UNITED NATIONS
ENVIRONMENT
PROGRAMME

UNITED NATIONS
EDUCATIONAL,
SCIENTIFIC AND
CULTURAL
ORGANIZATION

A WORLDWIDE SURFACE WATER CLASSIFICATION SYSTEM

INTERNATIONAL
HYDROLOGICAL
PROGRAMME

UNEP/
EMINWA

UNESCO

PARIS, 1988

UNEP **UNESCO**

A WORLDWIDE SURFACE WATER CLASSIFICATION SYSTEM

L.W.G. Higler

The report was printed by the Research Institute
for Nature Management, Leersum, The Netherlands

Unesco, Paris, 1988

CONTENTS

FOREWORD

The aim of the publication "A worldwide surface water classification system" is to propose a methodology and information for classifying water bodies that will facilitate the inter-comparison of hydro-environmental situations. This proposal is open to discussion, and critical comment and suggestions for changes and improvements would be welcomed and will be used for the preparation of a revised edition of the publication.

The publication was prepared in the framework of the UNEP/Unesco project "Integrated Environmental Evaluation of Water Resources Development", reference number FP/5201-85-01. The determination of the influence of man on the hydrological cycle and the impact of development projects on the water-related environment are priority areas for both UNEP and Unesco in their respective water programmes.

The water resources programme of Unesco is centered on the International Hydrological Programme (IHP). Within IHP the influence of man on the hydrological cycle has been a priority area since the start of the International Hydrological Decade in 1965. This section covers scientific studies of the influence of man on the hydrological cycle, including water quantity and quality. The activities of man are considered to include direct action such as land-use changes, consumptive use of water, physical operations on river systems, addition of contaminants of various kinds, as well as those of a more indirect nature such as, for example, man-induced climate changes. These studies also include the effect of changes in the hydrological cycle on social, environmental and ecological aspects relative to water resources.

The studies executed in the framework of the IHP will result in the synthesis of existing knowledge, guidance material for the execution of national studies, teaching notes and public information material. Publications issued in this area include:

- Man's Influence on the Hydrological Cycle" (with FAO)
- Hydrological Effects of Urbanization and Industrialization on Water Resources Planning and Management
- Casebook on Methods of Computation of Quantitative Changes in the Hydrological Regime of River Basins due to Human Activities
- Aquifer Contaminants and Protection
- Hydrological Problems related to the Development of Energy
- Study of the Relationship between Water Quality and Sediment Transport

- The Hydrological Regime as influenced by the Drainage of Wetlands
- Investigation of the Water Regime of River Basins affected by Irrigation
- Hydro-environmental Indices, a Review and Evaluation of their Use in the Assessment of the Environmental Impact of Water Projects.

UNEP's water programme is focussed on the Environmentally Sound Management of Inland Water (EMINWA). This programme is designed to assist governments to integrate environmental considerations into the management and development of inland waters, with a view to reconciling and ensuring the development of water resources in harmony with the water-related (natural and man-made) environment throughout entire water systems. It contributes to a harmonious river basin development and to a sustainable regional development.

The main activities of the EMINWA programme are:

(a) to assist governments to develop, approve and implement environmentally sound water management programmes in river basins by inland water projects;
(b) to prepare a manual of principles and guidelines for the environmentally sound management of inland water;
(c) to use the EMINWA inland water basins for demonstration purposes;
(d) to train experts and implement an institution-building programme;
(e) to make regular world-wide assessments of the state of the environment in inland water systems.

Besides this publication on the classification of surface water bodies the UNEP/Unesco project "Integrated Environmental Evaluation of Water Resources Development", issued in 1987, a report entitled "Methodological Guidelines for the Integrated Environmental Evaluation of Water Resources Development" in English, French and Spanish, and in 1988 a teaching guide in English for the use of the methodology for the evaluation.

Each water resources development project differs from all other water resources projects and no situation is, at first sight, comparable to another. Differences in climate, morphology of the river basin, geology, soil structure, land use, vegetation, ecology, etc. are such that it even appears difficult to compare the environmental status of undeveloped rivers.

It was felt, therefore, that a hydro-environmental classification of water bodies would be useful, in the first place, to make it possible to use knowledge obtained under different circumstances to systematically increase the body of knowledge on questions related to the environmental status of water bodies. It would also make possible the evaluations of the hydro-ecological status of water bodies as compared to other ones, and make it possible to more easily establish administrative and legal standards for the different water bodies in a country.

The ideal classification system would fulfil all these requirements, would be robust in the sense that a water body normally would remain in the same category and it would be easy to understand and to use by engineers and planners who do not have a specialized knowledge of hydro-biology.

It is probably impossible, and certainly unwieldy, to design a detailed classification on the basis of the above requirements which would cover all possible situations in the world. On the other hand, it is thought that a first approach classification on the basis of physical variables would be globally valid, would not be contradictory to existing classifications already in use and would allow for additions based on regional or local conditions.

As stated in the first paragraph of this chapter the proposed classification and the other information in this publication is not meant as the final word on the subject. It is open to discussion and critical comments. Suggestions for changes and improvements are welcome and will be used in the preparation of a second version of the document.

Please send your comments/suggestions to the Director of the Division of Water Sciences, Unesco, 7 Place de Fontenoy, 75700 Paris, France.

ACKNOWLEDGEMENTS

This report is part of the UNEP/Unesco project FP/5201/85-01 "Integrated Environmental Evaluation of Water Resources Development". I am grateful for the comments of the (other) members of the Scientific Export Group for this project, Prof. Dr. L. Hartmann (chairman), H.C. Torno (who corrected the english version), Dr. I. Bogardi, Drs. P. Leentvaar, Ir. F.H. Verhoog and L. David (the UNEP programme officer). Many figures and tables have been taken from books, and some from journals. All publishers have given their permission for reproduction, which is acknowledged here with gratitude.

INTRODUCTORY REMARKS

This report presents a worldwide classification of surface waters. The diversity of water types is immense and any attempt to bring some order to this diversity invariably confronts a multitude of exceptions. The resulting report therefore is an oversimplification of reality, based upon limited information and leaning heavily on research data from temperate regions.

Despite the endless variety of water types certain laws and regularities can be observed and these form the body of the classification. Local climatological and biogeographical circumstances will require adaptations and filling in of the system. These adaptations should be made only by local experts.

This report indicates a number of possible adaptations and gives examples from different areas in the world. Extensive literature lists which provide further details on all aspects of the classification system have been included. The first chapter gives an elemental classification with leading considerations as a summary of this study. The remaining chapters constitute the scientific basis for the classification and the appendices give background information and justification.

1 A CLASSIFICATION OF SURFACE WATERS

With respect to the uses of surface waters one can make different classifications. If the main interest is for drinking water purposes, quality and quantity are the first concerns. For navigation, hydraulic characteristics and the growth of water plants are important and so on.

We have opted for an ecological classification, which attempts to describe waters in their "natural state" and which uses biological as well as abiotic parameters. Biological parameters can be used as indicators of the natural state and also for deviations from the natural state. They can also give information about water quality, trophic status, the fishery potential etc.

Plants and animals in the water can influence chemistry, water movement, depth (by terrestrialization stages) and so on, but the starting point for an analysis of the suitability of a water for plants and animals is abiotic. Climate, composition of the soil, and morphometry of the landscape are the main factors, and derived from these are temperature (ranges), streamflow velocity in running waters, salinity, dimensions, nutrients, pH, etc.

These different conditions are characterized by different biocommunities, but the structure and functioning of these communities show simililarity within the discerned types, despite biogeographical variations. For this reason one can work with a generalized concept, which is then adapted to regional or local conditions.

In the simplified classification shown in Fig. 1, a first division has been made into running and stagnant waters (separately treated in the chapters 3 and 4). It seems to be practical to do this, as there are few common features or species of plants and animals in these two categories.

Running waters

In a recent paper Statzner and Higler (1986- Also included as Appendix IV) suggested that physical characteristics of flow (stream hydraulics) are the most important environmental factor governing the zonation of stream benthos on a world-wide scale. They recognized zones of transition in stream hydraulics from source to mouth to which the general pattern of assemblages of stream invertebrates can be related. A proposal was given for a general pattern of bentic fauna in pristine streams. For this they created an "ideal" stream from its source in the mountains to its delta or estuary in the sea. Isolated streams and stream sections can be related to parts of the idealized stream.

By rearranging the elements of the Manning equation Higler and Mol (1984- included as Appendix I) constructed a diagram (Fig. 23, Appendix II) in which running waters in The Netherlands can be characterized on the basis of measurements of streamflow velocity, terrain slope and dimensions. Hydraulic factors and dimensions determine the place in the diagram. As stream benthos is governed mainly by hydraulics it should be possible to indicate the place of assemblages of organisms that are to be found in certain parts of the diagram. In this way the idealized stream can be populated with organisms. They started with West-European invertebrates and although much work remains, the first results look very promising.

These considerations have been derived from work in temperate zones, but the Unesco/UNEP project is aiming at a broader application in developing countries. It is obvious that one cannot construct a worldwide system using names of organisms and circumstances from temperate regions. The reference situation must be filled in for any given area including an analysis of the deviations from the reference. A hierarchy of environmental factors must be used, in which the climatological factors are the most important. In the different climatological zones criteria like drought, ice cover, precipitation extremes influence the conditions in streams. The zonobiomes described by Walter & Breckle (1983) (Fig. 2) can function very well as large ecological units on a global scale.

Temporary streams have been treated separately, because the extreme environmental conditions require many adaptations of the biocenosis. Streams in the arctic can be frozen for a considerable period whereas those in the tropics may dry out completely for many months. In temperate regions the upper course often dries out in summer. Mound springs in Australia however evaporate after some tens of meters, and only in the rainy season does their length (and the population of the biocommunity) increase. Table 1 (page 29) presents some generalized characteristics for running waters along their course in temperate regions.

Stagnant waters

Stagnant waters have been first divided into non-saline and saline waters, because the salinity is of such importance that it overrules all other factors (4.4). In stagnant freshwaters there is no single factor such as hydraulics in running waters that dominates all processes. Historically, therefore classifications have been made from different points of view based on different variables. Forel (1901) made the first classification, based on temperature regime. In the first decades of this century Naumann and Thienemann made classifications of lakes on the basis of productivity, and later Hutchinson (1957) discerned 76 types of lakes on the basis of origin. Morphometry has been considered as a good criterion for classification by several authors. Ökland (1964) summarizes seven categories of parameters: climate, morphometry, chemical and physical properties, sediment, flora, fauna and productivity.

In classic limnology attention has been directed more to deep lakes than to shallow waters and much more is known from temperate regions than from others. Of course there are well known exceptions to this rule, such as Thienemann (1931), but in general the existing classifications support the rule. Depth is a very important ecological factor, and stagnant waters should be divided into three main groups according to depth. The exact depth for the division is depending on local conditions. In hot weather in the tropics, for instance, a very shallow water (1.5 m) can dry out totally, whereas in a temperate region, an even shallower pool will remain water throughout the year.

The division between deep and shallow waters depends on a few physical parameters, related to light and temperature. The existence of a thermocline is very important, as is the maximum depth where plants will grow. A depth of 10 m has been arbitrarily selected, but it could be as little as 6 m and as much as 14 m under certain conditions.

Table 6 (page 51) presents some characteristics of the 3 types of stagnant waters. One might expect that species diversity would be highest in the the deep system, because the littoral zone represents the same conditions as those in shallow and very shallow waters. This is not true. The shallow systems have the highest diversity and they probably represent the standard stagnant water. Deep and very shallow waters (wetlands) would be biologically derived from them. Exceptions are the very old lakes like Baikal, Victoria, Biwa etc.

Figure 1 summarizes the main conclusions of the report. Considerations for the important divisions are derived from a.o. some figures and tables as indicated in the figure.

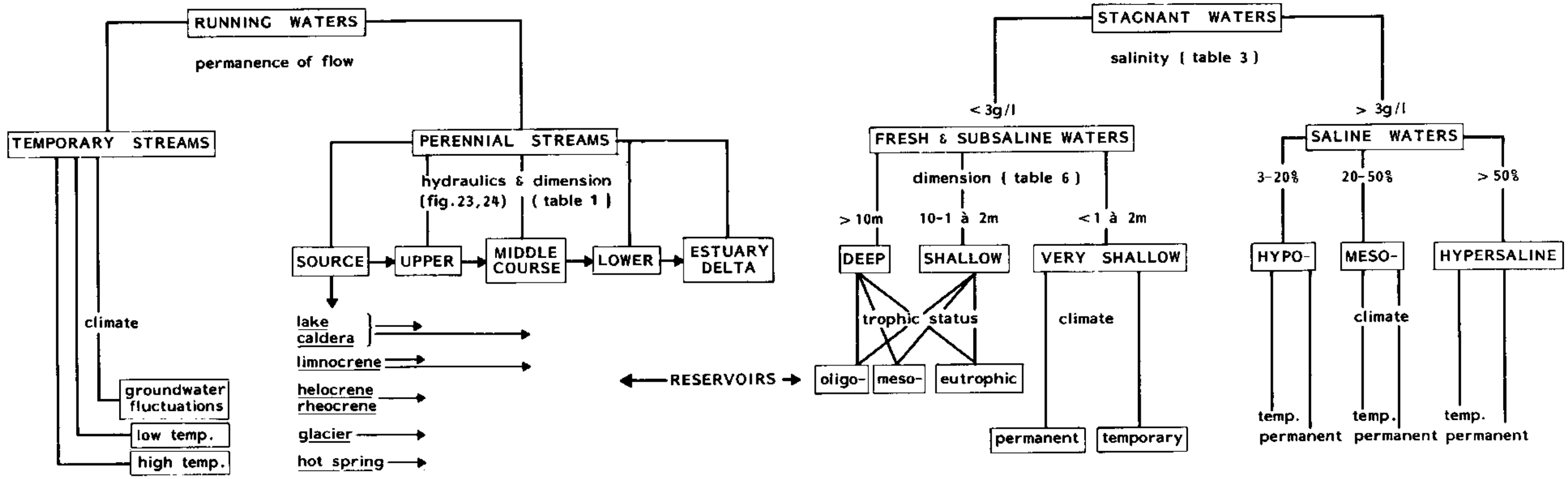


Fig. 1. A simplified classification of waters of the world.

2 CLIMATE AND HYDROLOGY

2.1 Climatological regions

The availability of water in any region is dependent on a number of factors such as: precipitation, evaporation, run-off, ground water reservoir, and/or soil moisture. It is obvious that in the Sahara conditions are different from those in the Amazon basin and different again from those in the Antarctic. The existence of climatological regions with respect to their position relative to the poles or the equator has been established, and has recently been described in terms of ecological systems called zonobiomes and zonoecotones (Walter & Breckle 1983). (Fig. 2).

Such a classification of regions, based largely on the fate of water, is an adequate tool for the classification of waters on a worldwide basis. The following zones or regions are described in this context. Examples of major precipitation regimes are given in Fig. 3.

I. Equatorial zone. High annual rainfall (> 100 mm a month) with two equinoxial maxima. No annual seasons based on temperature differences.

II. Tropical zone. Heavy rain in summer, extreme drought in winter. Annual rainfall tends to become lower the further from the equator. Marked seasonal temperature difference. In this zone several types of surface waters can be found. Rivers in tropical deciduous forest or in savannah have different characteristics. The precipitation-evaporation ratio is very important and can change markedly within the zone.

III. Subtropical desert zone. Annual rainfall < 200 mm, and in deserts < 50 mm. Surface waters in this zone are seldom perennial, and generally short-lived. Stagnant waters tend to be salt plains during most of the year.

IV. Mediterranean climate zone. Winter rain and summer drought. Generally more evaporation than precipitation. Intermittent rivers, and few or no stagnant waters.

V. Warm temperate zone. Maximum rainfall in summer. As the summers are very wet and the winters mild, this zone is rich in surface waters.

VI. Typical temperate zone. Short, cold winters and warm/hot summers. Sufficient moisture, especially near the oceans. Rich in surface waters.

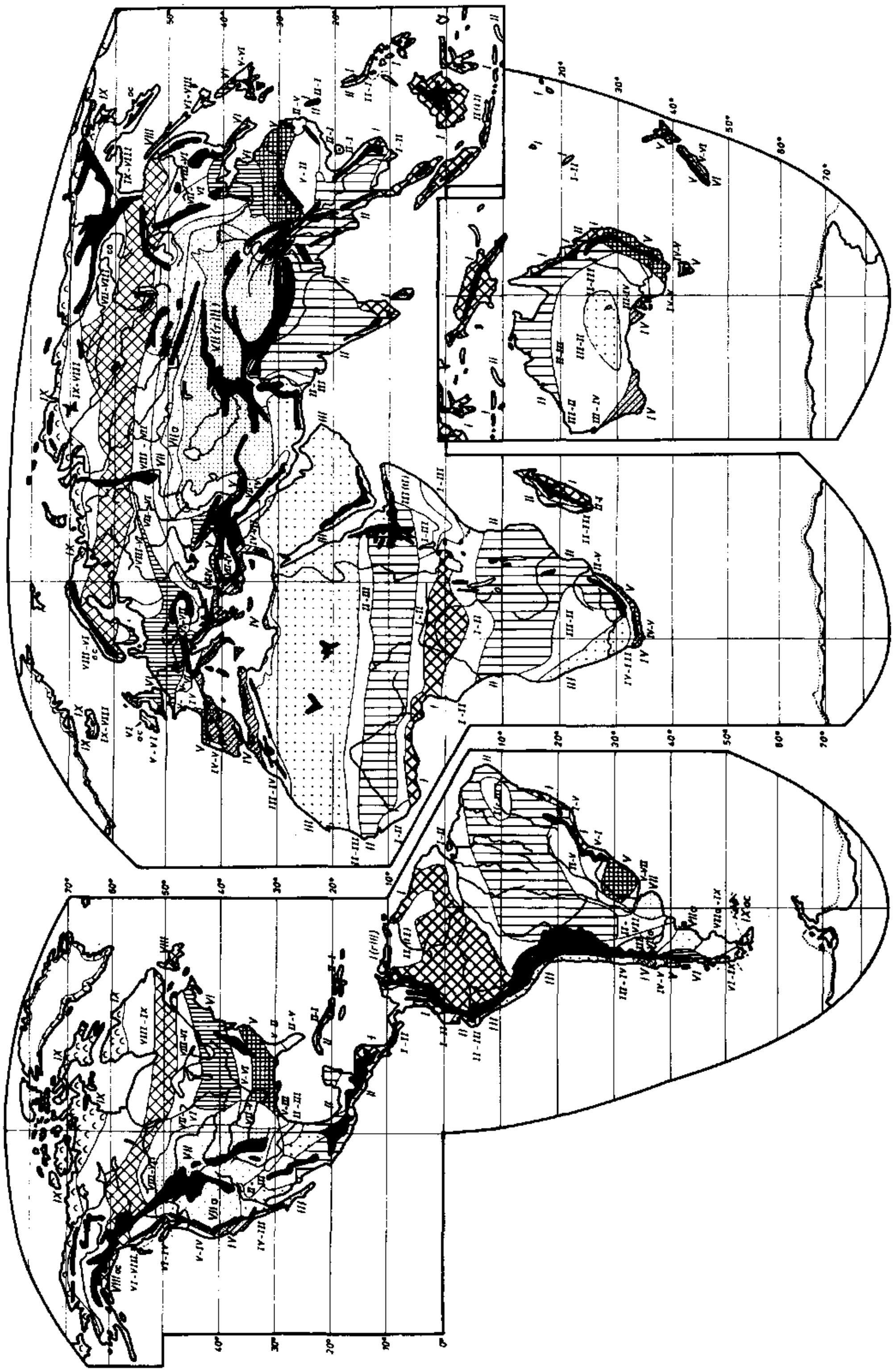


Fig. 2. The distribution of zonobiomes I-IX, showing the zono-ecotones between them (Walter & Breckle 1983).

VII. Arid-temperate zone. Low rainfall, dry summer or drought throughout the year. Conditions are not very favourable for surface waters.

VIII. Boreal zone. Cold-temperate with cool summers and long winters. Zone with many lakes and rivers.

IX. Arctic zone. Wet cool summers, long cold winters. Precipitation is predominantly snow. Lakes and rivers are frequently frozen for long periods of time.

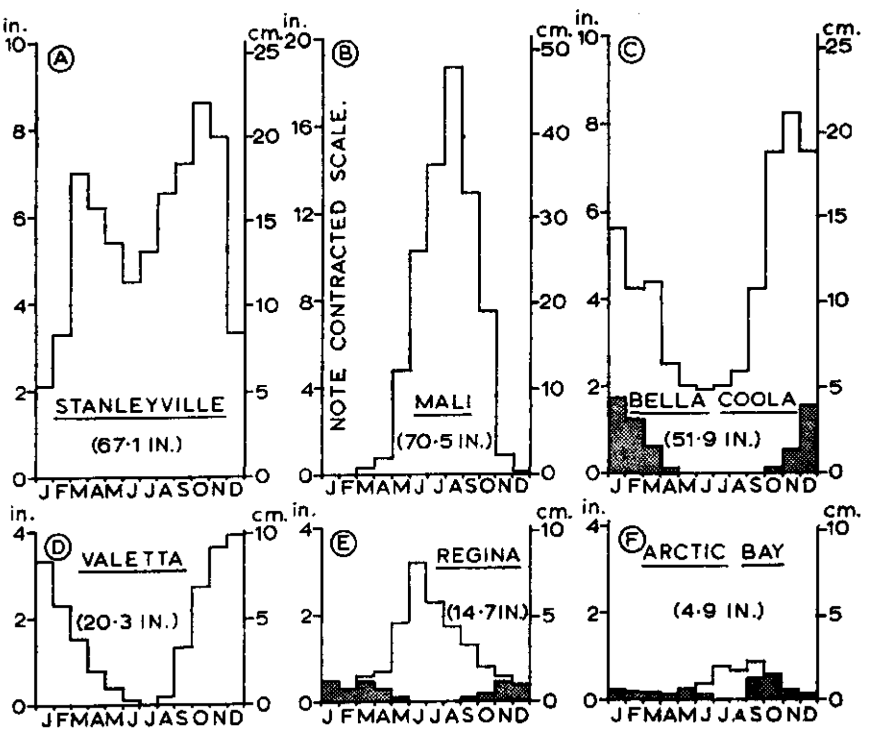


Fig. 3. Examples of the major types of precipitation regimes (Stippled portions indicate snowfall). A -Equatorial; B -Tropical; C -Temperate Oceanic; D -Mediterranean; E -Temperate Continental; F -Arctic (Chorley 1969).

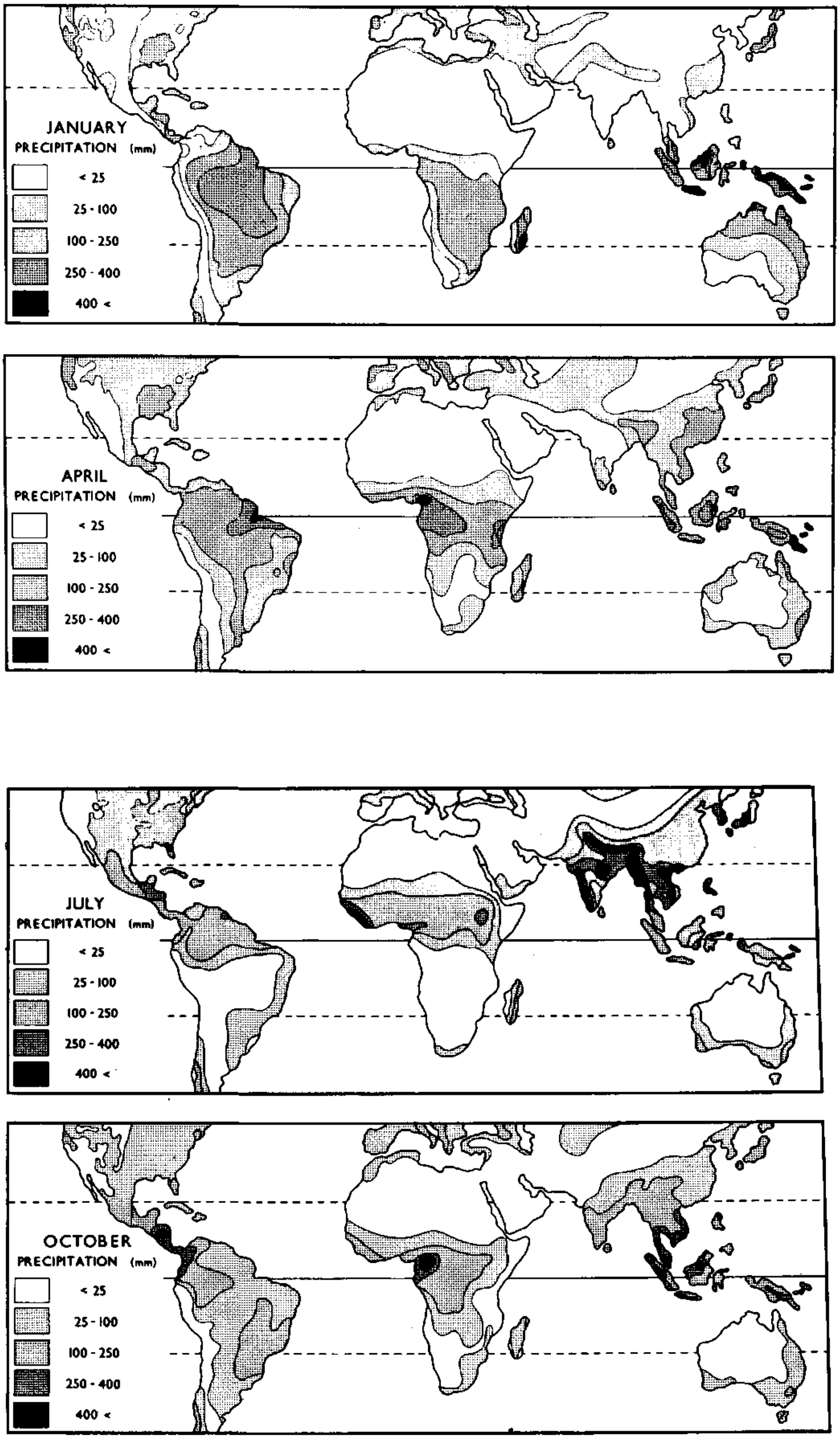


Fig. 4. Precipitation in four seasons (Jackson 1977).

It is obvious that precipitation plays an important role, not only quantitatively, but also with respect to frequency. Fig. 4 shows seasonal variations in precipitation. The relation to Fig. 2 is clear.

A few comments are in order.

1. There is not a very clear zonation of climatic zones according to latitude. This is due to the shape and magnitude of the continents and the presence of mountains. Moreover, the distribution of land masses in the northern and southern hemispheres is unequal (Fig. 5).

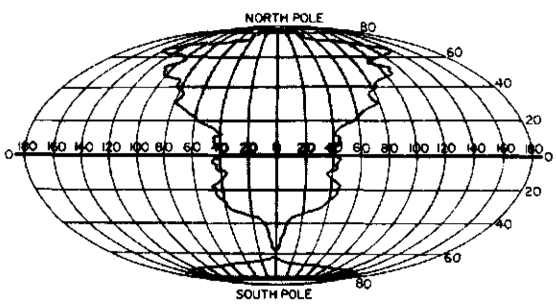


Fig. 5. The unequal distribution of landmasses illustrated by a 'summarized continent' (Ward 1985).

2. There is a rough correlation between latitude and the distribution of humid and arid zones (Fig. 6).

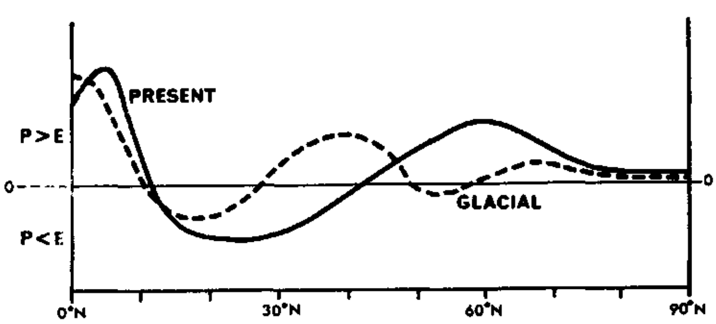


Fig. 6. The location of humid and arid zones in glacial times and the present day (Chorley 1969).

3. Precipitation alone is less important to the presence of surface waters than resulting variables such as annual run-off (Fig. 7).

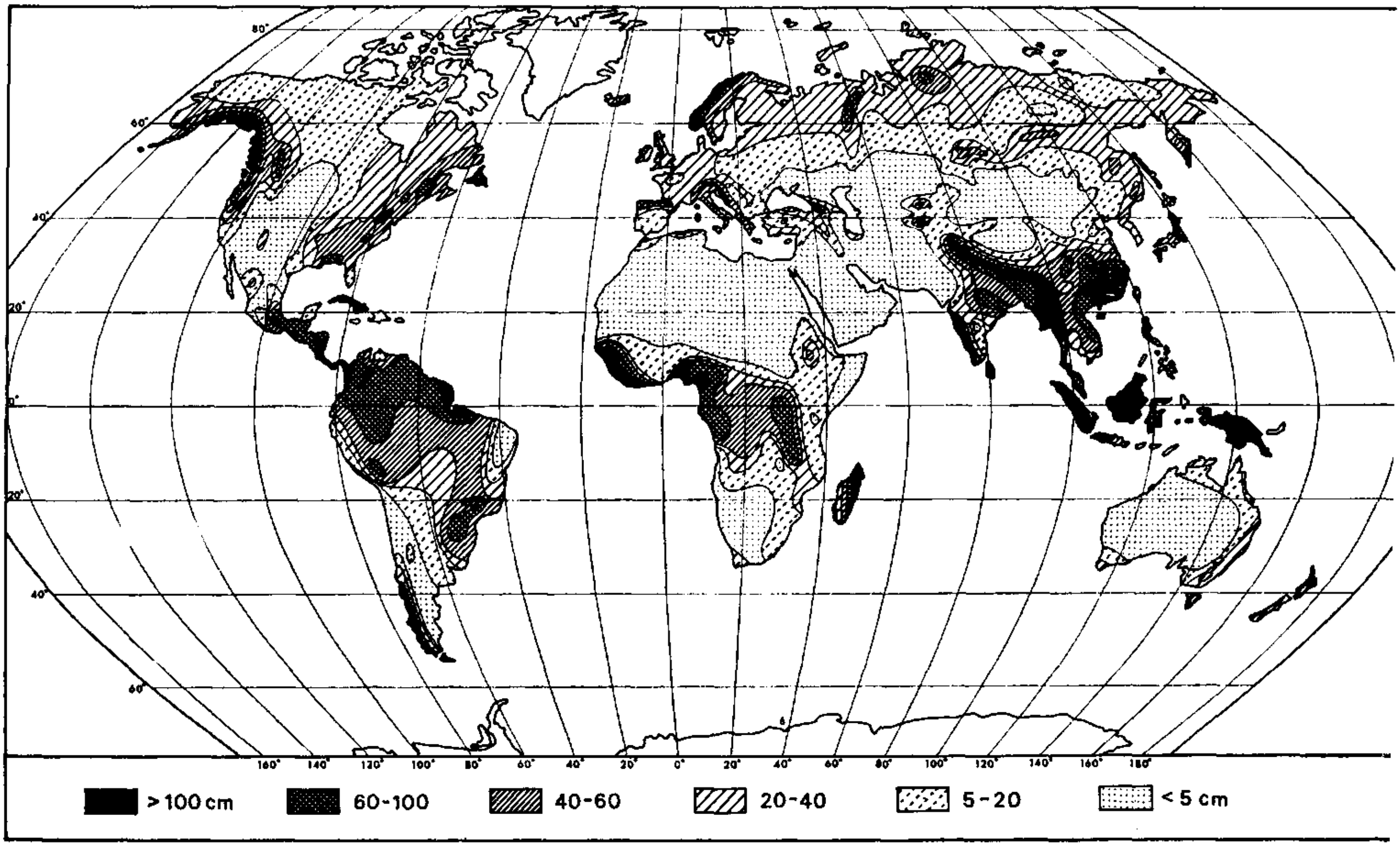


Fig. 7. Annual run-off in cm. Information is not available for areas left blank (Chorley 1969).

4. It is remarkable that some of the world's greatest drainage basins occupy large parts of arid zones (Fig. 8). The place of the sources and the amount of water from these sources is obviously of more importance.

5. It is to know whether precipitation can be predicted for a specific season. Two stations in East Africa (Fig. 9) demonstrate this. The stations are not very far from each other in zones I-II and I-III, but the precipitation patterns are quite different.

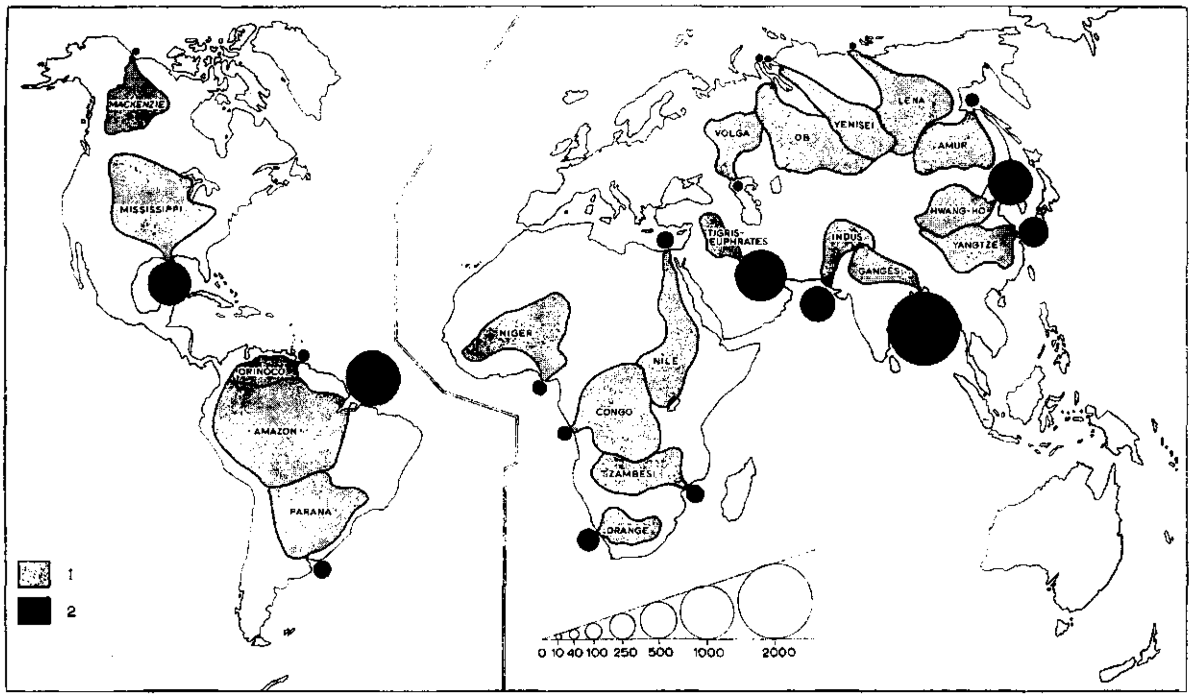


Fig. 8. World's largest drainage basins (1) and magnitude of solid load (2) (Chorley 1969).

