Introduction to Limnology

Seminar and field course
Kharaa/Ulaanbaatar June 2007

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Contents

1. Introduction

- Life in freshwater systems: A unique habitat
- Aquatic ecosystems: how do they work ?
- The Individual in its habitat

2. Lakes

- Lake ecosystem concept
- Types of stratification
- Productivity of lakes I: Oxygen
- Productivity of lakes II: classification
- Inorganic Carbon in Freshwater Systems
- Organic Carbon Cycling and Detritus
- The Nitrogen Cycle in Lakes
- Ammonia / Ammonium
- The Phosphorus Cycle in Lakes

3. Streams and Rivers

- Interactions of major factors forming stream and river ecosystems
- Four-dimensional nature
- Scales
- Stream Orders
- Longitudinal Gradients
- Microhabitats
- Channel Morphology and Typology
- Discharge
- Current and Shear Stress
- Oxygen
- pH
- Biochemical Oxygen Demand
- Temperature
- Chemical characteristics

- Life in running waters: Algae
- Life in running waters: Macrophytes
- Life in running waters: Invertebrates
- River Continuum Concept
- Longitudinal Zonation of streams and rivers
- The Hyporheic Zone

4. Anthropogenic influences on running waters

- Water resources, stores and fluxes in natural landscapes and cultivated landscapes
- Trophy- Saprobity
- Water pollution and degradation
- Self purification in running waters
- Eutrophication, Acidification, Organochlorines
- Development of human impacts on rivers in Central Europe since the 19th century

Life in freshwater systems

A unique habitat:

High density of water (775 times the density of the air)

- specific weight of organisms is about 1.05, this is only little more than the density of water
- the total volume of a water body can be used for living
- moving in the water requires much energy
- structural tissues (to support the shape of cells and tissues) are not important

Freshwaters are relatively low in salt content

- organsims are hypertonic in relation to the surrounding water
- osmoregulation and ionregulation is necessary

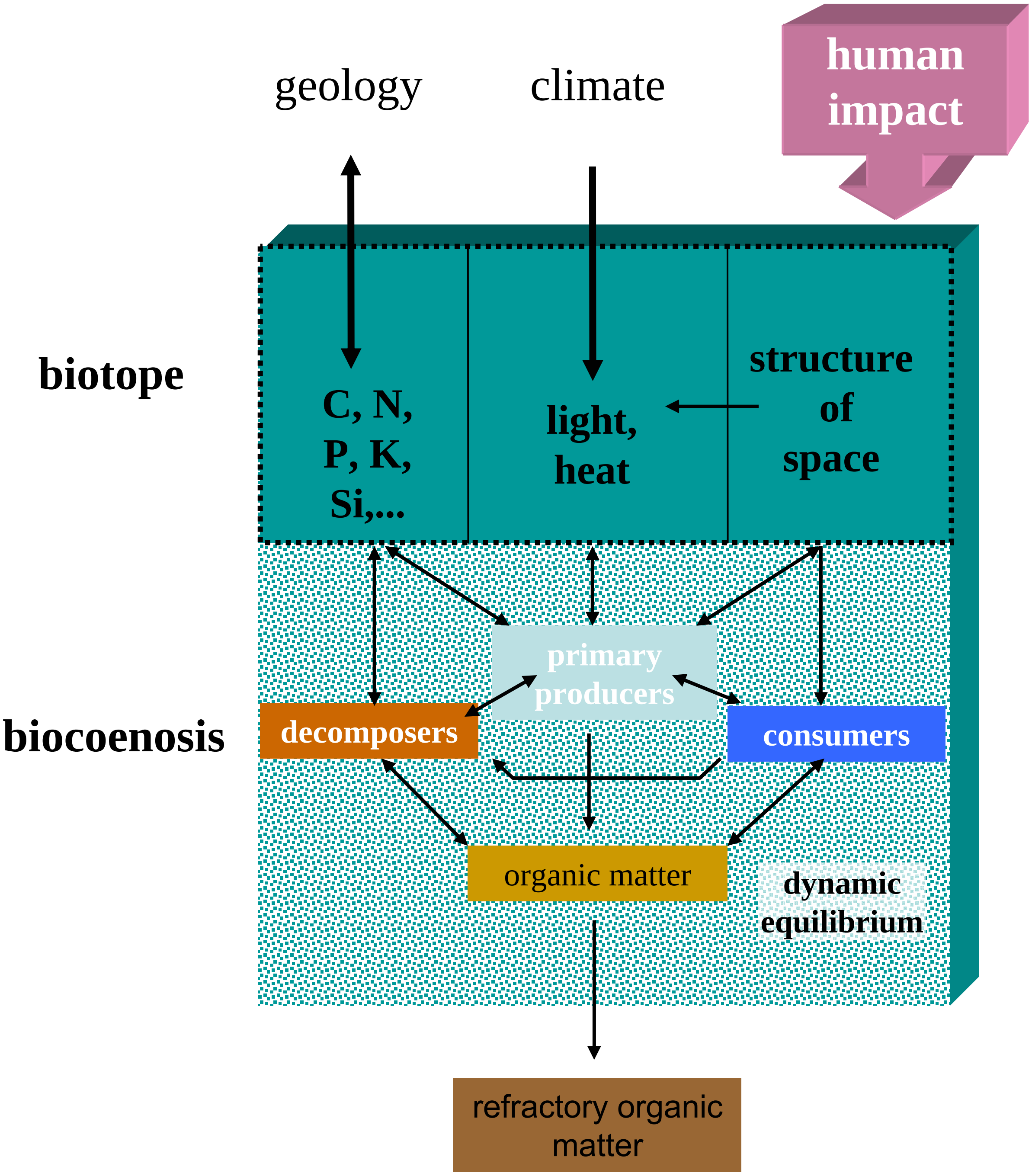
Water is an excellent solvent

- uptake of substances via the total organismic surface area
- formation of vertical gradients
- pheromons (intraspecific, e.g. sexual attractants)
- allomones (interspecific, profit for the sender, e.g. substances to fend off predators)
- kairomones (interspecific, profit for the receiver)

Formation of vertical gradients

- pressure, light, oxygen
- unequal distribution of organisms in the water body
- vertical migrations

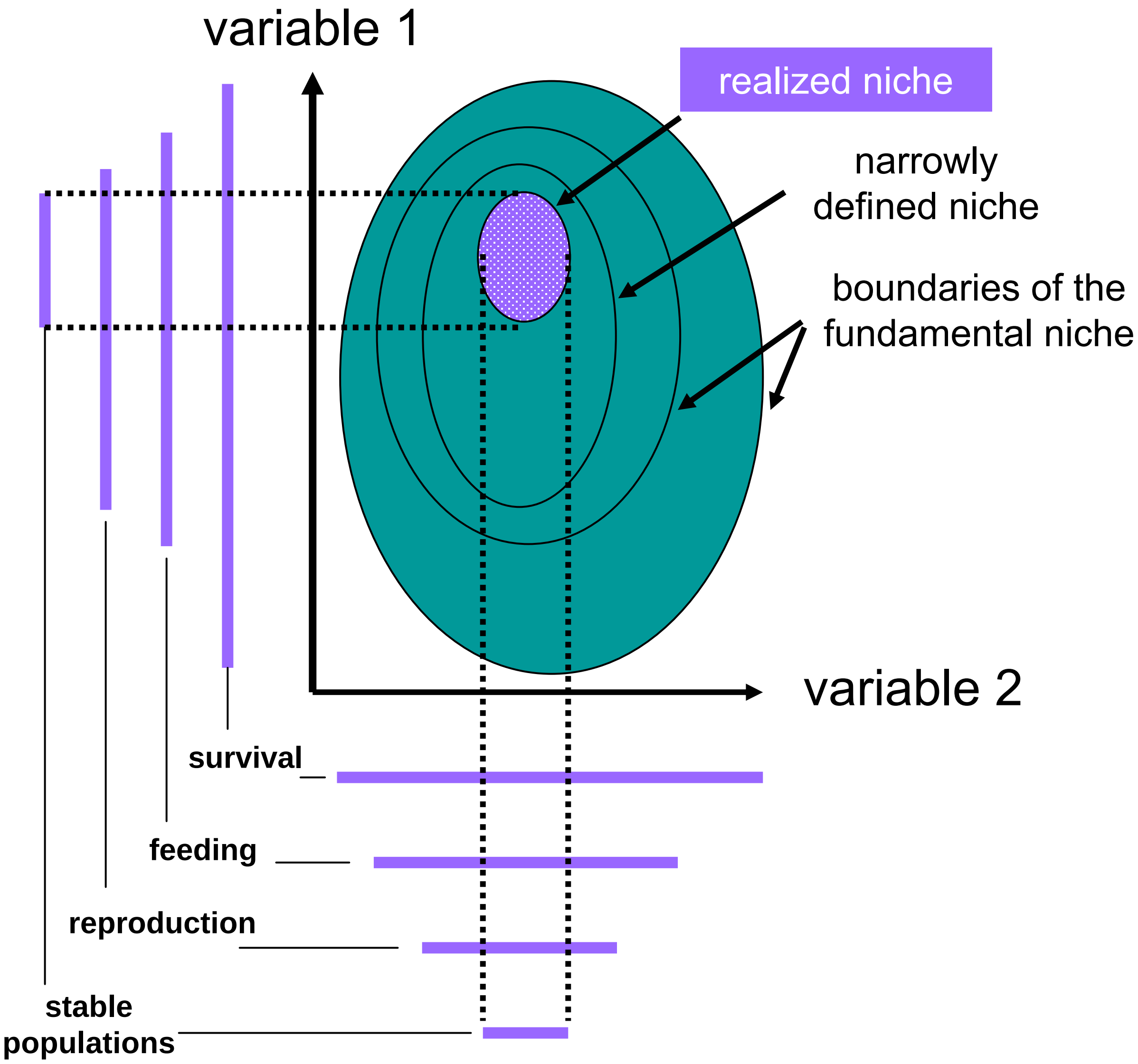
Aquatic ecosystems: how do they work ?



Ecosystems = biotic community and its abiotic environment. Ecosystems are open systems, they can regulate themselves to a certain degree.

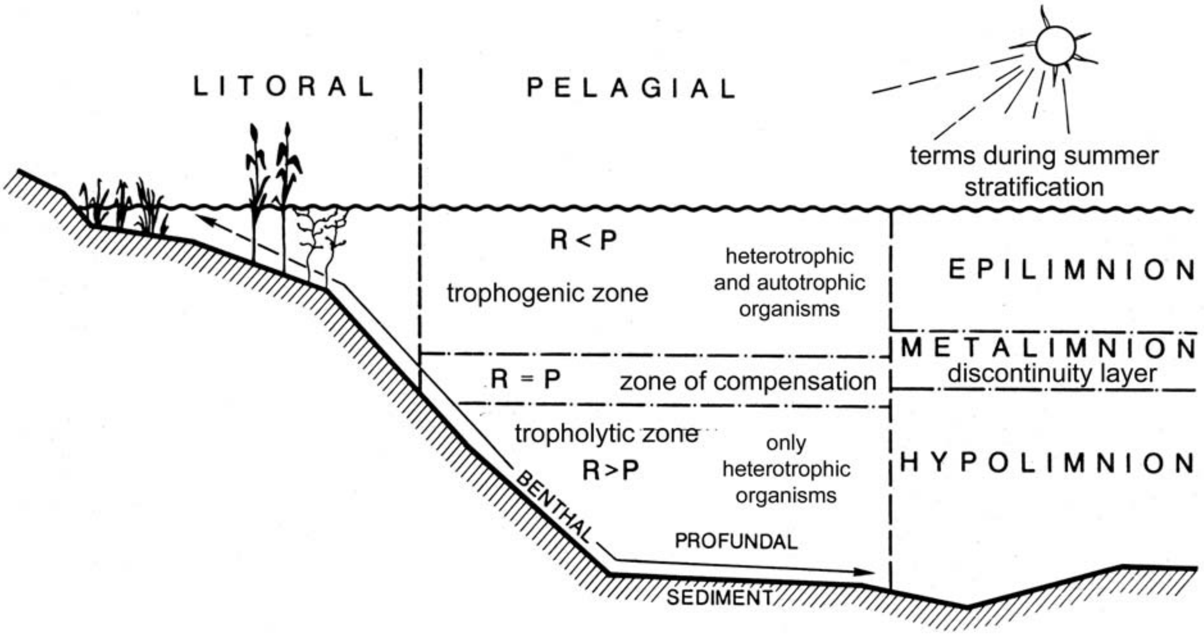
The Individual in its habitat

- **Niche**: The role or "profession" of an organism in the environment; its activities and relationships in the community
- **Habitat**: The range of environments in which a species occurs.



Organisms have **ranges of tolerance** for many environmental factors, rather for only a single factor. Each environmental factor corresponds to an axis in a hypothetical multidimensional coordinate system. The niche is accordingly an n-dimensional volume within this coordinate system (Lampert & Sommer (1997).

Lake ecosystem concept



Lake ecosystem concept. R = respiration, P = production (Kummert & Stumm 1987).

epilimnion = upper stratum of more or less uniformly warm, circulating and fairly turbulent water

hypolimnion = lower stratum, more or less cold and relatively undisturbed region

metalimnion = stratum between epi- and hypolimnion that exhibits a marked thermal discontinuity

benthal zone = bottom of the lake

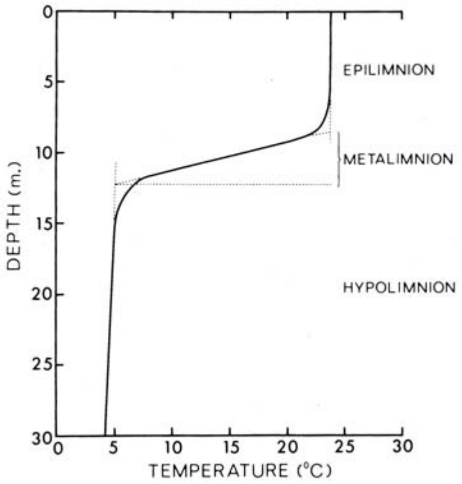
pelagial zone = free open water

littoral zone = part of the benthal zone, where primary production occurs

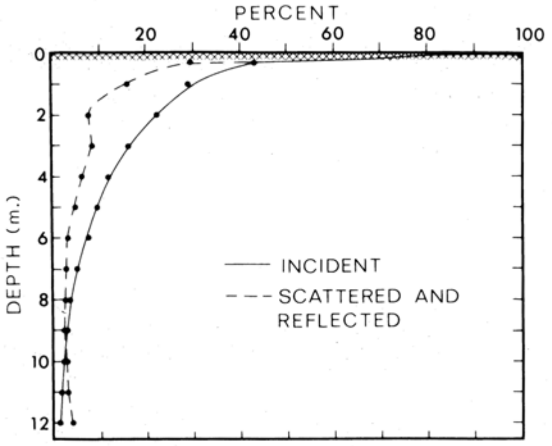
profundal zone = part of the benthal zone, where no primary production occcurs, free of vegetation

trophogenic zone = upper stratum of a lake in which photosynthetic production predominates

tropholytic zone = aphotic deep stratum where decomposition of organic matter predominates

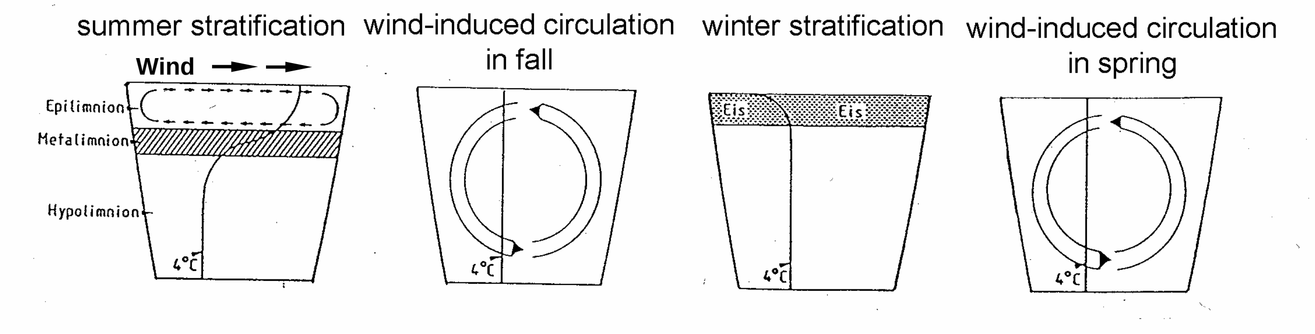


Typical thermal stratification of a lake



Incident light penetration with depth and backscattered light from concentration of plankton, especially at 3 m.

Types of stratification I



(Elster 1964)

Dimictic Lakes: lakes that circulate freely twice a year in spring and fall and are directly stratified in summer und inversely stratified in winter. Cool temperate regions.

Warm momomictic lakes: temperatures do not drop below 4°C and they stratify directly in the summer. Warm regions of the temperate zones.

Oligomictic lakes: lakes with rare circulation periods at irregular intervals, temperatures well above 4°C. Generally tropical. Lakes often maintain stable stratification (especially small or very deep lakes), even though only a small temperature difference may exist between surface and bottom strata.

Popymictic lakes: lakes with frequent or continuous circulation.

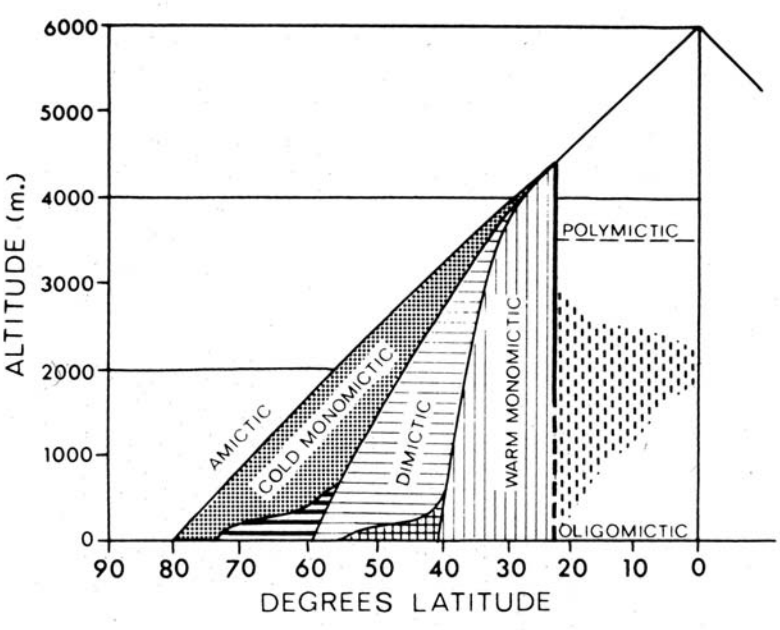
Cold polymictic lakes: circulate continually at temperatures near or slightly above 4°C. Equatorial regions of high wind and low humidity, where little seasonal change in air temperatures occurs.

Warm polymictic lakes: usually tropical lakes that exhibit frequent periods of circulation at temperatures well above 4°C. Annual temperature variations are small in the equatorial tropics and result in repeated periods of circulation between short intervals of heating and weak stratification, followed by periods of rapid cooling. Under these circumstances, convectional circulation is sufficient, in combination wirth wind, to disrupt stratification.

Amictic lakes: lakes that are sealed off perennially by ice from most of the annual variations in temperature. These lakes are rare and largely limited to Antarctica, or, more rarely, to very high mountains.

Cold Monomicitc lakes: lakes with water temperature never greater thar 4°C, and with only one period of circulation in the summer at or below 4°C. Arctic and mountain lakes, which, although they may be ice-free for brief periods in the summer, are in frequent contact with glaciers or pemafrost.

Types of stratification II



(Wetzel 1983)

Schematic arrangement of thermal lake types with latitude and altitude. *Black dots*: cold monomictic; *black and white horizontal bars*: transitional regions; *horizontal lines*: dimictic; crossed lines: transitional regions; *vertical lines*: warm monomictic. The two equatorial types occupy the unshaded areas labelled oligomictic and polymictic, separated by region of mixed types, mainly variants of the warm monomictic type (*broken vertical lines*).

Many exceptions exist !

