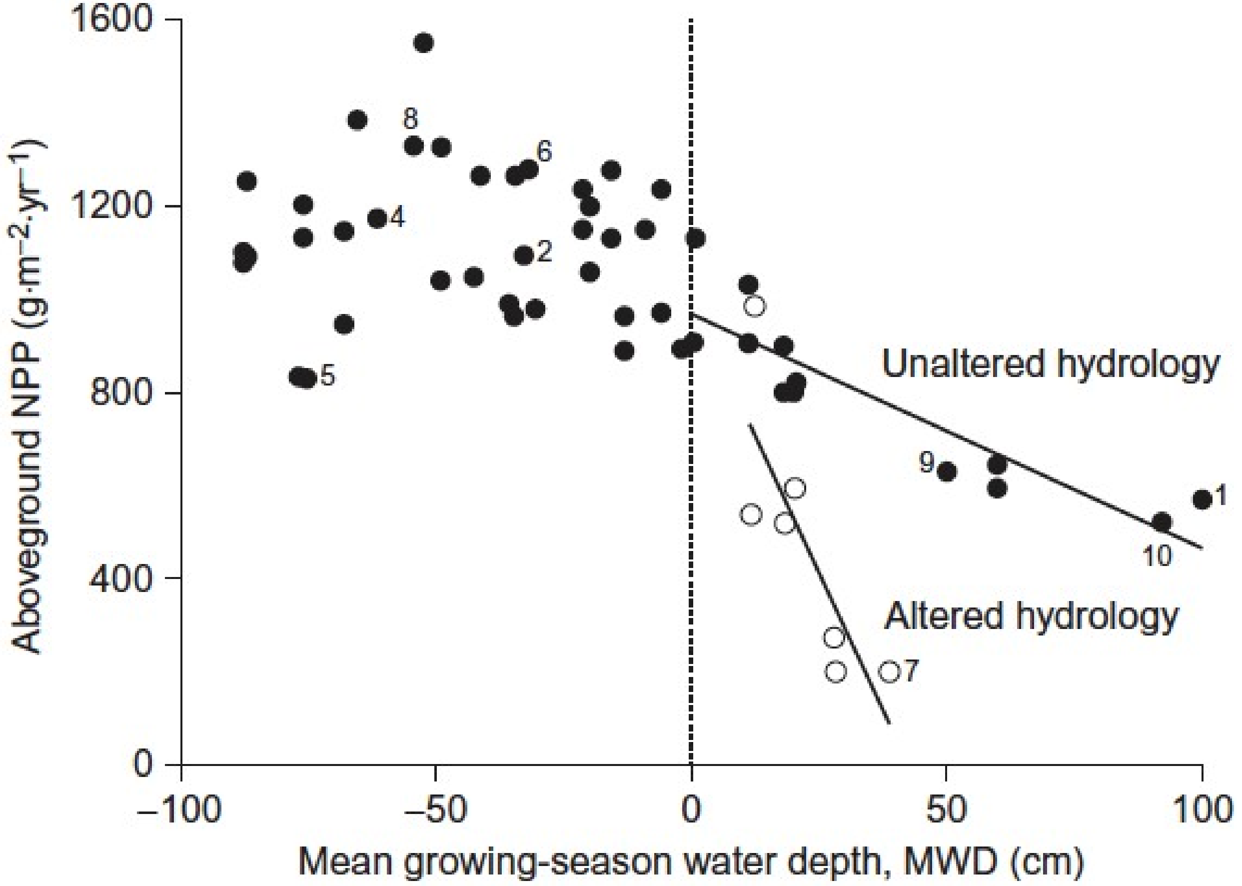


FIGURE 7.6 Water depth was negatively correlated with aboveground NPP for southern coastal wetlands. The effect of inundation was more pronounced when levees were built to maintain permanent flooding (plots shown in open circles). *Source: From Megonigal et al. 1997. Used with permission of Springer.*