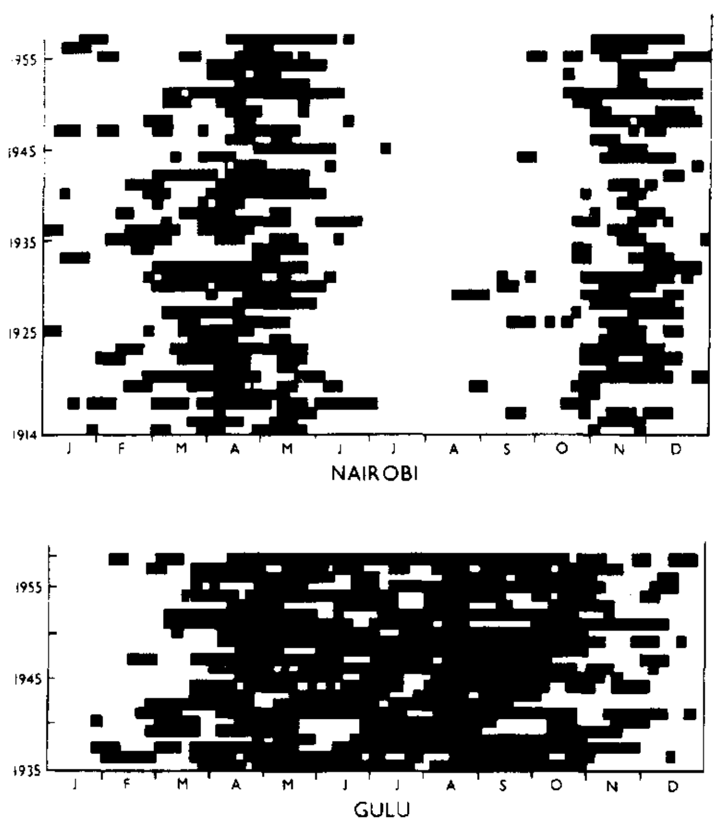


Fig. 9. Rainy pentades in Nairobi and Gulu (Jackson 1977).

2.2 Hydrological systems/regimes

All surface waters depend on processes such as precipitation, evaporation, and transport of water through air or soil. In Chapter 1 global conditions in climatological zones were treated; here we shall go into matters such as the quantity of water in lakes and rivers, hydraulics, processes in drainage basins and factors that govern living conditions for aquatic organisms.

Fig. 10 describes the basic hydrological cycle. Many variables can be measured, providing good opportunities for modelling and predicting (Fig. 11).

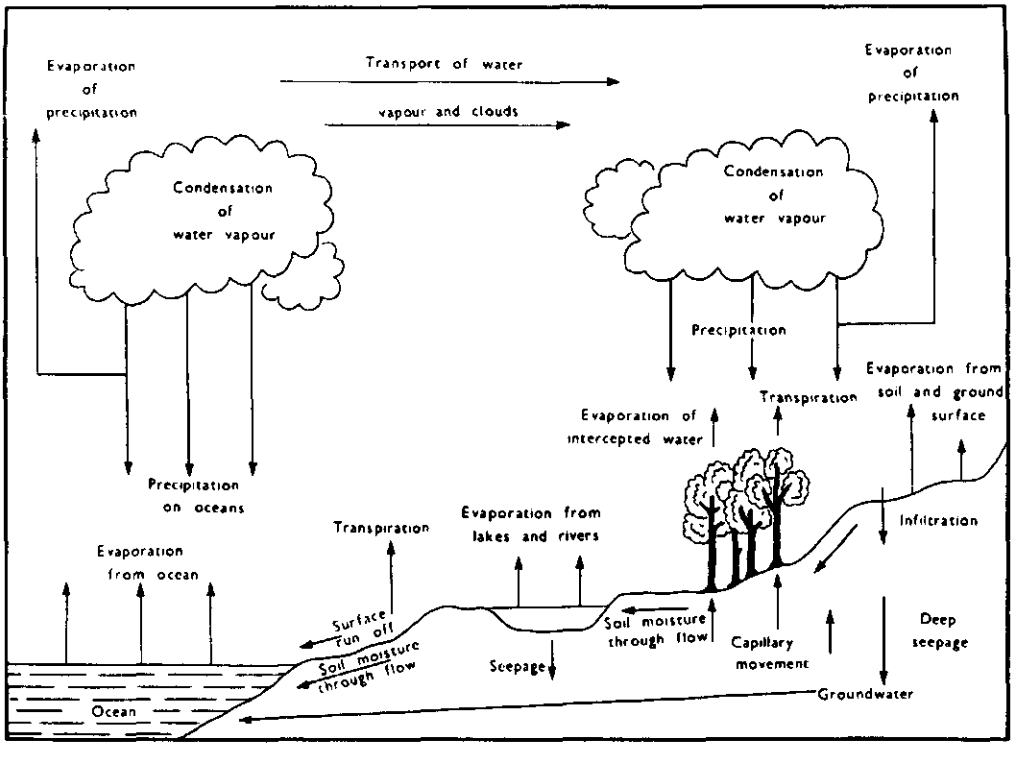


Fig. 10. The hydrological cycle (Jackson 1977).

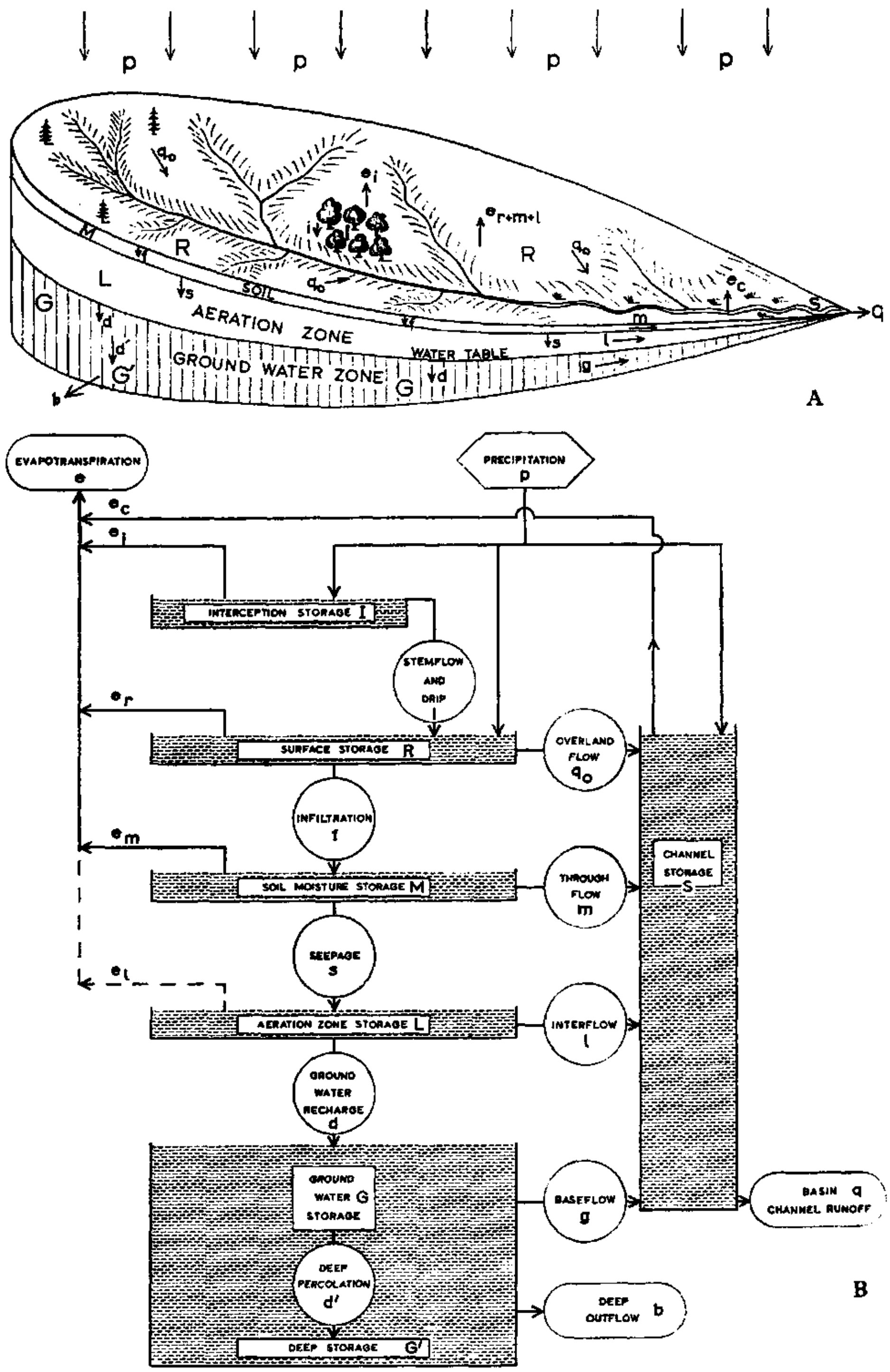
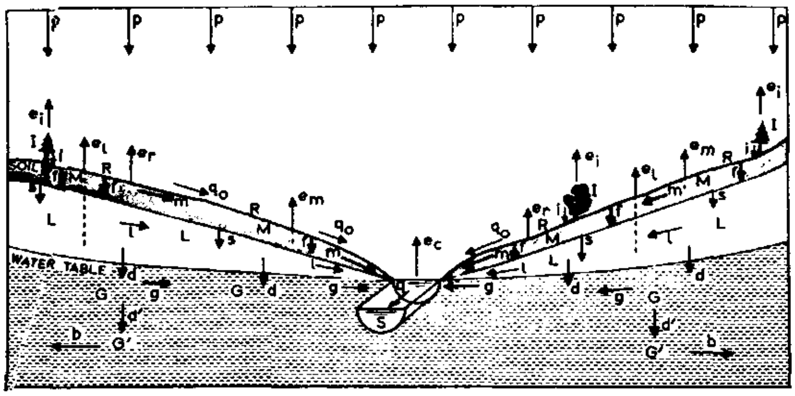


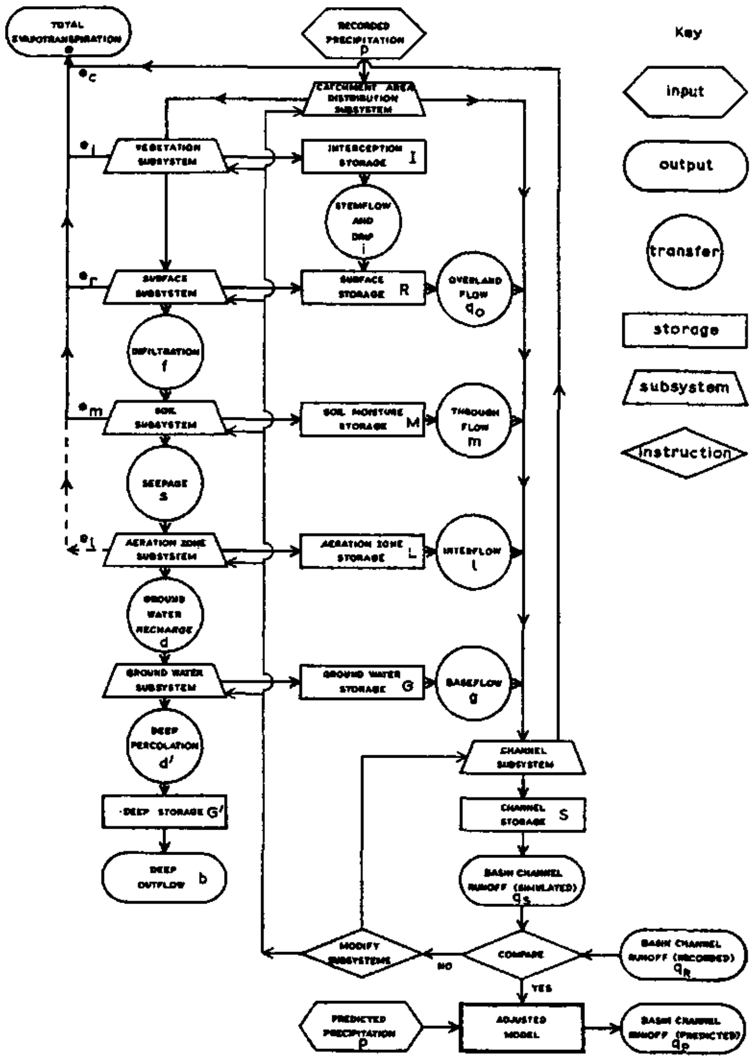
Fig. 11. The components of the basin hydrological cycle.

A. Block diagram of the basin.

B. Schematic inter-relationships of the basin components (Chorley 1969).



C



D

Fig. 11 (cont'd). The components of the basin hydrological cycle.
C. Cross-section of the basin.
D. Flow diagram of the basin components.

Before going into detail of watershed areas some data on water amounts in the global hydrological cycle will be presented. Fig. 12 gives the worldwide distribution of water in the different phases over the hydrological cycle.

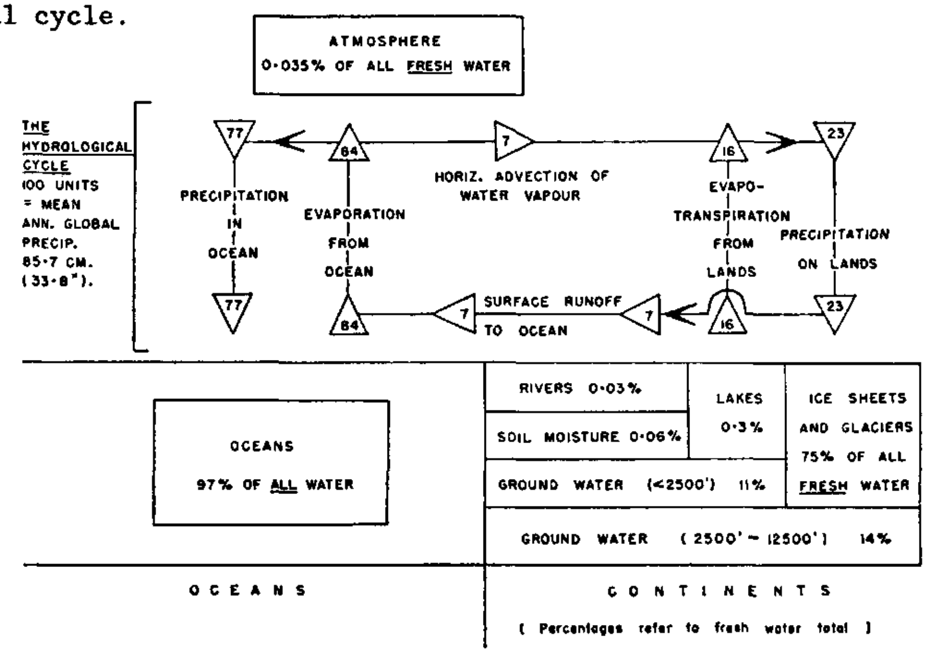


Fig. 12. The global hydrological cycle and water storage (Chorley 1969).

In Appendix VI all major rivers, lakes, and reservoirs are listed (Unesco 1978). Such a survey may seem unnecessary in this context, but experience has taught that it is very difficult to find data like these if needed. Moreover the survey gives a better idea where what quantities of water in which phase are to be found, although we must never forget that during the year considerable changes in the phases can occur (Fig. 13).

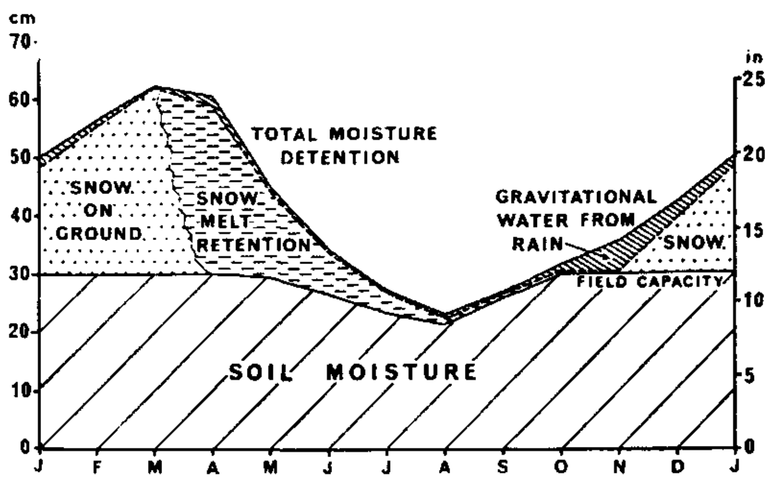


Fig. 13. The four components of total moisture at Sapporo, Japan (43^{o} N) (Chorley 1969).

3 CLASSIFICATION OF RUNNING WATERS

Fig. 14 gives a hierarchical scheme from continental to microhabitat level for running waters. The scheme is based on the factors which influence the distribution of macro-invertebrates in streams. It is useful for the classification of running waters.

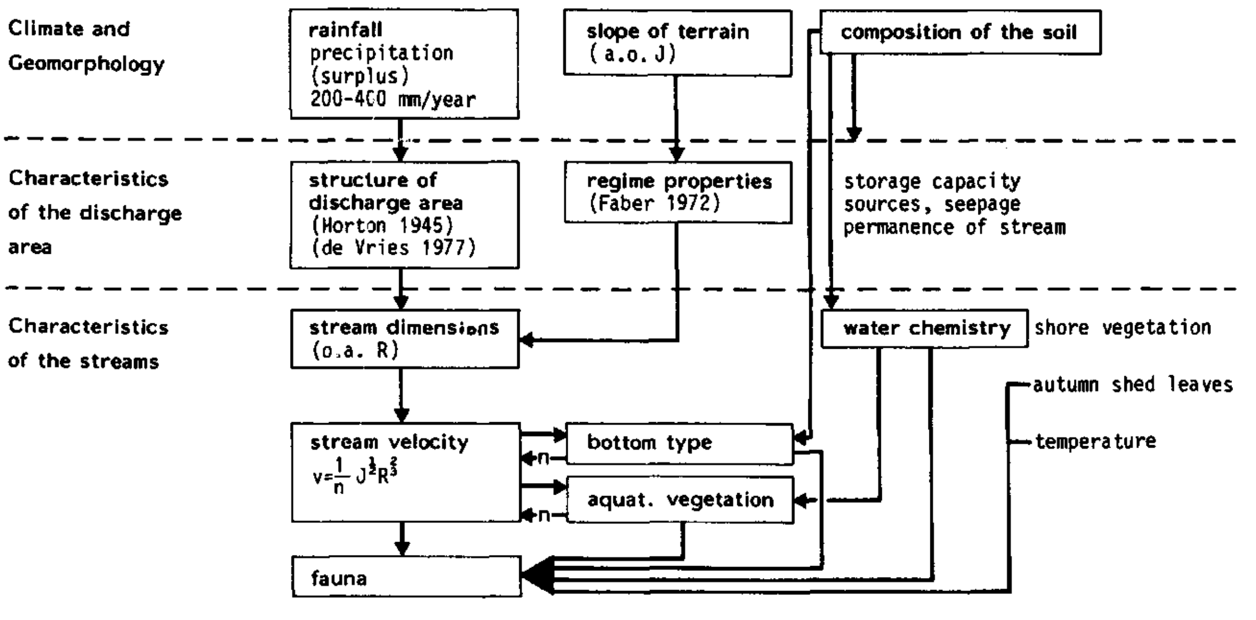


Fig. 14. Factors controlling the conditions for aquatic fauna in running waters (translated from Higler 1981).

Climatological and geomorphological factors were discussed briefly in the preceding pages. Some data on precipitation (Figs. 15 and 16) show that the amount of precipitation can differ from year to year, as well as throughout the year, causing different discharges, current velocities etc.

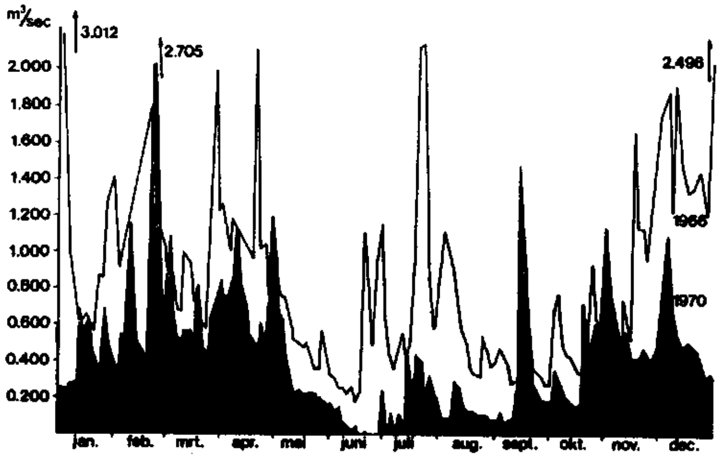


Fig. 15. Discharge of the Hierden Stream in 1966 and 1970 (Higler & Repko 1981).

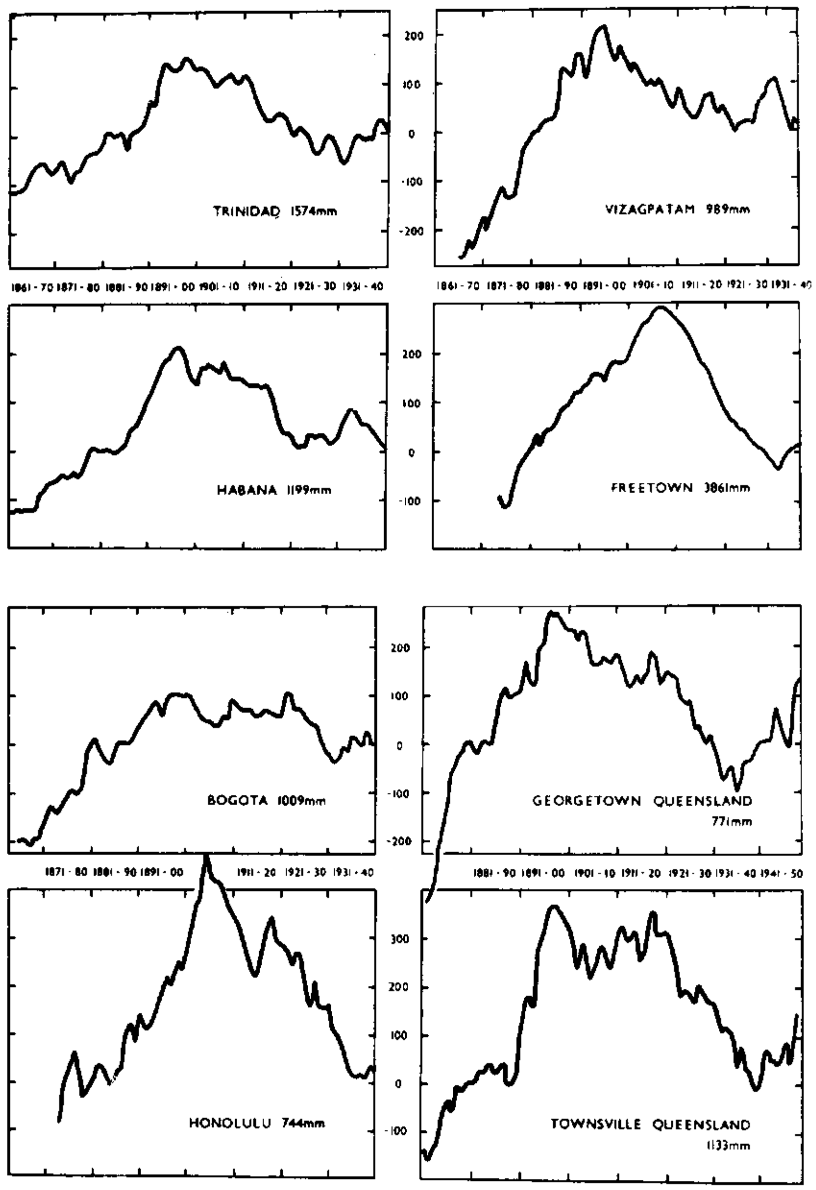


Fig. 16. Rainfall fluctuations 1861-1940 (Jackson 1977).

Characteristics of the discharge area, as a result of the first level characteristics climatology and geomorphology, are the shape and dimensions of the discharge area (Fig. 17), the number of orders in relation to the stream length (Fig. 18), the range of drainage density (Fig. 19) and accordingly the drainage pattern (Fig. 20).

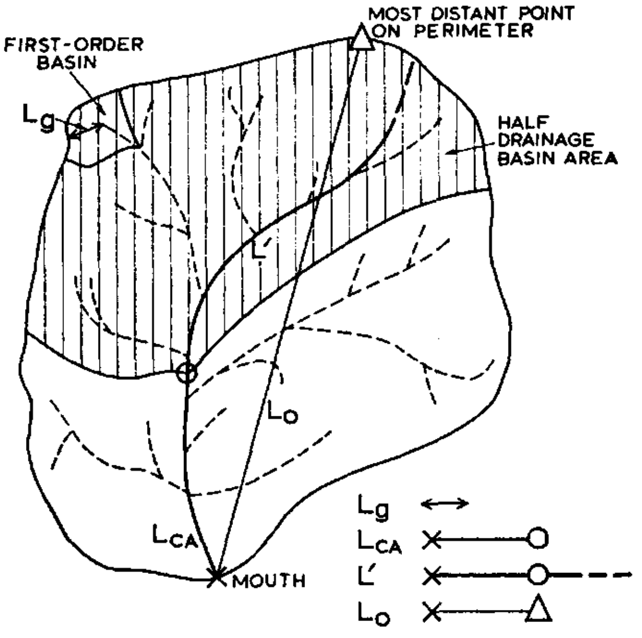


Fig. 17. Some common drainage basin length parameters (Chorley 1969).

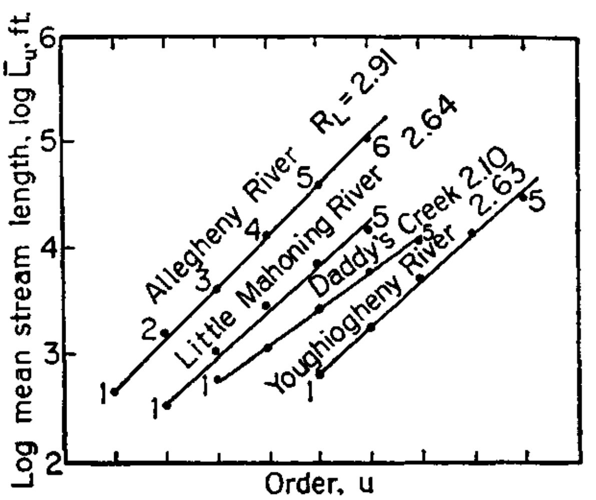


Fig. 18. Regression of logarithm of mean stream segment length versus order for four drainage basins in the Appalachian Plateau (Chorley 1969).

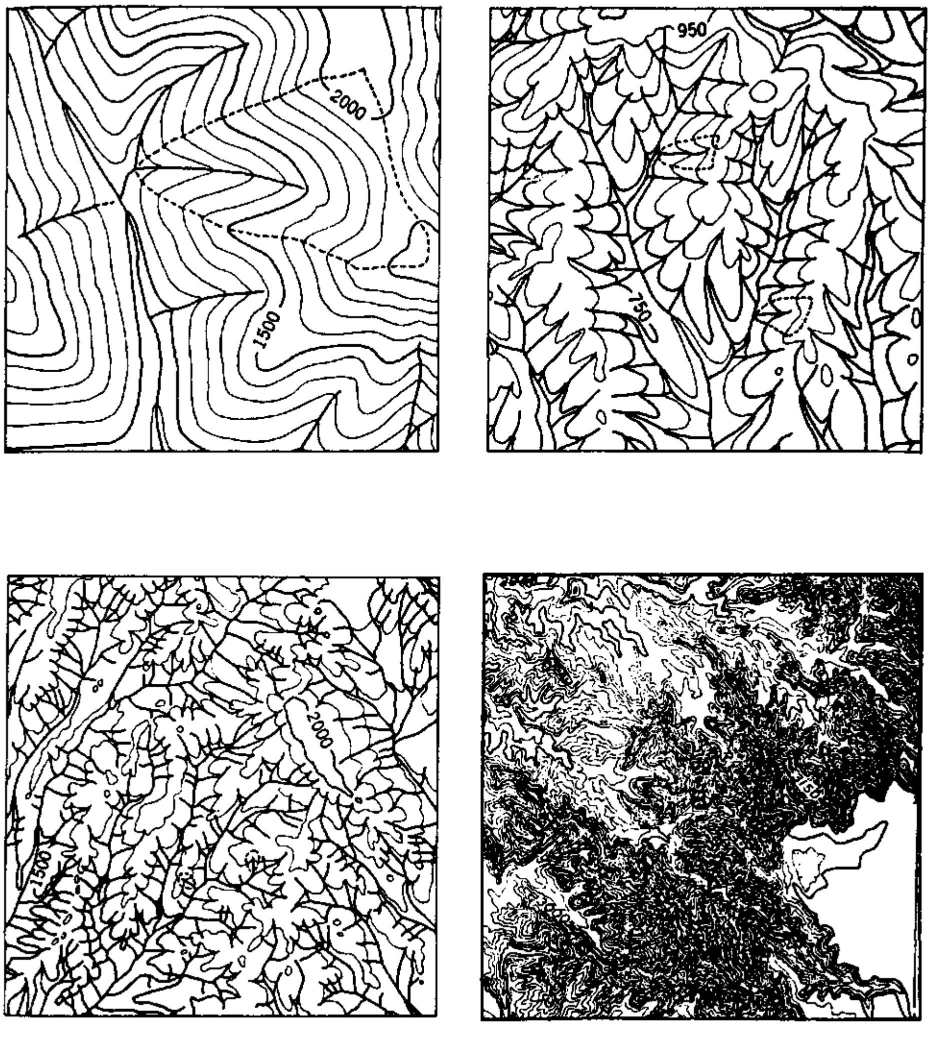


Fig. 19. Four areas, each of 1 square mile, illustrating the natural range of drainage density (Chorley 1969).

Top left: Low drainage density: Driftwood Quad., Penn.
Top right: Medium drainage density: Nashville Quad., Ind.
Bottom left: High drainage density: Little Tujungo Quad., Cal.
Bottom right: Very high drainage density: Cuny Table West Quad., S.Dak.

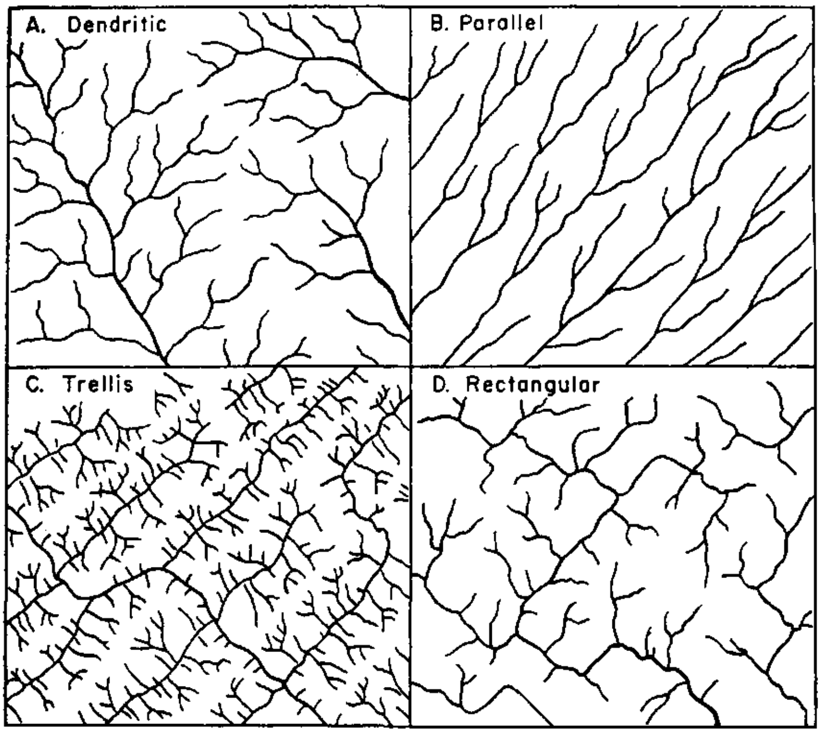


Fig. 20. Four basic drainage patterns, each occurring at a wide range of scales (Chorley 1969).

A relationship between stream length and stream order can be indicated (Fig. 18) and a relationship also exists between stream channel slope and stream order (Fig. 21). A combination of these cases is illustrated in Fig. 22.

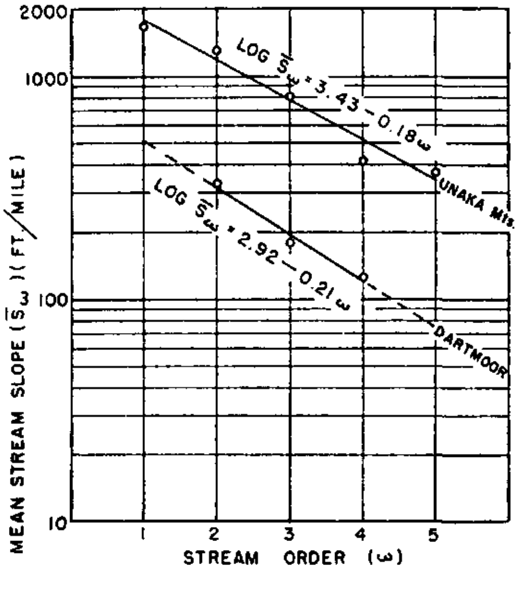


Fig. 21. Regressions of mean channel slope versus order for streams in the Unaka Mountains, Tenn. and N. Car., and Dartmoor, England (Chorley 1969).