Productivity of lakes I: Oxygen

oligotrophic lakes

lakes that are low in primary production, very clear, low in nutrients,
these lakes contain at the end of summer density stratification more than 70% oxygen in deeper layers

mesotrophic lakes

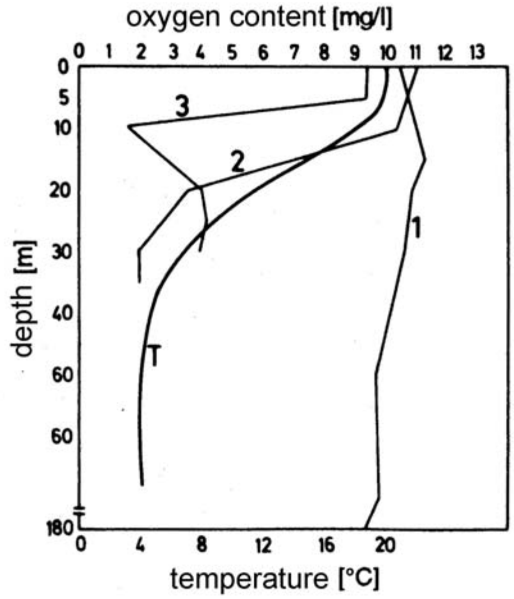
moderate content of nutrients, primary production is moderate, visibility more than 2 m,
these lakes contain at the end of summer density stratification 30 – 70 % oxygen in deeper layers

eutrophic lakes

high content of nutrients, primary production is high, visibility less than 2 m,
these lakes contain at the end of summer density stratification 0 – 30 % oxygen in deeper layers,
in surface layers occasionally more than 100 % oxygen content

polytrophic lakes

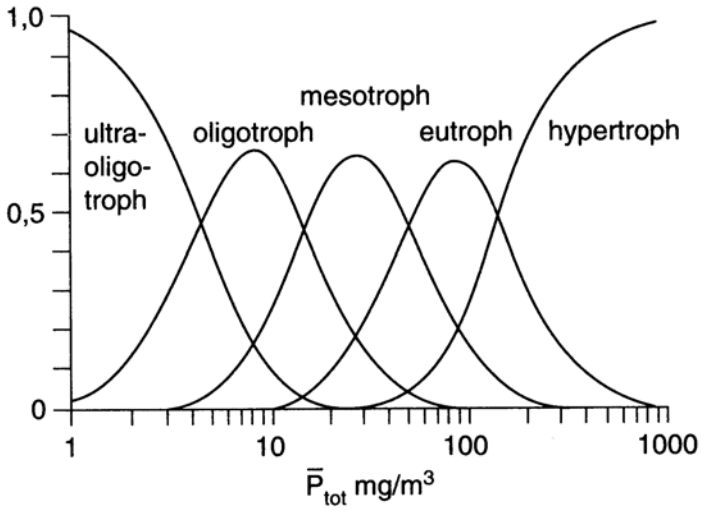
very high content of nutrients, no nutrient depletion, primary production is very high, visibility very low,
these lakes contain during summer no oxygen in deeper layers, formation of hydrogen sulfide



(Schwoerbel 1993)

Vertical profile of oxygen in
1 oligotrophic lakes => orthograde oxygen profile
2 eutrophic lakes => clinograde oxygen profile
3 eutrophic lakes => positive heterograde curve with metalimnic oxygen maxima
T = temperature

Productivity of lakes II: classification



Probable boundaries of the degrees of trophy of waterbodies with differing annual mean values of total phosphorus concentrations (Schwoerbel 1993).

Trophie-Klassen	P	ch	max ch	sec	min sec	% Sauerstoff-sättigung über Grund in Abhängig-keit von der Seetiefe
	(mg/m^3)			(m)		
Ultra-oligotroph	4,0	1,0	2,5	12,0	6,0	90%
Oligotroph	10,0	2,5	8,0	6,0	3,0	80%
Mesotroph	10–35	2,5–8	8–25	6–3	3–1,5	40%–89%
Eutroph	35–100	8–25	25–75	3–1,5	1,5–0,7	40%–0%
Hypertroph	100	25	75	1,5	0,7	10%–0%

General trophic classification of lakes and reservoirs in relation to phosphorus (P), chlorophyll a (ch), maximum chlorophyll a (max ch), mean annual and minimum secchi transparency depth (sec, min sec) and oxygen content above the bottom; according to OECD. (Schwoerbel 1993).

Inorganic Carbon in Freshwater Systems

Global average of CO_2 concentration in the athmosphere: about 0.033 %, increasing.

The amount of CO_2 dissolved in water from athmospheric concentrations is about 1.1 mg/l at 0°C, 0.6 mg/l at 15°C and 0.4 mg/l at 30°C.

Dilution of CO_2 in water:

$$CO_2 \text{ (air)} \rightleftharpoons CO_2 \text{ (dissolved)} + H_2O$$
$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

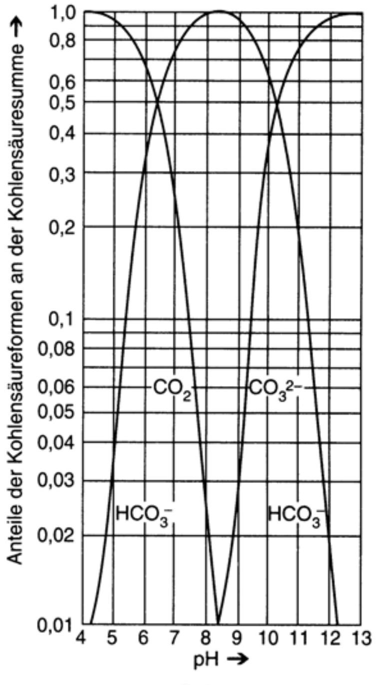
This reaction predominates at a pH of less than 8, H_2CO_3 is a weak acid that dissociates rapidly:

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$
$$HCO_3^- \rightleftharpoons H+ + CO_3^{2-}$$

The bicarbonate and carbonate ions also dissociate to establish an equlibrium:

$$HCO_3^- + H_2O \rightleftharpoons H_2CO_3 + OH^-$$
$$CO_3^{2-} + H_2O \rightleftharpoons HCO_3^- + OH^-$$
$$H_2CO_3 \rightleftharpoons H_2O + CO_2$$

Photosynthesis and respiration are two major factors that influence the amounts of CO_2 in water. However, the equilibria of the reactions given above result in the buffering action of alkaline waters, which contain appreciable amount of bicarbonate. Water tends to resist change in pH as long as these equilibria are operational. An addition of hydrogen ions neutralizes hydoxyl ions formed by the dissociation of HCO_3^- and CO_3^{2-}, but more hydroxyl ions are formed immediately by reaction of the carbonate with water. Consequently, the pH remains essentially unaltered, unless the supply of carbonate or bicarbonate ions is exhausted.



Relation between pH and the relative proportions of inorganic carbon species of CO_2, HCO_3^-, and CO_3^{2-} in solution (Schwoerbel 1993).

Inorganic Carbon in Freshwater Systems

The total inorganic carbon concentration in fresh water depends on the pH, which is governed largely by the buffering reactions of carbonic acid and the amount of bicarbonate and carbonate derived from the weathering of rocks.

If a solution of calcium bicarbonate in equilibrium with CO_2, H_2CO_3 and CO_3^{2-} loses a portion of the CO_2 required to maintain the equilibrium (e.g. CO_2 assimilated by photosynthetic organisms) $CaCO_3$ will precipitate until the equilibrium is reestablished by the formation of CO_2:

$$\boxed{Ca(HCO_3)_2 \rightleftharpoons CaCO_3 + H_2O + CO_2}$$

Alkalinity and Acidity of Natural Waters

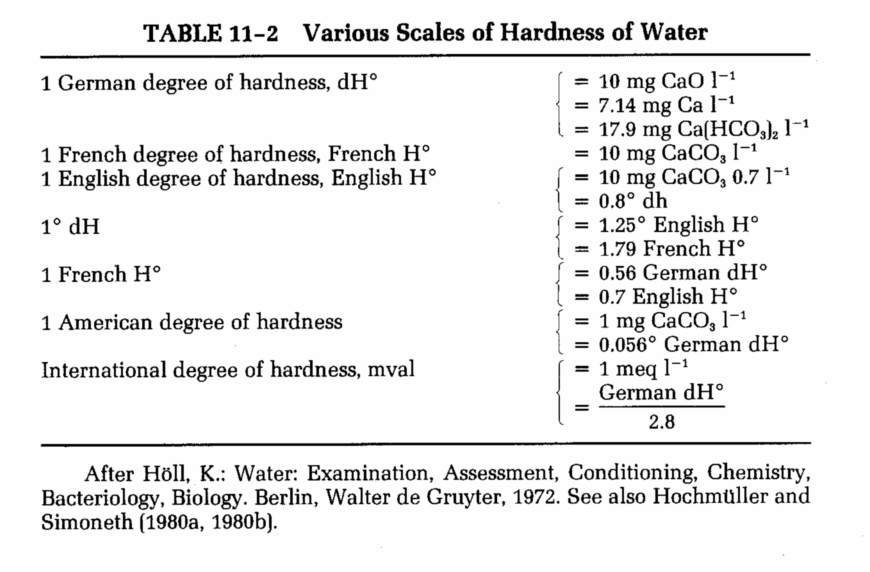
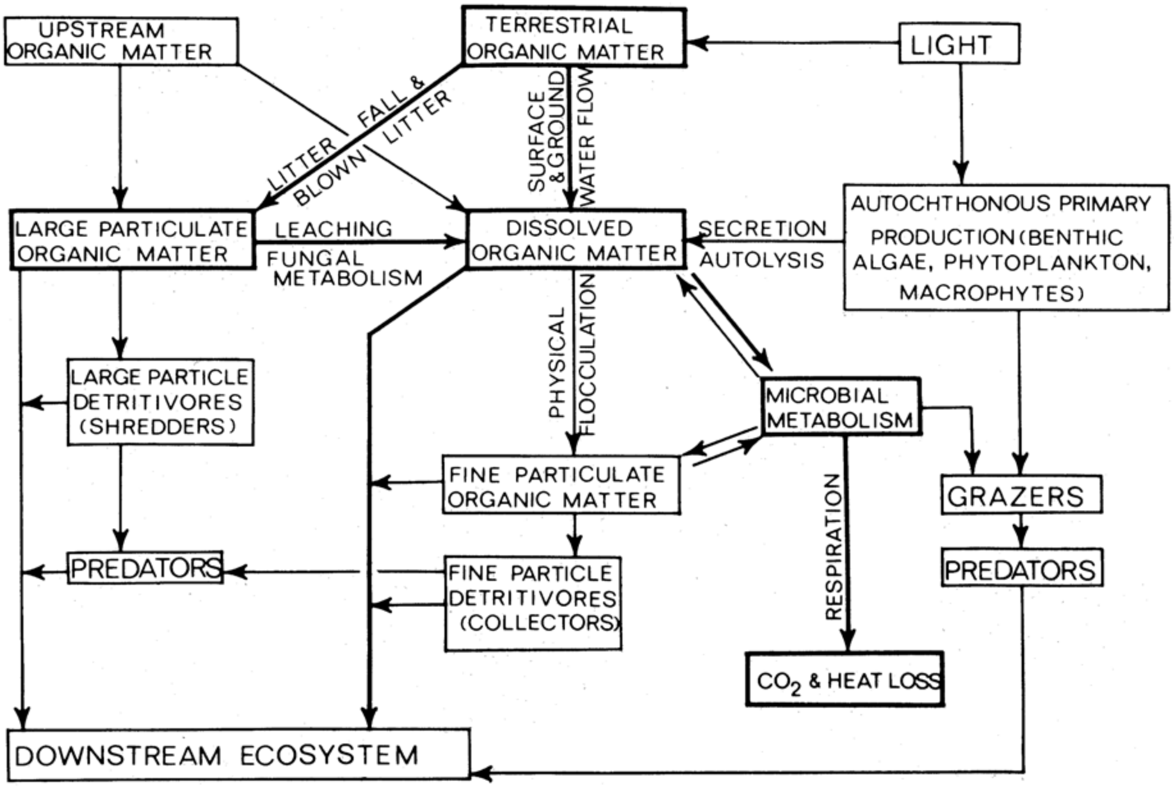


TABLE 11-2 Various Scales of Hardness of Water

1 German degree of hardness, dH°	$= 10$ mg CaO l^{-1} $= 7.14$ mg Ca l^{-1} $= 17.9$ mg $Ca(HCO_3)_2$ l^{-1}
1 French degree of hardness, French H°	$= 10$ mg $CaCO_3$ l^{-1}
1 English degree of hardness, English H°	$= 10$ mg $CaCO_3$ 0.7 l^{-1} $= 0.8°$ dh
1° dH	$= 1.25°$ English H° $= 1.79$ French H°
1 French H°	$= 0.56$ German dH° $= 0.7$ English H°
1 American degree of hardness	$= 1$ mg $CaCO_3$ l^{-1} $= 0.056°$ German dH°
International degree of hardness, mval	$= 1$ meq l^{-1} $= \frac{\text{German dH°}}{2.8}$

After Höll, K.: Water: Examination, Assessment, Conditioning, Chemistry, Bacteriology, Biology. Berlin, Walter de Gruyter, 1972. See also Hochmüller and Simoneth (1980a, 1980b).

Organic Carbon Cycling and Detritus



Compartment model of the structure of an idealized stream ecosystem. Heavier lines indicate dominant transport and metabolic pathways of organic matter (Wetzel 1983).

The Nitrogen Cycle in Lakes

Important reactions of nitrogen in aquatic ecosystems are:

Nitrification

Nitrosomonas: $NH_4^+ + 3/2\ O_2 \rightleftharpoons 2H^+ + NO_2^- + H_2O$
(total exothermic energy -276 kJ/mol)

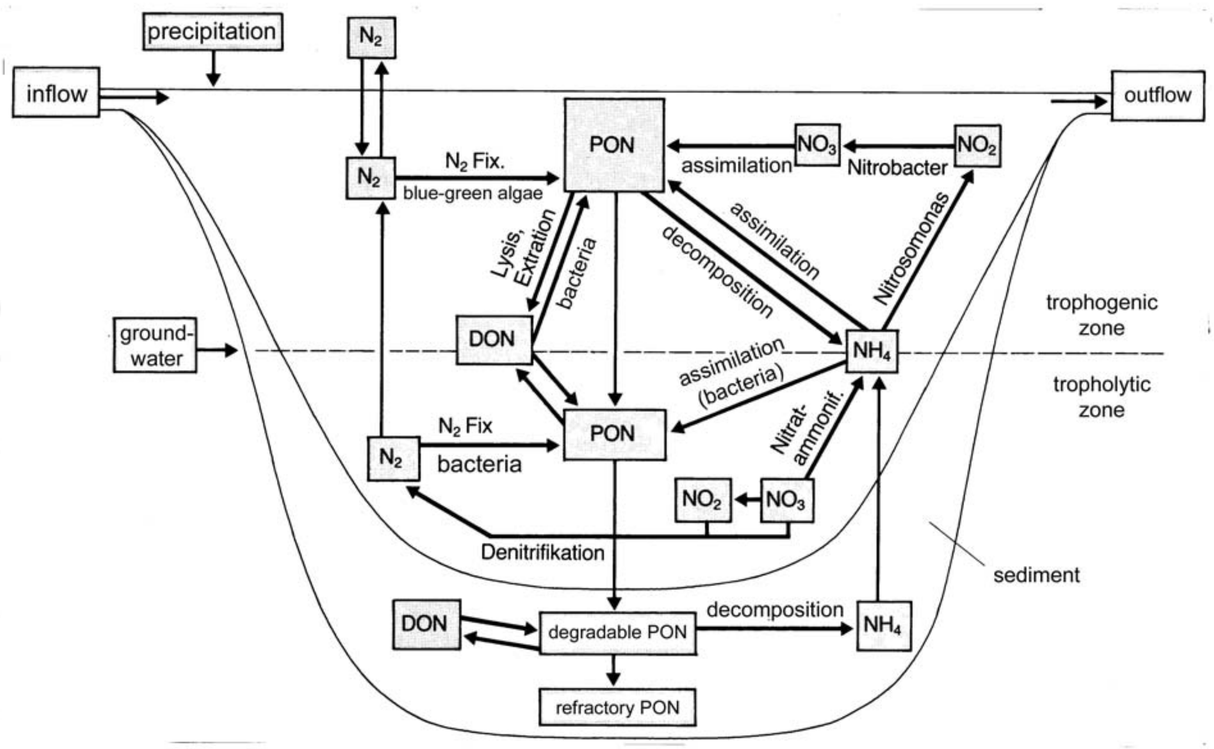
Nitrobacter: $NO_2^- + 1/2\ O_2 \rightleftharpoons NO_3^-$
(total exothermic energy -75 kJ/mol)

Nitrate reduction and denitrification

Denitrification by bacteria (*Pseudomonas, Achromobacter, Escherichia, Bacillus, Micrococcus*) is the biochemical reduction of oxidized nitrogen anions, NO3-N and NO2-N, with concomitant oxidation of organic matter. The general sequence of this process is:

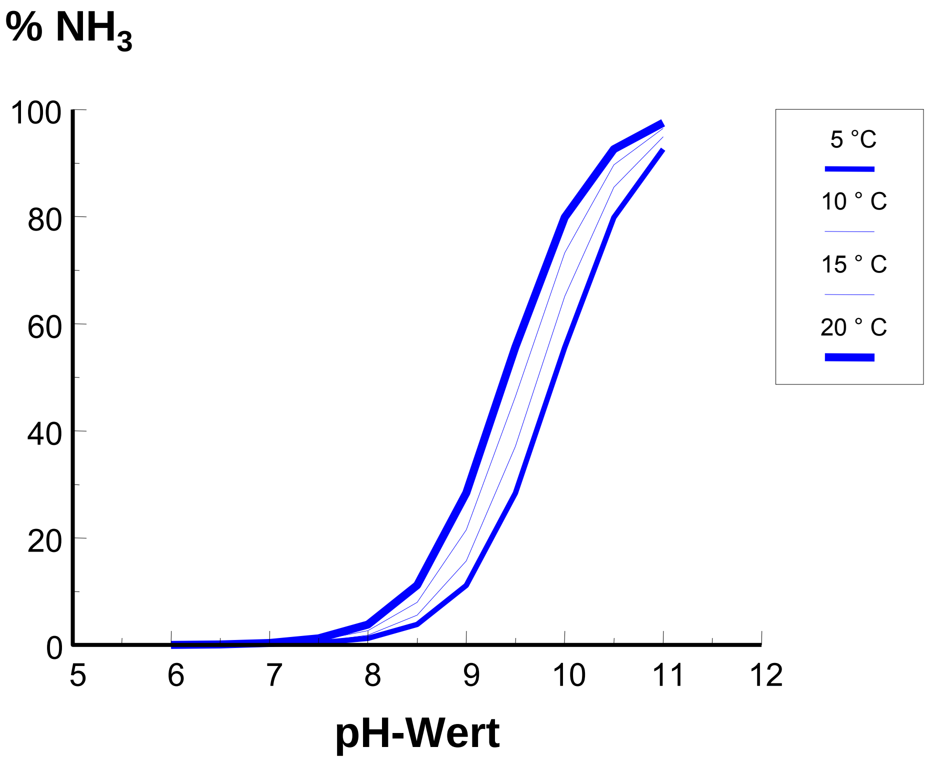
$$NO_3^- \rightarrow NO_2^- \rightarrow N_2O \rightarrow N_2$$

The nitrogen cycel in lakes (Lampert & Sommer 1999).