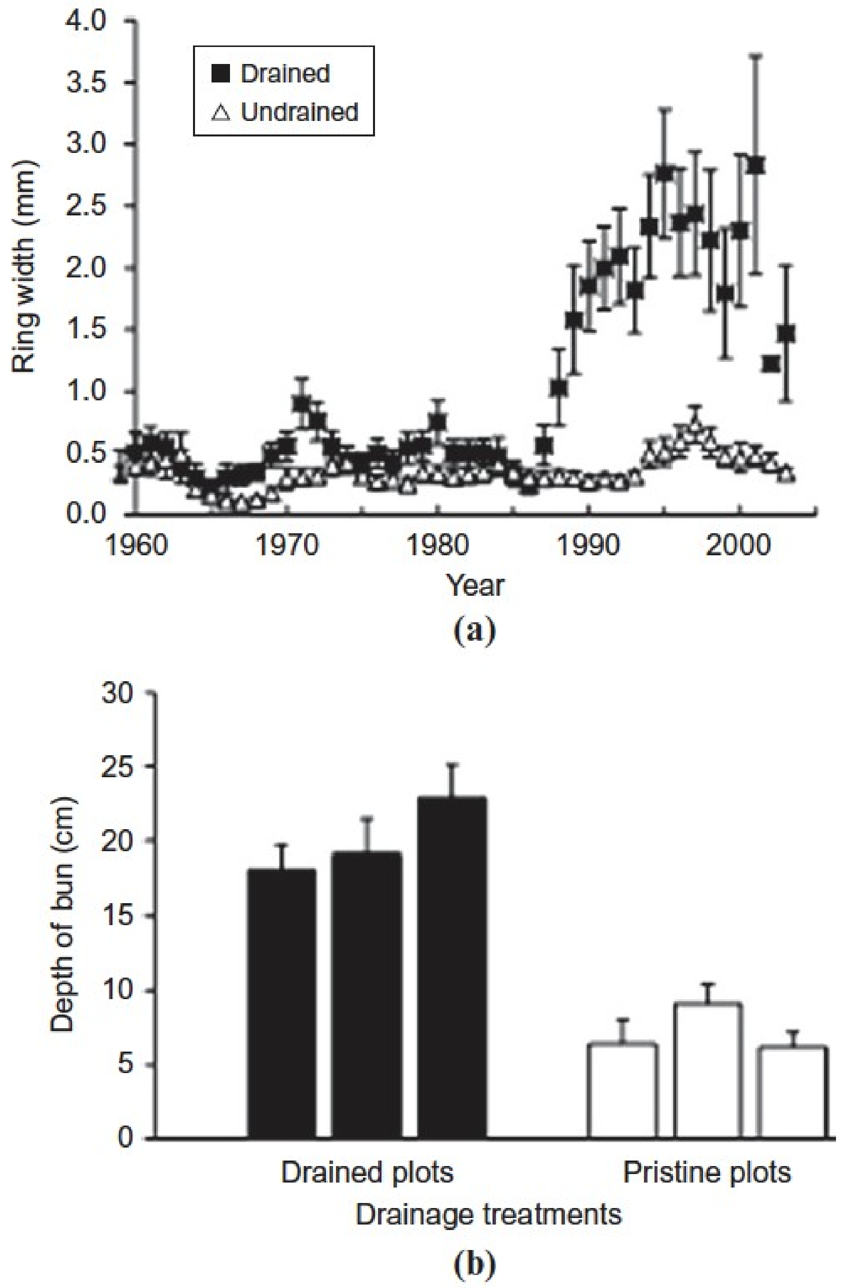


FIGURE 7.7 Drainage of a forested boreal fen in western Canada in 1986 doubled the rate of peat C accumulation through increases in tree biomass and detritus (indicated here by tree ring growth) (a), but also made the drained fen more susceptible to catastrophic losses of carbon in fire (b). In 2001, a wildfire burned ~450 years of accumulated peat in the drained portion while removing only ~58 years of accumulated peat in the undrained portions of the fen. *Source: Modified from Turetsky et al. (2011).*