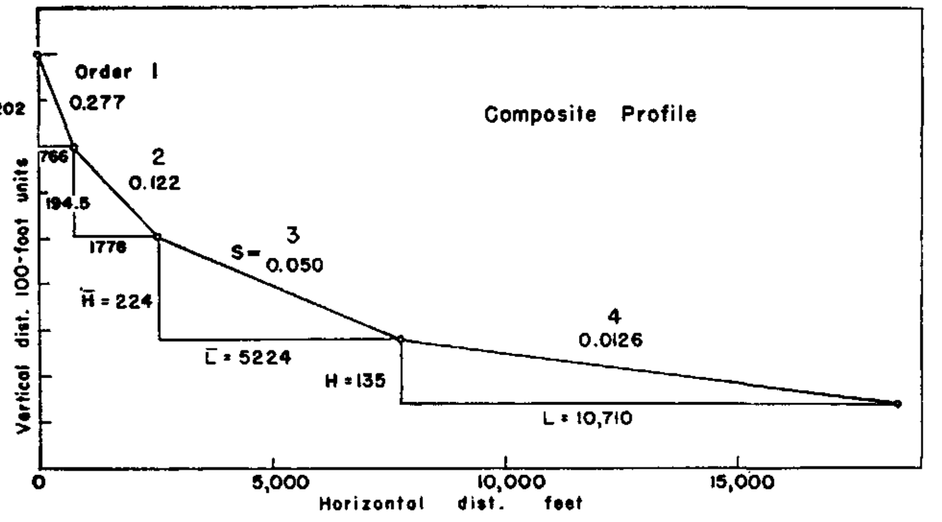


Fig. 22. Plot of the longitudinal profile of Salt Run, Penn., showing the difference in mean slope of each of the four segments of differing order (Chorley 1969).

The characterization of the streams themselves (lower part of Fig. 14) involves a multitude of factors. Pennak (1971) summarizes the ecologically most important ones:

1. width of the stream (6 categories)
2. flow regime (2 categories)
3. current speed (5 categories)
4. substrate (6 categories)
5. summer temperature (5 categories)
6. winter temperature (4 categories)
7. turbidity (5 categories)
8. total dissolved inorganic matter (4 categories)
9. total dissolved organic matter (4 categories)
10. water hardness (4 categories)
11. dissolved oxygen (5 categories)
12. rooted aquatic plants (4 categories)
13. streamside vegetation (4 categories)

Theoretically 184,320,000 combinations of these factors are possible and this obviously cannot be considered as a simple stream classification. A number of the factors from Pennak's list are interrelated and there is a definite hierarchy in their importance. In Fig. 14 a number of the main factors or combinations of factors have been depicted in a certain relationship in order to describe the conditions for aquatic fauna in streams. A central position is taken by the stream velocity and the Manning formula is used in its determination. It should be noted that the variables in this formula are derived from other characteristics in the scheme of Fig. 14, thus indicating their mutual relationship.

By rearranging the elements of Manning's formula it is possible to construct a diagram (Fig. 23) in which running waters can be characterized on the basis of measurements of current velocity, terrain slope, and dimensions (Higler & Mol 1984).

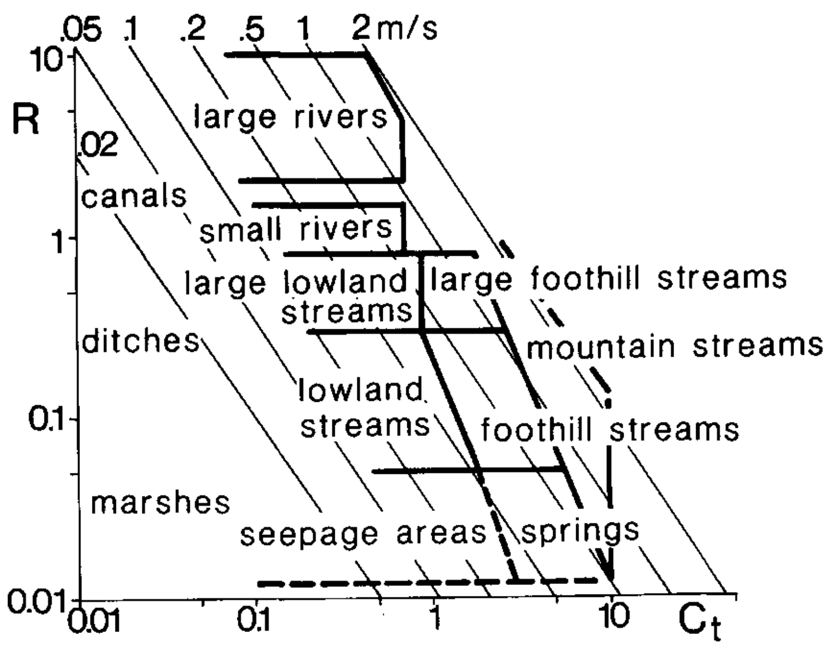


Fig. 23. Simplified diagram of running water types based on hydraulic factors as derived from Manning's formula.

In Appendix I an extensive description is given of the methods used to construct the diagram and to apply it for specific stream reaches. The advantage of this method is the simplicity with which a part of a stream can be characterized by measurements, which are of great practical use for management purposes. The diagram can also be used for a description of possible habitats for organisms.

Studies of running water have recognized a relationship between factors that change from source to mouth and organisms such as fish or macro-invertebrates. This concept is known as the zonation concept (Huet

1949; Illies 1961; Illies & Botosaneanu 1963) and the most frequently used terms for zones are krenon, rhitron and potamon (upper-, middle- and lower course). Each zone is assumed to contain a characteristic fauna. In 1980 a new concept was published (Vannote et al. 1980), known as the River Continuum Concept (RCC). Here a gradual change from source to mouth (from first order to highest order) is assumed, in which one links fluvial, geomorphic processes, physical structure, and the hydraulic cycle to "patterns of community structure and function and organic matter loading, transport, utilization and storage along the length of a river."

Both concepts contain very valuable information and Statzner and Higler (1985, 1986) have recently combined elements from both (Fig. 24). Both publications have been included as Appendices III and IV. They suggest that physical characteristics of flow (stream hydraulics) are the most important environmental factors governing the zonation of stream benthos on a worldwide scale.

In both Figures 23 and 24 no names of organisms have been given. It is impossible to do so for the whole world because of zoogeographic differences. The reference situation must therefore be filled in for a given area. The next step is an analysis of the specific water body to be considered, and where and how it deviates from the reference. For this a hierarchy of environmental factors can be used, not unlike the scheme of Fig. 14.

Streams can flow through lakes, interrrupting the continuum patterns, and this situation is more common currently due to man-made lakes. There are great differences in nutrient content when glacier streams are compared with lowland streams. The composition of the bottom can influence the pH and the nutrient content, as well as the vegetation in the drainage basin.

Some environmental factors are so dominant that no doubt exists about their impact. If a stream dries out during a certain time of the year, this influences the biocommunities in the stream radically. Many species are not able to survive drought, so the biocommunity will be impoverished. The organisms in glacier rivers must adapt to a cold, nutrient poor and turbid water, having its highest discharge in summer. Here, too, species diversity is small.

In general species diversity is lower in situations that deviate from the so-called reference situation. It is not necessary to investigate entire river systems in order to be able to evaluate the situation at a given station, but it is necessary to know how to place the variables

measured at that station into the hypothetical reference stream.
The foregoing considerations are based on numerous papers on zonation, classification, and the relation between abiotic and biotic characteristics in running waters. These references have been listed in Appendix I. Figures 23 and 24 summarized the most universal characteristics of running waters, and Table 1 provides details on the ecological characteristics. The data originate for the greatest part from research in temperate regions.

Appendix V gives a classification of European streams, made in the framework of the European Convention for the protection of international water courses against pollution. It illustrates the sequence of the process and the application of the aforementioned environmental factors. Moreover, biological data have been included.

The first step is the division of Europe (minus Eastern Europe) into five hydrobiological regions, which are a little less differentiated than the zonobiomes of Fig. 2. Figure V 1 gives the map of Europe with the regions. The streams are divided into three main categories, according to the sequence of stream system development with temperature (general level and annual fluctuations) as the principal differentiating factor. In Appendix V, stream hydraulics was a more or less hidden set of parameters about which we had more limited information than we have now. For practical purposes, however, the classification is adequate.

It may be desireable to classify running waters according to potential use, considering only physical and chemical parameters. An example of such a scheme is given in Table 2.

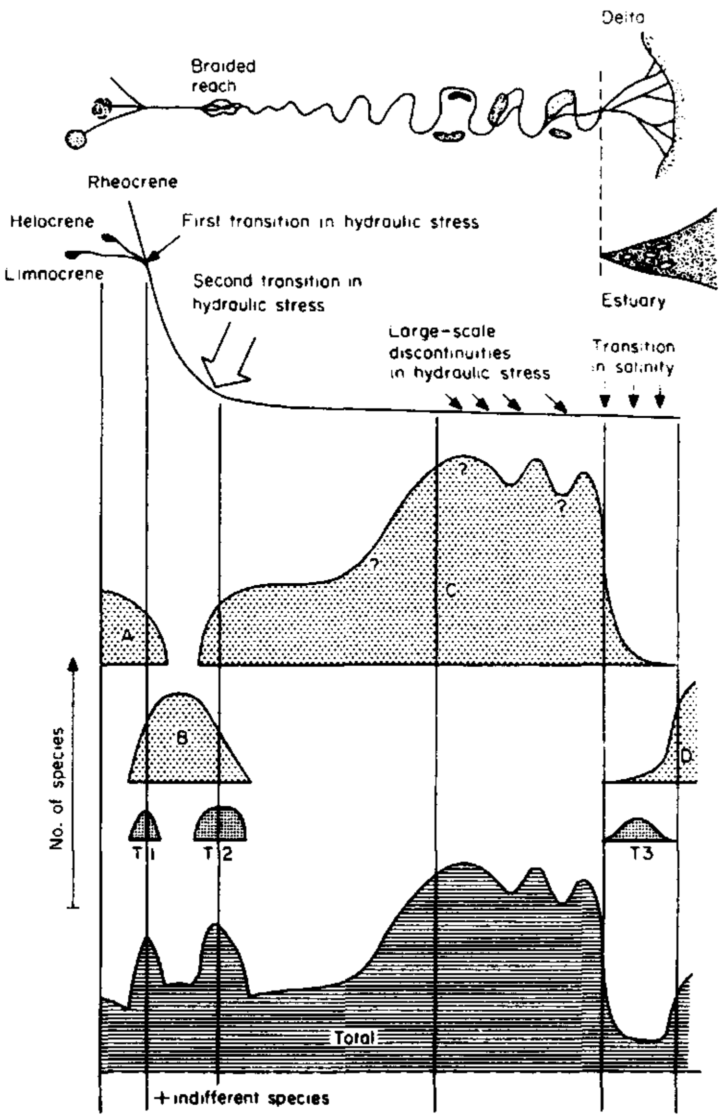


Fig. 24. Proposal for a general faunistic zonation pattern of the benthos in pristine streams (aerial view and slope) with "standard" flow characteristics. Source types:
rheocrene - source discharges directly into a channel
helocrene - source discharges into a marshy pond
limnocrene - source discharges into a pond.
Not all of the components shown here can be or must be present in a stream. The species distribution in a running water that starts with a helocrene and ends with an estuary is indicated in our example. Species occurring in the spring (A) and in the reach of high slope (B) overlap at the first transition in hydraulic stress. Species of group B and species occurring in the stream after it has entered the flood plain (C) overlap at the second transition in hydraulic stress, whereas pristine streams are frequently braided. Patterns in the large river are rather speculative due to sparse information. In the brackish zone, a third overlap is found between species of group C and the marine fauna (D). In all three zones of species overlap, few species occur which are solely found in these reaches of transition (T1, T2, T3). Species which do not characterize a zone are omitted. (Statzner & Higler 1986).

Table 1. Ecological characteristics along the course of runningwaters in Central Europe. This is an example of the statement that generalized concept of running waters has to be filled in according to regional conditions

SOURCE	glacier	$t<7^{\circ}C$: high turbidity in summer: no canopy: very few species.
	hot spring	$t>30^{\circ}C$: high turbidity by sulphur often: no canopy: very few species.
	lake	t depends of origin, so does turbidity: number of species and organisms in accordance with trophic status and origin.
	limnocrene	groundwater of low t follows annual t: clear water: in natural conditions canopy: lentic organisms.
	helocrene	as limnocrene, but t tends to be lower and with lotic organisms.
	rheocrene	t $5\text{-}12^{\circ}$: clear water: in natural conditions under timberline canopy: lotic and specialized organisms.
	seepage area	groundwater of low t follows annual t with smaller amplitude: clear water: generally canopy: species composition comparable to helocrene, but more adapted to semi-permanent conditions. The last four types dependent of slope of terrain.
UPPER COURSE		temperature and turbidity depend of source. P/R<1 (production is generally lower than respiration): allochtonous production from the bank vegetation is here not considered. Sometimes these courses can be temporary. Order 1-3: dimensions small (standard type) or large (lake outlet etc.). slope related to source is an important ecological factor. Canopy results in allochtonous organic matter and shredders dominate. If there is no canopy grazers and predators dominate at high current velocities, but non filtering collectors, grazers and predators at low ones. Fish species like trout and bullhead.
MIDDLE COURSE		extreme temperatures of glacier streams and hot springs tend to stabilize, the others have larger amplitudes than upper courses. P/R~1 or P/R > 1. Order 4-7: dimensions and slope are important ecological factors. High numbers of species (in "modern" streams highest numbers). Primary producers are algae on stones and beginning production of plankton. Invertebrates are filter feeders, collectors, grazers and predators. Fish are grayling/barbel (in temperate streams). Higher nutrient content than in upper course by input from the upstream part of the drainage area.
LOWER COURSE		daily temperatures have been stabilized, annual t follows air t. P/R > 1 or (generally by disturbances) P/R < 1. Under natural conditions many stagnant and periodically overflown waters in the winter-bed can ad to high production. Depth is the most important dimension variable. Sedimentation of sand and silt in the last stretch. Generally high numbers of species in natural conditions by backwaters, pools etc. in modern streams predominantly collectors, under natural conditions all types of functional groups accordig to local variation. High nutrient content: plankton and aquatic macrophytes. Berbel/bream in temperate streams.

Table 2. Classification of running waters according to Hartmann, L. & R. Jourdan (1987).

Class	(A)	(E)	(I)	(O)	(U)
BFQ (m^3/s)	> 1000	500-1000	100-500	10-100	< 10
Factor	<2	2 - 4	4 - 8	8 - 16	> 16
pH	~7	> 6.5 < 7.5	> 6.0 < 8.0	> 5.0 < 9.0	< 5.0 > 9.0
T (^oC)	< 5	5-10	10-15	15-20	> 20
Factor	< 2	2 - 4	4 - 8	8 - 16	> 16
Electric Conductivity (uS/cm)	< 250	250-750	750-2250	2250-4000	> 4000
Oxygen (mg O_2/l)	> 8	6-8	4-6	2-4	< 2
DOC (mg C/l)	1.2-2.1 (1.6)	1.6-3.0 (2.2)	2.2-4.0 (3.0)	3.4-7.2 (4.5)	8.7-10.5 (9.4)
BOD_5 (mg O_2/l)	0.9-1.7 (1.2)	1.5-3.3 (2.3)	2.2-6.8 (3.8)	4.1-9.5 (6.6)	4.9-17.0 (11.2)
PO_4-P (mg/l)	0.03-0.09 (0.06)	0.10-0.48 (0.21)	0.15-0.66 (0.30)	0.47-1.24 (0.78)	1.1-3.0 (2.48)
NH_4-N mg/l	0.06-0.21 (0.10)	0.09-0.29 (0.15)	0.21-0.94 (0.45)	0.55-4.7 (2.2)	2.4-28.0 (19.4)
DOCl (mg Cl/l)	< 0.01	0.01-0.02	0.02-0.04	0.04-0.08	> 0.1
E.coli (nr/100 cm^3)	< 10	10-100	100-500	500-1000	> 1000
P/R	~ 1	> 1 < 1	> 10 < 1/10	> 100 < 1/100	>> 100 << 1/100

Explanation and examples of Table 2

Base flow (BFQ) is a parameter used in water management. Factor (ratio of the minimal or maximal value to the average value) describes the potential for use on an annual basis.

Examples	Class	(A)	Rine, Danube
		(E)	Elbe, Weser
		(I)	Main, Neckar

pH is a measure of the hydrogen ion, which influences biological and chemical processes. For instance, if the potential water use is for fish habitat:

Class (A) / (E)	ideal	: pH 7-8
(U)	lethal	: pH < 4.5 or > 10.8 (carp)
		: pH < 4.5 or > 9.4 (rainbow trout)

Temperature influences the rate of chemical and biological processes. Extreme values are found in arctic and tropical waters, hot springs and heated cooling water.

Electric Conductivity is also used as a measure of salination. As such it is of importance for agricultural purposes (Achtnich 1980).

Classes	Electric Cond. (uS/cm)	Comparable Salt content (mg/l)
(A) For all plant species (drinking water till ± 350 mg salt/l)	< 250	0 - 200
(E) Slightly brackish Not for extremely salt-sensitive plants	250 - 750	200 - 500
(I) Strongly brackish For plants that can endure salt on soils with good permeability. Preferably with additional salt-swab out	750 - 2250	500 - 1500
(O) Very strongly brackish Only for plants with a high salt-tolerance on well drained soils. Reinforced salt-swab out is necessary	2250 - 4000	1500 - 2500
(U) Extremely brackish Only for plants with a very high salt-tolerance on very well drained soil and perfect salt-swab out	> 4000 (-6000)	> 2500

Oxygen, DOC, BOD_5, PO_4, NH_4. These parameters for the assessment of water quality have a certain interrelationship with respect to oxygen management and the load of organic substances.

The classes (A) - (U) represent different water quality classes; the figures in brackets are averages (Source: Ministerium für Ernährung, Landwirtschaft, Umwelt und Forsten Baden-Württemberg. Gütezustand der Gewässer in Baden-Württemberg 4, 1985/86).

Class (A) Very good oxygen supply, low amount of organic load
(I) Good oxygen supply, reasonable amount of organic load
(E) Critical oxygen supply and organic load
(O) Bad oxygen supply and high organic load
(U) Very bad oxygen supply and very high organic load

4 CLASSIFICATION OF STAGNANT WATERS

As long as limnologists have been active, they have made classifications of stagnant waters. Early work was restricted to deep, freshwater lakes in Europe. At a later stage, American and African lakes were studied and occasionally shallow waters and brackish or saline waters as well. As a result, literature on the classification of stagnant waters is based predominantly on studies of European and American lakes. Only recently has more attention been paid to shallow waters, intermittent waters, arctic and tropic waters, and saline waters.

The approach of the early European workers was focused on structural characteristics in lakes, while Americans developed methods to analyse the functional characteristics. Both approaches aim at a classification on the basis of trophic status. As biotic parameters result from a hierarchical set of factors such as geographical region, climate, physical and chemical factors etc. (in a way comparable to Fig. 14), classifications on the basis of abiotic characteristics will be treated first.

4.1 Classification according to origin

A well known classification, based on the origin of lakes, was made by Hutchinson (1957). He states: "It is more convenient to classify according to the general nature of the processes responsible for building, excavation, and damming. Since these processes have acted locally, the resulting classification tends to be regional, certain types of process occurring in certain areas of the earth's surface." In the preceding chapter on running waters the matter of regionality was also discussed. It was shown that it is possible to find general characteristics with regional applicability. The same procedure will be followed with stagnant waters. Hutchinson discerns 76 types of lakes, grouped into the following classes:

- Tectonic basins (9 types)
- Lakes associated with volcanic activity (10 types)
- Lakes formed by landslides (3 types)
- Lakes formed by glacial activity (20 types in 4 subclasses)
- Solution lakes (5 types)
- Lakes due to fluviatile actions (12 types in 3 subclasses)
- Lake basins formed by wind (4 types)
- Lakes associated with shorelines (5 types)
- Lakes formed by organic accumulation (3 types)

- Lakes formed by the complex behaviour of high organisms (3 types)
- Lakes produced by meteorite impact (2 types)

In this classification deep and shallow lakes are treated together within one class or even one type. For practical purposes it is often important to know how deep the water is. All biological processes in water depend on the input of radiation via the chain of primary producers, consumers, and decomposers. The primary production is restricted to the upper layers of the lake, where sufficient energy from sunlight can penetrate. Moreover, temperature conditions in deep lakes show certain patterns (4.3) that influence physical and biological properties in ways that are quite different from the situation in shallow waters. The origin of lakes can also be important for other factors of importance such as chemical composition, but generally it is not sufficient as a sole factor in the classification process.

4.2 Classification according to morphometry

Hutchinson (1957) gives the most important morphometric parameters describing a lake. The best representation is a bathymetric map (Fig. 25), because it gives details about the distribution of shallow areas, about the form (often an indication of the origin) and slope in all parts of the lake.

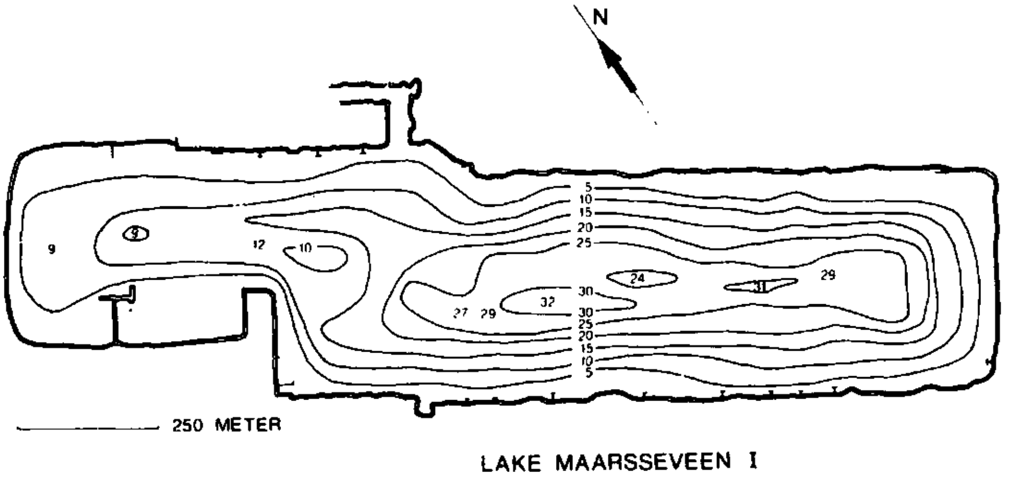


Fig. 25. Bathymetric map of Lake Maarsseveen I (Ringelberg 1981)

Morphometric parameters are:

Maximum depth (Z_m). It can vary in time with variations in water level

Mean depth ($\bar{z}$). The volume of a lake divided by its area (V/A).

Volume (V). It is calculated by an integration over the area at each depth.

Area (A). Determined by planimetry.

Length of the shoreline (L.).

Development of the shoreline (D_L). Ratio of the length of the shoreline to the length of the circumference of a circle of area equal to that of the lake. It is a measure of the potential effect of littoral processes on the lake, area being constant.

$$D_L = \frac{L}{2\sqrt{\pi A}}$$

Ratio $\bar{z}:Z_m$

There are other parameters, but these are the most used. Although they are excellent tools for describing a lake (and preferably a deep lake), they are generally not used in classification.

In The Netherlands the following classification scheme, based on morphometric characteristics, is used.

A <u>Flowing and running waters</u>

sources
brooklets, rivulets
streams and river-basins

B <u>Stagnant waters, originated principally by functional morphometry</u>

ditches, trenches
canals
urban waters in towns and villages
drinking pools
man-made lakes, impoundments

C <u>Stagnant waters, not principally originated by functional morphometry</u>

moorland lakes, mires, seepage lakes
coastal dune lakes
sand/gravel/peat-pits, quarries
alpine lakes
lowland lakes, meres, broads

D <u>Brackish waters</u>

brackish creeks
tidal waters

Although the categories are not consistent in all respects, it is nonetheless useful in practice. The classification is a dichotomal one, merely on the basis of morphometry. The number of possible combinations is very high, which moreover presents a problem of functionality when waters are considered as ecosystems. For instance, the biocommunity in a ditch with occasional flow resembles the biocommunity of a slow running, canalized stream, but both types are treated totally separately; the former in the category of stagnant, man-made, long and shallow waters, the latter in the category of lowland streams. This is only one example of possible problems with classifications based on a single factor that is rigidly applied.

4.3 Classification according to thermal stratification

Since the end of the last century measurements in deep lakes have shown the existence of different layers of water with respect to temperature. In temperate regions the water in a lake in early spring is about 4°C at all depths. Under the influence of radiation the upper water layers are heated and in theory an exponential temperature curve is formed. In practice however, two factors interfere: the upper water layer is cooled by evaporation, causing convection currents; wind mixing causes the downward transport of heat. A very characteristic temperature curve results (Fig. 26) indicating an upper layer (epilimnion), a lower layer (hypolimnion) and a relatively thin layer in between (thermocline or metalimnion).

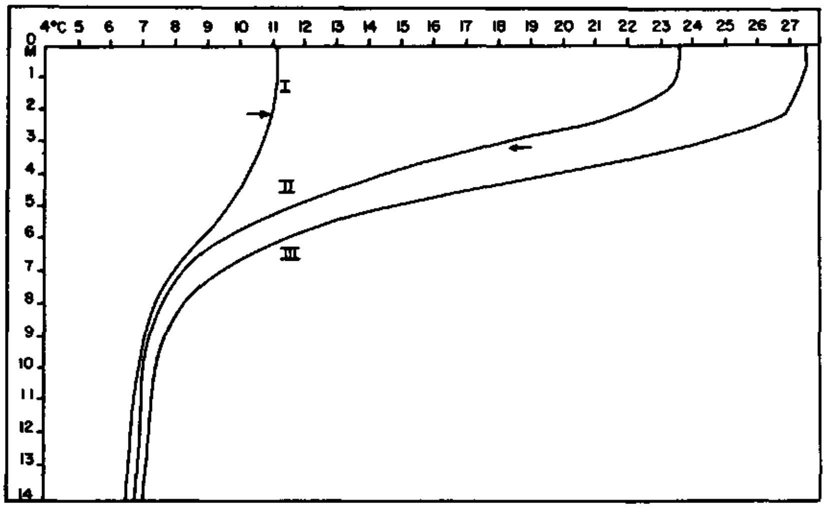


Fig. 26. Temperature curve for April 30 (I) and mean temperature curves for June 1-15 (II) and August 3-17 (III), 1936, Linsley Pond, Connecticut (Hutchinson 1957)

- place of thermocline

In autumn the reverse process is observed, when the upper layers are cooled and the water is mixed again, resulting in a homogeneous temperature condition. Lakes with two circulations a year are called dimictic.

There are conditions where circulation occurs only once a year or not at all (monomictic and amictic). They are usually related to geographical circumstances, but not always (Fig. 27). For the classical studies and a more complete discussion we refer to Hutchinson (1957). Hutchinson and Löffler (1956) devised a lake classification based on mixing patterns, which was revised by Lewis (1983). Two figures from Lewis' publication (Fig. 28 and 29) have been reproduced, and his definitions of the types are also given.

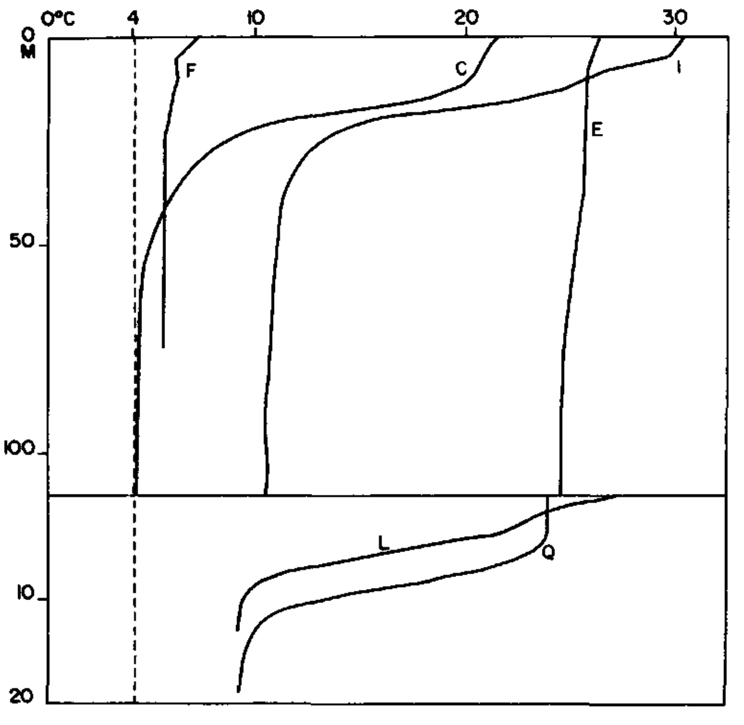


Fig. 27. Temperature curves at the height of summer stratification. Upper panel: F, Flakevatn, Norway, a subpolar dimictic lake: C, Lake Cayuga, New York, a first class temperate dimictic lake: I, Ikedako, Japan, a warm monomictic (subtropical) lake: E, Lake Edward, Uganda, an oligomictic lake (or more or less meromictic). Lower panel: Linsley Pond, and Q, Lake Quassapaug, shallower dimictic lakes of the second class, at about the same latitude as Lake Cayuga; note the identical slope in the metalimnion in spite of the greater area, and the more definite epilimnion in Lake Quassapaug in contrast to Linsley Pont (Hutchinson 1957).

The classification of Lewis is purely dichotomic and selfexplanatory (Fig. 28).

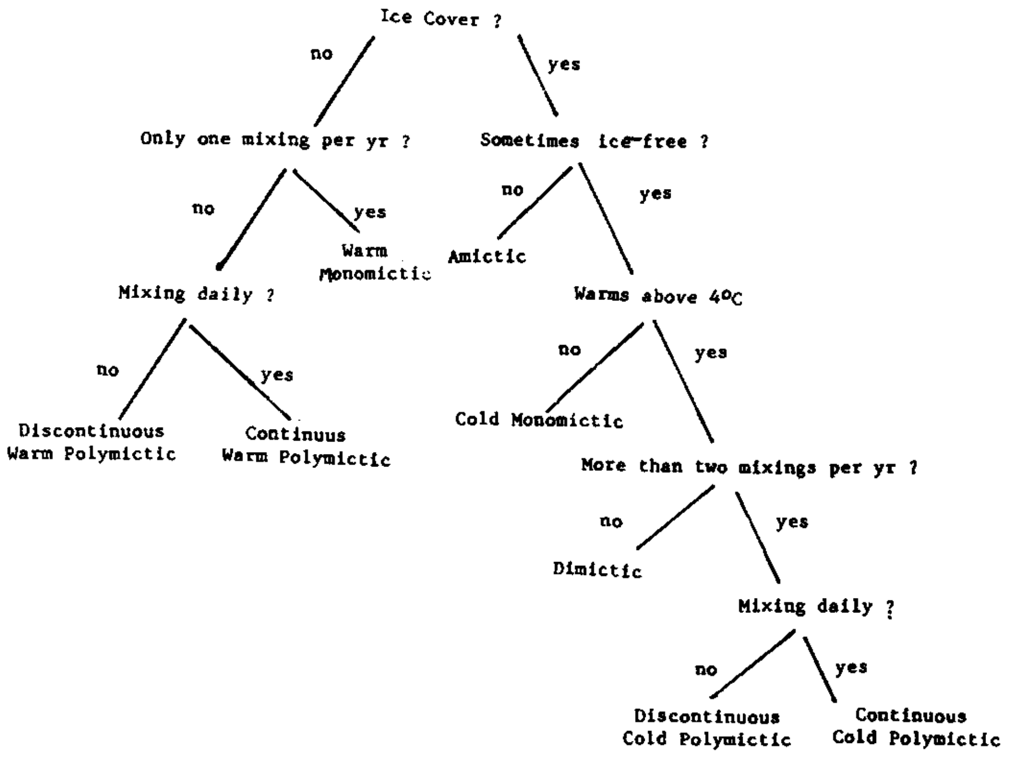


Fig. 28. Classification of lakes based on mixing (Lewis 1983).

Lewis (1983) describes the terms of Fig. 28 as follows:

1. Amictic: always ice-covered
2. Cold Monomictic: ice-covered most of the year, ice-free during the warm season, but not warming above $4^{o}C$
3. Continuous Cold Polymictic: ice-covered part of the year, ice-free above $4^{o}C$ during the warm season, and stratified at most on a daily basis during the warm season
4. Discontinuous Cold Polymictic: ice-covered part of the year, ice-free above $4^{o}C$ and stratified during the warm season for periods of several days to weeks, but with irregular interruption by mixing
5. Dimictic: ice-covered part of the year and stably stratified part of the year with mixing at the transitions between these two states
6. Warm Monomictic: no seasonal icecover, stratified part of the year, and mixing once each year
7. Discontinuous Warm Polymictic: no seasonal icecover stratified for days or weeks at a time, but mixing more than once a year

8. Continuous Warm Polymictic: no seasonal icecover, stratified at most for a few hours at a time.

The distribution of the types is related to the latitude and the elevation. Lewis combined these two factors into the so-called "adjusted latitude" and gives a graphic representation of the distribution of lake types (Fig. 29).