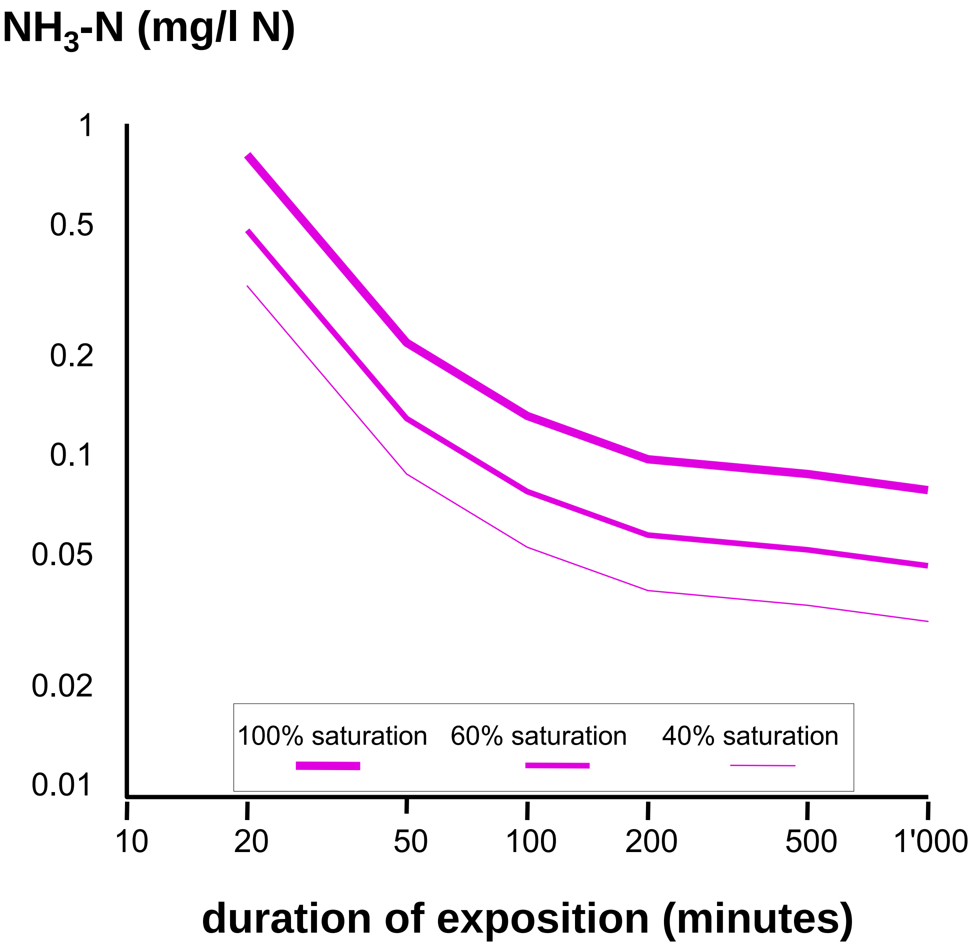


Dissociation dynamics of ammonia and ammonium are governed by pH and temperature

$$\% \, NH_3 = \frac{1}{10^{\left(0.09018 + \frac{2729.92}{273.2 + T} - pH\right)} + 1}$$



Effects of toxic substances are dependent on the duration of the exposition and the oxygen content



Limit values

about 0.1 mg/l NH_3-N are directly toxic to salmonid and cyprinid fish
about 0.025 mg/l NH_3-N are chronically toxic

The Phosphorus Cycle in Lakes

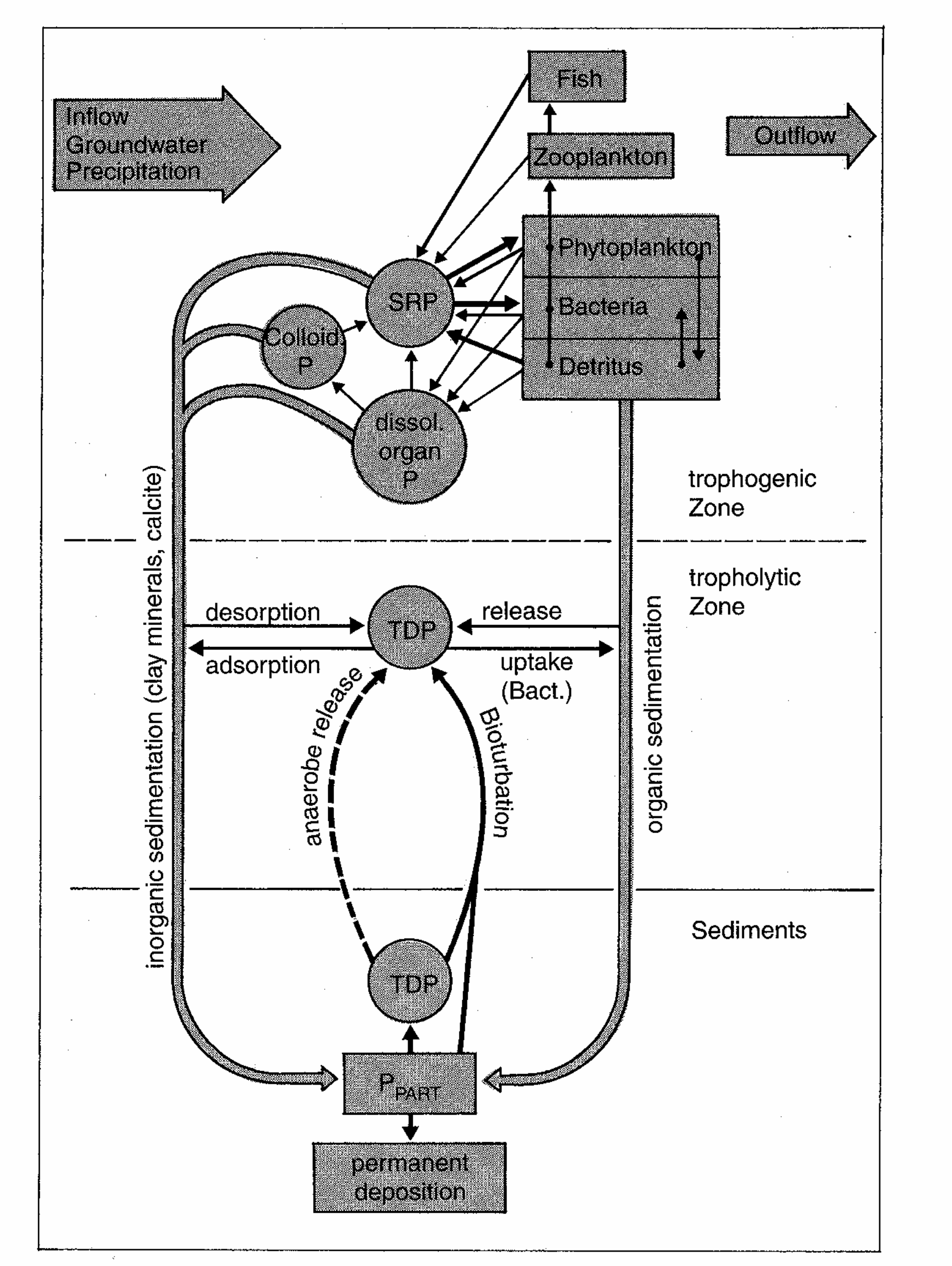
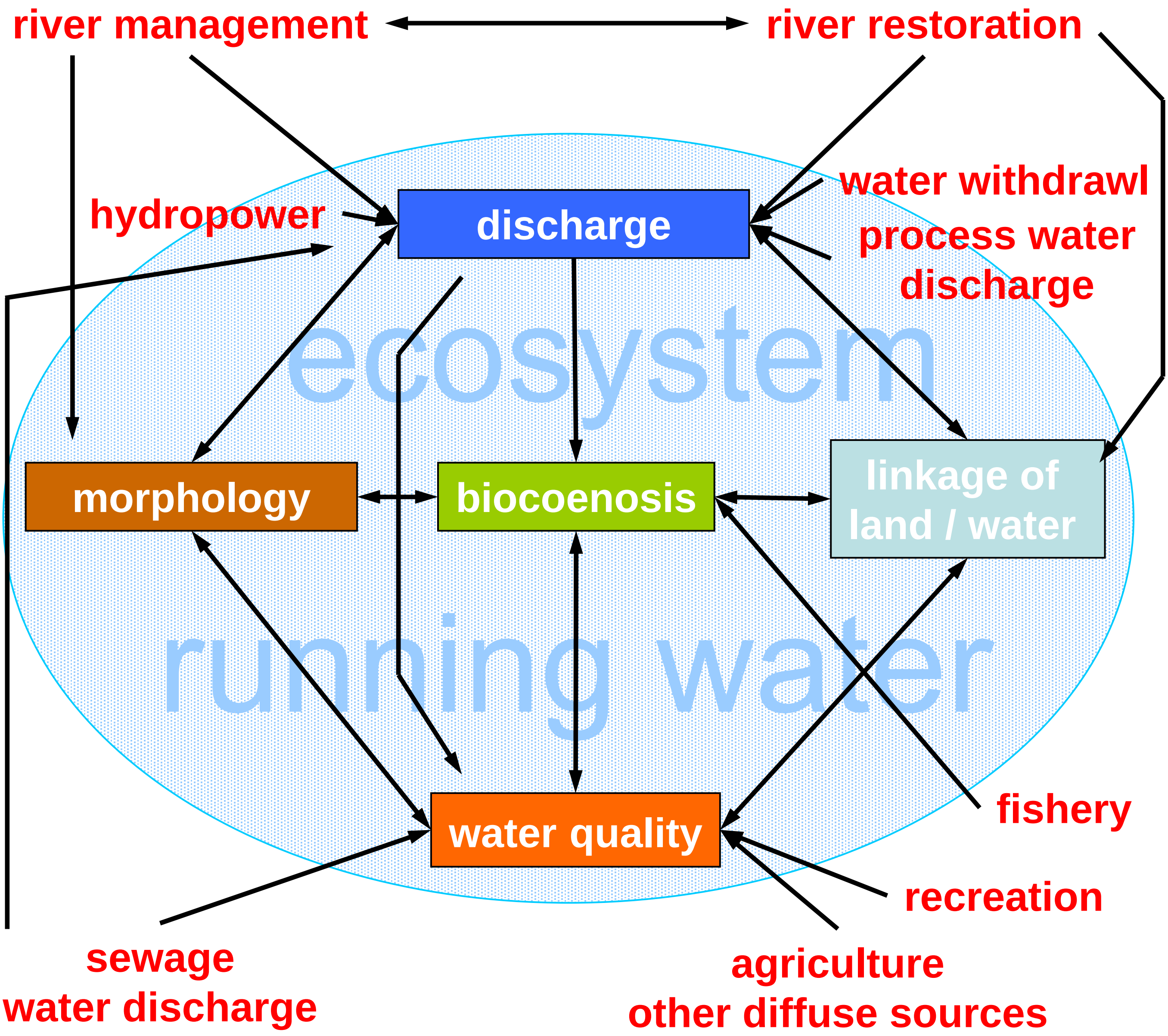
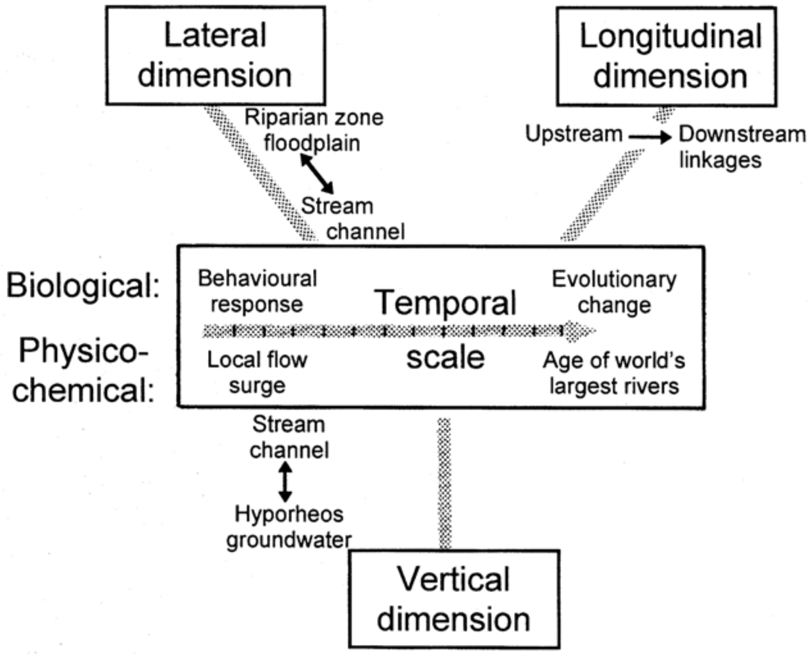


Diagram of the P cycle in a stratified lake. Gray arrows: physical transport; black arrows: biological transformations (Lampert & Sommer 1997).

Interactions of major factors forming stream and river ecosystems



Streams and Rivers: Four-dimensional nature



The four-dimensional nature of stream and river ecosystems (Ward 1989):

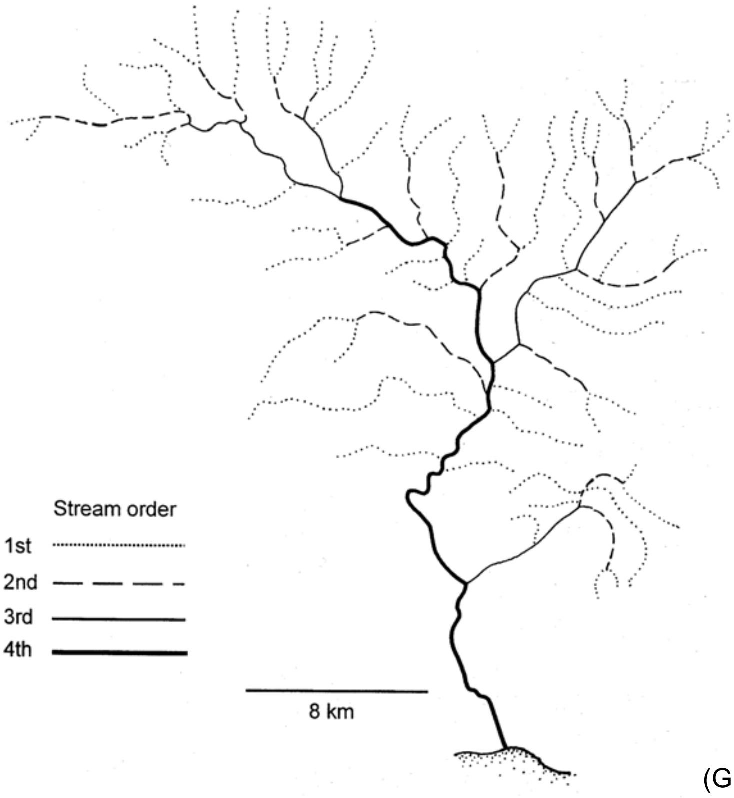
1. ***Longitudinal dimension*** – upstream and downstream – along which there is normally a profound and predictable change in the physicochemical conditions that in turn lead to longitudinal patterns in biotic colonisation

2. ***Lateral dimension***, involving the interactions between the stream channel, the riparian zone and the surrounding catchment (land-water interface). There is also some lateral interaction below the substrate surface
(=> hyporheic zones).

3. ***Vertical dimension***, primarily involving the interaction between the river water and the groundwater through the hyporheic zone. In this vertical dimension, one should consider the air-water interface, which plays a role in stream ecosystem function and on which a number of species forms live.

4. ***Temporal dimension***, where changes in physicochemical factors and the biota relate to seasonal and daily aspects. Changes in structure and function of stream and river ecosystems can be related to flood disturbances, climate changes and changes in land use vegetation of the catchment.

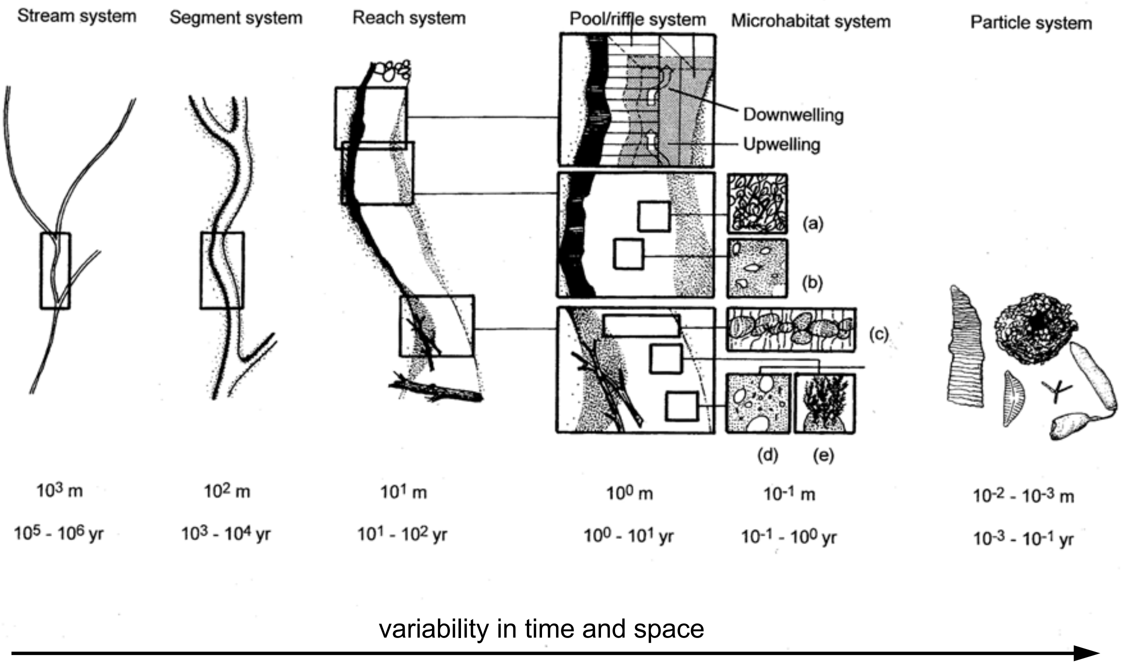
Stream Orders



(Giller & Malmqvist 2002)

An example of a river drainage basin (the River Ouse, Sussex, UK) showing the classification of stream orders according to Horton and Strahler. 1st order streams are single, unbranched headwater channels, 2nd order streams are formed when two 1st order streams meet, 3rd order streams are formed when two 2nd order streams meet, and so on. Stream order only increases when two streams of equivalent rank merge. Large rivers, such as the Mississippi and the Nile, are 10th order and the Amazon 12th order. Classifying streams in this way is a useful convenience for organizing information of a spatial nature and helps the biologist when analysing longitudinal changes in stream characteristics within a single catchment, but care should be taken when comparing across catchments.

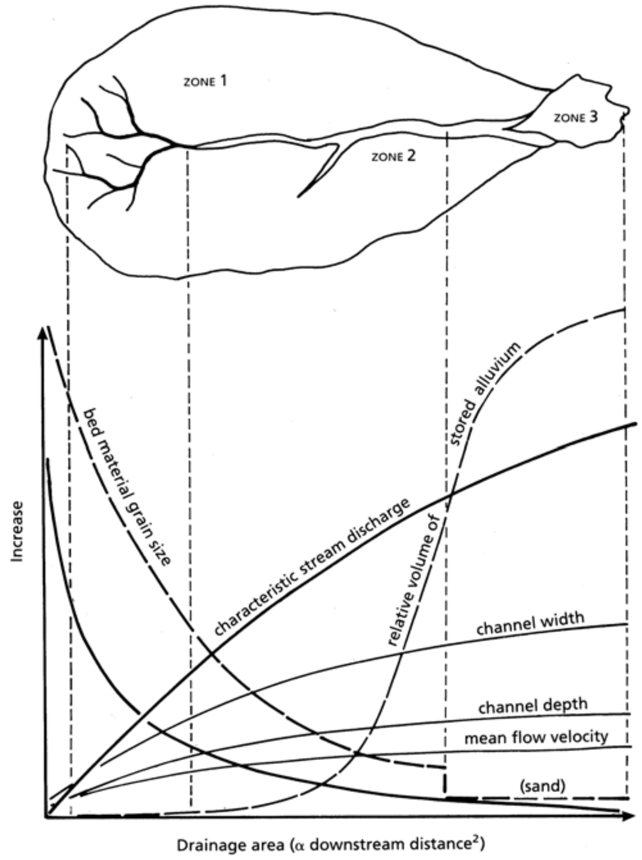
Streams and Rivers: Scales



Scale and persistence in stream systems (Giller & Malmqvist 2002). The figure illustrates the hierarchical classification of stream habitats. In the microhabitat system, (a) leaf and stick detritus in pool margin, (b) sand-silt over cobbles in the pool, (c) transverse bar over cobbles in riffle, (d) fine gravel patch, and (e) moss on boulder. The particle system contains mineral particles, faecal material, organic fragments, hyphomycete conidia etc.

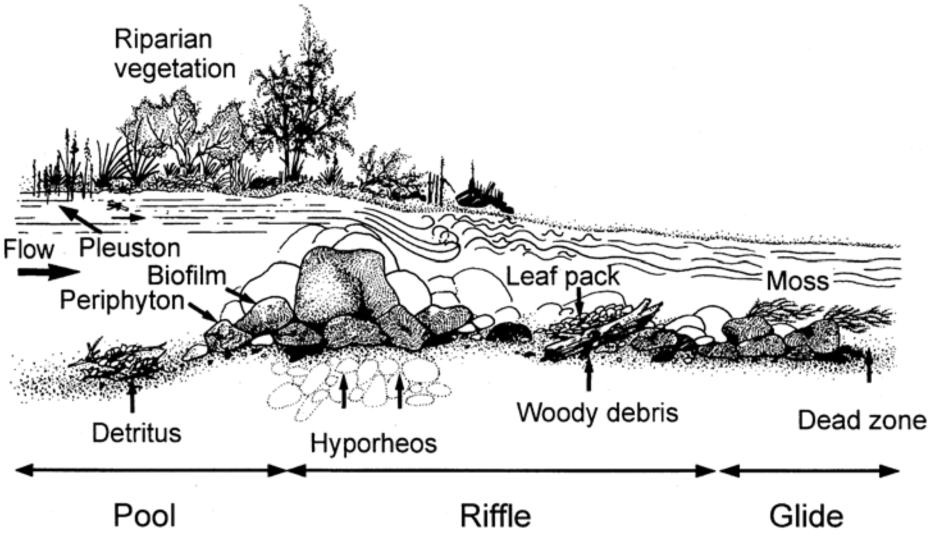
Longitudinal Gradients

Conceptual framework of processes determining a gradient of habitat heterogeneity in streams

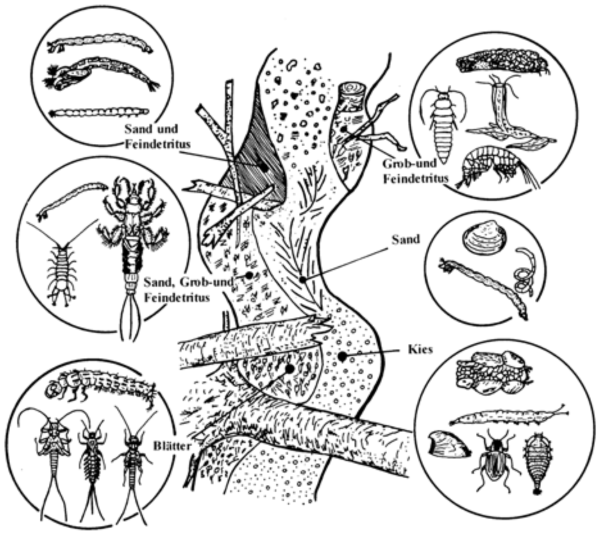


(Calow & Petts 1992)

Microhabitats



(Giller & Malmqvist 2002)

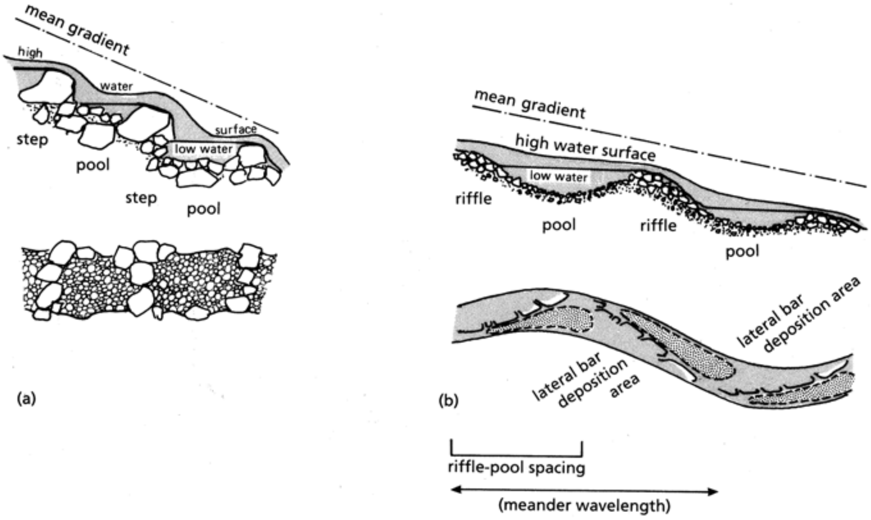


Bayerisches Landesamt für Wasserwirtschaft (1996)

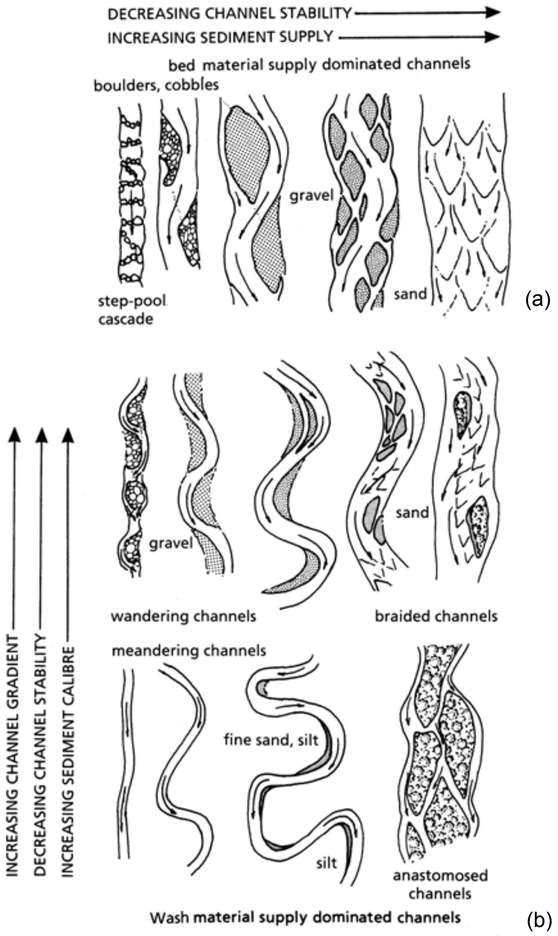
Stream reach of a first order stream in central europe: depending on channel morphology and water velocity a diverse pattern of **microhabitats** exist. Periphyton and biofilm coat the stones, pebbles, and boulders and detritus from the riparian vegetation collects in slow-flowing areas or forms leaf packs in front of obstructions like woody debris. Coarse substrate is found in the riffles where the flow is fast and turbulent. Fine substrate settles in the pools and in the lee of large stones and boulders where flow is slow.