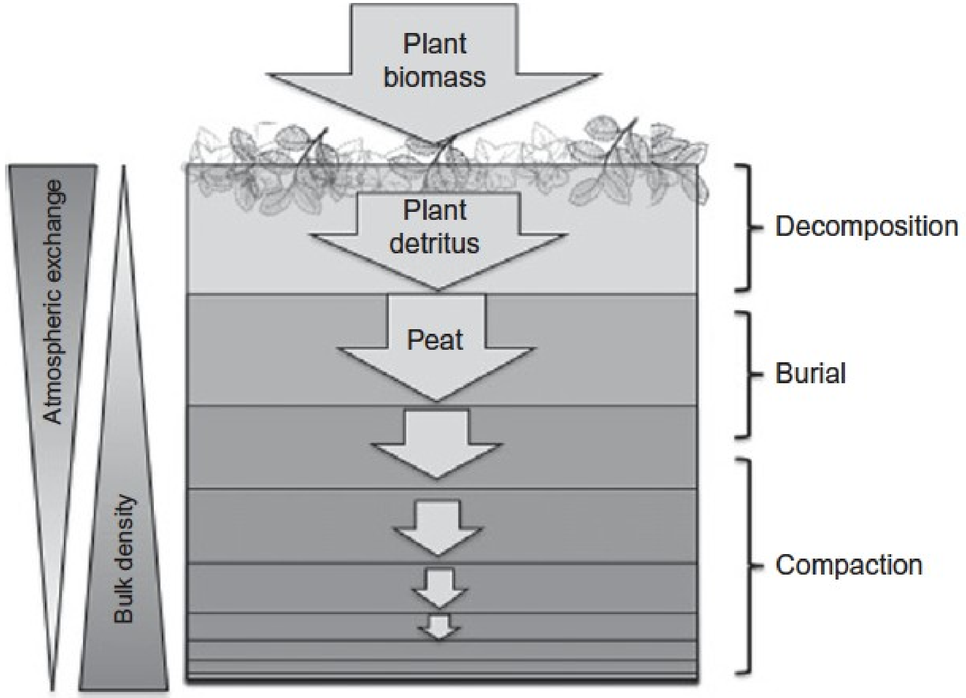


FIGURE 7.8 A model of peat accumulation and compaction over time. Fresh litter is deposited in the surface layers, where decomposition rates are highest due to oxygen diffusion and the supply of alternate electron acceptors. Organic matter that escapes decomposition is buried beneath new litter inputs and over time becomes compacted through the accumulation of overlying material. Models of peat accumulation predict that eventually peatlands reach a steady state where new biomass inputs are balanced by carbon losses through decomposition. *Source: Adapted from Clymo (1984).*