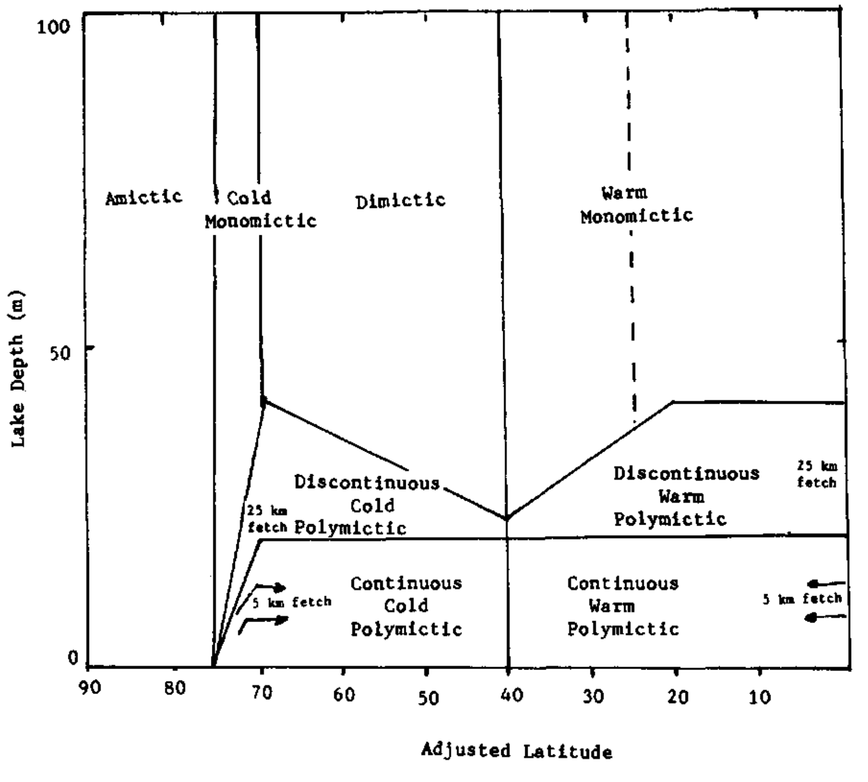


Fig. 29. Estimated distribution of the eight lake types in relation to latitude (adjusted for elevation) and water depth (Lewis 1983).
fetch - distance over which the wind has blown

The existence of stratification and the different modes of mixing lake water can greatly influence biological processes. If the water in the hypolymnion is devoid of oxygen, which is often the case in hypertrophic or polluted lakes, oxygen conditions in the whole waterbody can be very bad after the autumn turnover. This can lead to fish kills. Until recently the existence of stratification was thought to be restricted to deep lakes (> 6-10 m) but Marshall (1981) and Kersting (1983) have also shown steep temperature gradients with daily turnover in very shallow and stagnant waters, such as polder ditches. Mixing then results in unexpected low temperatures and low oxygen content in the waterbody during the morning and early afternoon.

4.4 Classification according to chemical composition

Chemical composition is of great importance as a classifying characteristic. Chemical compounds can have many sources. For instance, acid deposition not only acidifies the water, but also enriches it in many cases. Indirect effects are the mobilization of heavy metals (aluminium in particular) and a whole chain of events in the biocenosis. Another source of chemical compounds is the bottom material, either in the geological sense, or in the the form of deposited material. The latter can be internally formed, and also can be the result of transport from the catchment area by streams or transport over land. The input of inorganic and/or organic substances generally results in eutrophication or pollution. Literature on this pollution is extensive and we will not deal with polluted waters in this report.

As nutrients in the water influence primary production and further levels of the food chain, some other properties of chemical composition can be limiting for many organisms, such that only specialized species can survive. One such category of waters is that of acid and very acid waters (waters with very low or no alkalinity),and another is that with very high concentrations of ions, generally salt or brackish waters. This latter category especially deserves separate treatment, because the salinity dominates all other characteristics of the water bodies.

Saline lakes

The volume of saline lake water (104,000 km^3) is almost as great as the volume of the world's fresh waters (125,000 km^3) (Vallentyne 1972). These saline lakes are frequently the only surface waters in large dry climatic regions. Most saline lakes are small and shallow and may be ephemeral. Some are very large and permanent (Great Salt Lake, USA; Lake Urmia, Turkey, Lake Balkhash, USSR). Large shallow playa lakes (Lake Eyre, Australia) contain water only once in a varying number of years. There are also very deep saline lakes such as the Dead Sea (Israel/Jordan), Issyk Kul (USSR).

The existence of saline lakes depends on the following special conditions:

- evaporation exceeds precipitation;
- endorheic drainage basins;
- availability of soluble salts.

Potential evaporation exceeds precipitation in hyperarid, arid and semiarid regions of the world and also sometimes in subhumid regions.

Arid regions are not good candidates for saline lakes because water tends to be ephemeral on the surface as in the world's great deserts.

Saline lakes occur on every continent and research on them has been carried out since the late nineteenth century. It was established fairly early that species diversity decreased rapidly with increasing salinity. Examination of osmo regulation and ion regulation, mainly by crustaceans and insects, provided evidence that some species merely conformed to environmental salinity above specific concentrations while others maintained fairly stable internal concentrations as the external medium became more saline. The latter group contains members such as Artemia which are successful in extremely saline conditions. Primary production and, to a limited degree, secondary production of many of the salt lake ecosystems were studied. Part of the secondary production studies involved investigations of life cycles of little known saline organisms. Salt lakes cover the whole range of productivity; not all of them are extremely productive as early studies seemed to indicate. Few studies have looked at all trophic levels.

Saline lakes are also called athalassohaline, athalassic or poikilosaline lakes. The term brackish waters should be restricted to waters which are a mixture of seawater and freshwater (also called mixohaline). There is a clear difference between lakes in contact with the sea and real inland saline lakes. The latter can be "brackish" (nearly fresh to very saline) and generally the salt concentration shows great varability. The ion proportions of saline lakes are sometimes very different from those in seawater. Be it possible to indicate exactly which saline lakes are in real inland lakes, the salinity limit for the division with fresh waters is a place somewhere on a continuum. In table 3 this division is shown in the different systems that are used.

Classification of saline lakes. The response of organisms in saline waters has been related to salt concentration as a driving force for osmo regulation. The main classifications therefore are based on salinity concentrations as summarized in Table 3.

Hutchinson (1957) classified inland saline waters into three "extreme types based on the prevalent anion, and therefore termed carbonate, sulfate and chloride waters". He also pointed out that "all possible intermediate mixtures exist". Williams (1964) suggested the use of total dissolved matter and Talling & Talling (1965) used the electric conductivity. Iltis (1974) characterized the alkaline saline waters of Chad as oligo-, meso-, poly- and eucarbonate waters.

Some classifications on the basis of biota have been proposed. Ziemann (1968) developed a halobic index using diatom flora. Hussainy (1969) applied several diversity indices to zooplankton communities, but this method did not prove to be satisfactory in other lakes. Also macrophytes have been used, but the problem with these classifications is that they generally are site-specific and have no worldwide applicability. Moreover, the salinity tolerance differs considerably for the same species in different circumstances and the organisms do not fit in the rigid categories of chemical divisions. The dominating role of ion concentration justifies a classification on this basis. Hammer (1986) concluded (p. 15): "Athalassic saline waters are defined as those having salinities equal to or greater than 3 g l^{-1} salinity. Freshwater lakes have 500 or less milligrams per litre dissolved salts. Subsaline lakes are those which range from 0.5 to 3 g l^{-1} S. The saline lakes are categorized in three major groups according to salinity. These are hyposaline (3-20 g l^{-1}), mesosaline (20-50 g l^{-1}) and hypersaline (equal or greater than 50 g l^{-1}). Extreme hypersalinity may also be a justifiable category but its specific salinity is difficult to specify. Although biota overlap the borders of these categories, many species tend to be abundant in one or more of them. Some species can tolerate a broad range of salinities (are eurysaline) while other species occupy relatively narrow ranges and are, therefore, stenohaline and may more easily fit to a specific salinity category."

Hammer (1986) also proposed a model (Fig. 30) for the relationship between the number of species (algae, crustaceans, insects etc.) and salinity. In the right part of the figure (B) the model proposed by Remane (1934) for the transition from freshwater to brackish to marine water is depicted. It is obvious that the left part of the figure (A), indicating the circumstances in athalassic waters, is in distinct contrast with Remane's model. In this way the biological difference between the two types of saline waters is clearly demonstrated.

Table 3. Classification systems with respect to salinity of saline waters with emphasis on athalassic lakes (Hammer 1986).

System	Categories (in order of increasing salinity, g l⁻¹)
Rédeke 1926	oligohaline; 1 g l⁻¹ Cl; mesohaline; 10 g l⁻¹ Cl; polyhaline
Kolbe-Budde 1927, 1931	oligohalobien; 2 g l⁻¹ Cl; mesohalobien; 6 g l⁻¹ Cl; mesohalobien; 20 g l⁻¹ Cl; euhalobien; 50 g l⁻¹ Cl; polyhalobien; 80 g l⁻¹ Cl
Redeke-Valikangas 1933	0.5 fresh water; oligohaline; α-mesohaline; 8.0; β-mesohaline; 16.5; polyhaline; 30; sea water
Venice System 1959	fresh water; oligohaline; mesohaline; polyhaline; euhaline; hyperhaline
Gisiescu 1963	fresh water; 1.0; saline (lacuri salmastre); 25; salt lakes (lacuri sărate)
Beadle 1943a, Hammer 1978, Hammer *et al.* 1983	fresh water; subsaline; hyposaline; 20; mesosaline; 50; hypersaline
Williams 1964, 1968, 1981b	fresh water fauna; 3.0; salt tolerant fresh water fauna; halobiont fauna
	fresh water; saline; halo-philic fauna; 60
Fan 1981	fresh water; 1.0; salt lakes; 35; saline lakes

SALINITY (g l⁻¹)

brackish water

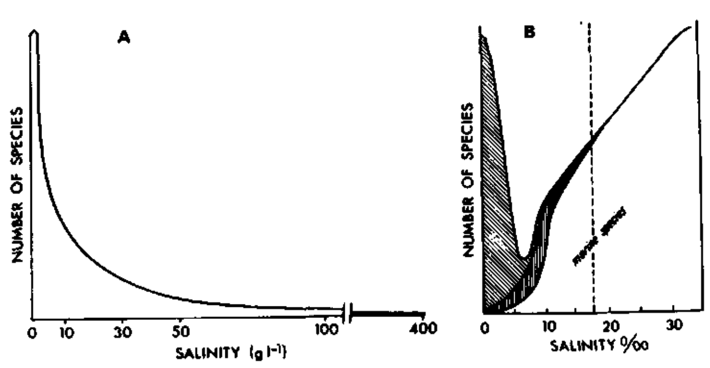


Fig. 30. The number of species in relation to aquatic salinity. A: Athalassic waters from fresh to hypersaline. B: Fresh to brackish to marine waters (Hammer 1986).

The division in deep, shallow, and very shallow stagnant waters (Table 6) is based on freshwater systems. The classification of saline waters can be treated separately, as long as it is clear that saline waters are considered. There is a transition zone between a few hundred mg $Cl^{-}l^{-1}$ and 3 $g.l^{-1}$ salinity. Salinity in this context is (according to Hutchinson 1957) "the concentration of all the ionic constituents present". It is recommended that Hammer's proposal of 3 $g.l^{-1}$ followed and that all stagnant waters with lower concentrations be considered to be fresh waters, that can be divided according to Table 6.

References
All information in this section is derived from Hammer (1986). His book gives appendices with numerous data. In Appendix VII of this report these have been copied to present a complete overview of data on saline waters in the world.

Acid waters
Pure water, in equilibrium with CO_2 from the atmosphere, has a pH of 5.6. Rainwater, therefore, must have a pH of 5.6 (if not polluted). Under natural conditions nitrogen oxides occur in small quantities in the atmosphere, so the pH of rainwater is slightly lower (5.5). Contributions from the natural sulphur cycle (Charlson & Rohde 1983) can further reduce the average pH to 5. This starting position can be influenced by pollution, as seems to be the case in large areas of the world. In surface waters, many of which are fed predominantly by naturally acid precipitation, the pH is directly related to the acid-neutralizing capacity or alkalinity of the water. The equilibrium:
$$2\,H^+ + CO_3^{2-} \rightleftharpoons H^+ + HCO_3^- \rightleftharpoons CO_2 + H_2O$$
is most important describing the distribution of biologically important ions over the pH range (Fig. 31).

Only a few species of aquatic plants can utilize free CO_2 (if $CaCO_3$ is present in the bottom). In this way, the absence of carbonate ions restricts the presence of aquatic vegetation.

The fauna in acid waters is strongly influenced by the pH, because physiological processes are related to acidity. To understand this we refer to the scheme Havas (1981) developed for freshwater organisms in acid water (Fig. 32).

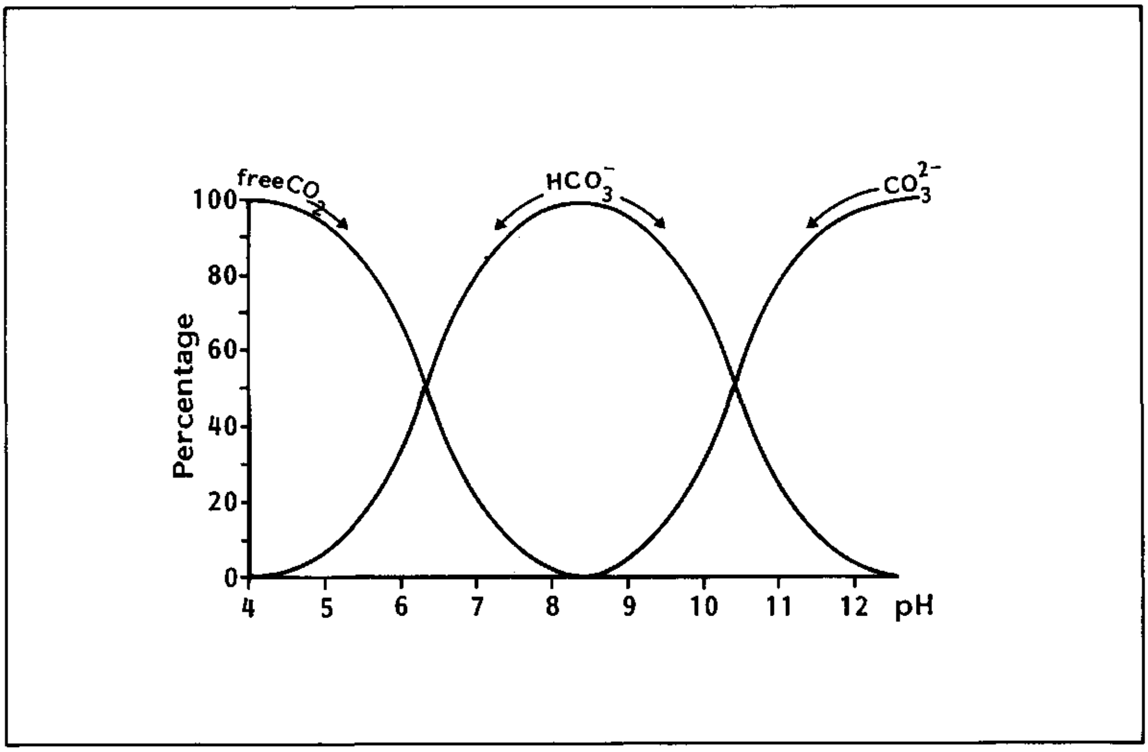


Fig. 31. Carbonate-bicarbonate equilibrium (Ringelberg 1976).

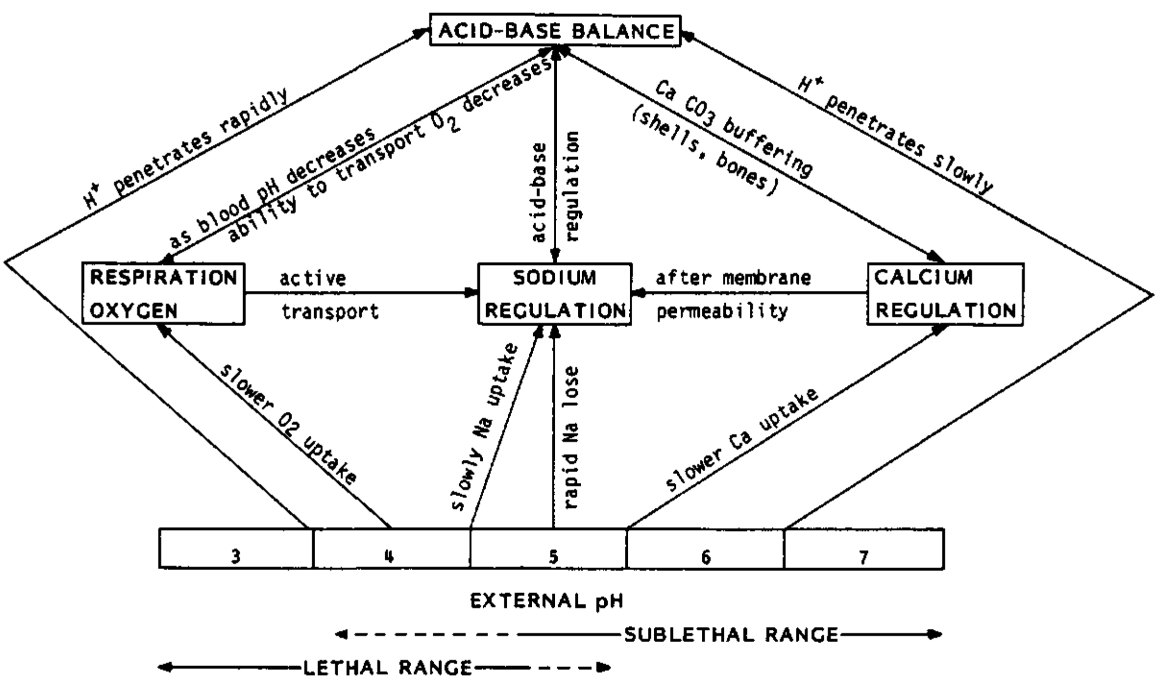


Fig. 32. The most important physiological responses of freshwater animals to a low pH (Havas 1981).

The calcium regulation is the first process (when pH is lowered) influencing animals such as snails, leeches that eat snails, and larger crustaceans. At pH 5.5 or lower representatives of these groups are not found. Some fish species are found in acid waters, but below pH 4.5 to 5 only adapted species occur. In the same way organisms from other groups can be found in decreasing numbers of species as pH is reduced and only specialized species survive in water with pH 4.5 or lower.

Unlike salinity, pH is not a factor requiring a separate classification on its basis, but it is one of the most important factors to be measured to evaluate the water environment for animals and plants (and subsequently for man).

4.5 Classification according to trophic status

Classification according to trophic status is a classic battleground for limnologists. From the beginning of limnological science, there have been attempts to define trophy in many ways and numerous systems have been constructed. Trophic status depends on the availability of the nutrients for primary producers. In this context one could consider trophic status as a chemical as well as biological matter. In general, the biological approach has been adopted. The most important nutrients are phosphate, nitrate and carbon. Elements like silicium, calcium, iron and some others are also indispensable for the growth of aquatic organisms. If one of these chemical compounds is missing or present in low concentrations, the growth of certain organims is hampered (limiting factors).

In essence, one distinguishes between low-productive (oligotrophic) and high-productive (eutrophic) lakes. Over the years more classes have been introduced such as mesotrophic, distrophic, hypertrophic etc. The terminology and general approach were developed primarily by Naumann and Thienemann early in this century. Naumann's was the most fundamental approach, connecting chemical properties and biological characteristics. Naumann (1931) stated that six factors play a dominant role in biological production (Ca, N, P, Fe, humic acids and suspended clay). Each of these factors acts along a transect from low to high influence, called oligo-, meso- and polytypic. No further quantification is given. Naumann studied shallow waters and the epilimnion of deep waters and in his opinion the system was applicable to many waters all over the world.

Table 4. Biological characteristics of various lake types after Naumann (1931).

Type	Ca	N and P	Fe	Humic acids	Suspended clay	pH
Alkalitrophic	polytypic	oligotypic	oligotypic	oligotypic	oligo- to mesotypic	8
Argillotrophic	oligo- to polytypic	oligo- to polytypic	?	oligo- to polytypic	polytypic	7
Eutrophic	oligo- to polytypic	meso- to polytypic	oligotypic	oligo-meso-typic	oligo- to mesotypic	7
Oligotrophic in a strict sense	oligotypic	oligotypic	oligotypic	oligo-meso-typic	oligo- to mesotypic	7
Acidotrophic	oligotypic	oligotypic	oligotypic	oligo-meso-typic	oligo- to mesotypic	7
Dystrophic	oligotypic	oligotypic	meso- to polytypic	meso- to polytypic	oligo- to mesotypic	7
Siderotrophic	oligotypic	oligotypic	meso- to polytypic	oligo- to polytypic	oligo- to mesotypic	7

In Table 4 the lake types are characterized by water colour, phytoplankton, higher plants and bottom deposits. Naumann stressed the direct relationship between nutrients and primary producers, unlike Thienemann and his pupils, who neglected this relationship.

Thienemann (1925) developed a system based primarily on the presence or absence of certain species of Chironomidae in the bottom sediments of deep lakes. This means that he restricted his classification to deeper lakes (temperate region) and that he based it on hypolimnion characteristics. He found a relationship between the depth of a lake, the temperature curve and the oxygen content in the hypolimnion, and the species of chironomids (Table 5).

Table 5. Lake types according to Thienemann (1925) modified

	Oligotrophic	Eutrophic	Dystrophic
Distribution	alpine and foot hills	Baltic lowlands and alps	mostly Scandinavia
Morphology	deep, narrow littoral	shallow, broad littoral	variable
Hypolimnion/Epilimnion	hypolimnion large	hypolimnion small	—
Water colour	blue-green	brown-green, green-yellow	yellow-brown
Transparency	great	small-very small	small
Water chemistry	poor in N and P humic material absent Ca variable	rich in N and P humic material slight Ca usually high	poor in N and P humic substances abundant Ca low
Suspended detritus	minimal	rich, planktogenic	rich, allochthonous
Deepest mud	non-saprobic	saprobic (gyttja)	peaty (dy)
O_2 in summer	60–70% minimum decrease even with depth	0–40% minimum decrease sharp in metalimnion	0–?% minimum decrease sharp in metalimnion
O_2 under ice	as above	shallow—as above deep—as oligotrophic	strongly depleted in deeper parts
Littoral plant production	low	rich	low
Plankton	low quantity, present at all depths, large diurnal migration, seldom blooms	large quantity, small diurnal migration often blooms	low quantity, rarely blooms
Benthos	diverse, *Tanytarsus* fauna, no *Chaoborus* 300–1000 animals/m² 1–4 g dry weight/m²	restricted, *Chironomus* fauna, *Chaoborus* usually present 2000–10 000/m² 100 g dry weight/m²	very restricted, *Chironomus* (no *C. anthracinus*) or none, *Chaoborus* probably always present 10–20/m² or none
Distribution with depth	constant	decreasing	
Further succession	to eutrophy	to pond or meadow	to peat-moor

Many authors have followed Thienemann in devising new systems or commenting on existing systems always using Chironomidae and occasionally including other benthic organisms (Alm 1922; Miyada 1933; Valle 1927). Valle was the first to introduce the term mesotrophic, which has been generally accepted and used. Brinkhurst (1974) gives an extensive overview of trophic systems, emphasizing those of Thienemann and his pupils (Alsterberg 1930; Berg 1938; Berg & Petersen 1956; Brundin 1942, 1949, 1956; Decksbach 1929; Deevey 1941; Järnefelt 1925, 1953; Lang 1931; Lastockin 1931; Lenz 1925, 1928ab, 1933; Lundbeck 1926, 1936; Pagast 1943; Pearsall 1921; Pesta 1929; Stahl 1959, 1966; Steinböck 1953, 1958; Thienemann 1913, 1918, 1931, 1954).

The use of chironomids undoubtedly was initiated by Thienemann and his school, but the taxonomy of the larvae was badly developed. Moreover, in some cases other benthic organisms were more dominant. This is one of the points of criticism Stahl (1966) has put forward against these classifications. Other points were that factors other than oxygen supply may limit the chironomid fauna (e.g. the nature of the sediment) and that the systems are heavily oriented to the Palaearctic fauna. Hilsenhoff & Narf (1968) found no real statistical correlations between the occurrence of chironomid and other benthic species and the chemical and physical characteristics of the system. Brinkhurst and collaborators have tried to correlate oligochaetes and lake types. Problems that may arise are the intralacustrine variations and the failure to relate the species to lake types. The relative abundance of worm species, however, and the degree of dominance of worms over other benthos turned out to be a useful tool. An important conclusion (Brinkhurst 1974: p. 29) is : "More precise sampling soon shows that species lists can usually be lengthened by both extensive and intensive sampling, but the proportional representation of worm species so revealed suggests the same story: the species found at a given spot in quick surveys are those that prove to be the most abundant at that site when proper samples are taken. Both in the saprobic system and the lake typology, sampling must be carried out very carefully in order to establish relative abundance of species rather than lengthy species lists."

Despite these criticisms many authors still use the systems of Thienemann (and Naumann) (Dambska 1984) or keep on trying to prove the use of chironomids for lake classification. Saether (1975, 1979) and Wiederholm (1980) improved Brundin's classification and Kansanen, Aho and Paasivirta (1984) tested this classification with multivariate statistical methods. They found that the availability of food is the primary controlling mechanism in the profundal chironomid communities and that at a depth of 3-5 m the controlling mechanisms are related to water quality and trophic status. The problem stipulated here concerning differences between the deep parts of lakes and the shallow littoral zone leads to one of their conclusions: "A need to produce a benthic lake typology based on sublittoral or littoral fauna is apparent from the practical point of view". Finally, with respect to chironomids, Åagaard (1986) studied 50 lakes in northern Norway and he gave the interrelationships of the chironomid communities and lake water parameters. The best correlation was found with organic parameters (chlorophyll a and P_{total} divided by the depth). Other abiotic and hydrographic parameters turned out to be of less value. This agrees with the results of studies from Saether (1979) and Wiederholm (1980). Åagaard concludes: "In relation to several other possible methods of monitoring trophic levels, the chironomid community classsification method represents an inexpensive and fairly reliable solution."

INTERMEZZO

While reviewing the literature on the classification of stagnant waters, it became clear to this author that a tripartite of stagnant waters would usually facilitate the approach to any water body. In practice scientists studying lakes generally refer to deep waters, they have their own methods and terminology, and they develop theories and hypotheses that are not applicable to shallow waters. On the other hand very shallow waters (or wetlands) have their own problems, quite different from those in lakes and students in this field of limnology form a separate world in comparison to the others. For this reason the tripartite of Table 6 was proposed at the 23rd meeting of the SIL in New Zealand, February 1987.

The reactions were very positive. People asked for preprints for their seminars and even for insertion in a handbook on limnology. One reaction was focused on the matter of brackish and saline waters (the reason for inserting the chapter on Saline Lakes). In the year following the construction of Table 6, many other publications have supported the value of a tripartite approach to stagnant water classification. The table is self-explanatory. The depth as criterion must be handled with some care; other characteristics may be more important in determining the category. A lake with a depth of 8 m deep, for example, that is protected against the wind, can exhibit all characteristics of a deep lake. The boundary depth of 10 m is obviously not valuable in that case. A very shallow ditch in The Netherlands (50 cm) can keep water during the summer and an African lake of 150 cm of depth can dry up totally. For this reason, the lower boundary between very shallow and shallow is somewhere between 1 and 2 m.

END OF INTERMEZZO

Table 6. Ecological characteristics of stagnant waters. The example is predominantly based on data from the temperate region.

DEEP (> 10 m)	Large water volume with minor impact of level fluctuations. Diurnal variations in temperature and oxygen content are small: (bi-)yearly circulation (sometimes one or none); stratification. Plankton in epilimnion: submerged and emergent macrophytes in littoral. Diptera larvae, Oligochaeta and Mollusca in hypolimnion: low diversity. Diversity in epilimnion (littoral included) generally high.
SHALLOW (10-1 m)	Water level fluctuations can be considerable in relation to volume. Diurnal and annual variations in temperature and oxygen content can be considerable. In deeper waters of this category real plankton; if shallow tychoplankton. Emergent macrophytes along the shore, submerged ones towards the centre. Diversity very high.
VERY SHALLOW (<1-2 m)	Water level fluctuations large (until drying up); in arctic zones this category can be completely frozen for months. Diurnal and annual variations in temperature and oxygen content high. Concentration of minerals etc. by evaporation; salination; the system is fundamentally changed when dried up. Emergent vegetation (sometimes covering the entire water body) and submerged vegetation: ingrowth of terrestrial and shore vegetation. Tychoplankton, epiphyton and filamentous algae. Organisms of shallow water and ephemeral water: also (semi-) terrestrial. Diversity low in extreme conditions, high in permanent pools where the conditions resemble those of shallow waters.

Table 4 shows Naumann's approach to lake typology which incorporates primary producers (phytoplankton and higher plants). This line of research has variably been followed, amended, improved or rejected. Phytoplankton has been used in a qualitative and a quantitative way, as net production, as chlorophyll a, as biomass and as a trophic index. Kuznetsov (1970) after giving a short historical view of classification systems, states: "A comprehensive classification of lakes is impossible because of their great variety in nature and the abundance of factors that can serve as the main identification. In our view, the problem can be solved by using certain gross features, and here we return to the classification of Thienemann-Naumann. Indeed the terms oligotrophic, mesotrophic, eutrophic, and dystrophic provide a fairly accurate general picture of a lake."

A frequent criticism of Naumann's approach is that he considered the biomass (standing crop) of the phytoplankton as directly related to the primary production of organic material. One must therefore talk about the biomass per time unit. The direct measurement of primary production, however, (Elster (1958), for example) meets enormous practical problems. Moreover, the actual production may not reflect the possible production (Ruttner 1952). Rohde (1958) proposed that an internationally accepted choice be made between the use of production or the production possibilities for a description of trophy. He proposed to use the rate of primary production and to abandon all trophic lake types except oligotrophic and eutropic noting that "Other characteristics of lakes (such as their chemical and physical conditions, morphometry, secondary production, as well as qualitative characters) may conveniently be compared and defined for various lakes, if plotted against the trophic axis as abscissa."

Here again one of the leading scientists returns to the original approach. One remark is necessary in this respect; when lakes are concerned one talks about deep lakes in general and about shallow lakes (Table 6) only when they are deep and large enough. Elster (1958) points to the necessity for measuring the primary production of the littoral as well, in order to be able to estimate the trophic status of the complete lake. Here again we find the division into deep and shallow, as was remarked in the discussion of chironomids. Nygaard (1958) gives an example of the productivity measurement of the bottom vegetation and Canfield et al. (1983) stress the necessity to include figures about the phosphate content of macrophytes in the littoral for estimation of the total P content in a lake.

Finally it is worthwhile to draw attention to Ohle (1958) who pleads for a quite different approach, namely bio-activity, which is the sum of kinetic energy converted to potential energy (and vice versa) per unit time and water volume or water surface area. He distinguishes oligo- and eudynamic water. Fig. 33 shows four types of lakes, where a and b are oligodynamic and c and d eudynamic. This method seems rather complicated for practical use, but fundamentally looks quite promising.

Trophic status is related to quantities of nutrients, so it seems logical to use quantitative parameters such as biomass, production, productivity etc. A qualitative approach may be used as well, because many organisms have been recognized as indicators of trophic status. Examples include applications using chironomids and oligochaetes. Despite a lot of criticism, people keep trying to make classifications with the help of species lists and/or trophic indices. Generally these are only applicable in a certain geographical area, particularly when secondary producers are used. Phytoplankton and to a lesser extent higher plants have been used with some success, especially since phytoplankton species tend to be more ubiquitous than most other aquatic organisms.

Nygaard (1949) counted the species of some phytoplankton groups and formulated his trophic quotient as the number of species of Cyanophyceae, Chlorococcales, centric diatoms and Euglenophyceae, divided by Desmidiaceae.

Pearsall & Pearsall (1925) have laid the basis for this approach and like Nygaard others have developed similar indices (Thunmark (1945) only used Chlorococcales and Desmidiaceae). Regionally-specific different quotients have also been developed. In The Netherlands some limnologists made new ones (Schroevers 1966; For Dresscher & van der Mark 1976).
Round (1958) is in favor of indicator organisms and he lists some phytoplankton species in North English lakes. Margalef (1958) combines indicator species in a phyto-sociological way, using plankton species from North Spanish waters. Hörnström (1981) as well as Rosén (1981) give extensive lists of phytoplankton species, together with well defined abiotic characteristics, thus describing the status of a water within clearcut limits with the help of these lists.

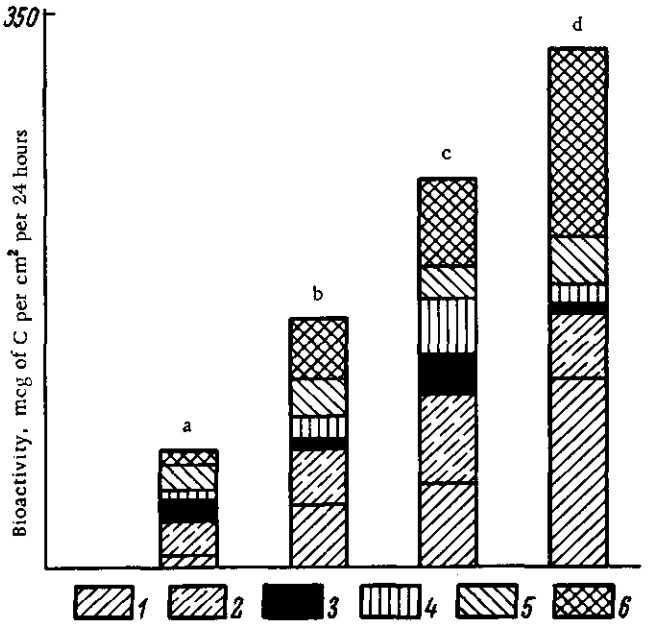


Fig. 33. Relationships between the different elements of the production process characterizing the bioactivity (after Ohle):
1) total production: 2) net production: 3) organic matter buried in sediments: 4) decay of organic matter in the sediments: 5) decomposition in the hypolimnion: 6) decomposition in the epilimnion: a) arctic lakes: b) alpine lakes; c) lakes of the temperate zone: d) tropical lakes. (Kuznetsov 1970).

The idea of associations of indicator organisms, characteristic of certain water types, is recognized in Reynolds' (1984) approach which includes the periodicity of phytoplankton in lakes of different trophic status (Fig. 34). This example is based on temperate lakes, but similar events also take place in African lakes. Talling (1984) relates phytoplankton seasonality in deeper tropical lakes to seasonal changes in thermal (density) stratification, which is often strongly influenced by the wind regime. In shallow tropical lakes without stratification, algal seasonality is either influenced by the hydrological regime or does not exist at all. Rott (1984) has followed the same procedure as Reynolds and finds a comparable scheme (Fig. 35). Two of his conclusions are: "phytoplankton assemblages follow some general patterns which are determined in quality and quantity by the trophic status" and "phytoplankton biovolume is at least as valuable a component of lake eutrophication studies as chlorophyll-a".

It seems that at least in deeper waters, promising progress is made with the use of phytoplankton for trophic or classification studies. In shallow waters in temperate regions periodicity has been observed, but it has not yet been as elegantly described as in Figs 34 and 35.