These microhabitats are colonized by different species of macroinvertebrates which represent different functional groups (functional feeding groups, functional locomotion groups ….).

Channel Morphology and Typology I

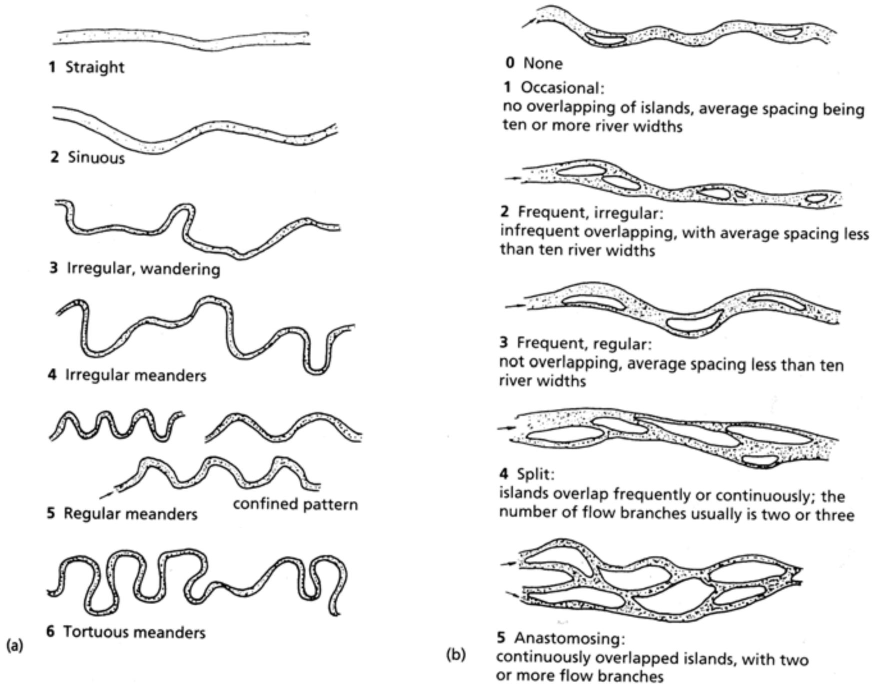


Small channels: formation of (a) step-pool and (b) pool-riffle channels (Calow & Petts 1992).

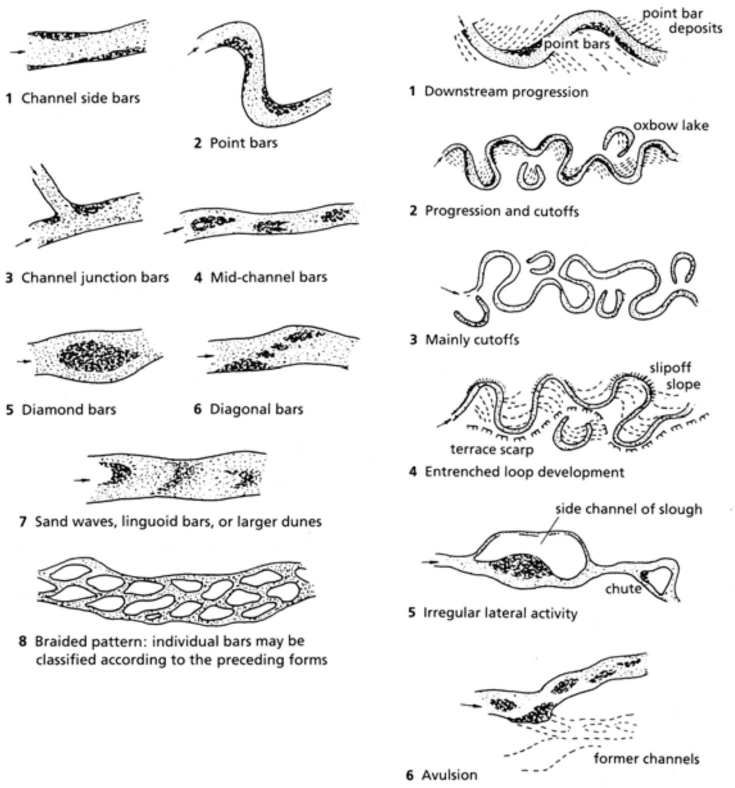


Conceptual pattern of morphological types of large channels. (a) Bed material supply-dominated channels; (b) wash material supply-dominated channels (Calow & Petts 1992).

Channel Morphology and Typology II

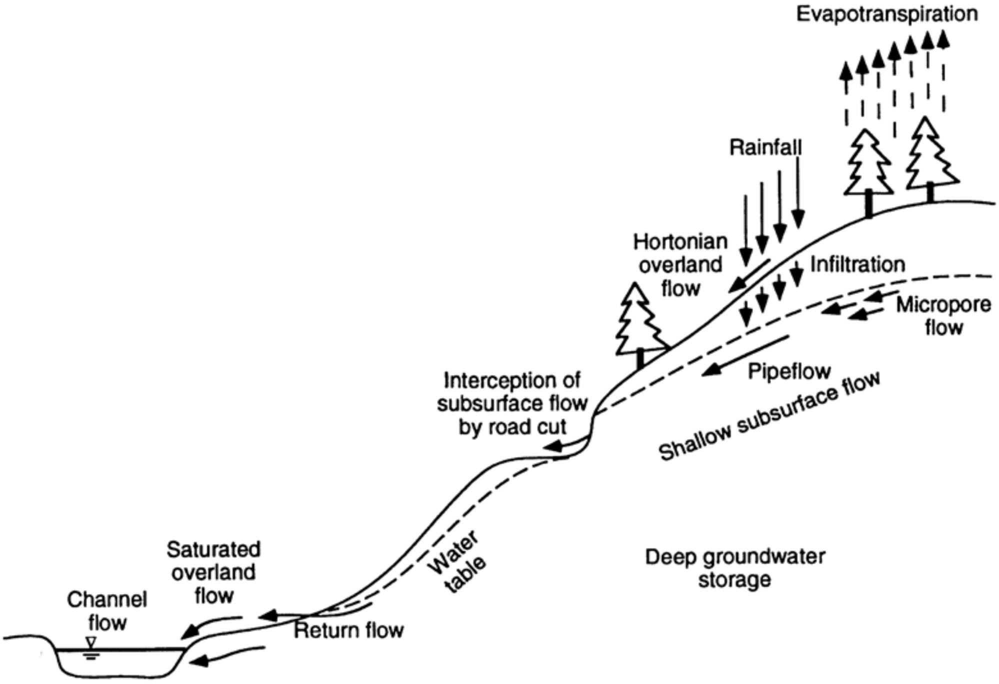


Morphological classification of large channels: plan-form pattern. (a) channel pattern, (b) channel islands (Calow & Petts 1992).

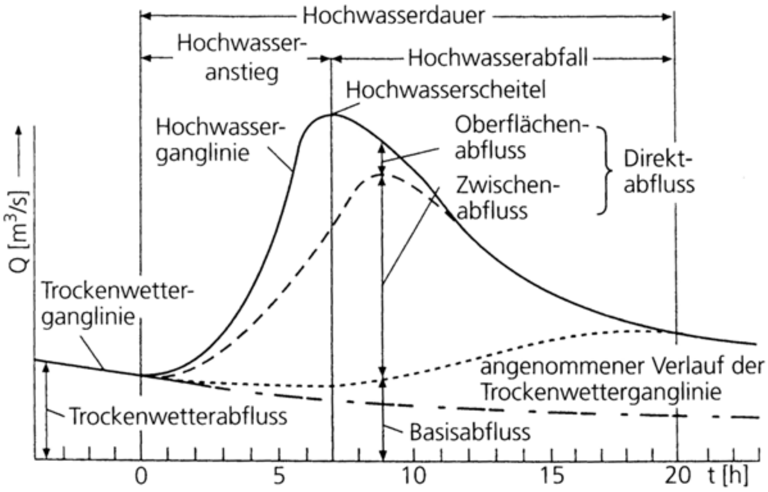


Classification of large channels: lateral activity (Calow & Petts 1992).

The Habitat Templet: Discharge

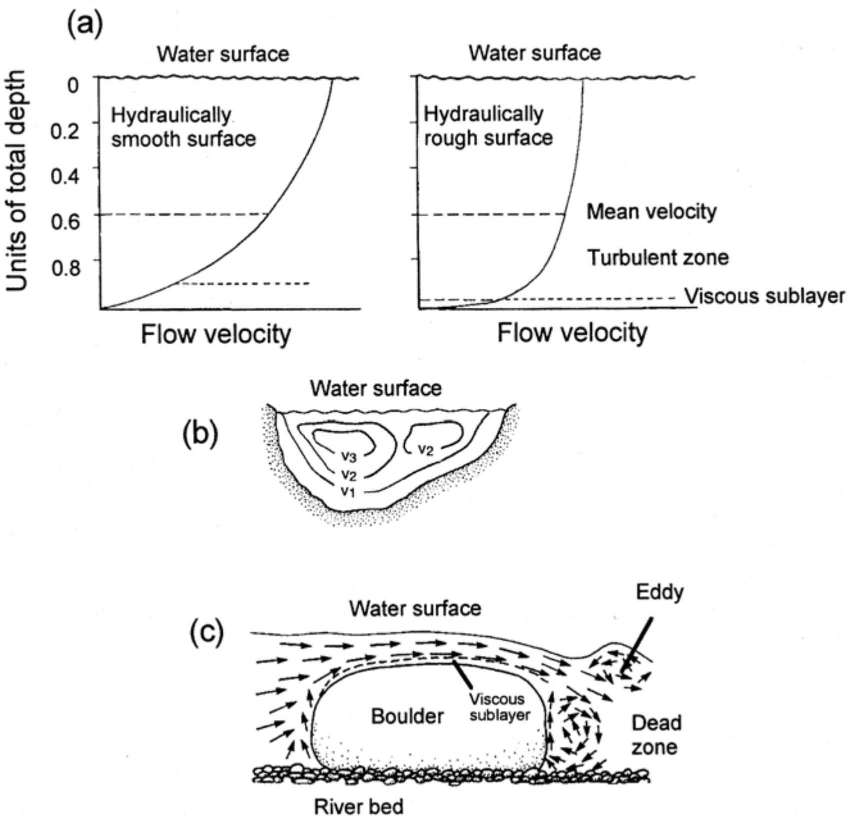


Distribution of hydrologic processes on an idealized hillslope (Ziemer & Lisle 1998).

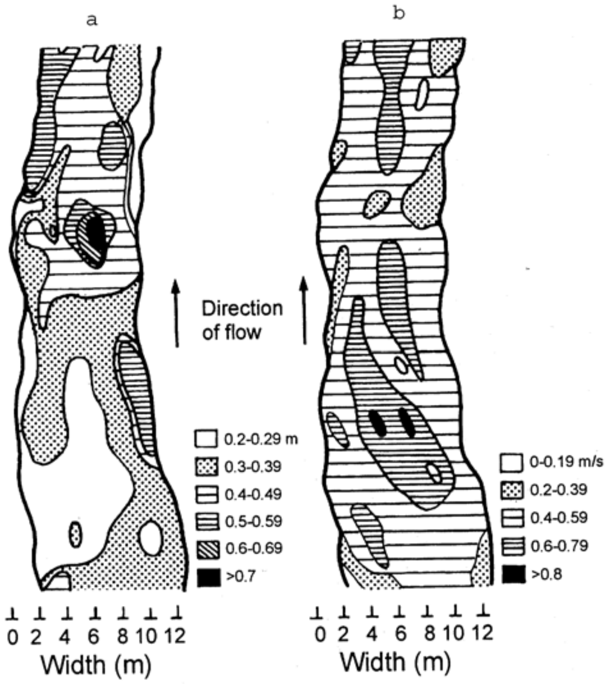


Hydrograph during a flood (Uhlmann 2001). Different water sources contribute to the flood (surface runoff, subsurface flow, groundwater).

The Habitat Templet: Current and Shear Stress



Velocity gradients in a stream. (a) vertical gradients over hydraulically smooth and rough substrates, (b) a transverse section through a smooth channel showing velocity contours (v_3 = high, v_1 = low velocity), (c) distribution of currents around a boulder (Giller & Malmqvist 2002).



Patchiness in flow in a river system. Depth (a) and current velocity contours for a low gradient reach of the River Coln, England (Giller & Malmqvist 2002).

The Habitat Templet: Oxygen

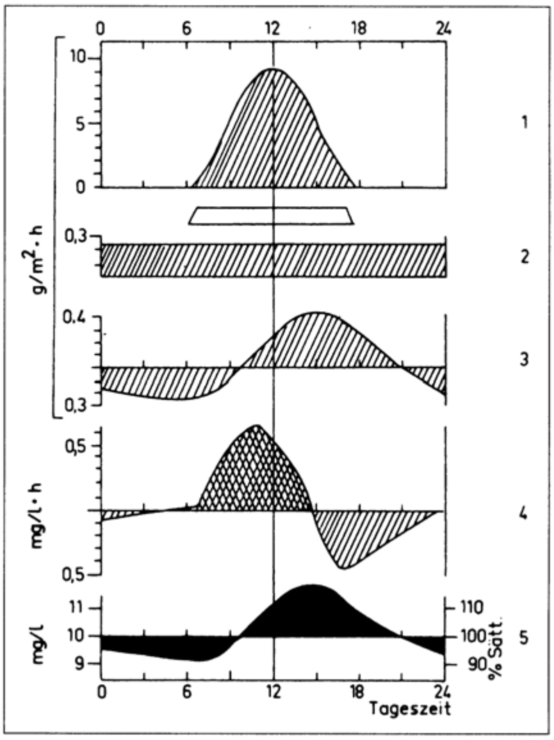
Solubility of gases at 1 bar (mg/l)

	O°C	10°C	20°C	30°C
O_2	69,5	53,7	43,3	35,9
N_2	28,8	22,6	18,6	15,9
CO_2	3350	2320	1690	1260

Concentration of gases in freshwater under normal conditions (mg/l)

	Partial Pressure %	O°C	10°C	20°C	30°C
O_2	20,99	14,5	11,1	8,9	7,2
N_2	78,0	22,4	17,5	14,2	11,9
CO_2	0,03	1,005	0,70	0,51	0,38

Dynamics of oxygen concentrations in streams

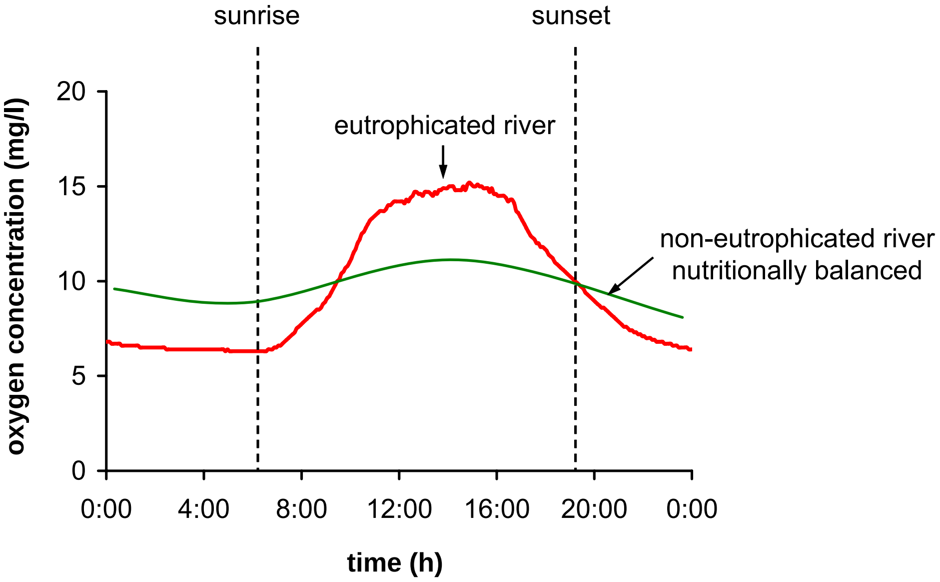


1. O_2-production by photosynthesis
2. Loss of O_2 by dissimilation
3. O_2-exchange water – air
4. resulting concentration of O_2-production (cross hatch) and O_2-consumption (lined)
5. actual diurnal variations in O_2

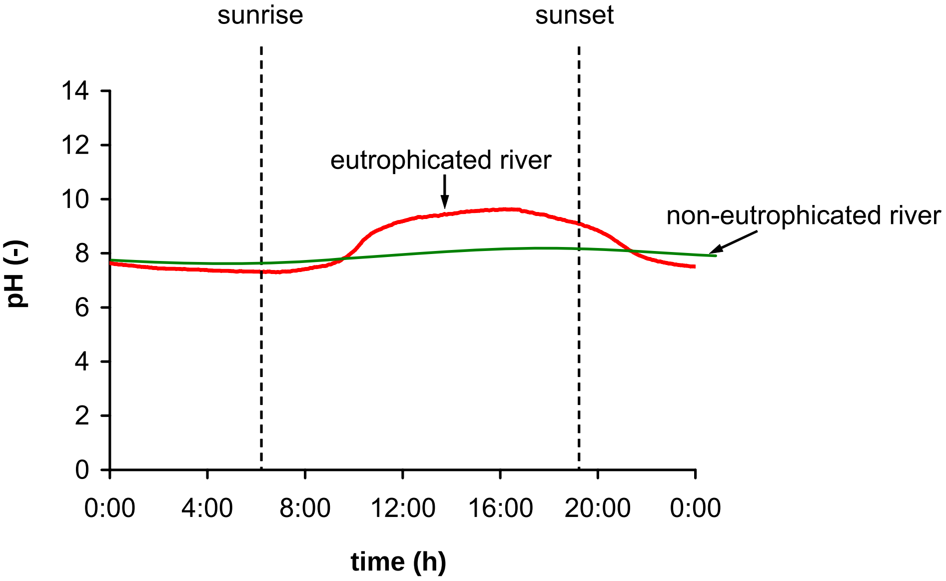
(Schwoerbel 1993)