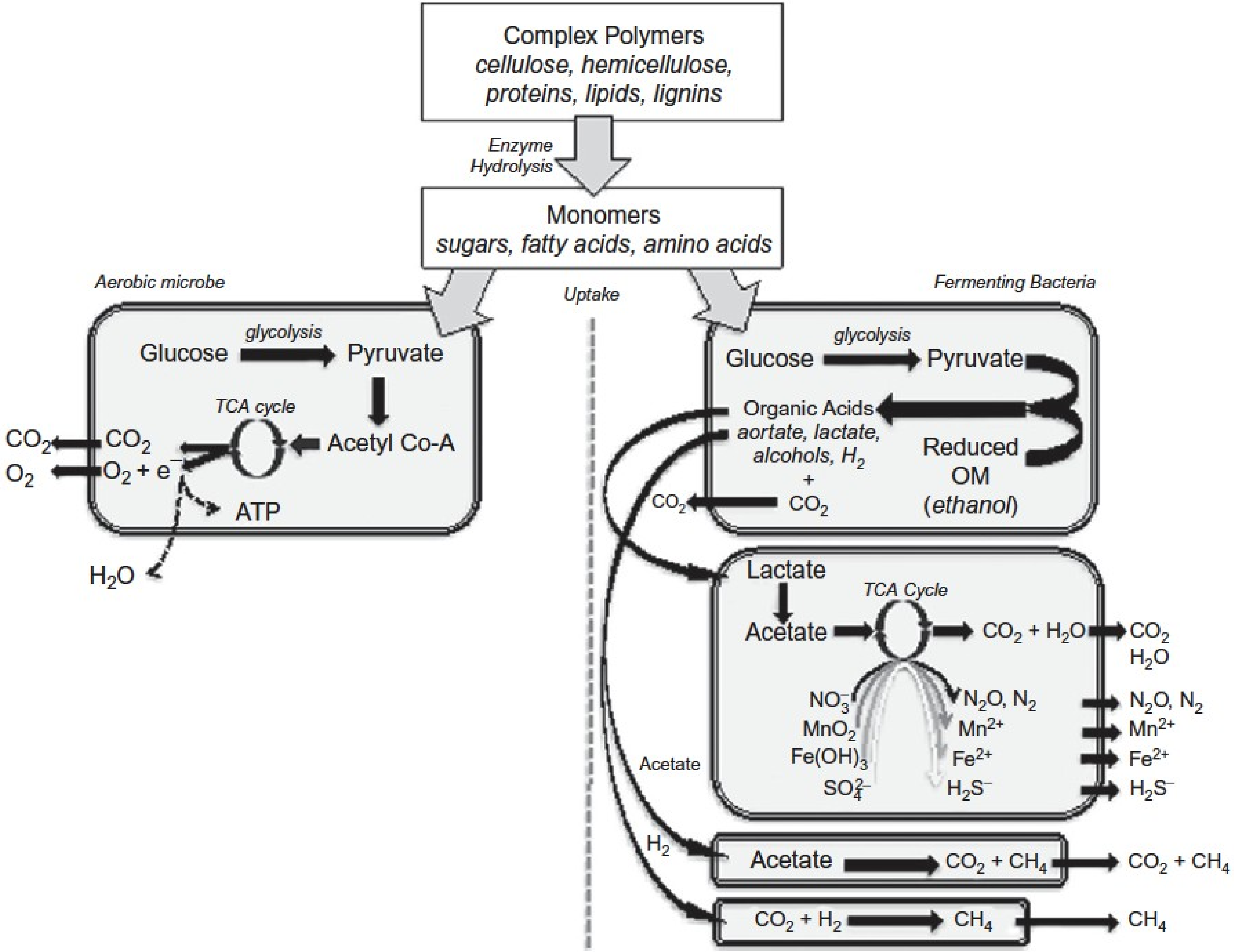


FIGURE 7.9 Contrasting the single aerobic respiration pathway with the multistage pathway involved in decomposition in the absence of oxygen. *Source: Figure drawn with inspiration from Megonigal et al. (2003) and Reddy and DeLaune (2008).*