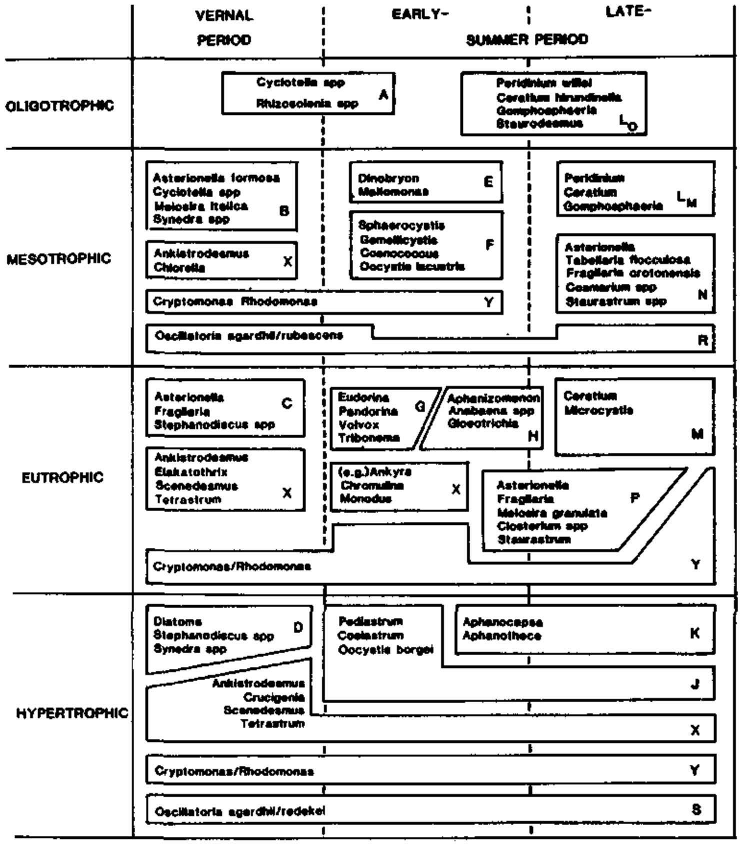


Fig. 34. Assemblages of temperate phytoplankton (A-S, X, Y) and some representative species, one or more of which grow well in the type of lake and during the approximate seasons of the year as indicated (Reynolds 1984).

4.6 Classification according to flora and fauna

In the preceding pages water classifications were occasionally based on organisms, and in most cases closely related to trophy. In general these systems are applied to deep waters. Shallow and very shallow stagnant waters have received less attention.

There are many organisms, plants as well as animals, about which the ecological requirements are well known, including the type of water they prefer. The problem, as mentioned before, is the restricted distribution of most of these organisms. Therefore, classifications on the basis of triclads (Reynoldson (1958), water boatmen (Savage 1982) or even ducks (Murphy et al. 1984) are restricted to regional conditions. The same can be said about fish (Tonn et al. 1983; Johnson et al. 1977), crustacean plankton communities (Patalas 1971) and diving beetle communities (Larson 1985). The latter includes small and shallow waters, as well as running waters, and seems to be applicable for general ecological classification purposes (Fig. 36). Schleuter (1985) studied small water bodies in a very restricted area. It is, however, one of the few examples where small water bodies are classified with the help of macro invertebrates.

Plant sociologists have a long tradition of classifying associations of plants, but they seldom classify water bodies on the basis of plant associations. The work of Haslam (1982) and Weber-Oldecop (1981) is certainly useful in this respect. Classifications utilizing aquatic macrophytes have been made predominantly in Northern Europe and generally on the basis of investigations of a great number of lakes (Iversen (1929) and Mathiesen (1969) in Denmark, Linkola (1916), Cedercreutz (1947), Maristo (1941) and Rintaanen (1981) in Finland, Braarud (1932), Braarud & Aalen (1938), Reiersen (1942) and Hauge (1957) in Norway, Blomgren & Naumann (1925), Samuelsson (1925), Almquist (1929), Lohammar (1938), Lundh (1951 a & b) and Jensén (1979) in Sweden, Grigelis (1985) in Lithuania and Donat (1926) and Sauer (1937) in Germany).

In general, these classifications take other characteristics of lakes such as trophic state, into account as well.

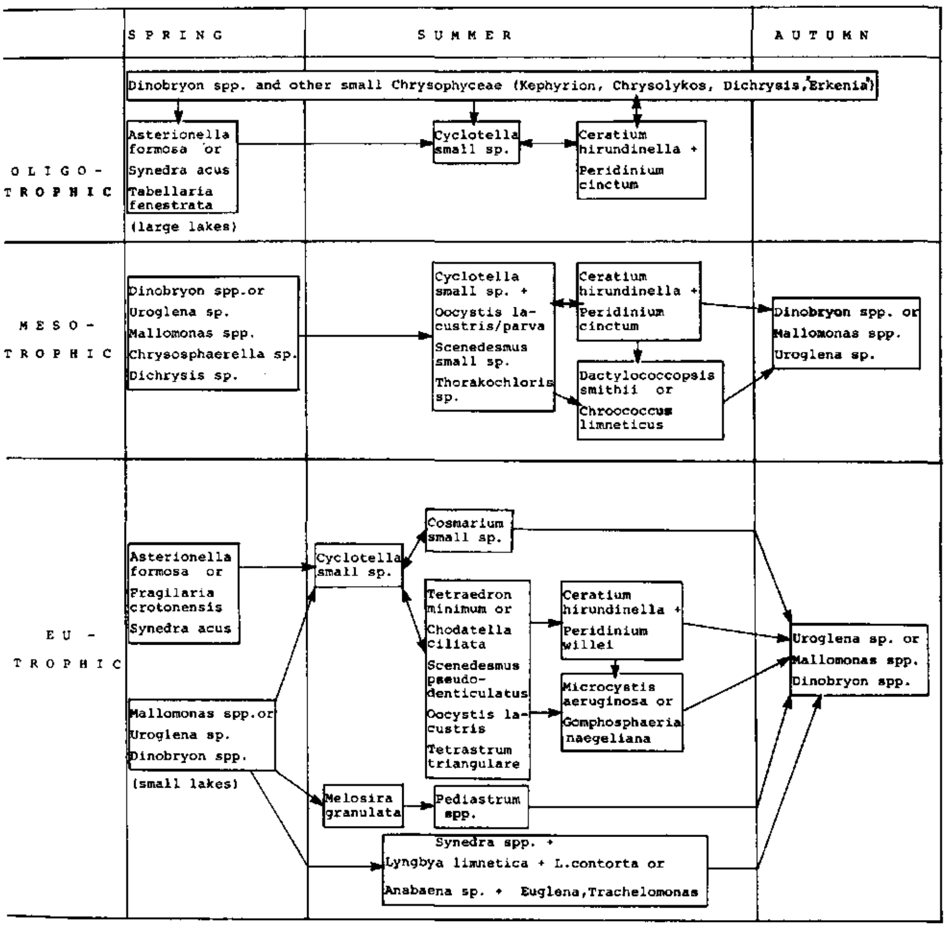


Fig. 35. General successional trends of phytoplankton assemblages in Tyrolean lakes of different trophic status (low- and mid-altitude (Rott 1984)).

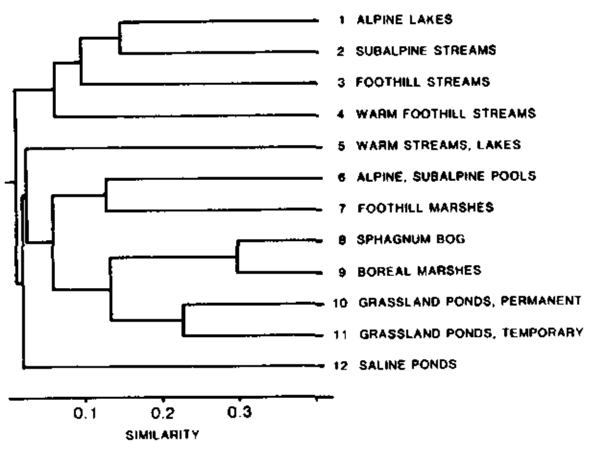


Fig. 36. Simplified cluster analysis of Alberta dytiscid beetle collection sites based on similarity in species occurence (Larson 1985).

Entire lakes can be classified using these methods, but there are also examples of different vegetation types within one lake. They are considered as a complex of types, occurring in the same basin (Jensén 1979). This internal variation can, for example, be caused by the occurrence of an inlet and an outflow. Some authors include these as different types, others ignore the vegetation at the lake ends and only consider the lake as a whole. Jensén (1978) gives a good overview of the literature and he advises classifying lakes on the basis of three life-forms. He distinguishes helophytes, nymphaeids and a life-form group elodids/lemnids/isoetids as the true macrophyte composition of a given lake. Methods like this one can also be used to classify shallow and very shallow waters.

Temporary waters

Lamoot (1977) made a classification of intermittent waters in the savannahs of the Lamto region in Ivory Coast. His classification is based on macrophytes and the heleoplankton. The pools are very shallow and dry out during the dry season. Although the area is small, the results can probably be used for more parts of Africa.

Intermittent pools are an important type of very shallow waters and they are to be found in large areas of the world. Wiggins, Mackay and Smith (1980) studied temporary pools in Ontario and they reviewed an enormous amount of literature on the subject, with emphasis on life strategies of organisms. The following summary provides a detailed picture of one class of waters.

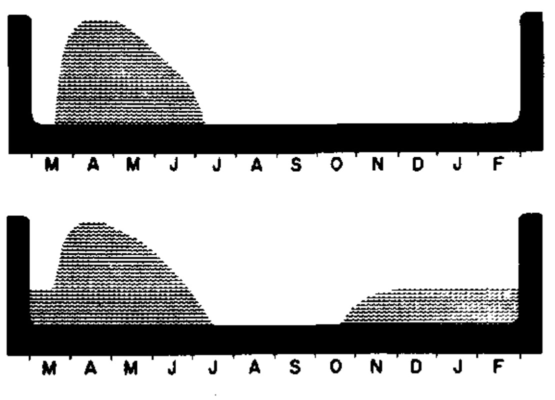


Fig. 37. Distinction between temporary vernal pool (upper figure) and temporary autumnal pool (lower figure); letters indicate months, vertical scale indicates depth of water (Wiggins, Mackay & Smith 1980).

In temperate latitudes one finds two types of temporary pools, vernal and autumnal (Fig. 37).

Classifications of temporary waters have been previously made on the basis of physico-chemical factors, but in the authors' opinion the dry period is of greater importance. They give a number of factors that have to be considered: - length of the dry/wet period; - canopy; - vegetation in the pool; - ion concentrations; - temperature

Generally the concentration of inorganic ions is comparable to that of non-temporary freshwater pools (in temperate regions!), but sometimes it is very high. Nutrients can reach the pool by run-off and they are adsorbed frequently to particles. The nutrients are used by plants in the dry period and may be released in the wet period when terrestrial plants die. Canopy provides dead leaves and is therefore an important source of organic material.

Life strategies of organisms in temporary pools can be of four types:

1. Permanent residents capable of only passive dispersal. Some of them aestivate and overwinter as stages resistent to desiccation (certain Turbellaria, Bryozoa, Anostraca, Cladocera, Copepoda and Ostracoda) or they periodically live in the bottom during dry periods (Oligochaeta, Hirudinoidea, Decapoda, and Mollusca).
2. Animals capable of some dispersal (certain Ephemeroptera, Coleoptera, Trichoptera, Diptera together with parasitic mites). Oviposition takes place in spring on water; aestivation and overwintering is in the dry basin in various stages of the life cycle.
3. Animals that enter the pool basin after surface water has disappeared, because oviposition is independent of water; eggs or larvae overwinter (certain Odonata, Trichoptera and Diptera)
4. Animals with well-developed powers of dispersal that leave the disappearing pool and usually pass the dry phase in permanent water. They return to oviposit in the temporary pool in the following spring (certain Ephemeroptera, Odonata, Hemiptera, Coleoptera, Diptera, Amphibia, and mite parasites of Hemiptera and Coleoptera).

The authors state that "This group concept allows distinction to be made among the varied ecological strategies for exploiting resources of temporary pools, and provides a framework for community analysis and prediction."

5 HOW TO PROCEED?

The main result of this study is the classification of Figure 1. For practical use an expert system must be developed, that can either be handled by personal computer or manually in the form of a decision key. The data in this report can be used as a basis for the extension of Fig. 1. Regional and local applications are possible but for many regions the data needed are limited or not available at all.

Classification is a method of combining similar elements out of a group of diverse elements, in order to achieve groups that differ more from each other than from the mutual elements within the group. Classification of surface waters on an ecological basis meets a multitude of criteria, as has been shown in the preceding chapters and the purpose could be described - rather vaguely - to divide waters into classes of a more or less homogeneous "ecological structure" (in its natural state).

We have described the most important criteria - those which have an overall impact on structure and functioning of aquatic ecosystems according to a hundred years of limnological research. The wide variation of plants and animals (the biotic part of ecosystems), as well as the fundamental differences in abiotic factors on a worldwide scale, make clear that only the roughest classification can be made for the waters of the world. All classification systems with practical applicability are therefore restricted to regional use. Many such systems have been developed, and in most cases they give good results. It is, however, rather difficult to make a choice from among these systems for any given new situation. The following method, used in recent studies in The Netherlands, should be of some help in classifying waters on an ecological basis. The method is called an ecological typology of surface waters.

Simply stated, the method consists of combining abiotic and biotic measurements of a number of surface waters into computable units, which are subjected to a clustering and an ordination program. In Fig. 38 the processing of the data is depicted. Further details on the method may be found in Ter Braak 1986.

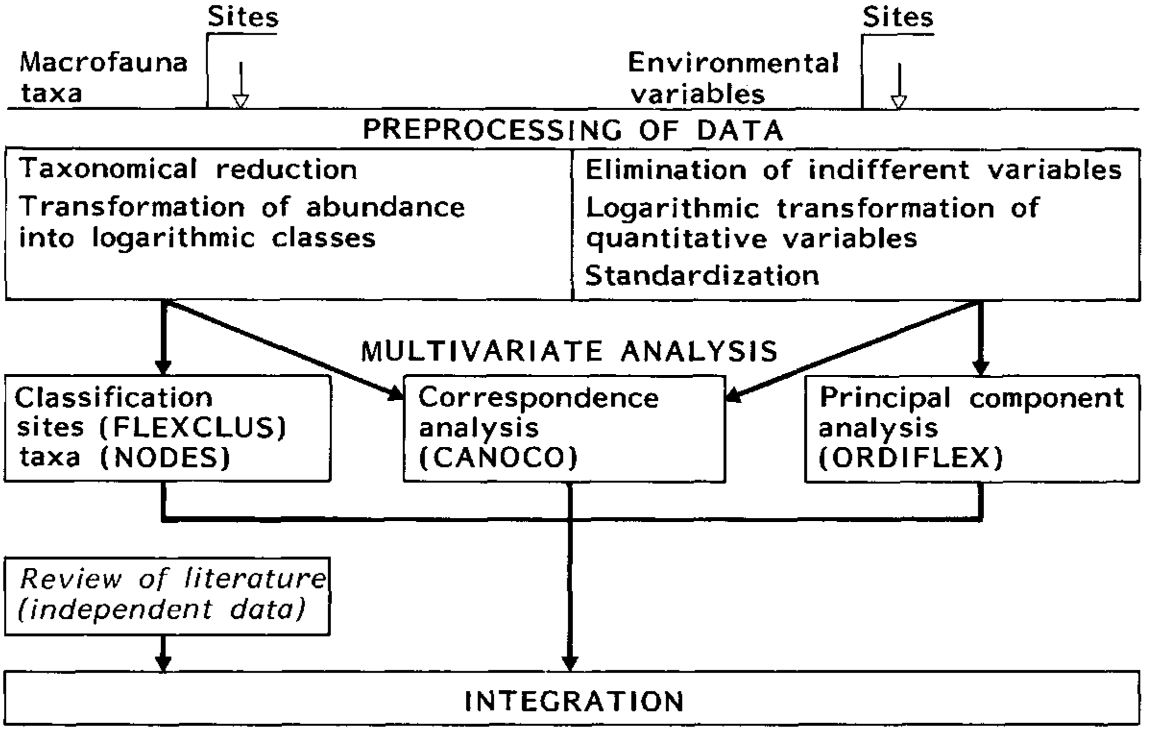


Fig. 38. Data processing of macrofaunal taxa and environmental variables of a number of sites (Verdonschot & Schot 1987).

As an example of the method a classification of springs in The Netherlands is given. In Fig. 39 the results of multivariate analysis of data from springs in the Province of Overijssel is depicted. The contour lines indicate the habitat clusters, the arrows the most important environmental variables (interset correlation greater than 0.3). A relationship is positive in the direction of the arrow and negative in the opposite direction. The position of the habitat clusters is determined by combinations of macro-invertebrates. The arrow of an environmental variable points approximately in the direction of steepest increase of that variable across the ordination diagram and the rate of change in that direction is equal to the length of the arrow. This means that the relationship of a site (or site group) to one of more important environmental variables is visualisized by its perpendicular projection on the environmental arrow or its imaginary extension (in both directions). Within the diagram these site groups and environmental arrows should be seen as relative projections upon each other. Sites in the centre of the diagram may have their optima here, but may be independent of the axes as well. Sites with a poor or aberrant taxonomic composition often lie in the peripheral area of the diagram, due to their specific environmental situation or to chance.

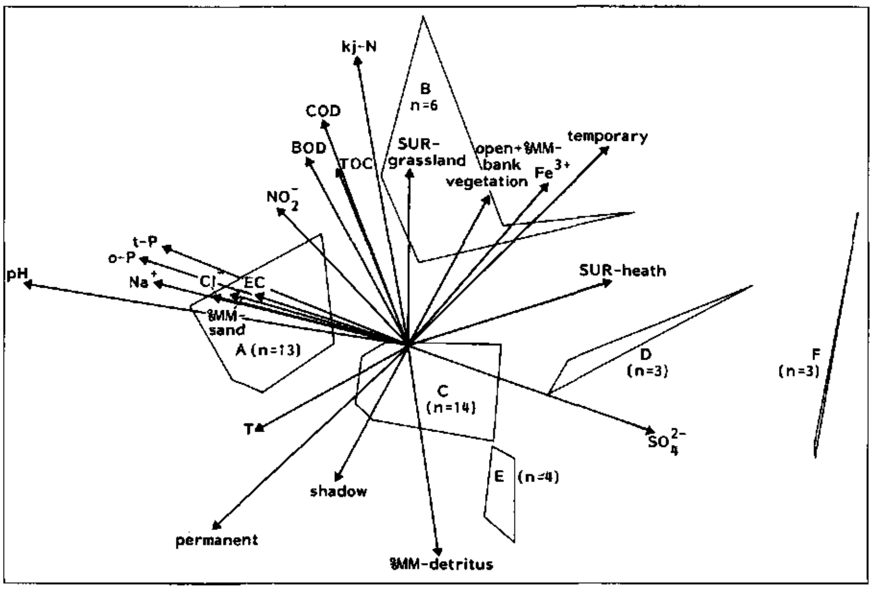


Fig. 39. Detrended canonical correspondence analysis ordination diagram of taxa and environmental variables for axes 1 and 2, with the six habitat clusters (contour lines) (Verdonschot & Schot 1987).

The six habitat clusters from Fig. 39 have been reorganized (Fig. 40), so that related clusters have been combined to form so called biotypes. Verdonschot & Schot give the following explanation.

"A biotype is defined als an ecological entity occurring in a certain biotope and meeting the specified typological criteria. A biotype develops or becomes impoverished in due course under the impact of environmental changes, and will therefore occur in a particular developmental stage (succession stage).

We conclude that clusters A. C and E belong to the biotype of helocrene springs. The cluster sequence (E. C, A) reflects an increase in eutrophication and/or (secondary) organic enrichment due to anthropogenic activity. Cluster B belongs to the biotype of temporary neutral seepage marshes. Clusters D and F belong to the biotype of temporary acid seepage marshes. The drought period is longer in F than in D."

The last step is combining the data from all over the country and processing these according to the described technique. Preliminary results have been depicted in Fig. 41. The letters A/F have been replaced by numbers, indicating the hierarchical nature of some of the clusters. The blocks represent species lists and some of these are directly related to the clusters from Fig. 40.

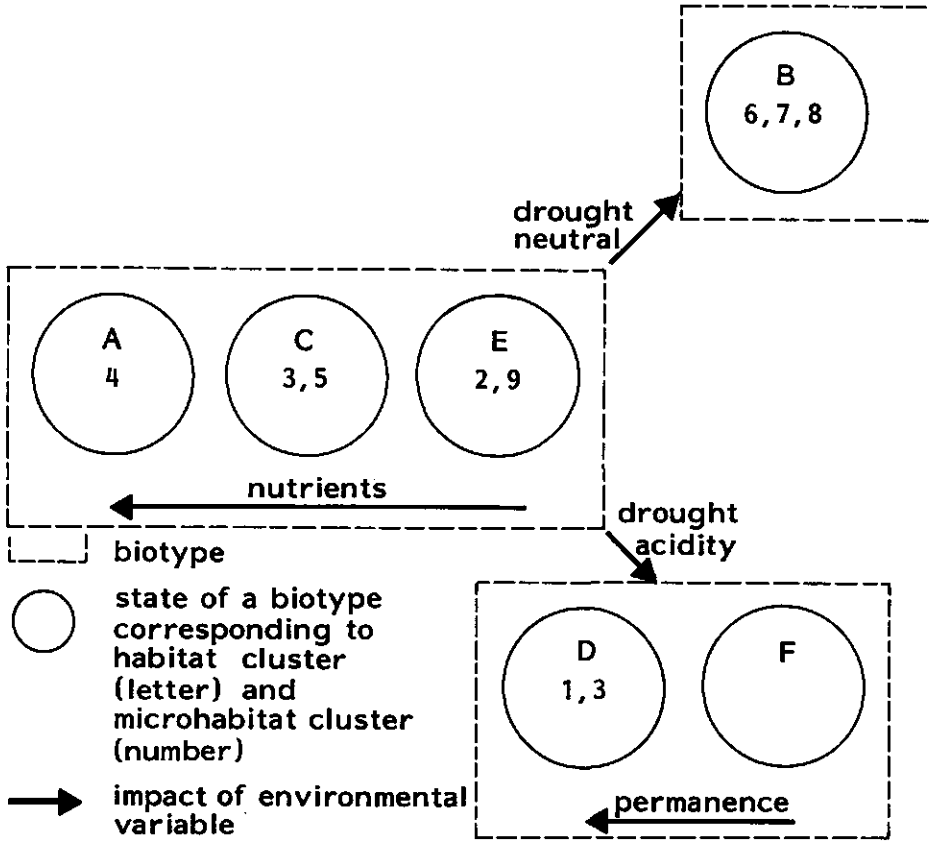


Fig. 40. Biotypes related to springs in the area under study (dotted lines). The circles correspond with habitat clusters (letters). The arrows indicate in increase in the state of the variable (Verdonschot & Schot 1987).

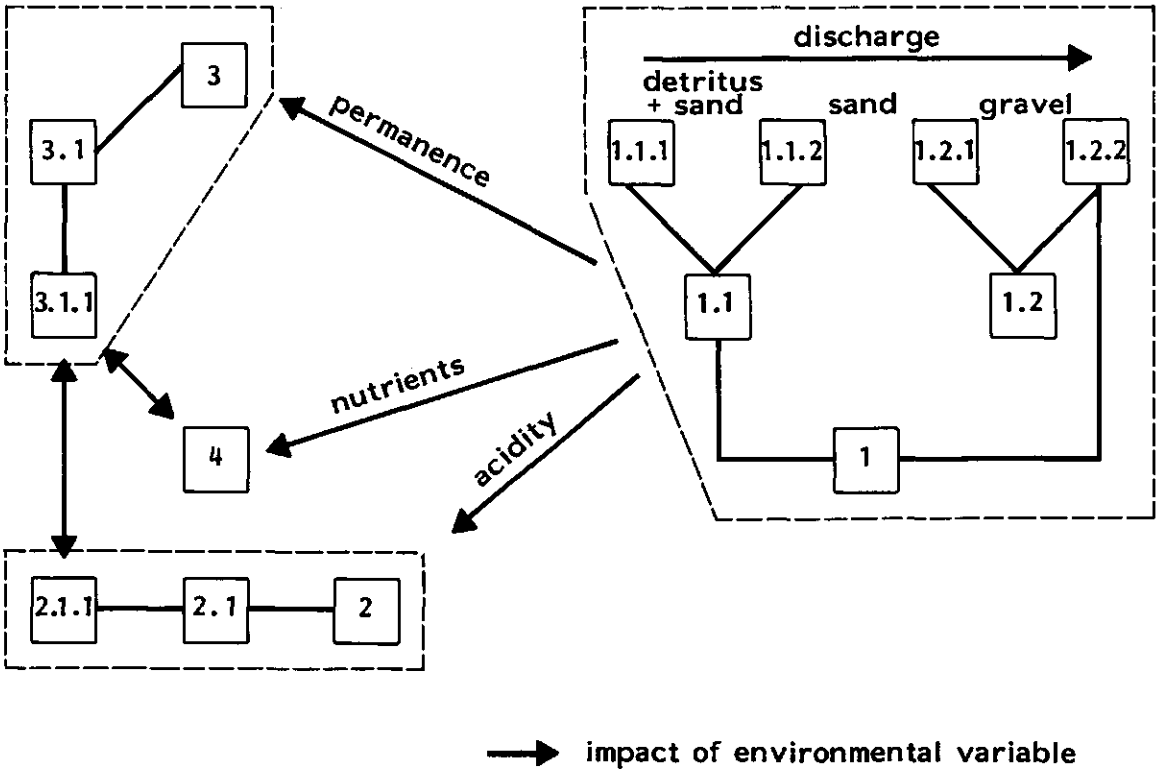


Fig. 41. Provisional typology of springs in The Netherlands. The arrows indicate an increase in the state of the variable. The blocks with numbers correspond with lists of typifying species (Verdonschot & Schot 1987).

1.1.1 cf. cluster	C
2	E
2.1	D
2.1.1	F
3	B
4	A

APPENDIX I References

References of literature on zonation and classification of streams used for chapter 3

Albrecht, M.L. 1953. Die Plane und andere Flämingbäche. Z. Fisch., N.F. 1: 389-476.

Albrecht, M.L. & E.M. Bursche 1957. Fischereibiologische Untersuchungen an Fliessgewässer. I. Physiographisch-biologische Studien an der Polenz. Z. Fish. N.F. 6: 209-240.

Allanson, B.R. 1965. Introduction (to Symposium, Biology of South African rivers, Durban 1963). Arch. Hydrobiol. 61: 378-379.

Allen, K.R. 1951. The Horokiwi stream. A study of a trout population. Fish. Bull. N.Z. 10, 231 p.

Allen, K.R. 1960. Freshwater fauna of Wellington. Science in Wellington, Roy. Soc. N.Z. Handbook: 23-24.

Allen, T.F.H. & T.B. Starr 1982. Hierarchy. Perspectives for ecological complexity. Chicago, University of Chicago Press. 310 p.

Ambühl, H. 1959. Die Bedeutung der Strömung als ökologischer Faktor. Schweiz. Z. Hydrol. 21: 133-264.

Angelier, E. 1952. Le peuplement en Hydracariens des eaux courantes franćaises et son origine. Fasc. hors-série. Soc. Biogeogr.: 67-74.

Ant, H. 1966. Die Benthos-Biozönosen der Lippe. Min. Ernährung Landwirtschaft und Forst Nordrhein-Westfalen Düsseldorf.

Ant, H. 1967. Korrelierte Artengruppen und Mosaikkomplexe im Bereich des Fliesswasserbenthos. Schriftenr. f. Vegetationsk. 2: 193-204.

Ant, H. 1971. Die Gewässertypen Westfalens. Naturk. Westf. 7: 73-84.

Armitage, K. 1961. Distribution of riffle insects of the Firehole River, Wyoming. Hydrobiologia 17: 152-174.

Armitage, K.B. 1958. Ecology of riffle insects of the Firehole River, Wyoming. Ecology 39: 571-580.

Arntz, W.E. 1981. Zonation and dynamics of macrobenthos biomass in an area stressed by oxygen deficiency. In: Stress effects on natural ecosystems (ed. G.W. Barrett & R. Rosenberg): 215-225. Chichester-Wiley.

Backiel, T. 1964. On the fish populations in small streams. Verh. Internat. Verein. Limnol. 15: 529-534.

Badcock, R.M. 1953. Studies of the benthic fauna in tributaries of the Känlinge River, Southern Sweden. Rep. Inst. Freshwater Res. Drottningholm 35: 21-37.

Balon, E.K. & D.J. Stewart 1983. Fish assemblages in a river with unusual gradient (Luongo, Africa-Zaire system), reflections on river zonation, a description of another new species. Environmental Biology of Fishes 9: 225:-252.

Barmuta, L.A. & P.S. Lake 1982. On the value of the River Continuum Concept. N.Z.J. Mar. Freshwater Res. 16: 227-229.

Beauchamp, R.S.A. & P. Ullyot 1932. Competitive relationships between certain species of freshwater triclads. J. Ecol. 20: 200-208.

Beck, W.M. 1965. The streams of Florida. Bull. Fla State Mus. 10: 91-126.

Behning, A. 1924. Zur Erforschung der am Flussboden der Wolga lebenden Organismen. Monogr. Biol. Wolga-Station 1: 1-388.

Behning, A. 1928. Das Leben der Wolga. Zugleich eine Einführung in die Fluss-Biologie. Die Binnengewässer 5, Stuttgart.

Behning, A. 1929. Das Leben der Wolga. ed. O. Vogt. Die Naturwissenschaft der Sovjet-Union, Berlin. 25 p.

Berg, K. 1948. Biological studies on the river Susaa. Fol. limnol. Scandinav. 4: 1-318.

Bergstrom, F.W. 1982. Episodic behaviour in badlands: its effects on channel morphology and sediment yield. In: F.J. Swanson, R.J. Janda, T. Dunne & D.N. Swanston (ed.). Sediment budgets and routing in forested drainage basins. U.S. Forest Service. Portland, OR. p. 59-66.

Berthélemy, C. 1966. Recherches écologiques et biogéographiques sur les plécoptèrés et coléoptères d'eau courante (Hydraena et Elminthidae) des Pyrénées. Annls Limnol. 2: 227-458.

Bick, G.H. et al. 1953. An ecological reconnaisance of a naturally, acid stream in Southern Louisiana. J. Tenn. Acad. Sci. 28: 221-231.

Bishop, J.E. 1973. Limnology of a small Malayan river Sungai Gombak. Monographiae Biologicae 22. Junk, The Hague.

Bloesch, J. 1980. Bodenfaunistische Untersuchungen in Aare und Rhein. Schweiz. Z. Hydrol. 42: 258-308.

Borne, V.D.M. 1877. Wie kann man unsere Gewässer nach den in ihnen vorkommenden Arten klassifizieren? Cirk. Dt. Ver. 4 p.

Botosaneanu, L. & F. Por 1957. Recherches hydrobiologiques sur les sources du bassin de l'Aries (II). Bull. scientific (Acad. RPR), Ser. Zool. 9: 19-66.

Botosaneanu L. 1959. Recherches sur les trichoptères du massif de Retezat et des Monts du Banat. Bibl. Biol. Animala (Bucarest) 1: 1-165.

Botosaneanu L., St. Negrea, A. Burghele, D. Dancau & V. Decou 1959.

Contributions à l'étude hydrobiologique d'une deereá de Dobrogea: la Casimcea. Arch. Hydrobiol. 55: 30-51.

Botosaneanu, L. 1979. Quinze années de recherches sur la zonation des cours d'eau: 1963-1978. Bijdragen tot de Dierkunde 49: 109-134.

Bovee, K.D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. U.S. Fish and Wildlife Service (FWS/OBS-82/26), Washington, D.C. 248 p.

Brehm, V. & F. Ruttner 1926. Die Biozönosen der Lunzer Gewässer. Internat. Rev. ges. Hydrobiol. 16: 330-392.

Bretschko, G. 1969. Zur Hydrobiologie zentralalpiner Gletscherabflüsse. Verhandlungen der deutschen Zoologischen Gesellschaft in Innsbruck 1968: 741-750.

Brinck, P. 1949. Studies on Swedish stoneflies. Opusc. Ent. Suppl. 11: 1-247.

Brodsky, K.A. 1980 Mountain torrent of the Tien Shan. Monographiae Biologicae 39. Junk, The Hague.

Bruns, D.A., G.W. Minshall, C.E. Cushing, K.W. Cummins, J.T. Brock & R.L. Vannote 1984. Tributaries as modifiers of the river continuum concept: analysis by polar ordination and regression models. Arch. Hydrobiol. 99: 208-220.

Budde, H. 1925. Die Algenflora des Sauerländischen Gebirgsbaches. Arch. Hydrobiol. 19: 433-520.

Burton, G.W. & E.P. Odum 1945. The distribution of stream fish in the vicinity of Mountain Lake, Viginia. Ecology 26: 182-194.

Butcher, R.W. et al. 1931. A biological investigation of the River Lark. Fishery Invest., London. 112 p.

Butcher, R.W. et al. 1933. Studies on the ecology of rivers. On the distribution of macrophytic vegetation in the rivers of Britain. J. Ecol. 21: 58-91.

Butcher, R.W. et al. 1937. Survey of the river Tees. Part III. The non-tidal reaches - chemical and biological. Tech. Pap. Wat. Pollut. Res. D.S.I.R. 6, 189 p.

Carpenter, K.E. 1928. Life in Inland Waters. Sidgwick & Jackson, London. 267 p.

Carpenter, K.E. 1928. On the distribution of freshwater Turbellaria in the Aberystwyth district, with special reference to two ice-age relicts. J. Ecol. 16: 105-122.

Chacko, P.I. & S.V. Ganapati 1952. Hydrobiological survey of the Surut River in the Highwavys, Mudurai District, India, to determining its suitability for the introduction of the rainbow trout. Arch. Hydrobiol. 46: 128-141.

Chandler, C.M. 1966. Environmental factors affecting the local distribution and abundance of four species of streamdwelling triclads. Invest. Indiana Lakes Streams 7: 1-56.

Chutter, F.M. 1970. Hydrobiological studies in the catchment of Vaal Dam. South Africa. Part I. River zonation and the benthic fauna. Internat. Rev. ges. Hydrobiol. 55: 445-494.

Clark, C.F. 1944 The freshwater naiades of Anglaize County, Ohio. Ohio J. Sci. 44: 107-176.

Clarke, A.H. & C.O. Berg 1959. The freshwater mussels of central New York. Cornell Univ. Agr. Exp. Sta.; Ithaca.