Oxygen and pH

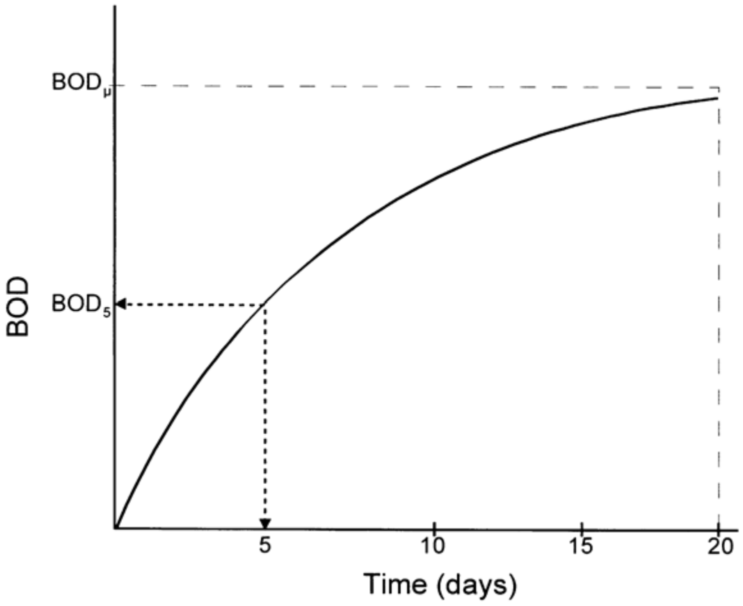
Daily variations in oxygen concentrations in streams



Daily variations in pH in streams



Biochemical Oxygen Demand

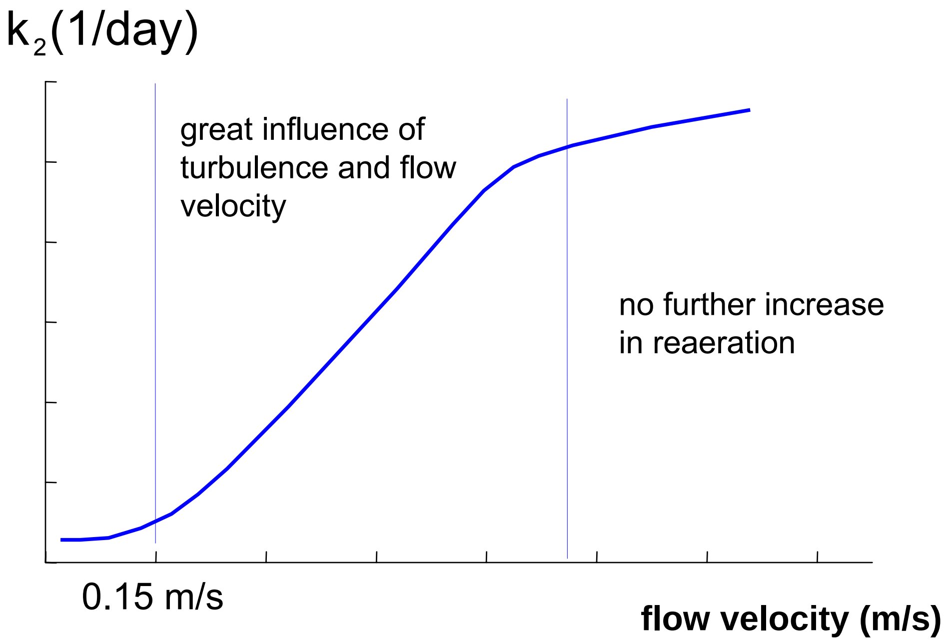


Biochemical oxygen demand (BOD) is a surrogate for dissolved and particulate organic carbon (DOC and POC) that is available for utilization by microorganisms. More specifically, BOD is a measure of the rate at which dissolved oxygen (DO) is demanded by the microbial community to aerobically oxidize organic matter. As such, BOD is usually determined over five days (BOD_5), and then used to estimate the ultimate demand (BOD_u in the figure). From the BOD_5 and exponential rate of oxygen demand, BOD_u can be calculated and used with the demand rate to predict the magnitude of DO depletion in a stream resulting from a source of organic matter input.

BOD_5 in nonpoint source runoff is typical higher than in natural streams (i.e. 10-20 mg/l versus 1-2 mg/l). Problems associated with low DO may occur with increased organic material input, however, within interstitial spaces in the stream substratum where intragravel flows have decreased (*intergravel flow* => see page 47).

Oxygen reaeration in running waters

$$\mathbf{O_2\ uptake = D_0 -\ e^{-k_2 * t}}$$



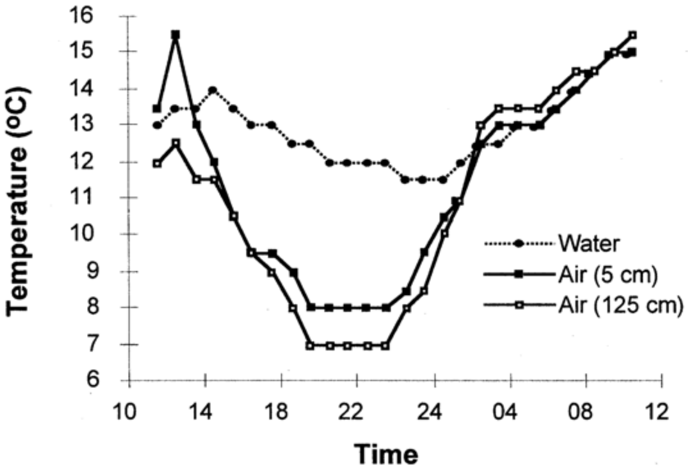
The **Streeter-Phelps model** ties together the two primary mechanisms governing dissolved oxygen in a stream receiving sewage water: decomposition of organic matter and oxygen reaeration. As such it provides an analytical framework for predicting the effect of both point and nonpoint sources of oganic wastewater on stream dissolved oxygen.

The model is based on the equation : $\mathbf{C_t = C_0 - [\ L_0 * (1\text{-}\ e^{(-K1\ *\ t)}) * e^{(-K2\ *\ t)}]}$

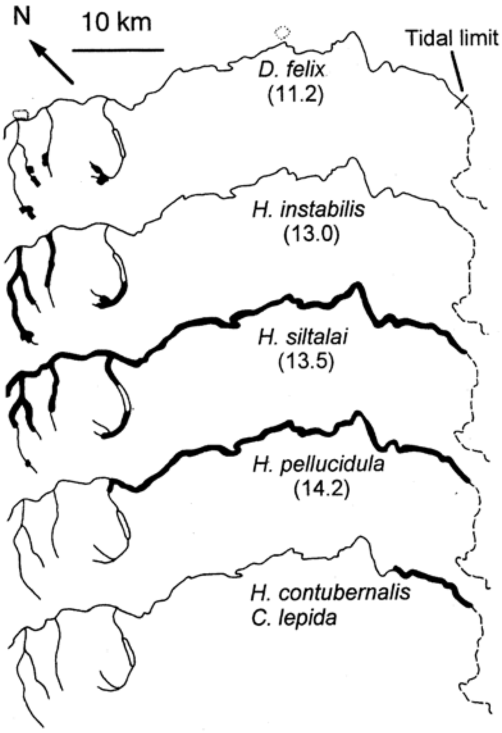
where: C_t = oxygen concentration at the time t
C_0 = oxygen concentration at the time t = 0
t = time (days)
K_1 = constant for the decomposition of organic matter (e.g. BOD)
K_2 = $[(3 + 40 / k_{st}) * v / h + 0,5] / h$ [1/day]
L_0 = BOD_5 [mg/l] in the stream after wastewater discharge

The constant K_2 stands for the rate of oxygen reaeration. The term k_{st} is needed (k_{st} = 25 $m^{1/3}/s$) that stands for the roughness of the river bottom.

The Habitat Templet: Temperature

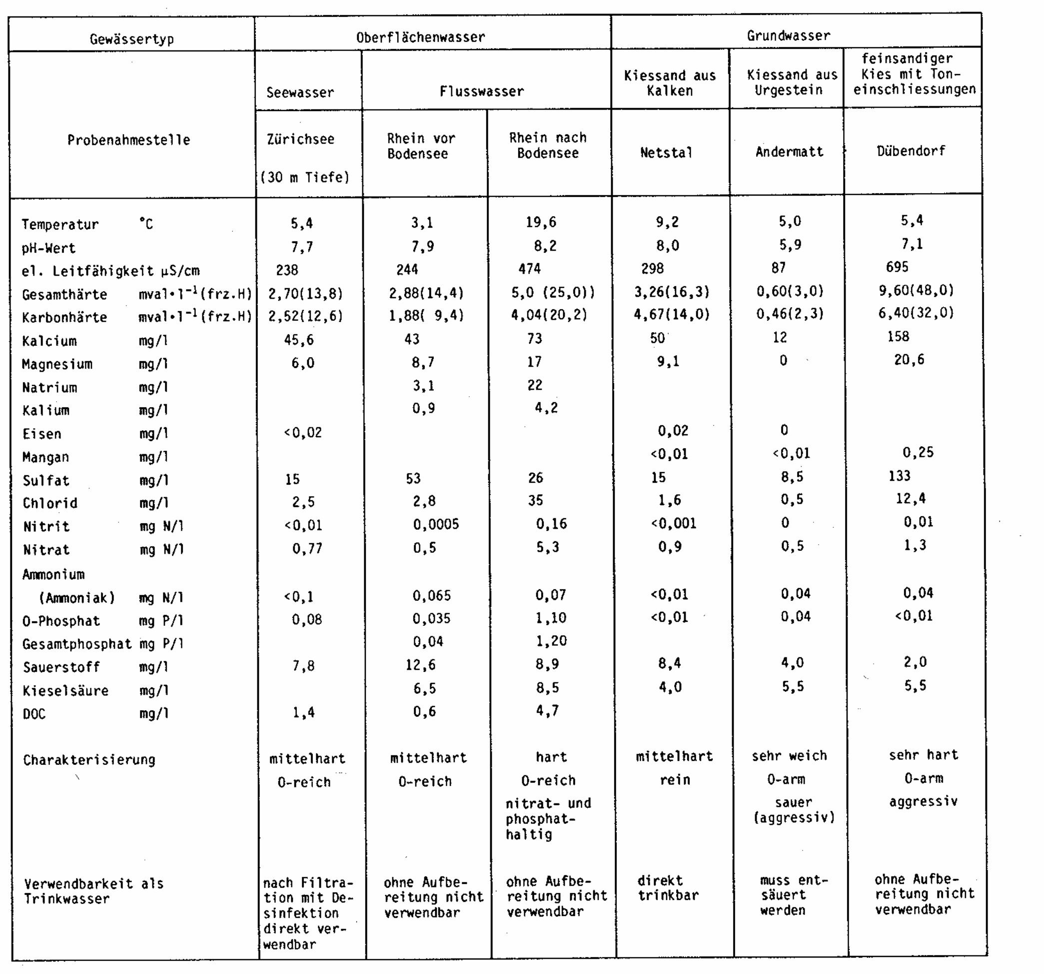


Diurnal **temperature** variations in a wooded, temperate, shallow stream in March, compared to air temperatures 5 cm and 125 cm above the stream (Giller & Malmqvist 2002). Most freshwater animals and all plants are poikilothermic, such that their temperature varies with that of their surroundings. Physiological processes (such as respiration, digestion, muscle activity, photosynthesis, etc.) are based on biochemical reactions and biochemical rates are dependent on ambient temperature. Growth rates, productivity, and length of life cycles are also temperature dependent in poikilotherms. Hence it is clear why temperature should directly influence freshwater organisms in addition to the indirect effects on oxygen concentrations.



The distribution of hydropsychid caddisflies larvae (Insecta, Trichoptera: *Diplectrona and Hydropsyche*) in tributaries and lower reaches of the River Usk in Wales. The values in parentheses give the mean summer temperatures (°C) (Giller & Malmqvist 2002).

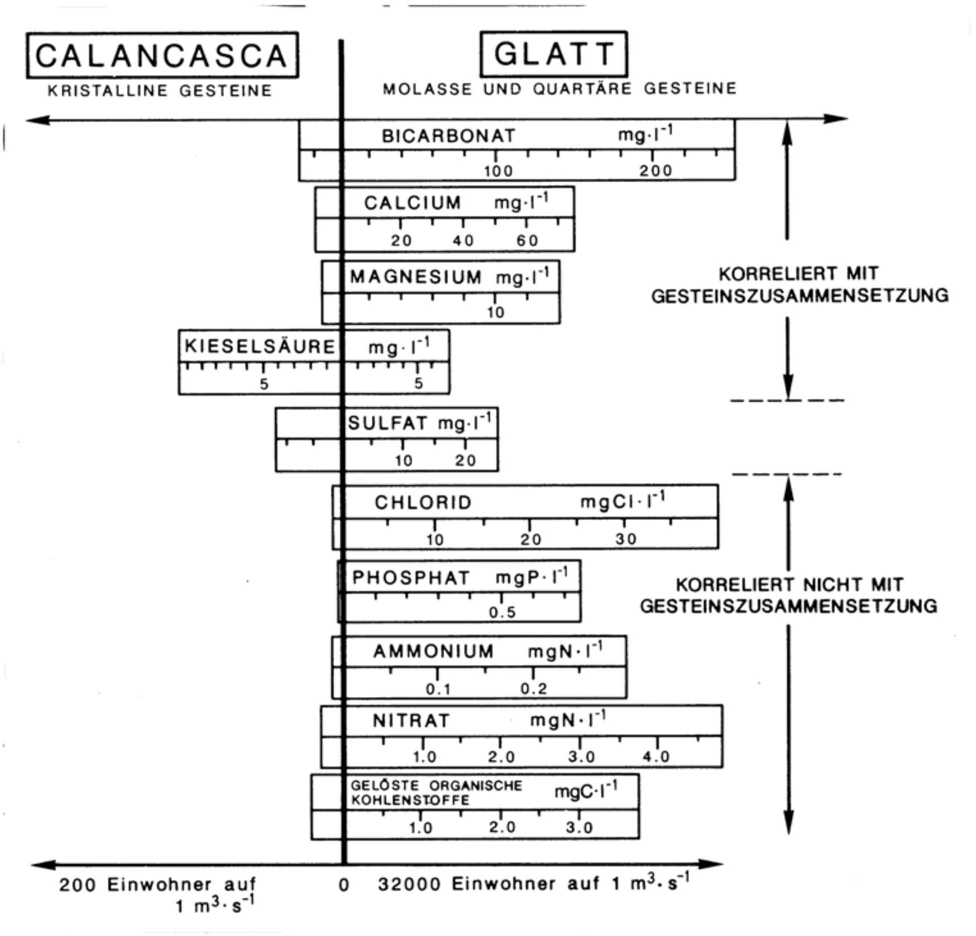
The Habitat Templet: Chemical characteristics I



Gewässertyp	Oberflächenwasser			Grundwasser		
	Seewasser	Flusswasser		Kiessand aus Kalken	Kiessand aus Urgestein	feinsandiger Kies mit Toneinschliessungen
Probenahmestelle	Zürichsee (30 m Tiefe)	Rhein vor Bodensee	Rhein nach Bodensee	Netstal	Andermatt	Dübendorf
Temperatur °C	5,4	3,1	19,6	9,2	5,0	5,4
pH-Wert	7,7	7,9	8,2	8,0	5,9	7,1
el. Leitfähigkeit µS/cm	238	244	474	298	87	695
Gesamthärte mval·l^{-1}(frz.H)	2,70(13,8)	2,88(14,4)	5,0 (25,0))	3,26(16,3)	0,60(3,0)	9,60(48,0)
Karbonhärte mval·l^{-1}(frz.H)	2,52(12,6)	1,88(9,4)	4,04(20,2)	4,67(14,0)	0,46(2,3)	6,40(32,0)
Kalcium mg/l	45,6	43	73	50	12	158
Magnesium mg/l	6,0	8,7	17	9,1	0	20,6
Natrium mg/l		3,1	22			
Kalium mg/l		0,9	4,2			
Eisen mg/l	<0,02			0,02	0	
Mangan mg/l				<0,01	<0,01	0,25
Sulfat mg/l	15	53	26	15	8,5	133
Chlorid mg/l	2,5	2,8	35	1,6	0,5	12,4
Nitrit mg N/l	<0,01	0,0005	0,16	<0,001	0	0,01
Nitrat mg N/l	0,77	0,5	5,3	0,9	0,5	1,3
Ammonium (Ammoniak) mg N/l	<0,1	0,065	0,07	<0,01	0,04	0,04
O-Phosphat mg P/l	0,08	0,035	1,10	<0,01	0,04	<0,01
Gesamtphosphat mg P/l		0,04	1,20			
Sauerstoff mg/l	7,8	12,6	8,9	8,4	4,0	2,0
Kieselsäure mg/l		6,5	8,5	4,0	5,5	5,5
DOC mg/l	1,4	0,6	4,7			
Charakterisierung	mittelhart O-reich	mittelhart O-reich	hart O-reich nitrat- und phosphathaltig	mittelhart rein	sehr weich O-arm sauer (aggressiv)	sehr hart O-arm aggressiv
Verwendbarkeit als Trinkwasser	nach Filtration mit Desinfektion direkt verwendbar	ohne Aufbereitung nicht verwendbar	ohne Aufbereitung nicht verwendbar	direkt trinkbar	muss entsäuert werden	ohne Aufbereitung nicht verwendbar

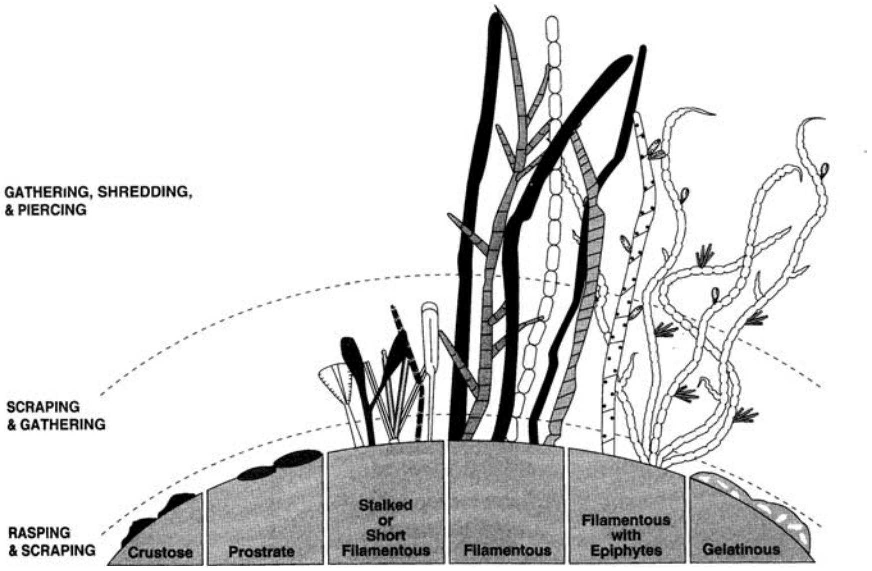
Typical concentrations of dissolved substances in rivers and groundwater in Switzerland (Kummert & Stumm 1987).

The Habitat Templet: Chemical characteristics II

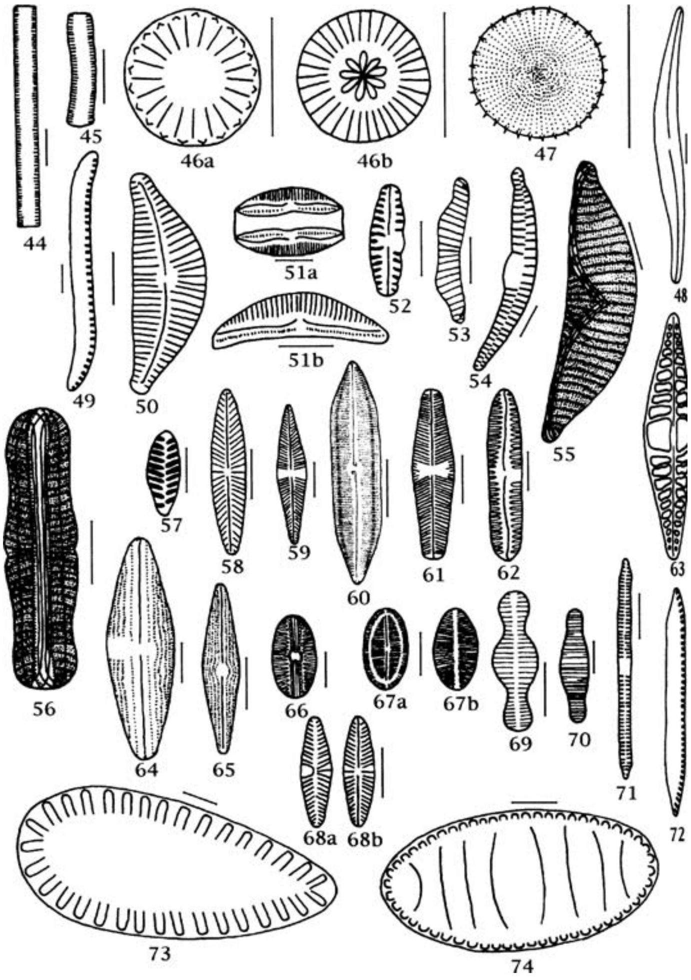


Comparison between the chemical composition of two rivers with different nutrient status and different catchment geology in Switzerland (Kummert & Stumm 1987). On the x-axis the number of inhabitants at base flow conditions is shown.

Life in running waters: Algae



Typical growth forms of benthic algae in streams and rivers. The relation to feeding zones occupied by different types of grazers are given (Steinmann 1996).