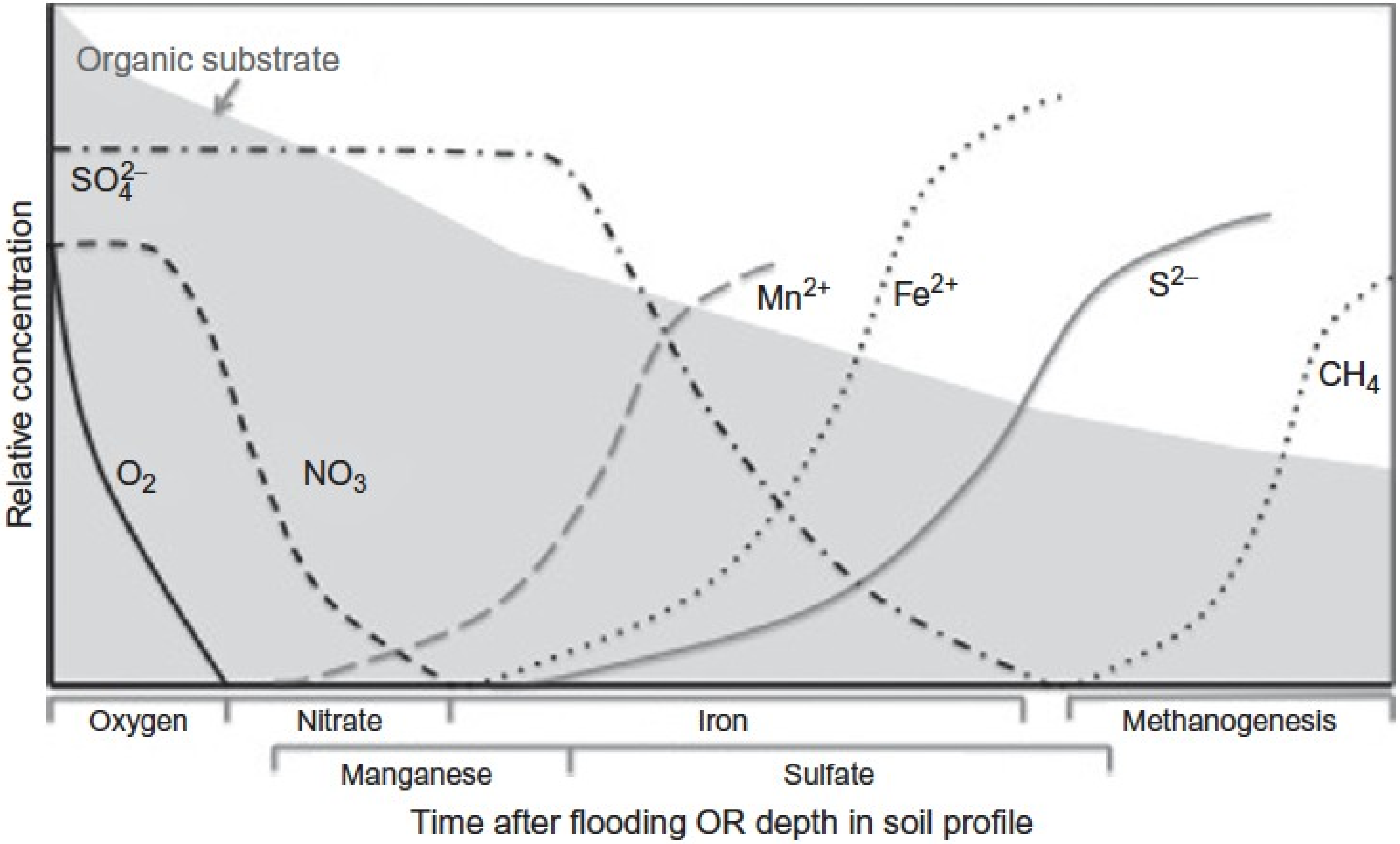


FIGURE 7.10 The concentrations of reactants and products of terminal decomposition pathways are shown for a wetland sediment over time following flooding. Rotating the figure 90° to the right shows the pattern of substrate concentrations (and the order of metabolic pathways) with depth in a soil profile.

Oxidized $\longrightarrow$ Reduced

Reduced $\longrightarrow$ Oxidized

	H_2O/O_2	C	N	S
H_2O/O_2	X	Photosynthesis $CO_2 \longrightarrow C$ $H_2O \longrightarrow O_2$		
C	Respiration $C \longrightarrow CO_2$ $O_2 \longrightarrow H_2O$	X	Denitrification $C \longrightarrow CO_2$ $NO_3 \longrightarrow N_2$	Sulfate-Reduction $C \longrightarrow CO_2$ $SO_4 \longrightarrow H_2S$
N	Heterotrophic Nitrification $NH_4 \longrightarrow NO_3$ $O_2 \longrightarrow H_2O$	Chemoautotrophy (Nitrification) $NH_4 \longrightarrow NO_3$ $CO_2 \longrightarrow C$	Anammox $NH_4 + NO_2 \rightarrow N_2 + 2H_2O$	?
S	Sulfur Oxidation $S \longrightarrow SO_4$ $O_2 \longrightarrow H_2O$	Chemoautotrophy (Sulfur-based Photosynthesis) $S \longrightarrow SO_4$ $CO_2 \longrightarrow C$	Autotrophic Denitrification $S \longrightarrow SO_4$ $NO_3 \longrightarrow N_2/NH_4$	X

FIGURE 1.4 A matrix showing how cellular metabolisms couple oxidation and reduction reactions. The cells in the matrix are occupied by organisms or a consortium of organisms that reduce the element at the top of the column, while oxidizing an element at the beginning of the row. *Source: From Schlesinger et al. (2011).*