Conrad, W. 1942. Sur la faune et la flore d'un ruisseau de l'Ardenne belge. Mém. Mus. r. Hist. nat. Belg. 99: 1-177.

Culp, J.M. & R.W. Davies 1982. Analysis of longitudinal zonation and the river continuum concept in the Oldman-South Saskatchewan River system. Can. J. Fish. Aquat. Sci. 39: 1258-1266.

Cummins, K.W. 1974. Structure and fuction of stream ecosystems. Bioscience 24: 631-641.

Cummins, K.W. 1975. The ecology of running waters, theory and practice. Internat. Joint Comm. on the Great Lakes. Sandusky River Basin Symp.: 278-293.

Cummins, K.W., R.C. Petersen, F.O. Howard, J.C. Wuycheck & V.J. Holt 1973. The utilisation of leaf litter by stream detritivores. Ecology 54: 336-345.

Cummins, K.W., J.R. Sedell, F.J. Swanson, G.W. Minshall, S.G. Fisher, C.E. Cushing, R.C. Petersen & R.L. Vannote 1983. Organic matter budgets for stream ecosystems: problems in their evaluation. In J.R. Barnes & G.W. Minshall (ed.). Stream ecology. Application and testing of general ecological theory. Plenum Press, New York. p. 299-353.

Cummins, K.W., W.G. Minshall, J.R. Sedell, C.E. Cushing & R.C. Petersen 1984. Stream ecosystem theory. Verh. Internat. Verein. Limnol. 22: 1818-1827.

Curry, R.R. 1972. Rivers - a geomorphic and chemical overview. In: R.T. Oglesby, C.A. Carlson & J.A. McCann (ed.). River ecology and man. Academic Press, New York. p. 9-31.

Cushing, C.E., C.D. McIntire, K.W. Cummins, G.W. Minshall, R.C. Petersen, J.R. Sedell & R.L. Vannote 1983. Relationships among chemical, physical and biological indices along river continua based on multivariate analyses. Arch. Hydrobiol. 98: 317-326.

Dahm, A.G. 1958. Taxonomy and ecology of five species groups in the family Planariidae. Malmö.

Davies, L. & C.D. Smith 1958. The distribution and growth of Prosimulium larvae (Diptera: Simuliidae) in hill streams in northern England. J. Anim. Ecol. 27: 335-348.

Décamps, H. 1968. Vicariances écologiques chez les Trichoptères des Pyrénées. Annls. Limnol. 4: 1-50.

Décamps, H., G. Larrouy & D. Trivellato 1975. Approche hydrodynamique de la microdistribution d'invertébrés benthiques en eau courante. Annls. Limnol. 11: 79-100.

Densen, R.D. van 1954. Maryland freshwater stream classification by watersheds. Contr. Chesapeake Biol. Lab. 106: 1-30.

Dodds, G.S. & F.L. Hisaw 1925. Ecological studies of aquatic insects. IV. Altitudinal range and zonation of mayflies, stoneflies and caddisflies in the Colorado Rockies. Ecology 6: 380-390.

Dorier, A. 1937. La faune des eaux courantes alpines. Verh. Internat. Verein. Limnol. 8: 33-41.

Dorier, A. 1961. Sur la répartition des Simuliidae (Dipt.) des Alpes françaises. Verh. Internat. Verein. Limnol. 14: 369-371.

Dudgeon, D. 1982. An investigation of physical and biological processing of two species of leaf litter in Tai Po Kau Forest Stream, New Territories, Hong Kong. Arch. Hydrobiol. 96: 1-32.

Dudich, E. 1958. Die Grundlagen der Fauna eines Karpaten-Flusses. Acta zool. hung. 3: 179-200.

Edington. J.M. 1966. Some observations on stream temperature. Oikos 15: 265-273.

Egglishaw, H.J. & N.C. Morgan 1965. A survey of the bottom fauna of streams in the Scottish Highlands pt. II. The relationship of the fauna to the chemical and geological conditions. Hydrobiologia 26: 173-183.

Eidel, K. 1933. Beiträge zur Biologie einiger Bäche des Schwarzwaldes, mit besonderer Berücksichtigung der Insektenfauna der Elz und Kinzig. Arch. Hydrobiol. 25: 543-615.

Einsele, W. 1960. Die Strömungsgeschwindigkeit als beherrschender Factor bei der limnologischen Gestaltung der Gewässer. Österr. Fischerei, Suppl. 1: 1-140.

Elgmork, K. & O.A. Saether 1970. Distribution of invertebrates in a high mountain brook in the Colorado Rocky Moutains. Studies of the

University of Colorado (Series Biology) 31: 1-51.

Elster, H.J. 1962. Stoffkreislauf und Typologie der Binnengewässer als zentrale Probleme der Limnologie. Naturwiss. 49: 49-55.

Engelhardt, W. 1951. Faunistisch-ökologische Untersuchungen über Wasserinsekten an den südlichen Zuflüssen des Ammersees. Mitt. Münch. ent. Ges. 41: 1-135.

Entz, B. 1961. Die Beziehungen der Wasserchemie und primären Produktion in kleinen Bächen der Balatonsee-Gegend. Verh. Internat. Verein. Limnol. 15: 495-48.

Findenegg, I. 1959. Die Gewässer Österreichs. Ein limnologischer Üeberblick. Biologische Station, Lunz.

Fisher, S.G. 1983. Succession in streams. In: J.R. Barnes & G.W. Minshall (ed.). Stream ecology. Application and testing of general ecological theory. Plenum Press, New York. p. 7-27.

Fittkau, E.J. 1953. Odonaten aus der Fulda. Ber. limnol. Flussstn. Freudenthal 5: 29-36.

Fittkau, E.J. 1964. Remarks on limnology of central-Amazon rain-forest streams. Verh. Internat. Verein. Limnol. 15: 1092-1096.

Fittkau, E.J. & F. Reiss 1983. Versuch einer Rekonstruktion der Fauna europäischer Ströme und ihrer Auen. Arch. Hydrobiol. 97: 1-6.

Funk, J.L. & R.S. Campbell 1953. The population of larger fishes in Black River, Missouri. Univ. Mo. Stud. 26: 69-82.

Gammon, J.R. 1980. A proposed stream classification. Proc. Indiana Acad. Sci. 89: 143.

Gaufin, A.R. 1959. Production of bottom fauna in the Provo River, Utah. Iowa St. Coll. J. Sci. 33: 395-419.

Gaufin, A.R. & C.M. Tarzwell 1956. Aquatic macroinvertebrate communities as indicators of organic pollution in Lytle Creek. Sewage Ind. Wastes 28: 906-924.

Gerking, S.D. 1945. Distribution of the fishes of Indiana. Invest. Indiana Lake Streams 3: 1-137.

Gersbacher, W.M. 1937. The development of stream bottom communities in Illinois. Ecology 18: 359-390.

Gibon, F.M. & B. Statzner 1985. Longitudinal zonation of lotic insects in the Bandama River system (Ivory Coast). Hydrobiologia 122: 61-64.

Goodrich, C. & H. van der Schalie 1944. A revision of the Mollusca of Indiana. Am. Midl. Nat. 32: 257-326.

Gore, J.A. 1978. A technique for predicting in-stream flow requirements of benthic macroinvertebrates. Freshwater Biology 8: 141-151.

Gray, L.J., J.W. Ward, R. Martinson & E. Bergey 19C83. Aquatic macro-invertebrates of the Piceance Basin. Colorado: community response along spatial and temporal gradients of environmental conditions. Southeast. Nat. 28: 125-135.

Gregory, K.J. & E. Walling 1973. Drainage basin form and process. Arnold, London. 456 p.

Grenier, P. 1949. Contribution à l'étude biologique des Simuliidés de France. Physiologia comp. Oecologia 1: 165-330.

Grimm, F. 1968. Das Abflussverhalten in Europa - Typen und regionale Gliederung. Wiss. Veröff. Dtsch. Inst. Länderkd. N.F. 25/26: 18-180.

Hallam, J.C. 1959. Habitat and associated fauna of four species of fish in Ontario streams. J. Fish. Res. Bd. Can. 16: 147-173.

Harrison, A.D. 1963. An ecological survey of the Great Berg River. Monographiae biol. 14: 143-158.

Harrison, A.D. 1965. River zonation in South Africa. Arch. Hydrobiol. 61: 380-386.

Harrison, A.D. 1978. Freshwater invertebrates (except molluscs). Biogeography and Ecology of Southern Africa (ed. M.J.A. Werger), p. 1139-1152.

Harrison, A.D. & J.F. Elsworth 1958. Hydrobiological studies on the Great Berg River, Western Cape Province. Part I. General description, chemical studies and main features of the flora and fauna., Trans. R. Soc. S. Afr. 35: 125-226.

Harrison, A.D. & J.D. Agnew 1961. The distribution of invertebrates endemic to acid streams, in the Western and Southern Cape Province. Nat. Inst. Water Res.; South African Counc. f. Sci. & Industr. Res. Ms.: 1-11.

Harrison, A.D. & J.J. Rankin 1976. Hydrobiological studies of Eastern Lesser Antillean Islands. II. St. Vincent: Freshwater fauna - its distribution, tropical river zonation and biogeography. Archiv für Hydrobiologie Supplement 50: 275-311.

Haslam, S.M. 1978. River Plants. The macrophytic vegetation of watercourses. Cambridge University Press. 396 p.

Haslam, S.M. 1982. A proposed method for monitoring river pollution using macrophytes. Science and Technology Letters Environm. Techn. Letter 3: 19-34.

Haslam, S.M. & P.A. Wolseley 1981. River Vegetation: its identification, assessment and management. Cambridge University Press. 154 p.

Hawkes, H.A. & L.J. Davies 1971. Some effects of organic enrichment on benthic invertebrate communities in stream riffles. In: E. Duffey & A.A. Watt (eds.), The Scientific Management of Animal and Plant Communities for Conservation. Blackwell, Oxford. p. 271-293.

Hawkes H.A. 1975. River zonation and classification. In: B.A. Whitton (ed.), River Ecology. Studies in Ecology 2: 312-374. Univ. Calif. Press.

Hermann, K. 1930. Die Entwicklung der Oder vom Natur- zum Kulturstrom. Jahrb. Gewässerkd. Norddtschl. Bes. Mitt. 6: 1-75.

Higler, L.W.G. & A.W.M. Mol 1984. Ecological types of running water based on stream hydraulics in the Netherlands. Hydrobiol. Bull. 18: 51-57.

Hofius, K. 1971. Das Temperaturverhalten eines Fliessgewässers, dargestellt am Beispiel der Elz. Freiburger geogr. Hft. 10: 1-111. Freiburg im Breisgau.

Höll, K. 1968. Wasser. Untersuchung, Beurteilung, Aufbereitung, Chemie, Bakteriologie, Biologie. De Gruyter, Berlin. 393 p.

Holton, G.D. 1953. A trout population study on a small creek in Gallatia County, Montana. J. Wildl. Mgmt. 17: 62-82.

Hoover, E.E. 1938. Fish populations of primitive brook trout streams in New Hampshire. Trans. N. Am. Wildl. Conf. 3: 486-496.

Hora, S.L. 1923. Observations on the fauna of certain torrential streams in the Khasi Hills. Rec. Indian Mus. 25: 579-600.

Hora, S.L. 1930. Ecology, bionomics and evolution of the torrential fauna, with special reference to the organs of attachment. Phil. Trans. R. Soc. B. 218: 171-282.

Horton, R.F. 1945. Erosional development of streams and their drainage basins. Bull. geol. Soc. Am. 56: 275-370.

Horwitz, R.J. 1978. Temporal variability patterns and the distributional patterns of stream fishes. Ecol. Monogr. 48: 307-321.

Howard, A.D. 1951. A river mussel parasitic on a salamander. Chicago Acad. Sci. nat. Hist. Misc. 77: 6 p.

Huet, M. 1938. Hydrobiologie piscicole du bassin moyen de la Lesse. Mem. Mus. r. Hist. nat. Belg. 82: 1-128.

Huet, M. 1949. Aperçu des relations entre la pente et les populations des eaux courantes. Schweiz. Z. Hydrol. 11: 333-351.

Huet, M. 1962. Influence du courant sur la distribution des poissons dans les eaux courantes. Schweiz. Z. Hydrol. 24: 413-432.

Hynes, H.B.N. 1941. The taxonomy and ecology of the nymphs of British Plecoptera, with notes on the adults and eggs. Trans. R. ent. Soc., London. 91: 459-557.

Hynes, H.B.N. 1948. Notes on the aquatic Hemiptera-Heteroptera of Trinidad and Tobago, B.W.I., with a description of a new species of Martarega B. White (Notonectidae). Trans. R. ent. Soc. Lond. 99: 341-360.

Hynes, H.B.N. 1955. Biological notes on some East African aquatic Heteroptera. Proc. R. ent. Soc. Lond. A 30: 43-54.

Hynes, H.B.N. 1961. The invertebrate fauna of a Welsh mountain stream. Arch. Hydrobiol. 57: 344-388.

Hynes, H.B.N. 1971. Zonation of the invertebrate fauna in a West-Indian stream. Hydrobiologia 38, 1: 1-8.

Hynes, H.B.N. & T.R. Williams 1962. The effect of DDT on the fauna of a central African stream. Ann. trop. Med. Parasit. 56: 78-91.

Hynes, H.B.N. 1972. The ecology of running waters. 2nd ed. University of Toronto Press, Downsview. Ont. 555 p.

Ide, F.P. 1935. The effect of temperature on the distribution of the mayfly fauna of a stream. Publs. Ont. Fish. Res. Lab. 50: 1-76.

Illies, J. 1953. Die Besiedlung der Fulda (insbes. das Benthos der Salmoniden-region) nach dem jetzigen Stand der Untersuchung. Ber. limnol. Flussstn. Freudenthal. 5:1-28.

Illies, J. 1955. Der biologische Aspekt der limnologischen Fliesswasser-typisierung. Arch. Hydrobiol. Suppl. 22: 337-346.

Illies, J. 1956. Seeausfluss-Biozönosen Lappländischer Waldbäche. Entomologisk Tidskrift 77: 138-153.

Illies, J. 1958. Die Barbenregion mitteleuropäischer Fliessgewässer. Verh. Internat. Verein. Limnol. 13: 834-844.

Illies, J. 1961. Versuch einer allgemein biozönotischen Gliederung der Fliessgewässer. Int. Rev. ges. Hydrobiol. 46: 205-213.

Illies, J. 1964. The invertebrate fauna of the Huállaga, a Peruvian tributary of the Amazon River, from the sources down to Tingo Maria. Verh. Internat. Verein. Limnol. 15: 1077-1083.

Illies, J. 1978. Vergleichende Emergenzmessung im Breitenbach 1969-1976 (Ins: Ephemeroptera, Trichoptera, Plecoptera). Arch. Hydrobiol. 82: 432-448.

Illies, J. 1982. Längsprofil des Breitenbachs im Spiegel der Emergenz (Ins: Ephemeroptera, Trichoptera, Plecoptera). Arch. Hydrobiol. 95: 157-168.

Illies, J. & L. Botosaneanu 1963. Problèmes et méthodes de la classification et de la zonation écologique des eaux courantes, considerées surtout du point de vue faunistique. Mitt. Internat.

Verein. Limnol. 12: 1-57.
Imanishi, K. 1941. Mayflies from Japanese torrents X. Life forms and life zones of mayfly nymphs. II. Ecological structure illustrated by life zone arrangement. Mem. Coll. Sci., Engng. Kyoto imp. Univ. B 16: 1-35.
Johnson, D.S. 1957. A survey of Malayan freshwater life. Malay. Nat. J. 12: 57-65.
Jones, J.R.E. 1941. The fauna of the river Dovey, West-Wales. J. Anim. Ecol. 10: 12-24.
Jones, J.R.E. 1943. The fauna of the river Teifi, West Wales. J. Anim. Ecol. 12: 115-123.
Jones, J.R.E. 1948. The fauna of four streams in the Black Mountain district of South Wales. J. Anim. Ecol. 17: 51-65.
Jones, J.R.E. 1949. An ecological study of the river Rheidol, North Cardiganshire, Wales. J.Anim. Ecol. 18: 67-88.
Junk, W.J. 1982. Amazonian floodplains: their ecology, present and potential use. Rev. Hydrobiol. Trop. 15: 285-301.
Kaiser, E.W. 1950. Sialis nigripes Ed. Pict., ny for Danmark, og udbredelsen af S. lutaria L. og S. fuliginosa Pict. i. Danmark. Flora Fauna 56: 17-36.
Kani, T. 1944 (1981). Stream classification in "Ecology of torrent-inhabiting insects" (1944): an abridged translation. Physiol. Ecol. Japan 18: 113-118.
Karaman, M.S. 1964. Über die Kategorisierung der Zoozönosen. Beitr. Ent. 14: 739-750.
Kelsy, H.M. 1982. Hillslope evolution and sediment movement in a forested headwater basin. Van Duzen River, North Coastal California. In: F.J. Swanson, R.J. Janda, T. Dunne & D.N. Swanston (eds.), Sediment budgets and routing in forested drainage basins. U.S. Forest Service, Portland OR. p. 86-96.
Kleerekoper, H. 1955. Limnological observations in Northeastern Rio Grande do Sul, Brazil. Arch. Hydrobiol. 50: 553-567.
Knight, A.W. & A.R. Gaufin 1967. Stream type selection and associations of stoneflies (Plecoptera) in a Colorado river drainage system. J. Kan. Ent. Soc. 40: 347-352.
Kopelke, J.P. 1981. Ökologische Studien an Eintagsfliegen am Beispiel der Emergenz des zentralafrikanischen Bergbaches Kalengo (Zaire) (Ephemeroptera). Entomol. Abh. (Dres.) 44: 9-43.
Kothé, P. 1961. Hydrobiologie der Oberelbe. Natürliche, industrielle und wasserwirtschaftliche Faktoren in ihrer Auswirkung auf das Benthos des

Stromgebietes oberhalb Hamburgs. Arch. Hydrobiol. Suppl. 24: 221-343.
Kownacki, A. 1971. Taxocens of Chironomidae in streams of the Polish High Tatra Mts. Acta Hydrobiol. 13, 4: 439-464.
Kuehne, R.A. 1962. A classification of streams, illustrated by fish distribution in an Eastern Kentucky creek. Ecology 43: 608-614.
Kühn, G. 1940. Zur Oekologie und Biologie der Gewässer (Quellen und Abflüsse) des Wassersprengs bei Wien. Arch. Hydrobiol. 36: 157-262.
Kühtreiber, J. 1934. Die Plecopterenfauna Nordtirols. Ber. Naturwiss. Med. Ver. Innsbruck 43/44: 1-219.
Lachner, E.A. 1956. The changing fish fauna of the Upper Ohio basin. Spec. Publ. Pymatuning Lan. Fld. Biol. 1: 64-78.
Lagler, K.F. 1949. Studies in freshwater fishery biology. Michigan.
Lan, H. An der 1962. Zur Turbellarien-Fauna der Donau. Arch. Hydrobiol. Suppl. 27: 3-27.
Lastochkin, D.A. 1943. A plain river sub-division into geomorphological and biological districts on the basis of its structural and biological unity. Dokl. Acad. Nauk. S.S.S.R. 41: 347-50.
Lauterborn, R. 1916/1918. Die geographische und biologische Gliederung des Rheistromes I-III. Sitz.-Ber. Heidelberger. Acad. Wiss. Math.-Naturwiss. Kl. Abt. B. I: (1916) Abh. 6; II: (1917) Abh. 5; III: (1918) Abh. 1.
Lehmann, J. 1979. Chironomidae (Diptera) aus Fliessgewässern Zentralafrikas. Teil I: Kivu-Gebiet. Ostzaire. Spixiana Suppl. (Münch.) 3: 1-144.
Lepneva, S.G. 1928. Les larves des trichoptères de la région Olonetz. Trav. de l'Expéd. Sci. d'Olonetz 6 (Zoologie) 5: 1-125.
Leopold, L.B., M.G. Wolman & J.P. Miller 1964. Fluvial Processes in Geomorphology. Freeman, San Francisco. 539 p.
Lévêque, C., C. Dejoux & A. Iltis 1983. Limnologie du fleuve Bandama, Côte d'Ivoire. Hydrobiologia 100: 113-141.
Likens, G.E., F.H. Bormann, R.S. Pierce et al. 1977. Biogeochemistry of a forested ecosystem. Springer, New York. 146 p.
Lindegaard-Petersen, C. 1972. An ecological investigation of the Chironomidae (Diptera) from a Danish lowland stream (Linding A). Arch. Hydrobiol. 69: 465-507.
Lotspeich, F.B. 1980. Watersheds as the basic ecosystem: this conceptual framework provides a basis for a natural classification system. Water Research Bulletin 16: 581-586.
Lotspeich, F.B. & W.S. Platts 1982. An integrated land-aquatic classification. In: N.B. Armantrout (ed.), Acquisition and utilization of

aquatic habitat inventory information. Western Division American Fisheries Society, Bethesda MD.

Ludwig, W.B. 1932. The bottom invertebrates of the Hocking River. Bull. Ohio Biol. Surv. 26: 223-249.

Macan, T.T. 1957. Ephemeroptera of a stony stream. J. Anim. Ecol. 26: 317-342.

Macan, T.T. 1961. A review of running water studies. Verh. Internat. Verein. Limnol. 14: 587-602.

Macan, T.T. 1976. The communities of running water in Cumbria. F.B.A. Annual rep. 44: 59-67.

Madoni, P. 1984. Relationship between ciliated protozoa and ecological zones in some water courses of the River Po basin. Int. J. Ecol. envir. Sci. 9: 87-88.

Madoni, P. 1984. Ecological characterization of different type of watercourses by the multivariate analysis of ciliated protozoa populations. Arch. Hydrobiol. 100: 171-188.

Maier, M.H., M. Takino, M.A. Basile-Martins & M.N. Cipolli 1985. River typology of Sao Paulo State, Brazil. Verh. Internat. Verein. Limnol. 22: 2161-2166.

Maitland, P.S. 1966. The fauna of the River Endrick. Studies on Loch Lomond, 2. Publ. Univ. Glasgow. Blackie, Glasgow. 194 p.

Malaisse, F. 1976. Écologie de la rivière Luanza. In: J.J. Symoens, Exploration hydrobiologique du bassin du lac Bangweolo et du Luapula. Cercle Hydrobiologique de Bruxelles. Vol. XVII, 2. 135 p.

Malicky, H. 1978. Der Temperaturgang einiger niederösterreichischer Gebirgsbäche. Wetter und Leben 30: 170-183.

Mangelsdorf, J. & K. Scheurmann 1980. Flussmorphologie. Oldenbourg, München. 262 p.

Margalef, R. 1960. Ideas for a synthetic approach to the ecology of running waters. Int. Rev. Ges. Hydrobiol. 45: 133-153.

Marlier, G. 1951. La biologie d'un ruiseau de plaine: le Smohain. Mém. Inst. r. Sci. nat. Belg. 114: 1-98.

Marlier, G. 1953. Etude biogéographique de bassin de la Ruzizi, basée sur la distribution des poissons. Annls. Soc. r. zool. Belg. 84: 175-224.

Marlier, G. 1954. Recherches hydrobiologiques dans les rivières du Congo oriental II. Etude écologique. Hydrobiologia 6: 225-264.

Marlier, G. 1981. Trichoptères. In: J.J. Symoens, Exploration hydrobiologique du bassin du lac Bangweolo et du Luapula. Cercle Hydrobiologique de Bruxelles. Vol. XIV, 7. 70 p.

Marten, M. 1983. Die Ephemeropteren, Plecopteren, Heteropteren und Coleopteren der Fulda. Diplomarbeit, Freie Universität, Berlin.

Meyer, J.L. & J. O'Hop. Leaf-shredding insects as a source of dissolved organic carbon in headwater streams. Am. Midl. Nat. 109: 175-183.

Mills, E.L. 1969. The community concept in marine zoology, with comments on continua and instability in some marine communities: a review. J. Fish. Res. Board Can. 26: 1415-1428.

Minckley, W.L. 1963. The ecology of a spring stream Doe Run, Meade County, Kentucky. Wildl. Monogr. Chestertown 11. 124 p.

Minshall, G.W., J.T. Brock & T.W. LaPoint 1982. Characterization and dynamics of benthic organic matter and invertebrate functional feeding group relationships in the upper Salmon River, Idaho (USA). Int. Rev. ges. Hydrobiol. 67: 793-820.

Minshall, G.W., K.W. Cummins et al. 1985. Developments in stream ecosystem theory. Can. J. Fish. Aquat. Sci. 42: 1045-1055.

Minshall, G.W., R.C. Petersen, K.W. Cummins, T.L. Bot, J.R. Sedell, C.E. Cushing & R.L. Vannote 1983. Interbiome comparison of stream ecosystem dynamics. Ecol. Monogr. 53: 1-25.

Mitis, H. von 1938. Die Ybbs als Typus eines ostalpinen Kalkalpenfluss. Eine vorläufige Mitteilung. Int. Revue ges. Hydrobiol. 37: 425-444.

Mizuno, N. & H. Kawanabe 1981. A topographical classification of streams, with an introduction of the system widely used in Japan I. Reach types, stream zone and stream type (Abstract). Verh. Internat. Verein. Limnol. 21: 913.

Mollenhauer, D. 1984. Gewässertypologien und A. Thienemanns Beiträge zur heutigen Limnologie. Natur. Mus. 114: 192-198.

Möller, B. & H. Pankow 1981. Algensoziologische und saprobiologische Untersuchungen an Vorflutern der Elbe. Limnologica 13: 291-350.

Moon, H.P. 1938. Importance of the substratum to the invertebrate animals on which fish feed. Ann. Rep. Avon. Biol. Res. 6: 36-40.

Morariu, T., I. Pisota & I. Buta 1962. Hidrologia generala. Bucarest.

Mordukhai-Boltovskoi, P.D. 1979. Zoobenthos and other invertebrates living on substrata. The River Volga and its life. Junk, The Hague. p. 235-268.

Moretti, G.P. 1949. Valutazione biologica del fiume Potenza come esponente delle acque fluviali delle Marche. Verh. Int. Verein. theor. angew. Limnol. 10: 335-338.

Moretti, G.P. & F. Cianficconi 1984. Zonation of Trichoptera populations from the source to the mouth of the Tiber River (Central Italy, Rome).

Proceedings of the 4th International Symposium on Trichoptera, Clemson 1983 (Ed. J.C. Morse). Junk, The Hague. p. 243-252.

Mosley, M.P. 1982. Analysis of the effect of changing discharge on channel morphology and instream uses in a braided river: Ohau River, New Zealand. Water Resour. Res. 18: 800-812.

Müller, K. 1951. Fische und Fischregionen der Fulda. Ber. limnol. Fluss-station Freudenthal 2: 18-23.

Müller, K. 1954. Die Fischbesiedlung und die regionale Einstufung der Fliessgewässer der nordschwedischen Waldregion. Ber. limnol. Fluss-station Freudenthal 6: 51-56.

Müller, K. 1955. Produktionsbiologische Untersuchungen in nordschwedischen Fliessgewässern. Teil 3. Die Bedeutung der Seen und Stillwasserzonen für die Produktion in Fliessgewässern. Report of the Institute for Freshwater Research Drotningholm 36: 148-162.

Naumann, E. 1932. Grundzüge der regionalen Limnologie. In: Die Binnengewässer, Bd. 11, Stuttgart.

Newbury, R.W. 1984. Hydrologic determinants of aquatic insect habitats. In: V.H. Resh & D.M. Rosenberg (eds.), The Ecology of Aquatic Insects. Praeger, New York. p. 323-357.

Nicolau-Guillamet, P. 1959. Recherches faunistiques et écologiques sur la rivière 'la Massane'. Vie et Milieu 10: 217-266.

Nielsen, A. 1942. Über die Entwicklung und Biologie der Trichopteren. Arch. Hydrobiol. Suppl. 17: 255-631.

Nietzske, G. 1937. Die Kossau. Hydrobiologische-faunistische Untersuchungen an schleswig-holsteinischen FLiessgewässer. Arch. hydrobiol. 32: 1-74.

Nikolski, G.V. 1933. On the influence of the rate of flow on the fish fauna of the rivers of Central Asia. J. Anim. Ecol. 2: 266-281.

Noel, M.S. 1954. Animal ecology of a New Mexico spring brook. Hydrobiologia 6: 120-135.

Nowicki, M. 1889. Fishes of River Systems of Wisla, Styr, Dniestr and Prut in Galicja. KraAkow, Wydz, Krapjowy, Poland. iv + 55 p.

Odum, H.T. 1956. Primary production in flowing water. Limnol. & Oceanogr. 1: 102-117.

Ohle, W. 1937. Kalksystematik unserer Binnengewässer und Kalkgehalt Rügener Bache. Geol. Meere und Binnengew. 1: 291-316.

Oliff, W.D. 1960. Hydrobiological studies on the Tugela River System. Part I: The main Tugela River. Hydrobiologia 14: 281-385.

Oliff, W.D. 1963. Hydrobiological studies on the Tugela River System.

Part III: The Buffalo River. Hydrobiologia 21: 355-379.

Oliff, W.D. & J.L. King 1964. Hydrobiological studies on the Tugela River System. Part IV: The Mooi River. Hydrobiologia 24: 567-583.

Oliff, W.D., P.H. Kempf & J.L. King 1965. Hydrobiological studies on the Tugela River System. Part V: The Sundays River. Hydrobiologia 26: 189-202.

Otto, A. 1980. Gewässertypologie im ländlichen Raum. Unveröff. Zwischenbericht, Bundesanstalt für Gewässerkunde Koblenz: 1-107.

Pattee, E. 1980. Coefficients thermiques et écologie de quelques planaires d'eau douce. VII: Leur zonation naturelle. Annls. Limnol. 16: 21-41.

Pawlowski, L.K. 1948. Contribution à la systématique des sangsues du genre Erpobdella de Blainville. Pr. Łódź Tow Nauk 3: 54 p.

Pawlowski, L.K. 1959. Remarques sur la répartition de la faune torrenticole des Carpathes. Bull. Soc. Sci. Lett. Łódź. 3: 1-54.

Pennak, R.W. & E.D. van Gerpen 1947. Bottom fauna production and physical nature of the substrate in a northern Colorado trout stream. Ecology 28: 42-48.

Pennak, R.W. 1971. Towards a classification of lotic habitats. Hydrobiologia 38: 321-324.

Percival, E. & H. Whitehead 1929. A quantitative study of the fauna of some types of stream-bed. J. Ecol. 17: 282-314.

Percival, E. & H. Whitehead 1930. Biological survey of the River Wharfe. II. Report on the invertebrate fauna. J. Ecol. 17: 282-314.

Persoone, G. 1978. Proposal for a biotypological classification of watercourses in the European communities. In: James & Evison (eds.), Biological Indicators of Water Quality. Chapt. 7: 1-28.

Pomeisl, E. 1953. Der Mauerbach. Beiträge zur Limnologie der Wienerwaldbäche. Wetter und Leben, Sonderheft 2: 103-121.

Reice, S.R. 1984. The impact of disturbance frequency on the structure of lotic riffle community. Verh. Internat. Verein. Limnologie 22: 1906-1910.

Richardot-Coulet, M., P. Richoux & C. Roux 1983. Structure et fontionnement des écosystèmes du Haut-Rhône français. 29. Structure des peuplements de macroinvertébrés benthiques d'un ancien méandre. Arch. Hydrobiol. 96: 363-383.

Richardson, R.E. 1921. The small bottom and shore fauna of the Middle and Lower Illinois River and its connecting lakes, Chillicothe to Grafton: its valuation: its sources of food supply: and its relation to the fishery. Bull. Ill. St. nat. Hist. Survey 13: 363-522.

Ricker, W.E. 1934. An ecological classification of certain Ontario streams. Univ. Toronto Stud. biol. Ser. 37: 1-114.

Roll, H. 1938. Die Pflanzengesellschaften ostholsteinischer Fliessgewässer. Arch. Hydrobiol. 34: 159-305.

Rounick, J.S. & M.J. Winterbourn 1983. Leaf processing in two contrasting beech forest streams: effects of physical and biotic factors on litter breakdown. Arch. Hydrobiol. 96: 448-474.

Savage, N.L. & F.W. Rabe 1979. Stream types in Idaho: an approach to classification of streams in natural areas. Biol. Conserv. 15: 301-315.

Schalie, H. van der 1938. The naiad fauna of the Huron River, in south eastern Michigan. Misc. Publs. Mus. Zool. Univ. Mich. 40. 83 p.

Scheele, M. 1952. Systematisch-ökologische Untersuchungen über die Diatomeenflora der Fulda. Arch. Hydrobiol. 46: 305-424.

Schlosser, I.J. 1982. Fish community structure and function along two habitat gradients in a headwater stream. Ecol. monogr. 52: 395-414.

Schmassmann, W. 1955. Die Stoffhaushaltstypen der Fliessgewässer. Arch. Hydrobiol./Suppl. 22: 504-509.

Schmitz, W. 1955. Physiographische Aspekte der limnologischen Fliessgewässertypen. Arch. Hydrobiol./Suppl. 22: 510-523.

Schmitz, W. 1957. Die Bergbach-Zoozönosen und ihre Abgrenzung, dargestellt am Beispiel der oberen Fulda. Arch. Hydrobiol. 53: 465-498.

Schmitz, W. 1961. Fliesswässerforschung - Hydrographie und Botanik. Verh. Internat. Verein. Limnol. 14: 541-586.

Schräder, T. 1959. Zur Limnologie und Abwasserbiologie von Talsperren - Obere Saale. Int. Revue ges. Hydrobiol. 44: 486-619.

Schubart, O. 1953. Über einen subtropischen Fluss Brasiliens, den Mogi-Guassu, insbesondere seine physikalischen Bedingungen wie Wasserstand, Temperatur und Sichttiefe. Arch. Hydrobiol. 48: 350-430.

Schwerdfeger, F. 1975. Ökologie der Tiere. III. Synökologie. Parey, Hamburg, Berlin. 451 p.

Schwoerbel, J. 1961. Die Bedeutung der Wassermilben für die biozönotische Gliederung. Verh. Internat. Verein. Limnol. 14: 355-361.

Schwoerbel, J. 1969. Ökologie der Süsswassertiere. Fortschr. Zoologie 20: 173-206.

Scott, K.F.M. 1958. Hydrobiological studies on the Great Berg River. Part 4. The Chironomidae. Trans. R. Soc. S. Afr. 35: 277-298.