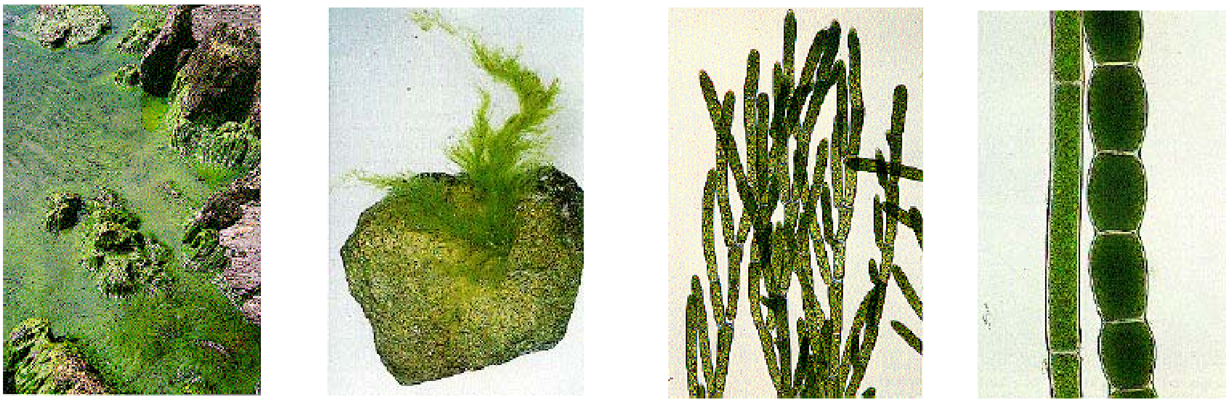


Examples of typical microalge in streams. All algae shown here belong to the diatoms, a group that is very rich in species and that is often considered as the most important food for many benthic herbovors. Diatoms are present in nearly every stream and can be found all the year round.

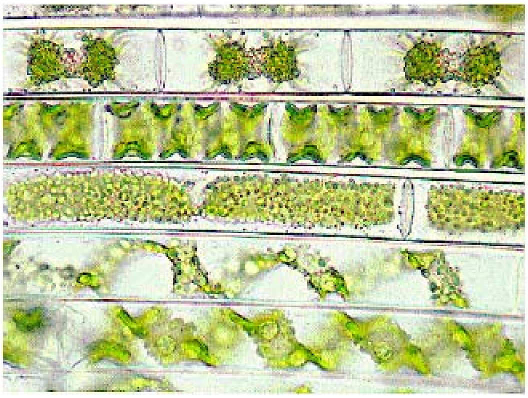
44 *Synedra*, girdle view; 45 *Achnanthidium*, girdle view; 46 *Cyclotella*: (a) *C. meneghiniana*, (b) *C. stelligera*; 47 *Stephanodiscus*; 48 *Gyrosigma*; 49 *Nitzschia*; 50 *Cymbella*; 51 *Amphora*; 52 *Reimeria*; 53 *Eunotia*; 54 *Hannaea*; 55 *Epithemia*; 56 *Rhopalodia*; 57 *Martyana*; 58 *Navicula*; 59 *Stauroneis*; 60 *Neidium*; 61 *Sellaphora*; 62 *Pinnularia*; 63 *Craticula*; 64 *Anomoeoneis*; 65 *Brachysira*; 66 *Diploneis*; 67 *Cocconeis* (a) raphe valve, (b) rapheless valve; 68 *Achnanthidium* (a) rapheless valve, (b) raphe valve; 69 *Tabellaria*; 70 *Diatoma*; 71 *Synedra*; 72 *Nitzschia*; 73 *Surirella*; 74 *Cymatopleura*.

Life in running waters: Algae

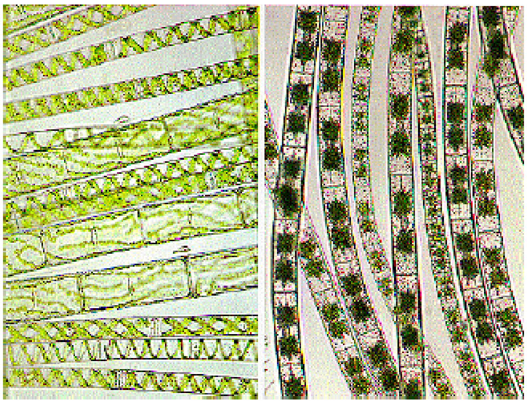
Cladophora spec.



Zygnema, Spirogyra, Mougeotia, Spirgyra (top down)

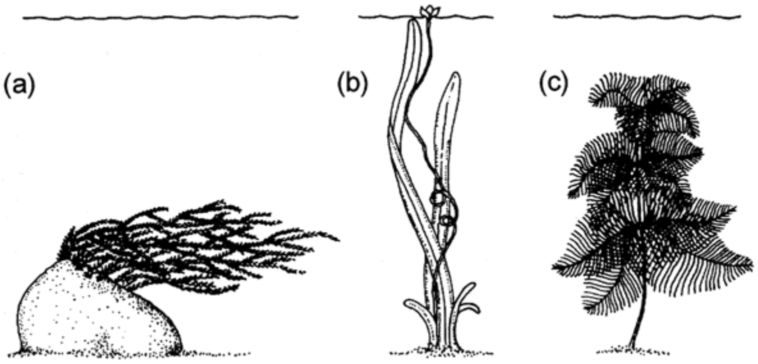


Spirogyra (left side), Zygnema (right side)



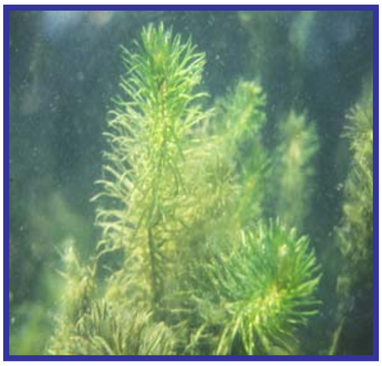
Life in running waters: Macrophytes

In most running water sytems, macrophytes, such as the examples shown in the figure, are generally restricted to those areas where the gradient and hence flow rate is low. Only there is sufficient accumulation of fine materials to provide the necessary substrate for rooting, and the eroding power of the water is low enough. Submersed plants are also dependent on sufficient light reaching them. Therefore, increased turbidity reduces the maximum depth at which plants can photosynthesize. When the water is very clouded from suspended particles, submersed vegetation may be completely absent. Low-order streams are often heavily shaded, which also eliminates the extensive primary production other than from algae.



Submerged *plants (a) moss which adheres to stone surfaces e.g. Fontinalis antipyretica; (b)* Vallisneria spiralis, with its smooth linear leaves; (c) *Myriophyllum spicatum* with its finely divided leaves (Giller & Malmqvist 2002).


(a)

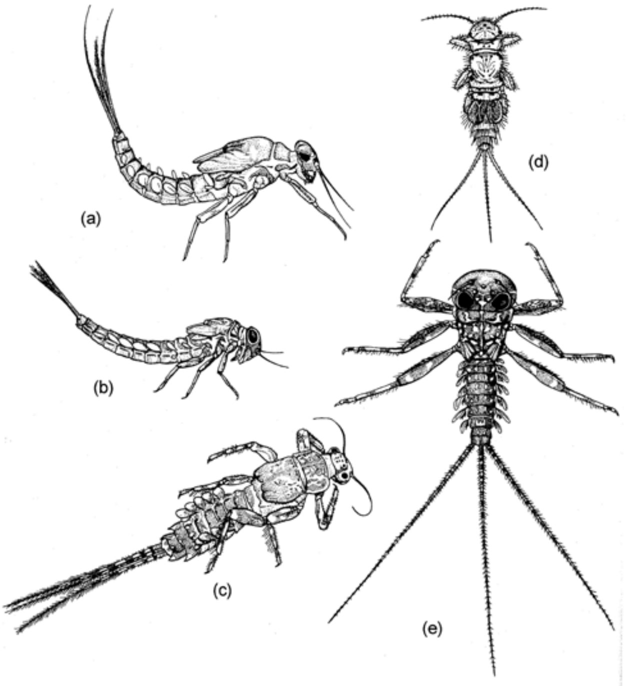

(b)


(c)

Typical macrophytes growing in lakes: (a) *Potamogeton crispus*; (b) *Hippuris vulgaris*; (c) *Chara hispida* (Photos: TU Muenchen).

Ephemeroptera

Representatives of some important mayfly families: (a) Baetidae (*Baetis*); (b) Siphlonuridae (*Ameletus*); (c) Ephemerellidae (*Ephemerella*); (d) Caenidae (*Caenis*); (e) Heptageniidae (*Heptagenia*).



(Giller & Malmqvist 2002)

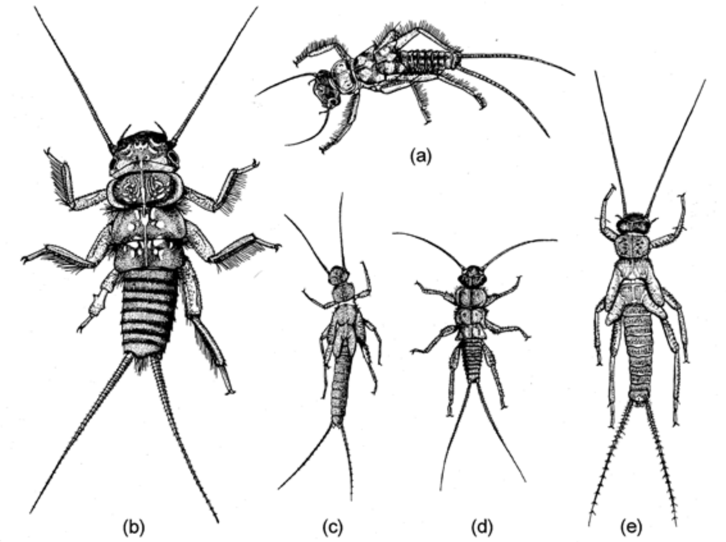
Main characteristics of mayflies (Ephemeroptera):

- Three tails (two cerci and between them usually a terminal filament).
- Hemimetabolous insects (where larvae and nymphs resemble wingless adults).
- Mainly grazers or collector-gatherers feeding on algae and fine detritus, few are predatory, filter particles using hair-fringed legs or maxillary palps. Shredders are rare.
- Respiration by the gills, which are paired organs on up to seven abdominal segments.
- Adult lifespan is short, ranging from a few hours to a few days, rarely up to two weeks, adults do not feed.

Life in running waters: Invertebrates

Plecoptera

Representatives of some major stonefly families: (a) Perlodidade; (b) Perlidae; (c) Leuctridae; (d) and (e) Nemouridae.



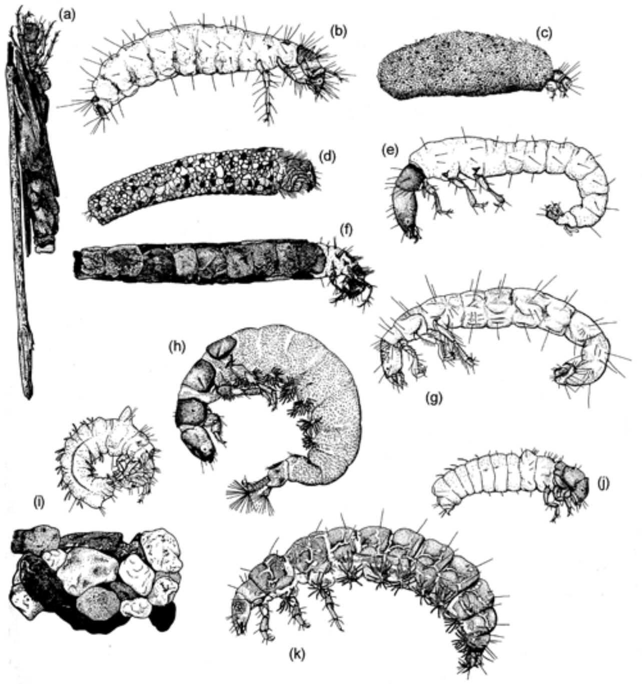
(Giller & Malmqvist 2002)

Main characteristics of stoneflies (Plecoptera):

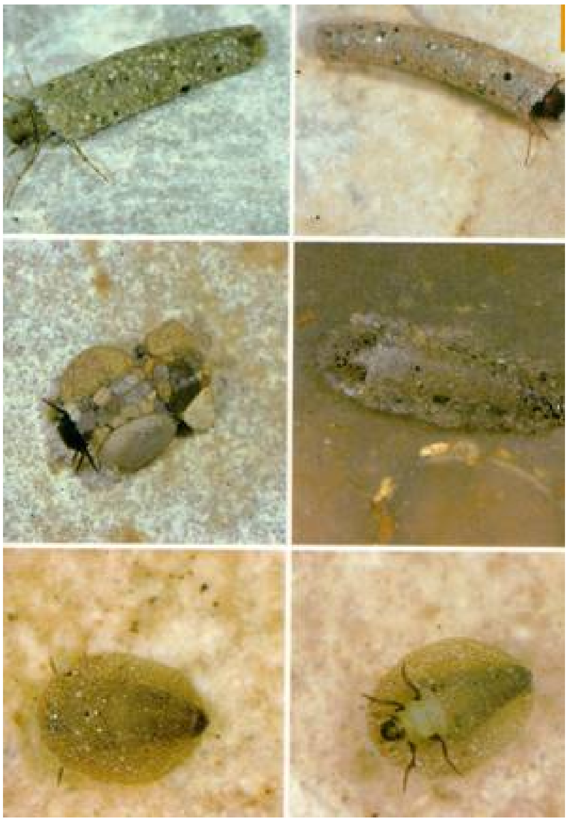
- Two long cerci (tails).
- Hemimetabolous life cycle.
- Characteristic inhabitants of cool, clean streams of low orders.
- Sensitive to organic pollution and low oxygen concentrations.
- Lack of extensive gills.
- Most stoneflies occur in stony habitats.
- Detritivorous species, predators and herbivors.
- Adult stoneflies are poor fliers. Often short wings or complete wing reduction.
- Some stonefly species feed in the adult stage.

Trichoptera

Larvae of some important caddisfly families: (a) Limnephilidae; (b) Glossosomatidae; (c) microcaddis Hydroptilidae; (d) Sericostomatidae; (e) Philopotamidae; (f) Lepidostomatidae; (g) Polycentropodidae, (h) Hydropsychidae; (i,j) Goeridae; (k) Rhyacophilidae.



(Giller & Malmqvist 2002)



Main characteristics of caddisflies (Trichoptera):

- Free-living (roving and net-spinning) and case-building species.
- Holometabolous insects (where the larvae undergo a complete metamorphosis to the adult stage during pupation) having five to eight larval instars.
- Can be found in the whole range of freshwater environments. This is related to their capacitiy for spinning silk, which is used for case-building, net-spinning and pupation. The materials of the cases range from pure silk to the gluing together of sandgrains and organic particles, often very specific for the genera or the species.
- Predators, Shredders,some do piercing, Filter-collectors and Grazers.
- Some adults of trichoptera feed on nectar.
- Adults live generally less than a month.

Life in running waters: Invertebrates

Water Flea
(Amphipoda, Gammarus)

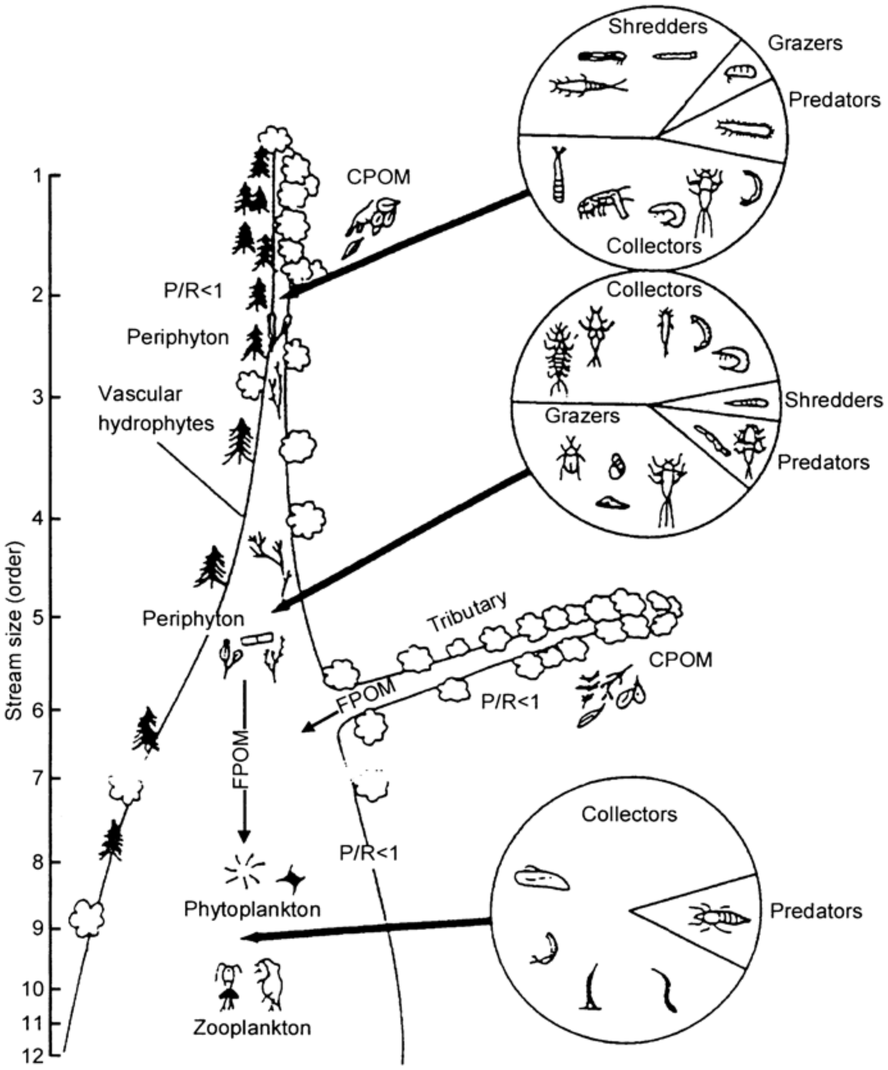
Freshwater Isopode
(Isopoda)

Leech (Hirudinea)

Non-biting midge larvae
(Chironomida)

Worm (Tubifex, Oligochaeta)

River Continuum Concept

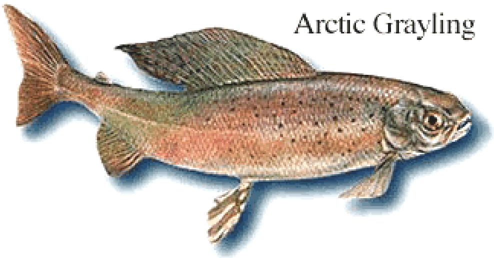


Predictions of the relative abundance of macroinvertebrate functional feeding groups in different stream orders according to the River Continuum Concept (after Vannote et al. 1980, figure taken from Hershey and Lamberti 1998).