Sedell, J.R. & J.L. Froggatt 1984. Importance of streamside forests to large rivers: the isolation of the Willomette River, Oregon, U.S.A., from its floodplain by snagging and streamside forest removal. Verh. Internat. Verein. Limnol. 22: 1828-1834.

Sedell, J.R. & K.J. Luchessa 1982. Using the historical record as an aid to salmonid habitat enhancement. In: N.B. Armantrout (ed.), Acquisition and utilization of aquatic habitat inventory information. Western Division American Fisheries Society, Bethesda, MD. p. 210-223.

Seeger, W. 1971. Die Biotopwahl bei Halipliden, zugleich ein Beitrag zum Problem der syntopischen (sympatrischen s.str.) Arten (Haliplidae; Coleoptera). Arch. Hydrobiol. 69: 155-199.

Shadin, V.I. 1956. Life in rivers [Russian]. Jizni presnih vod SSSR, Moscow. 3: 113-256.

Shelford, V.E. 1918. Conditions of existence. In: Ward & Wipple, Freshw. Biol. New York. p. 21-60.

Sioli, H. 1975. Tropical rivers as expressions of their terrestrial environments. In: F.B. Golley & E. Medina (ed.), Tropical ecological systems. Springer, New York. p. 275-288.

Sioli, H. 1982. Tropische Flüsse in ihren Beziehungen zur terrestrischen Umgebung und im Hinblick auf menschliche Eingriffe. Arch. Hydrobiol. 95: 463-485.

Slack, K.V., J.W. Naumann & L.J. Tilley 1979. Benthic invertebrates in a north-flowing stream and a south-flowing stream, Brooks Range, Alaska. Water Resources Bulletin 15: 108-135.

Smissaert, H.R. 1959. Limburgse beken. Natuurhist. Maandblad 48: 7-78.

Smith, I.R. 1975. Turbulence in lakes and rivers. Freshwater Biol. Assoc. Sci. Publ. 29: 1-79.

Sobolev, L.N. & V.D. Utekhin 1979. Russian (Ramensky) Approaches to Community Systematization. In: R.H. Whittaker, Ordination of Plant Communities. Junk, The Hague. p. 71-98.

Someren V.D. van 1952. The biology of Trout in Kenya Colony. Government Printer, Nairobi. 114 p.

Sommani, E. 1953. Il concetto di 'zona ittica' e il suo reale significato ecologico. Boll. Pesca Piscic. Idrobiol. N.S. 7: 61-71.

Sowa, R. 1961. The bottom fauna of the River Bajerka. Acta Hydrobiol. 3: 1-32.

Sowa, R. 1965. Ecological characteristics of the bottom fauna of the Wielka Puszcza stream. Acta Hydrobiol. 7: 61-92.

Sprules, W.M. 1947. An ecological investigation of stream insects in Algonquin Park. Univ. Toronto Stud. Biol. Ser. 56: 1-81.

Stanford, J.A. & J.V. Ward 1983. Insect species diversity as a function of environmental variability and disturbance in stream systems. In: J.R. Barnes & G.W. Minshall (eds.), Stream ecology. Application and testing of general ecological theory. Plenum Press. New York. p. 265-278.

Statzner, B. 1975. Zur Longitudinalzonierung eines zentralafrikanischen Fliessgewässersystems unter besonderer Berücksichtigung der Köcherfliegen (Trichoptera, Insecta). Arch. Hydrobiol. 76: 153-180.

Statzner, B. 1976. Die Köcherfliegen-Emergenz (Trichoptera, Insecta) aus dem zentralafrikanischen Bergbach Kalengo. Arch. Hydrobiol. 78: 102-137.

Statzner, B. 1978. Factors that determine the benthic secondary production in two lake outflows - a cybernetic model. Verh. Internat. Verein. Limnol. 20: 1517-1522.

Statzner, B. 1981a. The relation between 'hydraulic stress' and the microdistribution of benthic macroinvertebrates in a lowland running water system, the Schierensee brooks (North Germany). Arch. Hydrobiol. 91: 192-218.

Statzner, B. 1981b. A method to estimate the population size of benthic macroinvertebrates in streams. Oecologia (Berl.) 51: 157-161.

Statzner, B. 1981c. Shannon-Weaver diversity of the macrobenthos in the Schierensee brooks (North Germany) and problems of its use for the interpretation of the community structure. Verh. Internat. Verein. Limnol. 21: 782-786.

Statzner, B. & B. Higler 1985. Questions and comments on the river continuum concept. Can. J. Fish. aquat. Sci 42: 1038-1044.

Statzner, B. & B. Higler 1986. Stream hydraulics as a major determinant of benthic invertebrate zonation patterns. Freshwat. Biol. 16: 127-139.

Steffan, A.W. 1960. Phylogenetische Trends in der Gattung Dryops (Dryopidae, Coleoptera). Int. Congr. Ent. 11: 97-103.

Steffan, A.W. 1965. Zur Statik und Dynamik im Ökosystem der Fliesgewässer und zu den Möglichkeiten ihrer Klassifizierung. In: R.Tüxen (ed.), Biosoziologie. Junk, Den Haag. p. 65-110.

Steffan, A.W. 1974. Die Lebensgemeinschaft der Gletscherbach-Zuckmücken (Diptera: Chironomidae) - eine Extrembiozönose. Entomologisk Tidskrift, Supplement 95: 225-232.

Steinböck, O. 1942. Das Verhalten von Planaria alpina Dana in der Natur und im Laboratoriumversuch. Mem. Ist. ital. Idrobiol. 1: 63-75.

Steinmann, P. 1915. Praktikum der Süsswasserbiologie. 1. Die Organismen des fliessenden Wassers. Berlin.

Stjerna-Pooth, I. 1981. Die Rolle der Benthosorganimen bei der Klassifizierung von Fliesgewässern. Limnologica 13, 2: 351-362.

Stoneburner, D.L. 1977. Preliminary observations of the aquatic insects of the Smoky Mountains: altitudinal zonation in the spring. Hydrobiologia 56: 137-143.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. Trans. Am. Geophys. Union 38: 913-920.

Straskraba, M. 1966. On the distribution of the macrofauna and fish in two streams, Lucina and Morávka. Arch. Hydrobiol. 61: 515-536.

Stroot, Ph. 1984. Faunistique et répartition longitudinale des Trichoptères dans une rivière salmonicole de basse montagne, en Belgique. Hydrobiologia 108: 245-258.

Sutcliffe, D.W. & T.R. Carrick 1973. Studies on mountain streams in the English Lake District I, II and III. Freshwater Biol. 3: 437-462, 543-560, 561-568.

Tansley, A.C. 1939. The British Islands and their Vegetation. Cambridge University Press. 930 p.

Taylor, B.R. & J.C. Roff 1982. Evaluation of ecological maturity in three headwater streams. Arch. Hydrobiol. 94: 99-125.

Thienemann, A. 1920. Die Grundlagen der Biozönotik und Monards faunistische Prinzipien. Festschrift für Zschokke 4: 1-14.

Thienemann, A. 1925. Die Binnengewässer Mitteleuropas. Die Binnengewässer 1: 54-83.

Thienemann, A. 1926. Hydrobiologische Untersuchungen an den kalten Quellen und Bächen der Halbinsel Jasmund auf Rügen. Arch. Hydrobiol. 17: 221-336.

Thienemann, A. 1936. Alpine Chironomiden. Arch. Hydrobiol. 30: 167-262.

Thienemann, A. 1950. Verbreitungsgeschichte der Süsswassertierwelt Europas. Die Binnengewässer 18: 1-809, Stuttgart.

Thienemann, A. 1954. Chironomus. Leben, Verbreitung und wirtschatftliche Bedeutung der Chironomiden. Die Binnengewässer 20, Stuttgart.

Tischler, W. 1949/1951. Zur Synthese biozönotischer Forschung. Acta biotheoret. 9: 135-162.

Towns, D.R. 1979. Composition and zonation of benthic invertebrate communities in a New Zealand kauri forest stream. Freshwater Biol. 9: 251-262.

Towns, D.R. 1983. Life history patterns of six sympatric species of

Leptophlebiidae (Ephemeroptera) in a New Zealand stream and the role of interspecific competition in their evolution. Hydrobiologia 99: 37-50.

Townsend, C.R. & A.G. Hildrew 1984. Longitudinal pattern in detritivore communities of acid streams: a consideration of alternative hypotheses. Verh. Internat. Verein. Limnol. 22: 1953-1958.

Triska, F.J. 1984. Role of wood debris in modifying channel geomorphology and riparian areas of a large lowland river under pristine conditions: a historical case study. Verh. Intern. Verein. Limnol. 22: 1876-1892.

Uéno, M. 1938. Bottom fauna of lake Abasiri and the neighbouring waters in Hokkaido. Trans. Sapporo nat. Hist. Soc. 15: 140-167.

Ulfstrand, S. 1967. Microdistribution of benthic species (Ephemeroptera, Plecoptera, Trichoptera, Diptera, Simuliidae) in Lapland streams. Oikos 18: 293-310.

Ulfstrand, S. 1968. Benthic animal communities in Lapland streams. Oikos Suppl. 10: 1-117.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell & C.E. Cushing 1980. The River Continuum Concept. Can. J. Fish. Aquat. Sci. 37: 130-137.

Verneaux, J. 1973. Cours d'eau de Franche-Comté (Massif du Jura). Faculté des Sciences de Besançon. 257 p.

Verneaux, J. & G. Tuffery 1967. Une méthode pratique de détermination de la qualité biologique des eaux courantes. - Indices biotiques - Ann. Sci. Univ. Besançon Zool. 3: 79-90.

Vonnegut, P. 1937. Die Barbenregion der Ems. Arch. Hydrob. 32: 345-408.

Wachs, B. 1968. Die Bodenfauna der Fliessgewässer in Beziehung zu den bedeutendsten Substrattypen. Wasser und Abwasserforschung 4: 124-134.

Wallace, J.B., J.R. Webster & W.R. Woodall 1977. The role of filter feeders in flowing waters. Arch. Hydrobiol. 79: 506-532.

Wallace, J.B., J.R. Webster & T.F. Cuffney 1982. Stream detritus dynamics: regulation by invertebrate consumers. Oecologia (Berl.) 53: 197-200.

Ward, J.V. & L. Berner 1980. Abundance and altitudinal distribution of Ephemeroptera in a Rocky Mountain stream. In: J.F. Flannagan & K.E. Marshall (eds.), Advances in Ephemeroptera Biology. Plenum Press, New York. p. 169-177.

Ward, J.V. 1981. Altitudinal distribution and abundance of Trichoptera in a Rocky Mountain stream. Series Entomologica 20: 375-381.

Ward, J.V. 1982. Altitudinal zonation of Plecoptera in a Rocky Mountain stream. Aquatic Insects 4: 105-110.

Ward, J.V. & J.A. Stanford 1983. The serial discontinuity concept of lotic ecosystems. In: T.D. Fontaine & S.M. Bartell (eds.), Dynamics of lotic ecosystems. Ann Arbor Science Publishers Inc., Ann Arbor, MI. p. 29-42.

Ward, J.V. 1986. Altitudinal zonation in a Rocky Mountain stream. Arch. Hydrobiol. Suppl. 74: 133-199.

Weber-Oldecop, D.W. 1970/1971. Wasserpflanzengesellschaften im östlichen Niedersachsen (I) + (II). Int. Rev. ges. Hydrobiol. 55: 913-967; 56: 79-122.

Weber-Oldecop, D.W. 1977. Fliessgewässertypologie in Niedersachsen auf floristisch-soziologischer Grundlage. Göttinger Florist-Rd.-Briefe 10: 73-79.

Weber-Oldecop, D.W. 1981. Eine Fliessgewässer-Typologie. Limnologica 13: 419-426.

Webster, J.R. 1975. Analysis of potassium and calcium dynamics in stream ecosystems on three southern Appalachian watersheds of contracting vegetation. Unpubl. Ph. D. thesis Univ. Georgia, Athens. 232 p.

Webster, J.R. 1983. The role of benthic macroinvertebrates in detritus dynamics of streams: a computer simulation. Ecol. Monogr. 53: 383-404.

Whittaker, R.H. 1975.Communities and Ecosystem. MacMillan, New York. 387 p.

Whittaker, R.H. 1978a. Classification of plant communities. Junk, The Hague. 408 p.

Whittaker, R.H. 1978b. Ordination of Plant Communities. Junk, The Hague. 388 p.

Wiegleb, G. 1981. Struktur, Verbreitung und Bewertung von Makrophyten-gesellschaften niedersächsischer Fliessgewässer. Limnologica 13, 2: 427-448.

Williams, D.D. & H.B.N. Hynes 1977. The Ecology of Temporary Streams. II. General Remarks on Temporary Streams. Int. Revue ges. Hydrobiol. 62, 1: 53-61.

Wilser, J.L. 1937. Beziehungen des Flussverlaufes und der Gefällskurve des Neckars zur Schichtenablagerung am Südrand des Odenwaldes. Akad. Wiss. Math. Naturwiss. Kl. (Heidelberg) 37: 3-16.

Winkler, O. 1963. Beitrag zur Kenntnis der Bodenfauna der oberen Moldau vor der Errichtung der Talsperre in Lipno. Acta Univ. Carol. Biol. 1963: 85-101.

Winterbourn, M.J. 1982. The River Continuum Concept - a reply to Barmuta and Lake. N.Z. J. Mar. Freshwater Res. 16: 229-231.

Winterbourn, M.J., J.S. Rouninck & B. Cowie 1981. Are New Zealand stream ecosystems really different? N.Z. J. Mar. Freshwater Res. 15: 321-328.

Wright, J.F., P.D. Armitage, M.T. Furse & D. Moss 1984. The classification of sites on British rivers using macroinvertebrates. Verh. Internat. Verein. Limnol. 22: 1939-1943.

Wright, J.F., D. Moss, P.D. Armitage & M.T. Furse 1984. A preliminary classification of running-water sites in Great Britain based on macro-invertebrate species and the prediction of community type using environmental data. Freshwater Biol. 14: 221-256.

Zahner, R. 1959. Über die Bindung der mitteleuropäischen Calopteryx-Arten (Odonata, Zygoptera) an den Lebensraum des strömenden Wassers. I. Der Anteil der Larven an der Biotopbindung. Int. Revue ges. Hydrobiol. Hydrogr. 44: 51-130.

Zwick, H. 1974. Faunistisch-ökologische und taxonomische Untersuchungen an Simuliidae (Diptera), unter besonderer Berücksichtigung der Arten des Fulda-Gebietes. Abh. senckenb. naturforsch. Ges. 533:1-116.

REFERENCES OF GENERAL LITERATURE AND LITERATURE ON STAGNANT WATERS

The * marked references are not mentioned in the text, but contain useful information.

Aagaard, K. 1986. The chironomid fauna of North Norwegian lakes, with a discussion on methods of community classification. Holartct Ecol. 9: 1-12.

Alm, G. 1922. Bottenfaunan och fiskens biologi i Yxtasjön (Die Bodenfauna des Sees Yxtasjön) (Schw). Medd. fr. Kungl. Lantbruksstyrelsen 236, Stockholm.

Almquist, E. 1929. Upplands vegetation och flora. Acta Phytogeogr. Suec. 1: 1-624.

*Alonso, M. & M. Comelles 1984. A preliminary grouping of the small epicontinental water bodies in Spain and distribution of Crustacea and Charophyta. Verh. Internat. Verein. Limnol. 22: 1699-1703.

Alsterberg, G. 1930. Die thermischen und chemischen Ausgleiche in den Seen zwischen Boden- und Wasserkontakt sowie ihre biologische Bedeutung. Int. Revue ges. Hydrobiol. Hydrogr. 24: 290-327.

*Alzaki, M, A. Otsuki, T. Fukushima, M. Hosomi & K. Muraoka 1981. Application of Carlson's trophic state index to Japanese lakes and relationships between the index and other parameters. Verh. Internat. Verein. Limnol. 21: 675-681.

Berg, K. 1938. Studies on the bottom animals of Esrom Lake. K. danske Vidensk. Selsk. Naturv. Math. Avd. 8: 1-255.

Berg, K. & I.B.C. Petersen 1956. Studies on the humic acid Lake Gribso. Folia limnol. scand. 8: 1-273.

Blomgren, N. & E. Naumann 1925. Untersuchungen über die höhere Vegetation des Sees Straken bei Aneboda. Acta Univ. Lund N.F. Avd 2 Bd. 21: 6, 51 p.

Braak, C.J.F. ter 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. Ecology 67: 1167-1179.

Braarud, T. 1932. Die höhere Vegetation einiger Seen in Nord-Trondelag Fylke (Norwegen). Nyv. Mag. f. Naturv. 71: 73-93.

Braarud, T. & O.J. Aalen 1938. Undersokelser over makrovegetasjonen i indel Aust-Agder-vatn. Nyt. Mag. of Naturv. 79: 1-48.

*Brinkhurst, R.O. 1964. Observations on the biology of the lake dwelling Tubificidae. Arch. Hydrobiol. 60: 385-418.

*Brinkhurst, R.O. & B. Walsh 1967. Rostherne Mere, England, a further instance of guanotrophy. J. Fish. Res. Bd. Canada 24: 1299-1313.

Brinkhurst, R.O. 1974. The benthos of lakes. St. Martin's Press, New York. 190 p.

*Brinkhurst, R.O. & B.G.M. Jamieson 1971. The aquatic Oligochaeta of the world. Oliver & Boyd, Edinburgh. 860 p.

Brundin, L. 1942. Zur Limnologie jämtländischer Seen. Mitt. Anst. Binnenfisch. Drottningholm, Stockholm. 20: 1-104.

Brundin, L. 1949. Chironomiden und andere Bodentiere der Südschwedischen Urgebirgsseen. Rep. Inst. Freshwat. Res. Drottningholm 30: 1-914.

Brundin, L. 1956. Die bodenfaunistischen Seetypen und ihre Anwendbarkeit auf die Südhalbkugel. Zugleich ein Theorie der produktionbiologischen Bedeutung der glazialen Erosion. Rep. Inst. Freshwat. Res. Drottningholm 37: 186-235.

Canfield, D.E.Jr, K.A. Langeland, M.J. Maceina, W.T. Haller, J.V. Shireman & J.R. Jones 1983. Trophic state classification of lakes with aquatic macrophytes. Can. J. Fish. Aquat. Sci. 40: 1713-1718.

Cedercreutz, C. 1947. Die Gefässpflanzenvegetation der Seen auf Aland. Acta Bot. Fenn. 38: 1-77.

*Chacornac, J.M. 1984. Towards a typology of altitude lakes. Revue fr. Sci. Eau 3, 4: 439.

*Chapra, S.C. & H.F.H. Dobson 1981. Quantification of the lake trophic typologies of Naumann (surface quality) and Thienemann (oxygen) with special reference to the Great Lakes. J. Gt. Lakes Res. 7: 182-193.

Charlson, R.J. & H. Rohde 1983. Factors controlling the acidity of natural rainwater. Nature 295: 683-685.

Chorley, R.J. (ed.) 1969. Water, earth, and man. Methuen, London. 588 p.

Dambska, I. 1984. Les changements observés dans les lacs des différents types limnologiques dans l'Ouest de la Pologne. Verh. Internat. Verein. Limnol. 22: 970-972.

Decksbach, N.K. 1929. Über verschiedene Typenfolgen der Seen. Arch. Hydrobiol. 20: 65-80.

Deevey, E.S. 1941. Limnological studies in Connecticut. VI. The quantity and composition of the bottom fauna of thirty-six Connecticut and New York lakes. Ecol. Monogr. 11: 413-455.

Donat, A. 1926. Die Vegetation unserer Seen und die 'biologischen See-typen'. Ber. Deutsch. Bot. Ges. 44: 48-56.

Dresscher, T.G.N. & H. van der Mark 1976. A simplified method for the biological assessment of the quality of fresh and slightly brackish water. Hydrobiologia 48: 199-201.

*Dussart, B.H. 1963. Les grands lacs d'Europe occidentale. Année biologique T. II: 499-572.

Elster, H.J. 1958. Das limnologische Seetypensystem, Rückblick und Ausblick. Verh. Internat. Verein. Limnol. 13: 101-120.

*Elster, H.J. 1962. Seetypen, Fliessgewässertypen und Saprobiensystem. Int. Revue ges. Hydrobiol. Hydrogr. 47: 211-218.

*Elster, H.J. 1966. Über die limnologischen Grundlagen der biologischen Gewässerbeurteilung in Mitteleuropa. Verh. Internat. Verein. Limnol. 16: 759-785.

*Estrada, M. 1975. Statistical considerations of some limnological parameters in Spanish reservoirs. Verh. Internat. Verein. Limnol. 22: 1849-1859.

*Forsberg, C. & S. Ryding 1980. Eutrophication parameters and trophic state indices in 30 Swedish waste-receiving lakes. Arch. Hydrobiol. 89, 1/2: 189-207.

*Griffiths, J.F. 1959. Bioclimatory and the meteorological services. Proc. Symp. Trop. Meteor. Africa, Munitalp Foundation and World Metereological Organisation, Nairobi, Kenya: 282-300.

Grigelis, A. 1985. Biological classification of Lithuanian lakes. Acta Hydrobiologica Lituanica 5: 21-26.

Hammer, U.T. 1986. Saline ecosystems of the world. Monographiae biologicae 59. Junk, Dordrecht. 616 p.

Hartmann, L. & R. Jourdan 1987. Behandlung und Verwertung von Prozess-abwässern der Kartoffelverarbeitung. Heft 19. Inst. f. Ingenieurbiologie u. Biotechn. Abw., Univ. Karlsruhe.

Hauge, H.V. 1957. Vagnsvatn and some other lakes near Voss. Folia Limnol. Scand. 9. 189 p.

Havas, M. 1981. Physiological response of aquatic animals to low pH. In: R. Singer (ed.), Effects of acidic precipitation on benthos. Proc. Symp. Colgate University, Hamilton, N.Y. August 8-9-1980. p. 49-65. N.A.B.S.

Higler, L.W.G. 1981. Beken in Nederland. Natuur & Milieu 1981, 11/12: 4-8.

Higler, L.W.G. & F.F. Repko 1981. The effects of pollution in the drainage area of a Dutch lowland stream on fish and macro-invertebrates. Verh. Internat. Verein. Limnol. 21: 1077-1082.

Hilsenhoff, W.L. & R.P. Narf 1968. Ecology of Chironomidae, Chaoboridae, and other benthos in fourteen Wisconsin lakes. Ann. ent. Soc. Am. 61: 1173-1181.

Hörnström, E. 1981. Trophic characterization of lakes by means of qualitative phytoplankton analysis. Limnologica 13, 2: 249-261.

Hussainy, S.U. 1969. Ecological studies of some microbiota of lakes in Western Victoria. Ph.D. Thesis, Monash University, Melbourne.

Hutchinson, G.E. 1957. A treatise on Limnology. Vol. I. Geography, physics and chemistry. Wiley, New York.

*Hutchinson, G.E. 1973. Eutrophication - the scientific background of a contemporary practical problem. Am. Sci. 61: 269-279.

Hutchinson, G.E. & H. Löffler 1956. The thermal classification of lakes. Proc. Nat. Acad. Sci. 42: 84-86.

Iltis, A. 1974. Phytoplancton des eaux natronées du Kanem (Tchad). VII Structure des peuplements. Cahiers ORSTOM, sér. Hydrobiol. 8: 51-76.

Iversen, J. 1929. Studien über die pH-Verhältnisse dänischer Gewässer und ihren Einfluss auf die Hydrophyten-Vegetation. Bot. Tidsskr. 40: 277-333.

*Jaatinen, S. 1951. Bidrag till kännedomen om de aländska sjöarnas strandvegetation. Acta Bot. Fenn. 45: 1-354.

Jackson, I.J. 1977. Climate, water and agriculture in the tropics. Longman, London & New York. 248 p.

Järnefelt, H. 1925. Zur Limnologie einiger Gewässer Finnlands. I. Ann. Soc. zool-bot. fenn. Vanamo 2: 185-356.

Järnefelt, H. 1953. Die Seetypen in bodenfaunistischer Hinsicht. Ann. Soc. zool-bot. fenn. Vanamo 15: 1-38.

Jensén, S. 1978. Sampling methods and numerical treatments applied to a classification of lakes in southern Sweden based on macrophyte composition. Thesis Dept. of Plant Ecology, Univ. of Lund.

Jensén, S. 1979. Classification of lakes in Southern Sweden on the basis of their macrophyte composition by means of multivariate methods. Vegetatio 39: 129-146.

Johnson, M.G., J.H. Leach, C.F. Minss & C.H. Olver 1977. Limnological characteristics of Ontario lakes in relation to associations of Walleye (Stizostedion vitreum vitreum), Northern Pike (Esox lucius), Lake Trout (Salvelinus namaycush), and Smallmouth Bass (Micropternus dolomieui). J. Fish. Res. Board Can. 34: 1592-1601.

*Jonasson, P.M. 1963. The growth of Plumatella repens and P. fungosa (Bryozoa, Ectoprocta) in relation to external factors in Danish eutrophic lakes. Oikos 14: 121-137.

*Jonasson, P.M. 1964. The relationship between primary production of profundal bottom invertebrates in a Danish eutrophic lake. Verh. Int. Verein. Limnol. 15: 471-479.

*Jonasson, P.M. & J. Kristiansen 1967. Primary and secondary production in Lake Esrom. Growth of Chironomus anthracinus in relation to seasonal cycles of phytoplankton and dissolved oxygen. Int. Revue ges. Hydrobiol. Hydrogr. 52: 163-217.

Kansanen, P.H., J. Aho & L. Paasivirta 1984. Testing the benthic lake type concept based on chironomid associations in some Finnish lakes using multivariate statistical methods. Ann. Zool. Fennici 21: 55-76.

Kersting, K. 1983. Bimodal diel dissolved oxygen curves and thermal stratification in polder ditches. Hydrobiologia 107: 165-168.

Kuznetsov, S.I. 1970. The microflora of lakes and its geochemical activity. University of Texas Press, Austin & London. 503 p.

Lamoot, E. 1977. Données limnologiques sur quelques écosystèmes aquatiques caratéristiques de la région de Lamto (Côte d'Ivoire). Le milieu et la faune héléoplanctonique. Ann. Univ. Abidjan, E.X.: 27-41.

Lang, K. 1931. Faunistisch-ökologische Untersuchungen in einigen seichten oligotrophen bzw. dystrophen Seen in Südschweden mit besonderer Berücksichtigung der Profundalfauna. Lunds Univ. Arsskrift N.F. Avd. 27: 1-175.

Larson, D.J. 1985. Structure in temperate predaceous diving beetle communities (Coleoptera: Dytiscidae). Holarct. Ecol. 8: 18-32.

Lastockin, D. 1931. Beiträge zur Seetypenlehre. Arch. Hydrobiol. 22: 546-579.

*Leentvaar, P. 1967. Observations in guanotrophic environments. Hydrobiologia 29: 441-489.

*Legendre, P., F. Long & A. Beauvais 1980. Ecological typology of a group of lakes in northwestern Quebec. Annls. Limnol. 16: 135-158.

Lenz, F. 1925. Chironomiden u. Seetypenlehre. Naturwissenschaften 13: 5-10.

*Lenz, F. 1927. Chironomiden aus Norwegischen Hochgebirgsseen. Zugleich ein Beitrag zur Seetypenfrage. Nyt Magasin for Naturvidenskaberna 62.

Lenz, F. 1928a. Chironomiden aus Norwegischen Hochgebirgsseen. Zugleich ein Beitrag zur Seetypenfrage. Nyt Mag. Naturvid. 66: 111-192.

Lenz, F. 1928b. Ökologische Chironomidentypen. Biol. Listy 14: 413-422.

Lenz, F. 1933. Das Seetypenproblem und seine Bedeutung für die Limnologie

IV. Hydrologische Konf. Balt. Staat. 1-13, Leningrad.

Lewis, W.M. Jr. 1983. A revised classification of lakes based on mixing. Can. J. Fish. Aquat. Sci. 40: 1779-1787.

Linkola, K. 1916. Studien über den Einfluss der Kultur auf die Flora in den Gegenden nördlich von Ladogasee I. Allgemeiner Teil. Akad. Sc. Fauna Flora Fenn. 45: 1-149.

Lohammar, G. 1938. Wasserchemie und höhere Vegetation schwedischer Seen. Symb. Bot. Ups. III: I. Uppsala.

Lundbeck, J. 1926. Die Bodentierwelt norddeutscher Seen. Arch. Hydrobiol. Suppl. 7: 1-473.

Lundbeck, J. 1936. Untersuchungen über die Bodenbesiedlung der Alpenrandseen. Arch. Hydrobiol. Suppl. 10: 208-358.

Lundh, A. 1951a. Studies on the vegetation and hydrochemistry of Scanian lakes I. Higher aquatic vegetation. Bot. Notiser Suppl. 2: 1-141.

Lundh, A. 1951b. Studies on the vegetation and hydrochemistry of Scanian lakes III. Distribution of macrophytes and some algal groups. Bot. Notiser Suppl. 3: 138 p.

Margalef, R. 1958. 'Trophic' typology versus biotic typology, as exemplified in the regional limnology of Northern Spain. Verh. Int. Verein. Limnol. 13: 339-349.

*Margalef, R. 1975. Typology of reservoirs. Verh. Internat. Verein. Limnol. 19: 1841-1848.

Maristo, L. 1941. Die Seetypen Finnlands auf floristischer und vegetationsfysionomischer Grundlage. Ann. Bot. Soc. Zool. Bot. Fenn. Vanamo 15, 5. 314 p.

Marshall, E.J.P. 1981. The ecology of a land drainage channel 1. Oxygen balance. Wat. Res. 15: 1075-1085.

Mathiesen, H. 1969. Soernes plante. In: Danmarks Natur, Band 5. De ferske Vande: 237-280. Politikens Forlag, Kopenhagen.

Miyada, D. 1933. Studies on the bottom fauna of Japanese lakes: X. Regional characteristics and a system of Japanese lakes based on the bottom fauna. Jap. J. Zool. 4: 417-437.

*Montecino, V. & S. Cabrera 1984. Limnological pilot project for the characterization of temporate lakes in Central Chile. Verh. Int. Verein. Limnol. 22: 1332-1334.

Murphy, S.M., B. Kessel & L.J. Vining 1984. Waterfowl populations and limnologic characteristics of Taiga ponds. J. Wildl. Manage. 48: 1156-1163.

*Naumann, E. 1919. Nagra synpunkter angaende planktons ökologi. Medd.

sarskild hänsyn till fytoplankton. Svensk. bot. Tidskr. 13: 129-158.

Naumann, E. 1931. Limnologische Terminologie. Urban & Schwarzenberg, Berlin. 776 p.

*Naumann, E. 1932. Grundzüge der regionalen Limnologie. Die Binnengewässer Bd. 11. Stuttgart.

Nygaard, G. 1949. Hydrobiological studies on some Danish ponds and lakes: Part II. The quotient hypothesis and some of the little known phyto-plankton organisms. Biol. Skrifter 7: 1-293.

Nygaard, G. 1958. On the productivity of the bottom vegetation in Lake Grane Langso. Verh. Internat. Verein. Limnol. 13.

Odum, E.P. 1971. Fundamentals of Ecology. 3rd ed., Saunders, Philadelphia.

Ohle 1958. Die Stoffwechseldynamik der Seen in Abhängigkeit von der Gasausscheidung ihres Schlammes. Vom Wasser 25: 127-194.

Pagast, F. 1943. Über die Bodenchironomiden des Lunzer Untersees. Int. Revue ges. Hydrobiol. Hydrogr. 43: 470-479.

Patalas, K. 1971. Crustacean plankton communities in forty-five lakes in the Experimental Lakes Area, northwestern Ontario. J. Fish. Res. Bd. Canada 28: 231-244.

Pearsall, W.H. 1921. The development of vegetation in the English lakes, considered in relation to the general evolution of glacial lakes and rock basins. Proc. R. Soc. 92: 259-284.

Pearsall, W.H. & W.H. Pearsall 1925. Phytoplankton of the English lakes. Journ. Limn. Soc. Bot. 97: 55-73.

*Pennak, R.W. 1958. Regional lake typology in northern Colorado U.S.A. Verh. Int. Verein. Limnol. 13: 264-283.

Pesta, O. 1929. Der Hochgebirgssee der Alpen. Binnengewässer 8: 1-156. Stuttgart.

Reiersen, J. 1942. Investigations of the freshwater vegetation of Southern Tromsø. Tromsø Mus. Aarsb. 61: 2-BF.

Remane, A. 1934. Die Brackwasserfauna. Zool. Anz. Suppl. 7: 34-74.

Reynolds, C.S. 1984. Phytoplankton periodicity: the interactions of form, function and environmental variability. Freshwat. Biol. 14: 111-142.

Reynoldson, T.B. 1958. Triclads and lake typology in northern Britain. Qualitative aspects. Verh. Int. Verein. Limnol. 13: 320-330.

Ringelberg, J. 1981. Introduction to the research area. Hydrobiol. Bull. 15: 5-9.

Rintanen, T. 1982. Botanical lake types in Finnish Lapland. Ann. Bot. Fennici 19: 247-274.

*Rohde, W. 1949. The ionic composition of lake waters. Verh. Int. Verein. Limnol. 10: 377-386.

Rohde, W. 1958. Primärproduktion und Seetypen. Verh. Int. Verein. Limnol. 13: 121-141.

Rosén, G. 1981. Phytoplankton indicators and their relation to certain chemical and physical factors. Limnologica 13, 2: 263-290.

Rott, E. 1984. Phytoplankton as biological parameter for the trophic characterization of lakes. SIL 22: 1078-1085.

Round, F.E. 1958. Algal aspects of lake typology. Verh. Int. Verein. Limnol. 13: 306-310.

Ruttner, F. 1952. Planktonstudien der Deutschen Limnologischen Sunda-Expedition. Arch. Hydrobiol., Suppl. 21: 1-274.

*Ryder, R.A. 1965. A method for estimating the potential fish production of north-temperate lakes. Trans. Ann. Fish. Soc. 94: 214-218.

Saether, O.A. 1975. Nearctic chironomids as indicators of lake typology. Verh. Int. Verein. Limnol. 19: 3127-3133.

Saether, O.A. 1979. Chironomid communities as water quality indicators. Holarct. Ecol. 2: 65-74.

Samuelsson, G. 1925. Untersuchungen über die höhere Wasserflora von Dalarme. Svenska Växtsociologiska sällskapets Handlingar IX: 31 p.

Sauer, F. 1937. Die Makrophytenvegetation ostholsteinischer Seen und Teiche. Archiv. Hydrobiol. Suppl. Bd. 6: 431-574.