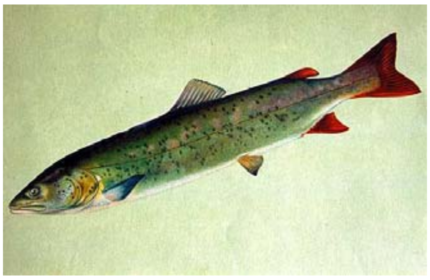
Life in running waters: Fish

Typical species found at the research area Chonin Nuga

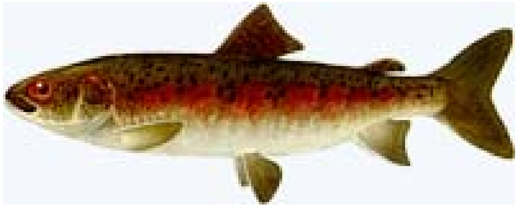
Thymallus arcticus



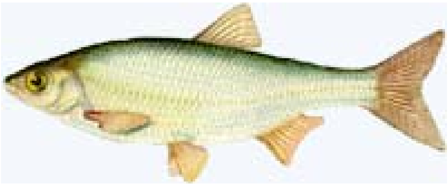
Hucho taimen



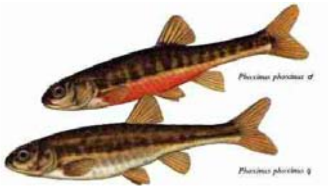
Brachymystax lenok



Leuciscus leuciscus baicalensis



Phoxinus phoxinus



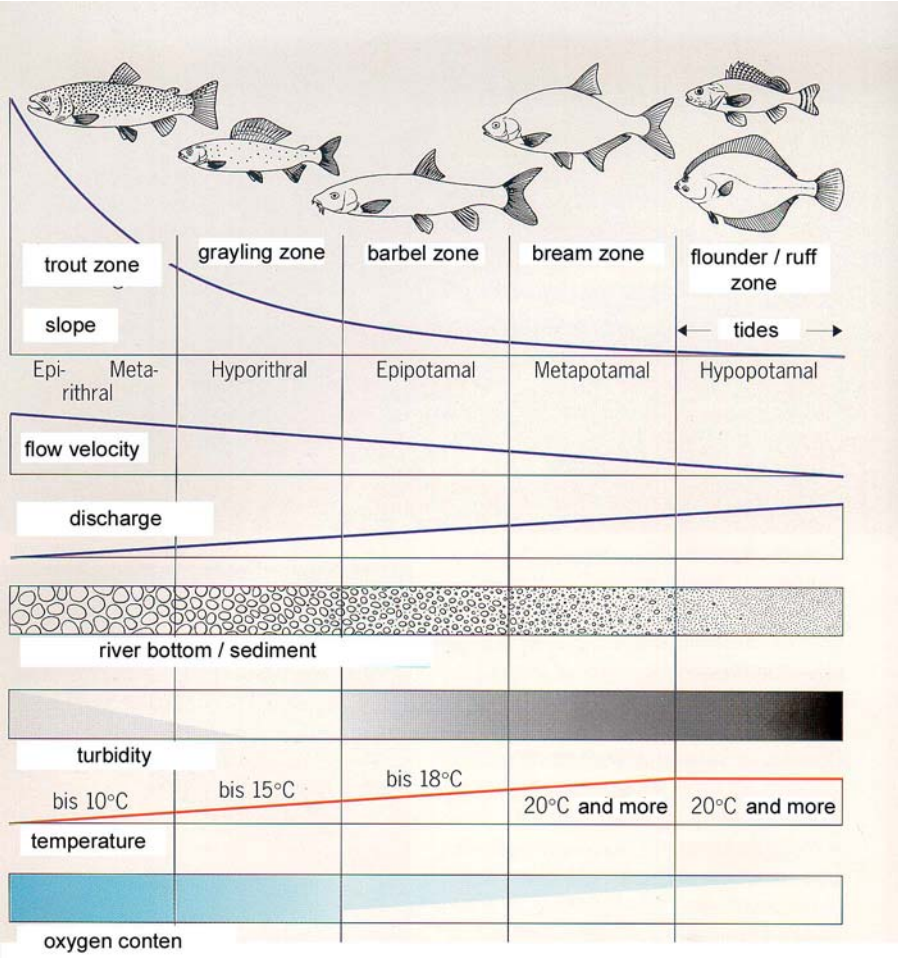
Cobitis melanoleuca

Lota lota

Life in running waters: Patterns of fish communities

Longitudinal Zonation of streams and rivers:

five zones- characterized by fish fauna



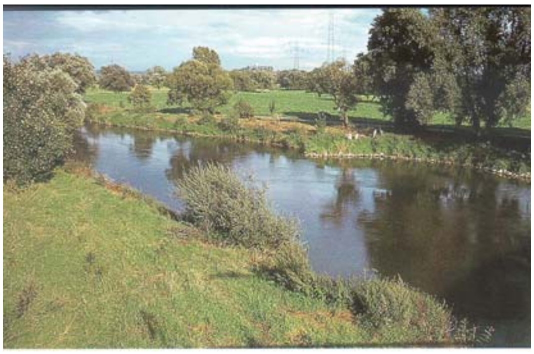
Pattern of fish community attibutes along a gradient of increasing habitat heterogeneity and pool development in a small stream (modified from Gerstmeier & Romig 1998)

Life in running waters: Patterns of fish communities

trout zone

grayling zone

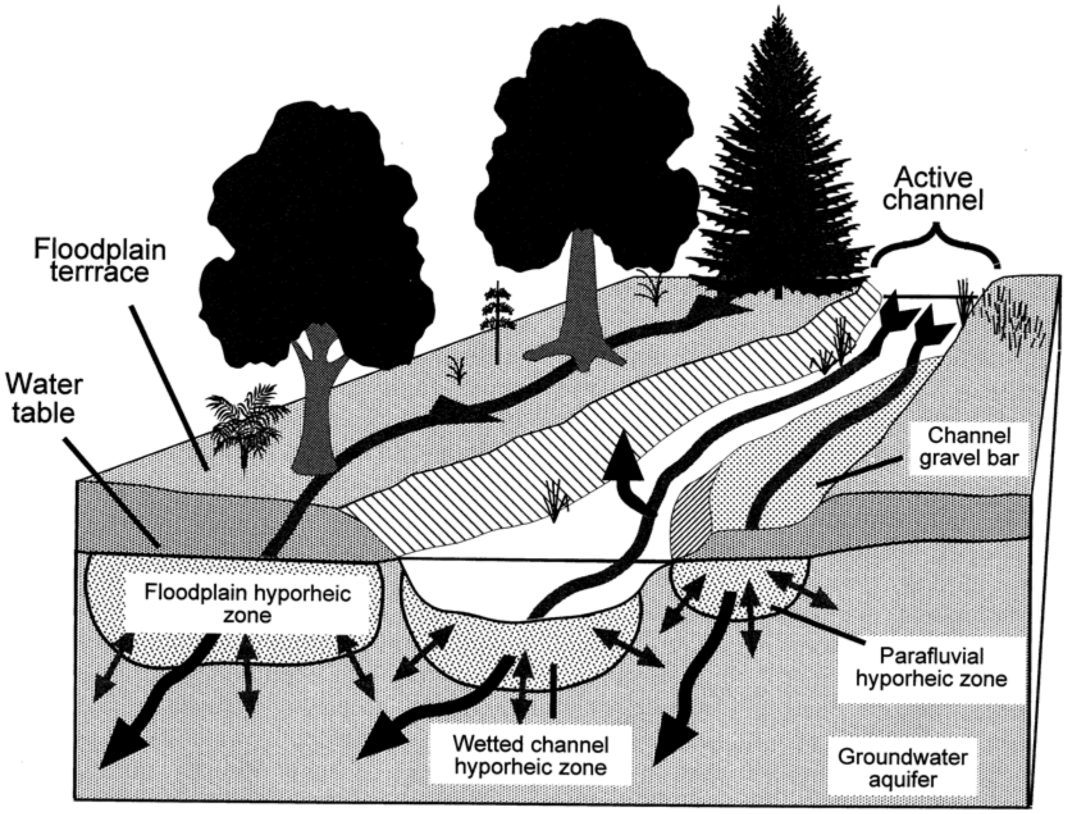
barbel zone



bream zone

flounder / ruff
zone

The Hyporheic Zone



(Edwards 1998)

The **hyporheic zone** is the volume of saturated sediment beneath and beside streams and rivers where ground water and surface water mix.

Hyporheic zones in alluvial rivers are one of the dominant links between the riparian forest and the stream channel. The porous, hydraulically conductive sediments characteristic of alluvial rivers indicate the presence of extensive hyporheic zones.

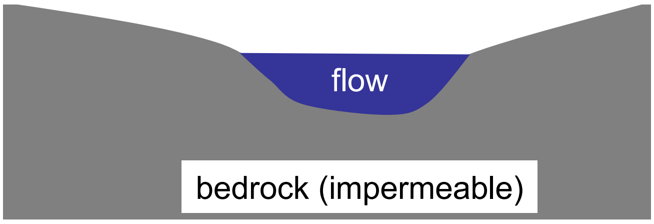
Hyporheic zones are hotspots of biological diversity that contain intensive physical and chemical gradients.

Hyporheic zone processes can dominate surface water quality. Rivers with extensive hyporheic zones retain and process nutrients with greater efficiency than rivers without. Organic matter elimination can be two times greater in rivers with intact hyporheic zones.

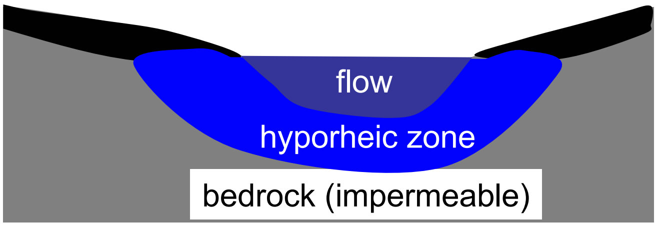
Hyporheic habitats contain a diverse and abundant fauna often dominating the biological productivity of rivers. Extensive hyporheic zones may serve as a refuge for stream biota, buffering them from disturbances in discharge and food supply.

The Hyporheic Zone

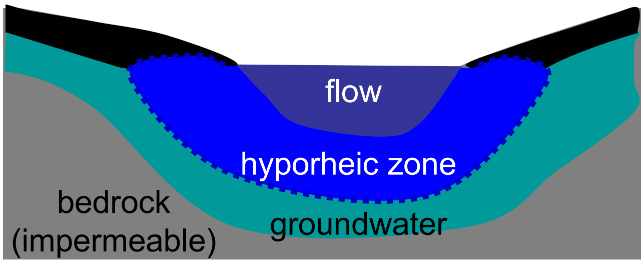
Extension of the hyporheic zone (White 1993)



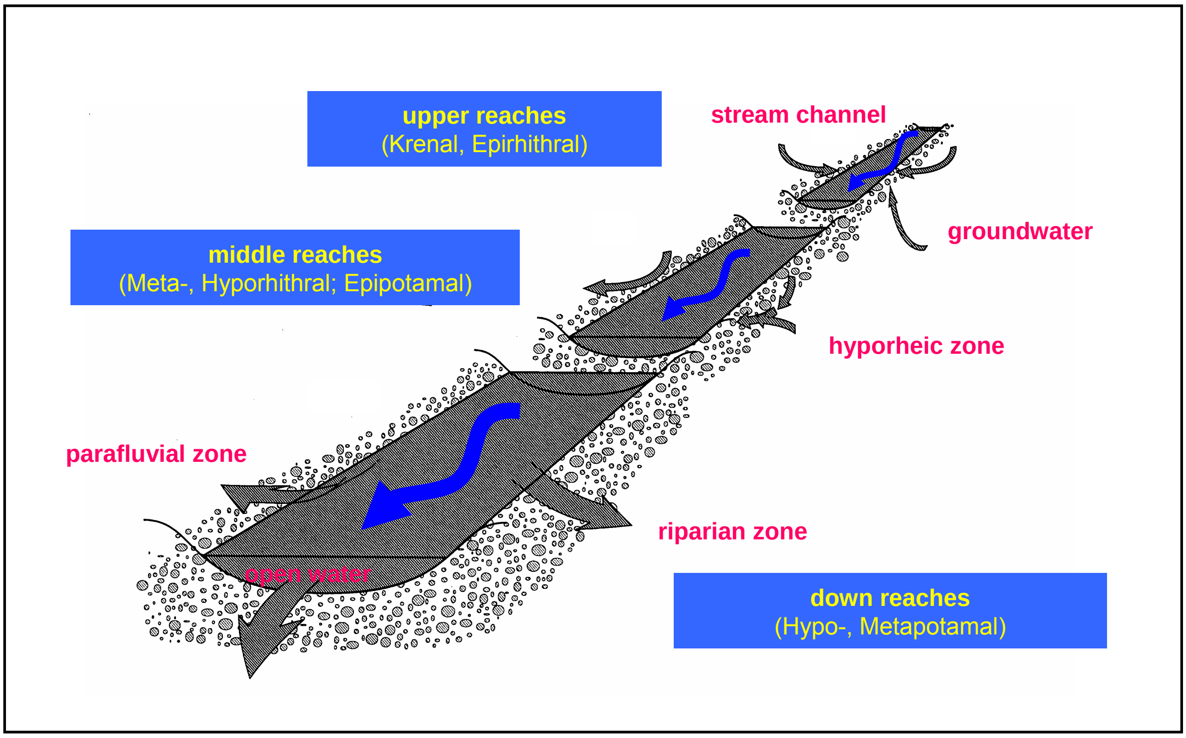
no hyporheic zone



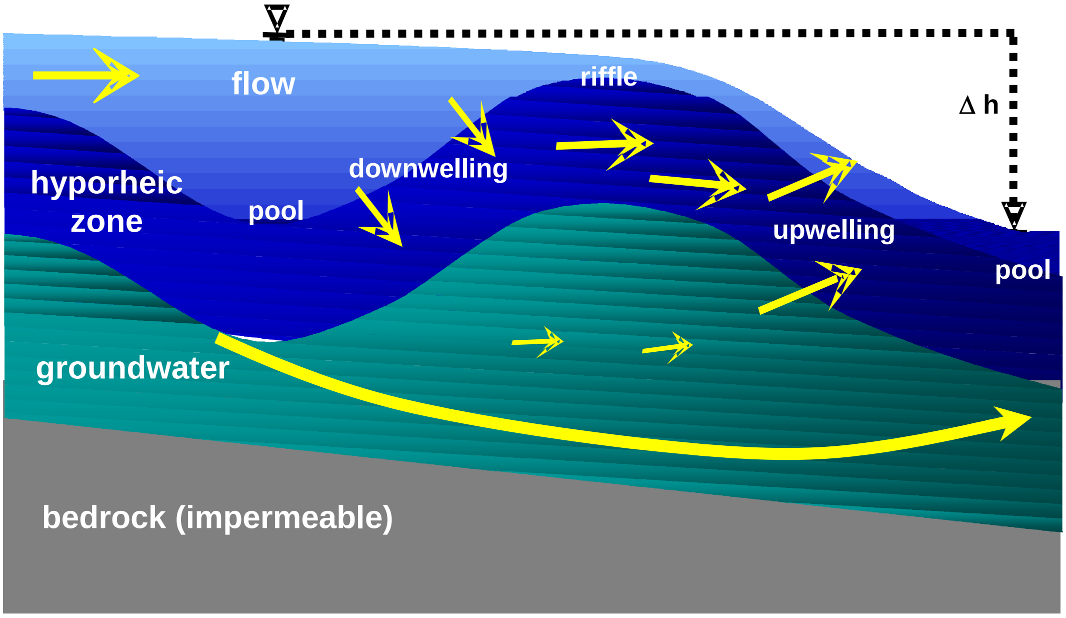
formation of a hyporheic zone through the advective infiltation of surface water

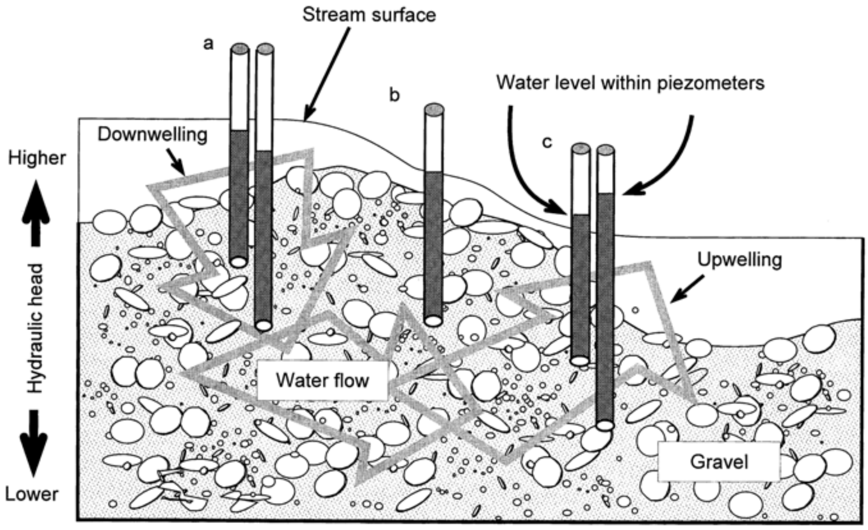


formation of a hyporheic zone through the advective infiltation of surface and ground water



Hydrology and Hyporheic Interactions





Piezometers are used to measure hydraulic head and detect potential or actual vertical water movements. Water flows from higher to lower head areas. Within the wetted channel, movement into the sediments can be detected unig one or more piezometers. (a) Where downwelling occurs, the stream surface head is greater than that in a piezometer. (b) Where no vertical water movement occurs, the piezometer head is equal to the water surface head. (c) Where water is upwelling back into the overlying water, the head within the piezometer is greater than the stream water surface. Where surface water is absent, such as in floodplains, vertical water movements can be detected as head differences among two or more nested piezometers at a site (Edwards 1998).

The Hyporheic Zone

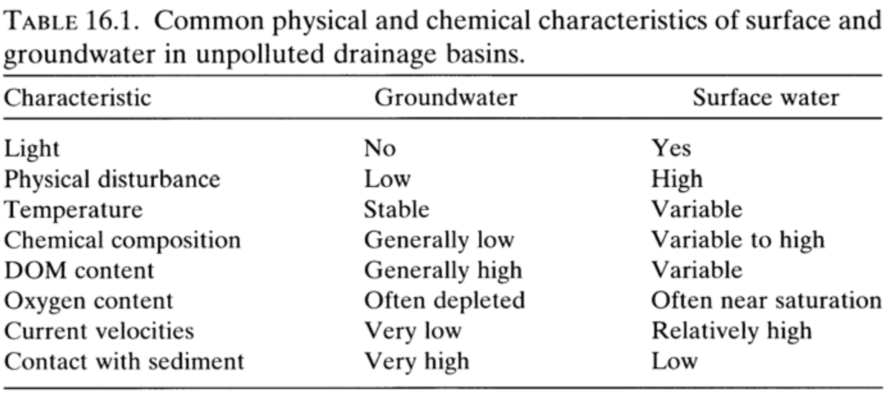
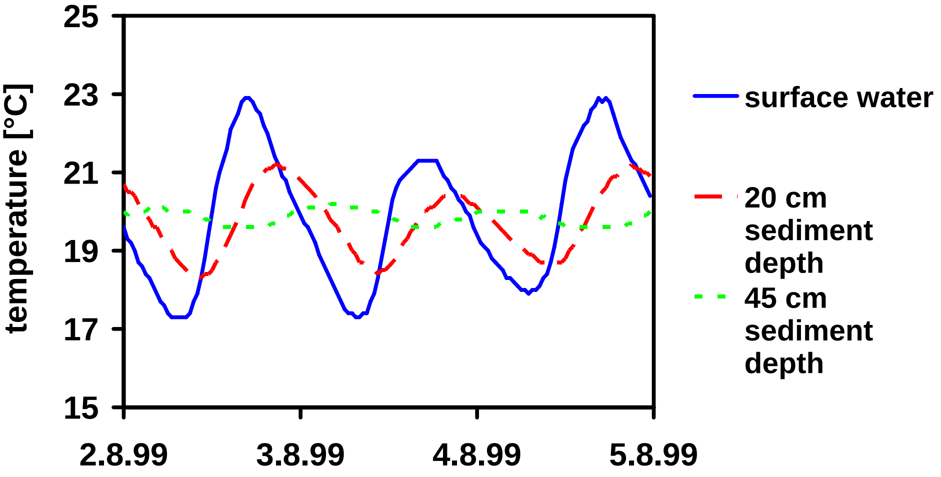


TABLE 16.1. Common physical and chemical characteristics of surface and groundwater in unpolluted drainage basins.

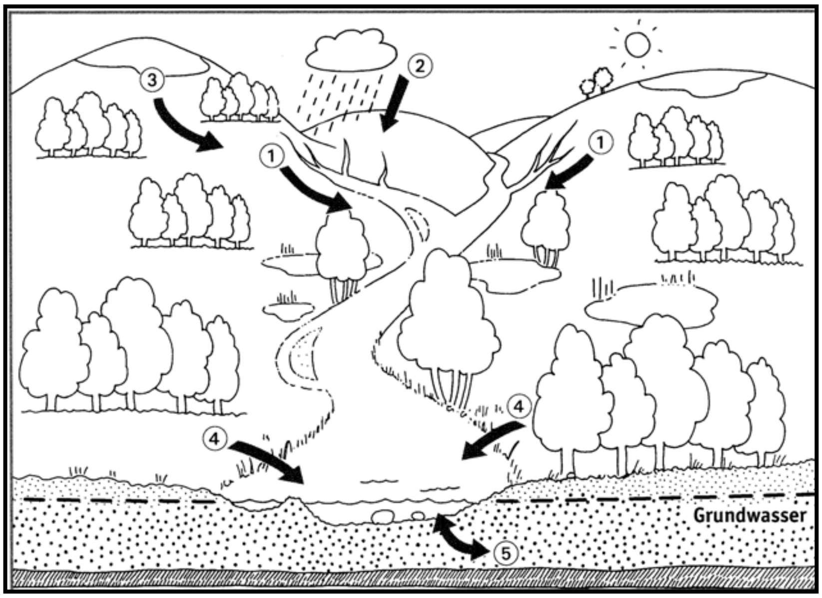
Characteristic	Groundwater	Surface water
Light	No	Yes
Physical disturbance	Low	High
Temperature	Stable	Variable
Chemical composition	Generally low	Variable to high
DOM content	Generally high	Variable
Oxygen content	Often depleted	Often near saturation
Current velocities	Very low	Relatively high
Contact with sediment	Very high	Low

(Edwards 1998)

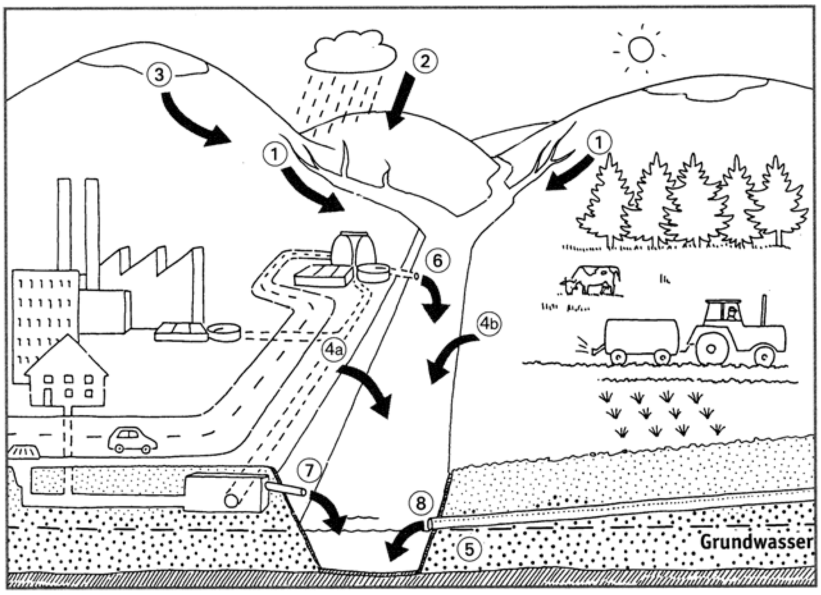
- Example: The hyporheic zone may serve as a refuge for organisms, buffering them from variations in temperature.



Water resources, stores and fluxes in natural landscapes and cultivated landscapes



rivers in a natural landscape



rivers in a cultivated landscape

(1) wells, (2) precipitation, (3) snowmelt, (4a) surface runoff from sealed areas, (4b) surface runoff from agricultural areas, (5) groundwater, (6) outflow from wastewater treatment plants, (7) outflow from the sewage water system, (8) drainage.

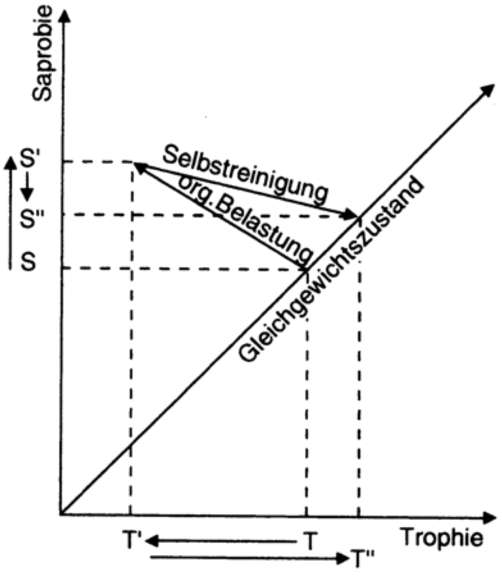
Trophy

=> Intensity of Primary Production

Saprobity

=> Amount of decompositionable organic material

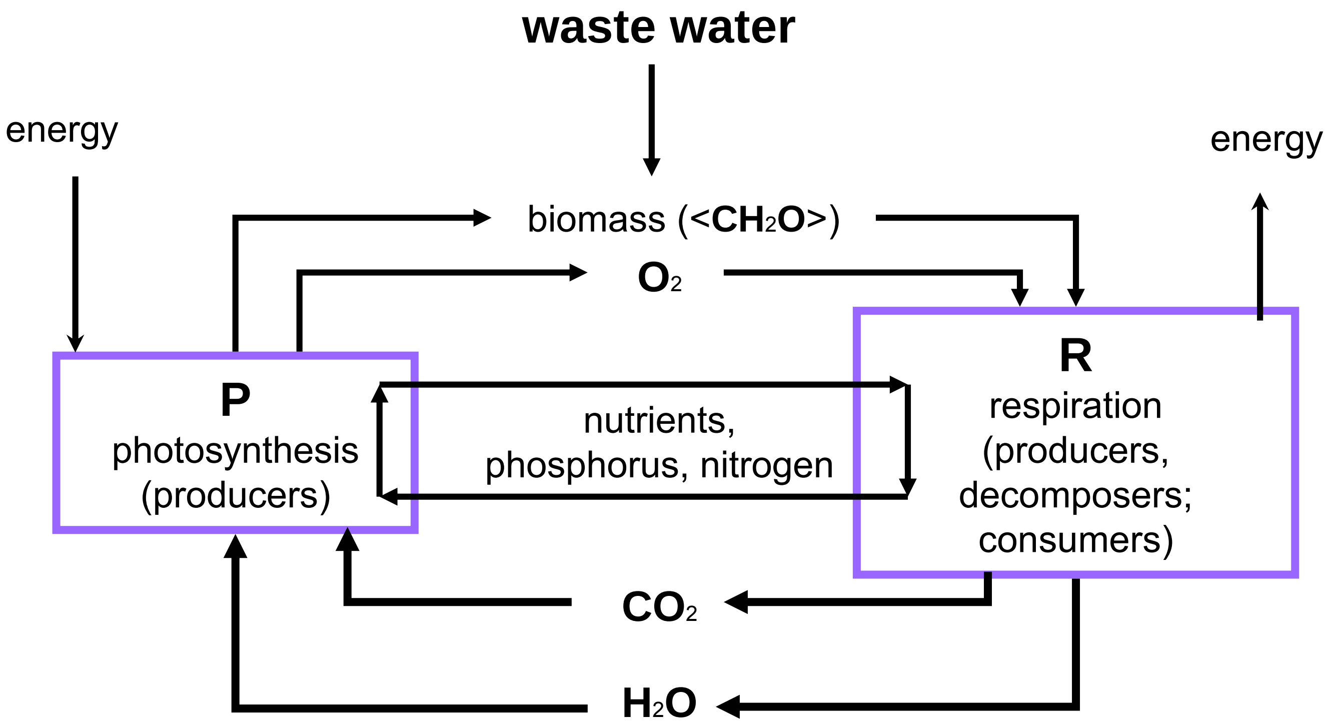
=> Biomass and metabolic rate of bacteria



Relation between trophy and saprobity in rivers. If rivers are loaded with organic waste water, saprobity increases from S to S´, at the same time trophy decreases from T to T´. During self purification the equilibrium is adjusted at a higher level (Schwoerbel 1994).

Trophy- Saprobity

Production (=> trophic state) and Respiration (saprobic state)
are both related to the metabolism of the biota and play a central role in
freshwater ecosystems



waste water

energy

energy

biomass (<CH_2O>)

O_2

P
photosynthesis
(producers)

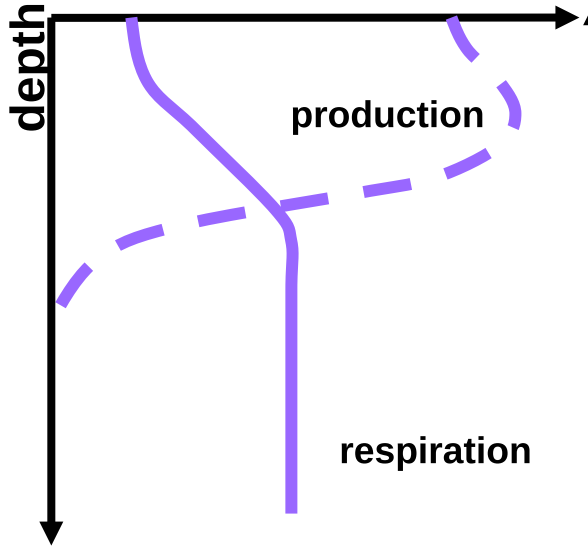
nutrients,
phosphorus, nitrogen

R
respiration
(producers,
decomposers;
consumers)

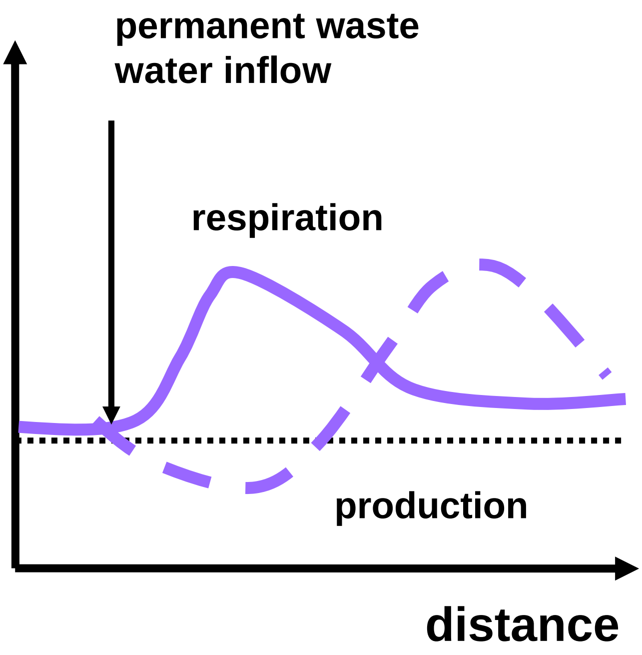
CO_2

H_2O

Lakes



Rivers



Water pollution and degradation

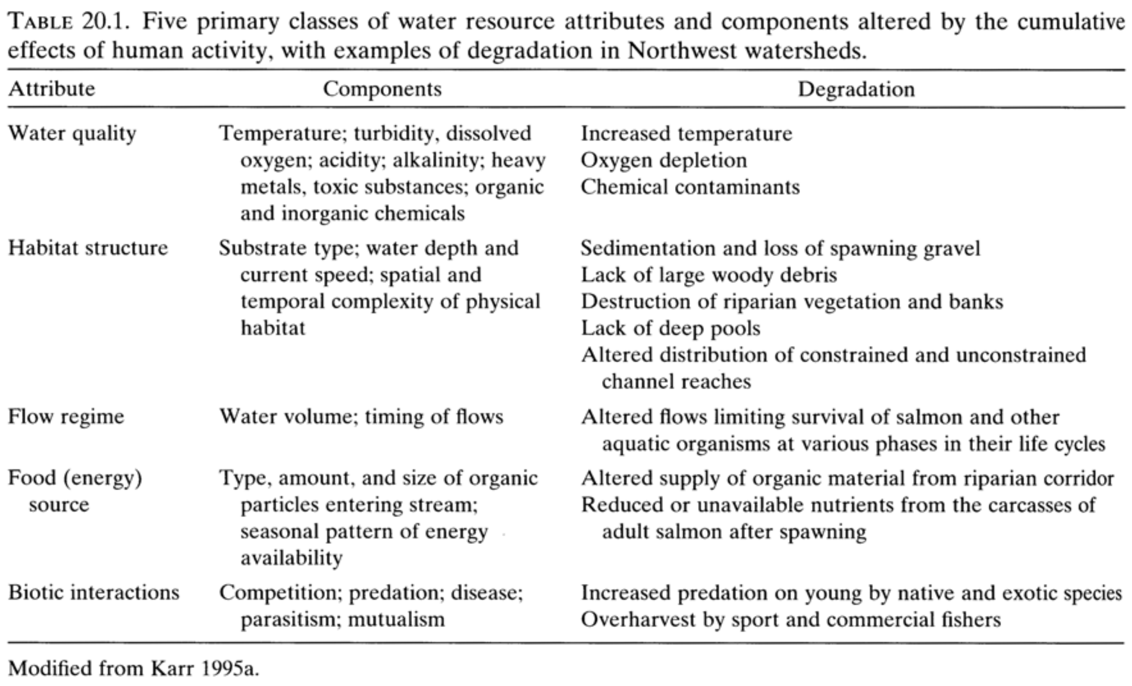
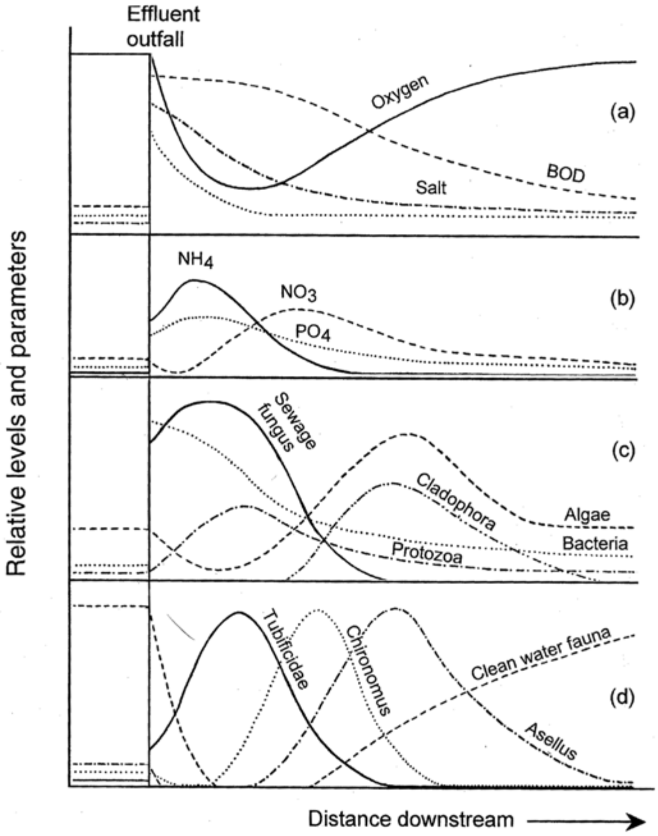


TABLE 20.1. Five primary classes of water resource attributes and components altered by the cumulative effects of human activity, with examples of degradation in Northwest watersheds.

Attribute	Components	Degradation
Water quality	Temperature; turbidity, dissolved oxygen; acidity; alkalinity; heavy metals, toxic substances; organic and inorganic chemicals	Increased temperature Oxygen depletion Chemical contaminants
Habitat structure	Substrate type; water depth and current speed; spatial and temporal complexity of physical habitat	Sedimentation and loss of spawning gravel Lack of large woody debris Destruction of riparian vegetation and banks Lack of deep pools Altered distribution of constrained and unconstrained channel reaches
Flow regime	Water volume; timing of flows	Altered flows limiting survival of salmon and other aquatic organisms at various phases in their life cycles
Food (energy) source	Type, amount, and size of organic particles entering stream; seasonal pattern of energy availability	Altered supply of organic material from riparian corridor Reduced or unavailable nutrients from the carcasses of adult salmon after spawning
Biotic interactions	Competition; predation; disease; parasitism; mutualism	Increased predation on young by native and exotic species Overharvest by sport and commercial fishers

Modified from Karr 1995a.

Self purification in running waters



A diagrammatic representation of the longitudinal zonation established downstream of the outfall of a continuous organic effluent discharge: (a) and (b) are physical and chemical changes; (c) changes in microorganisms and plants; (d) changes in larger organisms. (After Hynes 1960).

Eutrophication

- inorganic plant nutrients arise from groundwater and surface runoff draining intensively managed agricultural land (from fertilizers and animal waste), or from catchments undergoing land use change (such as deforestation).
- N and P enhance primary production .
- Also from organic matter input which is broken down to inorganic nutrients.
- Change in physico-chemical conditions.
- Extreme growth of macrophytes, algae, and large blooms of phytoplankton.
- More organic detritus is generated by enhanced primary production, what leads in turn to sedimentation and reduced oxygen levels.
- Invertebrate and fish communities are affected directly, hence the whole food web can be altered.
- Eutrophication can cause problems for the use of water resources (e.g. drinking water).

Acidification

- Acidification can be a problem in the more remote upland regions, for catchments lying on poorly weathered rocks and thin soils on poorly buffered geologies.
- Primary source is atmospheric pollution (in particular in Central Europe until the 1960s). Oxides of sulphur and nitrogen are generated during combustion of fossil fuels by power-generating plants. Chemical change in the atmosphere, production of acids (nitric and sulphuric), hence acid rain.
- Acid rain can reach a pH as low as 2.1
- Impact on organisms from all trophic levels.
- Direct acidity and toxic effects of elevated aluminium leached from the surrounding soil.
- In sensitive animanls, accumulation of aluminium ion in ion-regulating organs, perhaps affecting osmoregulation. Physical irritation of gills of fish and mayflies may affect respiration.

Organochlorines

- Some chemicals also enter rivers and streams from diffuse sources and of these the most serious are the organochlorines, such as pesticides like DDT (application now fobidden) and dieldrien (application now fobidden) and polychlorinated biphenyls (PCBs).
- Transported over wide areas by winds and washing into waterbodies with precipitation.
- Highly persistent.
- Sediment-based PCBs are taken up by riverine zooplankton and planktivouous fish, as well as bottom-living fish like eels.
- Benthic invertebrates accumulate PCBs, thus concentrations get magnified into top predators.
- Effects are sublethal but particularly influence reproductive processes.

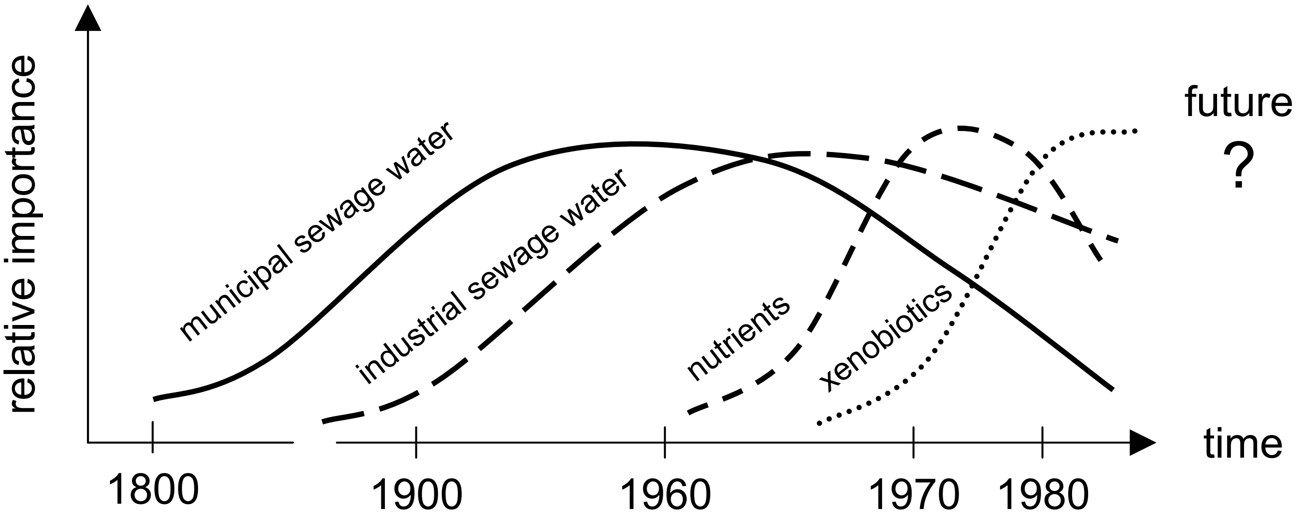
The potential for eutrophication in streams and rivers depends on stream order, discharge and shading

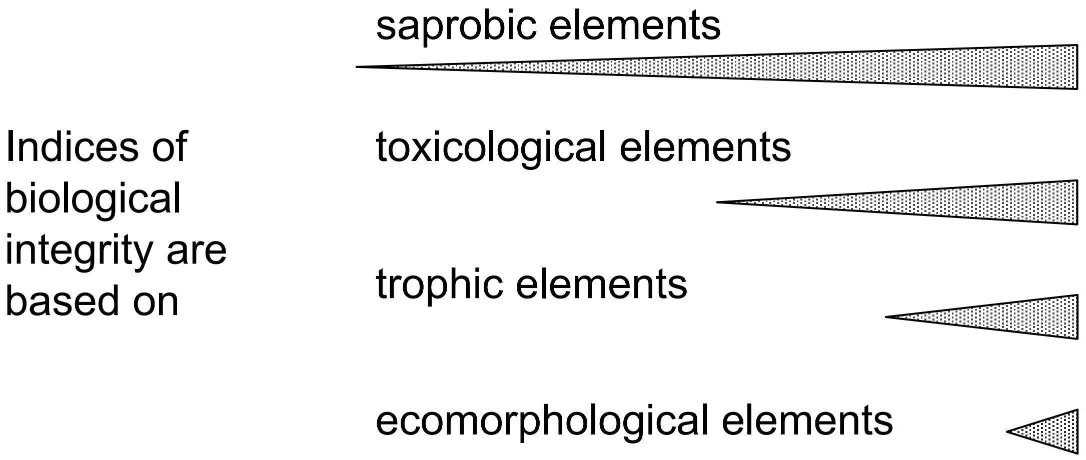
(after Gunkel 1997)

stream order	**water regime**	**riparian vegetation**	**potential for eutrophication**
near the source	freely flowing	unshaded	low potential for eutrophication (macrophytes and periphyton), in general low nutrient content, low biomass of primary producers
	freely flowing	shaded	no potential for eutrophication
headwaters	freely flowing	unshaded	low (macrophytes, periphyton), depending on nutrient content low biomass of primary producers
	freely flowing	shaded	very low potential for eutrophication
	impounded	unshaded	increases in primary production are possible (macrophytes, periphyton, to some extent plankton)
middle reaches	freely flowing	unshaded	increases in primary production, when rich in nutrients then eutrophication is possible
	freely flowing	in general no complete shading	increases in primary production, when rich in nutrients then eutrophication is possible
	enlargement, like in lakes	no shading possible	increases in primary production (macrophytes and plankton), risk of eutrophication
	impounded	in general no complete shading	increases in primary production (macrophytes and plankton), risk of eutrophication is great
down reaches	freely flowing	no shading possible	increases in primary production, (predominantly plankton), accumulation of fine sediments, risk of eutrophication is high
	enlargement, like in lakes	no shading possible	increases in primary production, (predominantly plankton), accumulation of fine sediments, risk of eutrophication is high
	impounded	no shading possible	strong increase in primary production, (predominantly plankton), accumulation of fine sediments, risk of eutrophication is very high
reach partly separated from the main channel	slowly flowing	in general no complete shading	increases in primary production (macrophytes, partly plankton), risk of eutrophication is high
reach totally separated from the main channel	no flow	in general no complete shading	generally eutrophic, increases in primary production (macrophytes, partly plankton) transform aquatic ecosystems into terrestrial ecosystems

Anthropogenic influences on running waters

- Development of human impacts on rivers in Central Europe since the 19th century




Indices of biological integrity are based on

saprobic elements

toxicological elements

trophic elements

ecomorphological elements

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