Savage, A.A. 1982. Use of waterboatmen (Corixidae) in the classification of lakes. Biological Conservation 23: 55-70.

*Schanz, F. 1984. Chemical and algological characteristics of five high mountain lakes near the Swiss National Park. Verh. Int. Verein. Limnol. 22: 1066-1070.

Schleuter, A. 1985. Untersuchungen der Makroinvertebratenfauna stehender Kleingewässer des Naturparks Kottenforst-Ville unter besonderer Berücksichtigung der Chironomidae. Thesis Bonn. 217 p.

Schroevers, P.J. 1966. Kontakt zwischen oligotroph und eutroph in einem Hochmoorgebiet. Verh. Int. Verein. Limnol. 16: 612-618.

*Sprules, W.G. 1984. Towards an optimal classification of zooplankton for lake ecosystem studies. Verhand. Int. Verein. Limnol. 22: 320-325.

Stahl, J.B. 1959. The developmental history of the chironomid and chaoborus faunas of Myers Lake. Invest. Indiana Lakes Streams 5: 47-102.

Stahl, J.B. 1966. Characteristics of North America Sergentia lake. Gewässer und Abwässer 41/42: 95-122.

Steinböck, O. 1953. Ein neurer Seetyp: der kryoeutrophe See. Mem. Ist. Ital. Idrobiol. 7: 153-163.

Steinböck, O. 1958. Grundsäzliches zum 'kryoeutrophen' See. Verh. Int. Verein. Limnol. 13: 181-190.

*Suzuki, S. 1981. Characteristics of the distribution of aquatic phycomycetes in the bottom muds of Japanes lakes. Environ. Pollut. Ser. A. 25: 249-257.

Talling, J.F. 1984. An overview of phytoplankton seasonality in African lakes. Verh. Int. Verein. Limnol. 22: 1174.

Talling, J.F. & I.B. Talling 1965. The chemical composition of African lake waters. Int. Revue ges. Hydrobiol. 50: 421-463.

Thienemann, A. 1913. Der Zusammenhang zwischen dem Sauerstoffgehalt des Tiefenwassers und der Zusammensetzung der Tierfauna unserer Seen. Int. Revue ges. Hydrobiol. Hydrogr. 6: 243-249.

Thienemann, A. 1918. Untersuchungen über die Beziehungen zwischen dem Sauerstoffgehalt des Wassers und der Zusammensetzung der Fauna in Norddeutschen Seen. Arch. Hydrobiol. 12: 1-65.

Thienemann, A. 1925. Die Binnengewässer Mitteleuropas. Eine limnologische Einführung. Binnengewässer 1: 1-255.

Thienemann, A. 1931. Tropische Seen und Seetypen. Arch. Hydrobiol. Suppl. 9: 205-231.

Thienemann, A. 1954. Chironomus Leben. Verbreitung und wirtschaftliche Bedeutung der Chironomiden. Binnengewässer 20: 1-834.

Thunmark, S. 1945. Zur Soziologie des Süsswasserplanktons. Eine methodologische ökologische Studie. Fol. Limnol. Skand. 3.

Tonn, W.M., J.J. Magnuson & A.M. Forbes 1983. Community analysis in fishery management: an application with Northern Wisconsin lakes. Trans. Amer. Fish. Soc. 112: 368-377.

Torenbeek, R., P.F.M. Verdonschot & L.W.G. Higler 1987. Biologische effecten van vergroting van waterinlaat in Drenthe. RIN-rapport 87/20. Rijksinstituut voor Natuurbeheer, Leersum. 76 p. + annexes.

*Tundisi, J.G. 1981. Typology of reservoirs in Southern Brazil. Verh. Int. Verein. Limnol. 21: 1031-1039.

Unesco 1978. World water balance and water resources of the earth. Unesco Press.

Valle, K.J. 1927. Ökologisch-limnologische Untersuchungen über die Boden- und Tiefenfauna in einigen Seen nördlich vom Ladogasee I. Acta zool. fennica 2, Helsingforsiae.

Vallentyne, J.R. 1972. Freshwater supplies and pollution: effects of the demophoric explosion on water and man. In: N. Polunin (ed.), The Environmental Future. MacMillan Press: 181-211.

Walter, H. & S.W. Breckle 1983. Oekologie der Erde Bd. I. Oekologische Grundlagen in globaler Schicht. Fischer, Stuttgart.

Ward, J.V. 1985. Thermal characteristics of running waters. Hydrobiologia 125: 31-46.

Wiederholm, T. 1980. Use of benthos in lake monitoring. J. Water Poll. Contr. 52: 537-547.

Wiggins, G.B., R.J. Mackay & I.M. Smith 1980. Evolutionary and ecological strategies of animals in annual temporary pools. Arch. Hydrobiol./Suppl. 58: 97-206.

Williams, W.D. 1964. A contribution to lake typology in Victoria, Australia. Verh. Int. Verein. Limnol. 15: 158-168.

*Yoshimura, S. 1936. A contribution to the knowledge of deep water temperatures of Japanese lakes. Jap. J. Astr. Geophys. 13: 61-120; 14: 57-83.

APPENDIX II

Ecological types of running water based on stream hydraulics in The Netherlands

HYDROBIOLOGICAL BULLETIN 18(1): 51 - 57 (1984)

ECOLOGICAL TYPES OF RUNNING WATER BASED ON STREAM HYDRAULICS IN THE NETHERLANDS

L.W.G. HIGLER and A.W.M. MOL

INTRODUCTION

In common parlance one speaks of streams and rivers, meaning smaller and larger running waters. For many purposes however, a more detailed division in running waters is needed and here the problem of the definition of types arises. One of these purposes is the water quality assessment by means of biological criteria which requires frames of reference. To avoid circular arguments a thorough analysis of the factors that determine life conditions for organisms has to be made. In this study we réstrict ourselves to running waters in The Netherlands, but the method is applicable to most running water systems in the world.

LIFE CONDITIONS IN RUNNING WATERS

Except for the large rivers all running waters in The Netherlands are fed by ground water. The ground water level in its turn is fed by the precipitation surplus averaging some 200 - 400 mm.yr^{-1}. This is the main climatological parameter determining the discharge of Dutch streams. The composition of the soils and the slope of the terrain form sink and source functions determining place and quantity of the visible discharge. The Dutch streams are situated in areas with sandy soils where impermeable clay and loam layers prevent the disappearance of water to greater depths. In the hierarchical scheme of Fig. 1 the climatological and geomorphological parameters feature the Dutch situation. They define the characteristics of

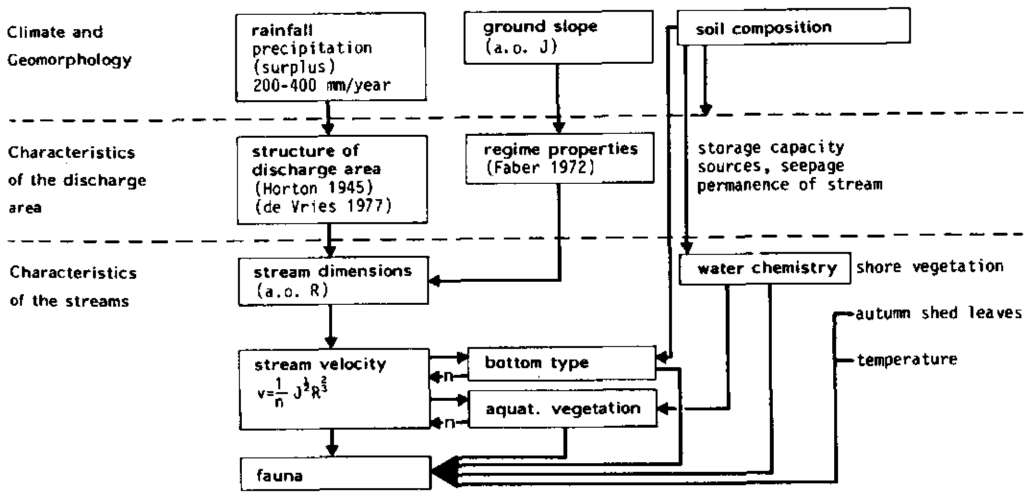


Fig. 1. Scheme of factors controlling the conditions for the aquatic fauna in running waters. J = measure for the slope of a stream; R = hydraulic radius; n = measure of the roughness (in streams from 0.025 to 0.050); v = mean velocity.

discharge areas such as the pattern of the branching water courses of a main stream and its tributaries. This pattern can be a widely branched system with numerous tributaries, fed in its turn by smaller tributaries etc. It can also be formed by a stream in a long and narrow valley with only primary tributaries that run more or less parallel to the main stream. These spatial characteristics are summarized as 'structure of discharge area'.

The temporal characteristics, indicated as 'regime properties', point to the yearly discharge pattern. Many streams have low discharges in summer and high discharges in winter or spring; others have deviating discharge patterns (FABER, 1972). At this level of the hierarchical system we are dealing with phenomena like the storage of ground water, springs, seepage and lasting or stagnant discharge.

The spatial and temporal characteristics of discharge areas directly influence the dimensions of streams of which the hydraulic radius (R) is an important mean. Together with the slope of the terrain (virtually the slope of the energy line), here represented by J, this radius determines the stream velocity as indicated by the well-known formula of Manning. A number of other factors influence the stream velocity by means of the roughness (n). In considering the life conditions for invertebrates in running waters we have to deal with secondary factors such as water chemistry, canopy, etc. as is indicated in Fig. 1. For the purpose of this study, however, we focus on stream hydraulics, being the basic parameters for a classification of running waters.

STREAM HYDRAULICS

Manning's formula runs as follows: $v = 1/n.J^{1/2}.R^{2/3}$ (1)

in which v = mean current velocity (in $m.s^{-1}$)
n = roughness
J = ground slope
R = hydraulic radius (in m)

The factors defining the current velocity can be divided into two groups. Ground slope and roughness are local conditions, whereas the hydraulic radius is the result of factors concerning the total discharge area and the amount of precipitation.

Ground slope and roughness are taken together as a single local factor, the 'terrain factor' C_t.

$$C_t = 1/n.J^{1/2} \quad (2)$$

From (1) and (2) follows :

$$v = C_t.R^{2/3} \quad \text{or}$$

$$\log R = 3/2 \log v - 3/2 \log C_t \quad (3)$$

In a logarithmic C_tR-diagram therefore the current velocity is represented by straight lines with a slope of – 3/2 (Fig. 2).

Of the two components of C_t the ground slope can be measured easily. It is the difference in height between two stream localities, divided by the distance along the stream course.

The roughness (n) is experimentally determined as varying between 0.01 and 0.05 (NORTIER and VAN DER VELDE, 1968). The extremes are found in straight concrete gutters with little resistance on the one hand and in natural, meandering streams with stones and vegetation on the other. In natural streams n may vary from 0.035 to 0.05 depending on the season and soil conditions.

As a consequence, there is a variation in C_t described by

$$\Delta C_t = \log C_{t(max)} - \log C_{t(min)} = \log \frac{C_{t(max)}}{C_{t(min)}} = \log \frac{l/n_{(max)} \cdot J_1^{1/2}}{l/n_{(min)} \cdot J_2^{1/2}}$$

At a certain locality the ground slope is a constant factor. The natural variation of C_t, therefore, caused by micro-geological factors, may be described by

$$\Delta C_t = \log \frac{n_{(min)}}{n_{(max)}} = \log \frac{0.050}{0.035} = 0.155$$

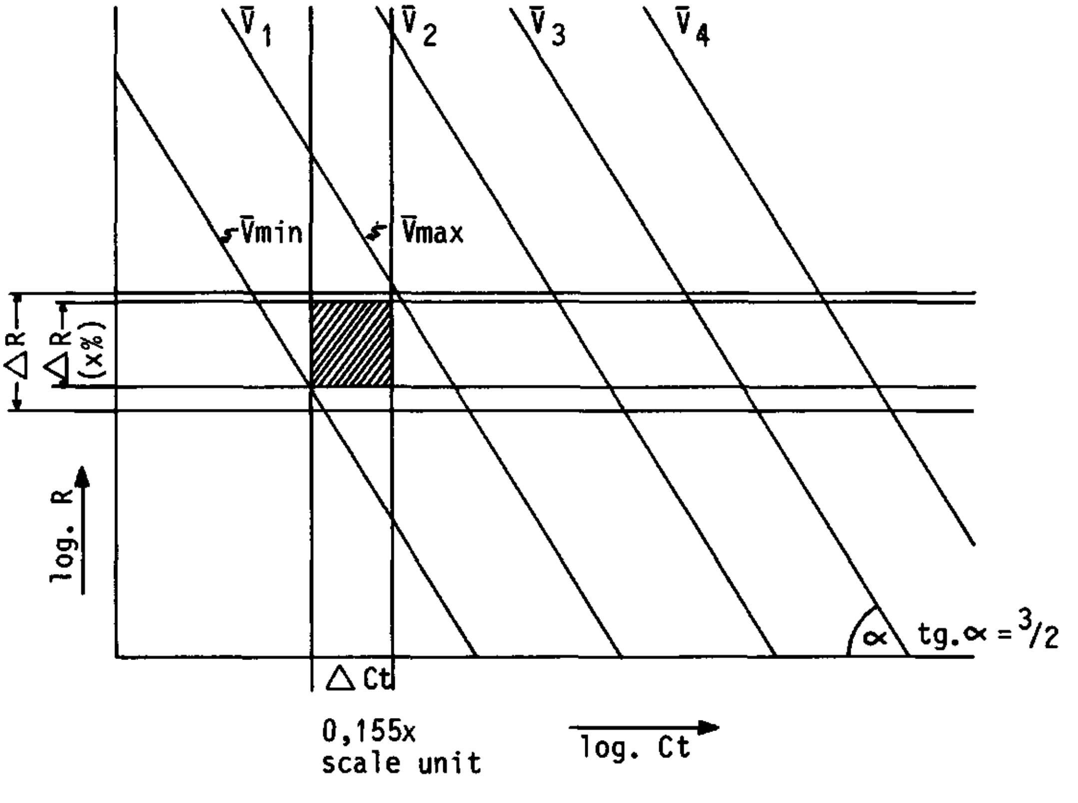


Fig. 2. Localization of a sampling station in the C_tR-diagram (explanation in the text).

Therefore, all localities with the same ground slope in the C_tR-diagram can be found in a vertical belt with a width of 0.155 times the scale unit (Fig. 2).

The hydraulic radius (R) is composed of the wet cross-sectional area of the stream (A), divided by the wet outline of this cross section (O). R is not a constant, but it varies with the water level, as variation of the water depth affects both A and O in different ways.

In most streams there is a large difference between maximum and minimum water depth, if measured over longer periods. This variation rate decreases rapidly, however, when the extremes are excluded (Fig. 3). The natural variation rate of R, Δ R, of a locality may be reduced to ΔR_x % (Fig. 2).

Owing to the specific values of ΔC_t and Δ Rx %, each stream locality can be represented in the C_tR-diagram by a limited area, including x % of all natural conditions occurring on that locality (hatched area in Fig. 2). The maximum and minimum mean velocity ($\bar{v}_{max}$; $\bar{v}_{min}$) on that very locality can be read from Fig. 2.

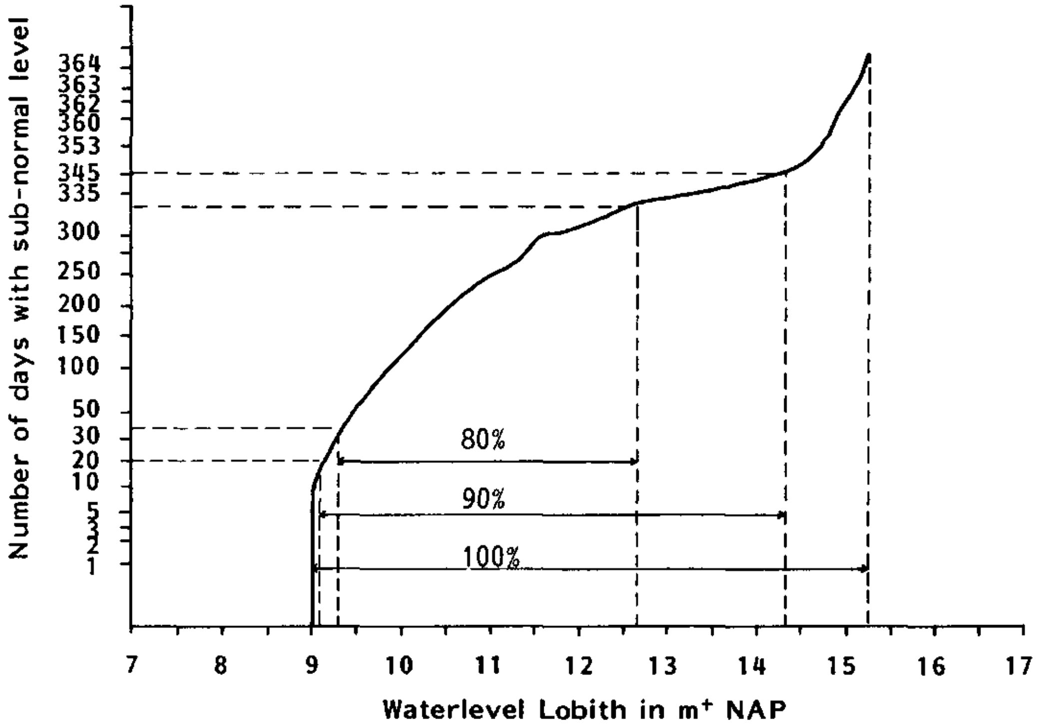


Fig. 3. Waterlevel duration-curve of the river Rhine at Lobith in 1982. Sub-normal level in this case means the number of days with a water level lower than the level indicated by the curve. NAP = Normal Amsterdam Level.

APPLICATIONS FOR A TYPOLOGY OF RUNNING WATERS

If observations of a large number of water courses are plotted in a C_tR-diagram, isolated clusters on a world-wide scale are not to be expected. All features involved show a gradual variation.

Obviously, water courses with about the same features are found together in certain parts of the diagram. Whether isolated or not, groupings of observations enable us to distinguish types of running water which are represented by blocks in the diagram. Vertical border-lines of these blocks separate types of landscape whereas horizontal borderlines separate water courses of different dimensions. The hydraulic radius has proven to be a useful tool to define the horizontal subdivision.

A classification of Dutch running water based on the method described is presented in Fig. 4. A large number of data from literature and own measurements provided the means for clear definitions of well-known, but so far woolly described water types such as 'large rivers', 'foothill brooks' or 'lowland streams'.

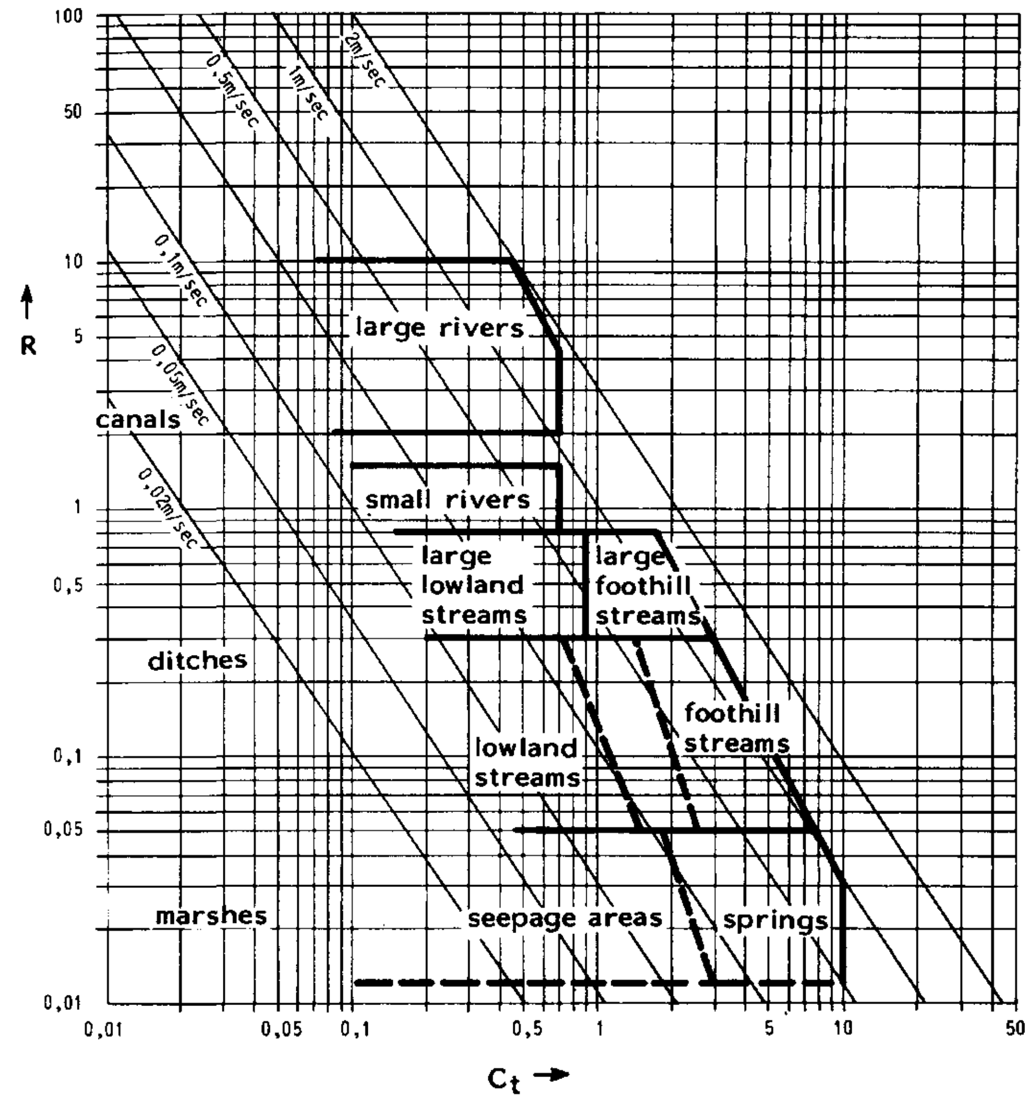


Fig. 4. The C_tR-diagram, defining types of running water in The Netherlands based on measurements of the slope of the water surface and the hydraulic radius. The mean current velocity follows from the diagonal lines. Further explanation in the text.

Fig. 4 covers a wide range of implications. Apart from specific water types, there are intermediate ones. These intermediates may be found between the vertical border-lines, *e.g.* between foothill brooks and lowland streams. An example is found in the 'Rodebeek' in the central eastern part of the province of Limburg. Larger streams and rivers can follow a path from source to lower reaches running through several blocks. In our concept therefore, a river cannot belong to one certain type.

The right part of the diagram offers the possibility to incorporate mountain streams, a type not present in The Netherlands. In Fig. 4 there is a right-left gradient leading from fast running to stagnant waters, and, besides, a top-bottom gradient leading to nearly terrestrial systems.

BIOLOGICAL IMPLICATIONS

In the frame of this article we shall not deal with detailed lists of species as can be found for the different categories of stream habitat, defined by the C_tR-diagram. We only make some general remarks.

No running water species is present in all parts of the C_tR-diagram. Some have a very restricted distribution and are only to be found in a small area of the diagram, often only in one block. Others are more tolerant and are to be found in two or more blocks. Such differences can be found within one genus, as is indicated for species of the caddisfly genus *Hydropsyche* (HIGLER and TOLKAMP, 1983), as well as in higher taxonomic levels. In Ephemeroptera, for example, we found species restricted to foothill brooks, others only occurring in lowland streams and also a special group of species, characteristic in its combination for the intermediate type as mentioned before (Rodebeek).

The zonation of streams is a well established phenomenon (ILLIES and BOTOSANEANU, 1963; BOTOSANEANU, 1979). In this light it will be obvious that a succession of species groups from bottom right to the top can be visualized in Fig. 4 in accordance with this concept of zonation. In The Netherlands, we only have historical data about the occurrence of insect larvae in the lower stretches of the large rivers.

Even then, a succession in large groups of caddis, mayfly and stonefly larvae can be demonstrated.

ABSTRACT

The factors determining life conditions in running waters can be arranged in a hierarchical scheme. One of the main factors is stream velocity, which is described by Manning's formula. By transformation of the formula a set of variables is acquired with which a diagram is constructed to contain all hydraulic conditions in running water. By measuring the ground slope and the hydraulic radius at a certain station this station can be placed in the diagram. Data from Dutch streams and rivers form definite clusters enabling us to describe types of running waters on this base. The distribution patterns of stream organisms in accordance with stream hydraulics can be fit into the diagram as well.

REFERENCES

BOTOSANEANU, L., 1979. Quinze années de recherches sur la zonation des cours d'eau: 1963-1978. Bijdragen tot de Dierkunde, 49: 109-134.

FABER, TH., 1972. Regimes and regime-related basin properties of some Dutch small rivers. Thesis V.U., Amsterdam: 186 p.

HIGLER, L.W.G. and H.H. TOLKAMP, 1983. Hydropsychidae as bio-indicators. Environmental Monitoring and Assessment, 3: 331-341.

ILLIES, J. and L. BOTOSANEANU, 1963. Problèmes et méthodes de la classification et de la zonation écologique des eaux courantes, considerées surtout du point de vue faunistique. Mitt. Internat. Verein. Limnol., 12: 1-57.

NORTIER, I.W. and H. VAN DER VELDE, 1968. Hydraulica voor waterbouwkundigen. Stam, Culemborg: 321 p.

Vries, J.J. DE, 1977. The stream network in The Netherlands as a groundwater discharge phenomenon. Geol. Mijnb., 56: 103-122.

APPENDIX III

Questions and comments on the River Continuum Concept

PERSPECTIVES

Questions and Comments on the River Continuum Concept

Bernhard Statzner

Zoologisches Institut I der Universität, Postfach 6380, D-7500 Karlsruhe, Fed. Rep. Germany

and Bert Higler

Rijksinstituut voor Natuurbeheer, Postbus 46, 3956 ZR Leersum, The Netherlands

Statzner, B., and B. Higler. 1985. Questions and comments on the River Continuum Concept. Can. J. Fish. Aquat. Sci. 42: 1038–1044.

The River Continuum Concept (RCC) is a generalized conceptual framework for characterization of pristine running water ecosystems. Of the numerous tenets of the concept we particularly reevaluated the following: biological analogues of energy equilibrium and entropy in the physical system; maximization of energy consumption through continuous species replacement over a year; absence of succession in stream ecosystems, which can thus be viewed in a time-independent fashion; and maximization of biotic diversity in midreaches of streams as a result of the occurrence of highest environmental variability there together with spatial abundance shifts of insects, molluscs, and crustaceans. When emphasis is placed on rapid changes in the downstream hydraulics dependent on discharge and slope (both of which are expressed by stream order in the RCC and are key factors of the concept) and on results from tropical studies, some of these tenets are partly refuted or need extension. Some of them are in conflict with the current state of knowledge in other domains of stream ecology or are at least open to various interpretations. Therefore, we advocate modifications of the theoretical background of the RCC.

Le concept de continuum du milieu fluvial (CCMF) est un cadre conceptuel généralisé pour la caractérisation des écosystèmes lotiques vierges. Parmi les nombreux principes de ce concept, les auteurs ont réévalué en particulier les suivants : les analogues biologiques de l'équilibre énergétique et de l'entropie dans le système physique; la maximalisation de la consommation d'énergie par le remplacement continu des espèces au cours d'une année; l'absence de succession dans les écosystèmes lotiques qui peuvent donc être considérés indépendamment du temps; et la maximalisation de la diversité de la faune et de la flore dans les sections mitoyennes de cours d'eau, maximalisation due à la présence d'une variabilité environnementale optimale en plus de variations spatiales de l'abondance d'insectes, de mollusques et de crustacés. Certains de ces principes sont en partie réfutés ou doivent être élargis quand on met l'accent sur les variations rapides de l'hydrodynamique des eaux d'aval qui dépend du débit et de la pente (ces deux facteurs-clés du CCMF sont exprimés selon la position du cours d'eau dans le concept), et sur les résultats d'études du milieu tropical. Quelques-uns de ces concepts entrent en conflit avec les connaissances actuelles sur d'autres aspects de l'écologie lotique ou au moins peuvent être interprétés de diverses façons. Les auteurs recommandant donc des modifications des éléments théoriques du CCMF.

Received August 10, 1984
Accepted January 29, 1985
(J7909)

Reçu le 10 août 1984
Accepté le 29 janvier 1985

The question of how headwater and downstream ecosystems vary in structure and/or function was and remains a central issue of running water ecology. At the beginning of the 1970's a group of North American stream ecologists started a new approach to this question, which resulted in the River Continuum Concept (RCC) (Vannote et al. 1980). The authors of the concept consider it as a framework for a characterization of pristine running water ecosystems, "describing the structure and function of communities along a river system" in relationship to the abiotic environment. The RCC stimulated immediate comment and avid discussion (Winterbourn et al. 1981; Barmuta and Lake 1982; Culp and Davies 1982; Hauer and Stanford 1982; Taylor and Roff 1982; Winterbourn 1982; Cole 1983; Gray et al. 1983; Rounick and Winterbourn 1983; Stanford and Ward 1983; Ward and Stanford 1983; Townsend and Hildrew 1984[1]). Recent contributions from the RCC proponents (Cummins et al. 1983; Cushing et al. 1983; Minshall et al. 1983; Bruns et al. 1984) modify some ideas of Vannote et al. (1980), but generally support the RCC. From personal discussions and unpublished manuscripts we gather that further modifications and clarifications of the RCC

[1]Paper delivered at the SIL meeting in Lyon 1983. Here and in other cases we refer to the oral presentation and the abstract.

can be expected from its proponents (e.g. Sedell and Froggatt 1984; Cummins et al. 1984).[2]

During an analysis of the information available on the RCC we realized that some of its basic assumptions or tenets, as we interpret them, affect the domain of stream ecology to a greater degree than is evident at first glance and certainly more than is discussed in the above papers. Some tenets are at variance with our view of the current state of knowledge. Other assumptions can be interpreted in various ways and require clarification.

We will discuss some of these assumptions briefly, concentrating particularly on five tenets: biological analogues for (1) energy equilibrium and (2) entropy pattern in the physical system; (3) maximization of energy consumption through continuous species replacement over a year; (4) absence of succession in stream ecosystems, which can thus be viewed in a time-independent fashion; and (5) maximization of species diversity in midreaches of streams as a result of the occurrence of the highest environmental variability there and spatial abundance shifts of insects, molluscs, and crustaceans.

The aim of this paper is to suggest some modifications in the theoretical background of the RCC. But first we would like to stress that we accept many parts of the RCC as they stand and respect the scientific ideas that our North American colleagues have compiled in their framework.

General Remarks on the RCC

Before we deal with the five RCC tenets mentioned above, some of the general aspects of the concept as well as the limitations contained in it will be briefly outlined and commented on.

The main goal of the RCC is to link fluvial geomorphic processes, physical structure, and the hydrologic cycle to "patterns of community structure and function and organic matter loading, transport, utilization and storage along the length of a river." This is very expressively illustrated in Vannote et al. (1980, Fig. 1), in which the influence of riparian vegetation, the status of trophy, load, transport, and the relative importance of functional feeding groups (shredders, collectors, etc.) is related to stream order (Leopold et al. 1964) as an expression of the physical component. However, as stream order is not, in any case, a meaningful description of the physical environment (Gregory and Walling 1973), it should be regarded only as an indication of the relative position of a stream reach within the entire running water system. A physical characterization of each reach under study must therefore be added.

The RCC as published in 1980 includes qualifications about certain environmental situations. Some of the criticisms of the RCC so far published are not appropriate when these limitations and modifications (Vannote et al. 1980) to the RCC are taken into account: (i) the RCC has been developed for natural, unperturbed stream ecosystems; (ii) streams at high elevations and latitudes, xeric regions, and deeply incised valleys may deviate from the general pattern with regard to autotrophy/heterotrophy; (iii) tributaries entering the main stream have localized effects of varying magnitude depending on the volume and the nature of the input.

The RCC does not particularly deal with the various types of sources (limnocrene, helocrene, rheocrene) and mouths (delta, estuary) of stream systems (see Fig. 3) nor does it mention natural lakes that occupy intermediate positions on the "river continuum." And, a fact we regard as very important, the RCC is not restricted to a certain geographical area, i.e. we consider it a concept of worldwide applicability.

Classification of the benthic invertebrates into functional feeding groups (Cummins 1974) is a fundamental attribute of the RCC, and stresses the importance of ecological functions. We applaud this approach, which, however, poses some practical problems: the diet of a macroinvertebrate species can be varied, depending on age (e.g. Schröder 1976; Fuller and Stewart 1977) as well as on site (e.g. Martinson and Ward 1982; Williams and Williams 1982).

Special problems are posed when ecological study involves assumptions about unperturbed stream conditions, because our knowledge of the ecology of pristine headwater streams is scarce and of pristine rivers is almost nonexistent (see Horwitz 1978; Sedell and Luchessa 1982). Hence, such an approach is necessarily based to some extent on speculation. We explicitly welcome the RCC's endeavour to describe natural stream ecosystems, since in most cases this may be the most appropriate way to illustrate the deviations of our "modern" streams from their historic nature.

Today, most lower reaches of streams have been radically changed by human activities. The original condition of certain stream systems in North America have been demonstrated in a fascinating way by Sedell and Froggatt (1984) and Triska (1984): riparian trees from eroded banks formed large organic debris dams, blocking the channel, creating lakes, new side channels, and so on. A similar situation occurred in Europe. Behning (1928) described a unique biocoenosis on trees washed into the Volga. And there is historical evidence that in the twelfth century, servants on horseback had to guide ships through the Oder in order to avoid collisions with the dangerous oak trees lying in the river (Herrmann 1930). Besides the main channel, smaller ones occurred with flow characteristics resembling those in reaches further upstream (Krause 1976). Similar conditions have been described in the Amazon (Junk 1982; Sioli 1982) and the Congo (Stanley 1874–77). This "original state" of larger pristine rivers was not considered in Vannote et al. (1980): thus, we will discuss its consequences for the RCC below.

On Five RCC Tenets

Tenet I: Energy Equilibrium of the Physical System and Biological Analogue

In our opinion the central statement of the RCC is that "biological communities should become established which approach equilibrium with the dynamic physical conditions of the channel" (Vannote et al. 1980, p. 132). To understand this statement we must go back to Leopold et al. (1964, p. 266 ff) who discussed in detail the physical dynamic equilibrium of streams: power expended per unit length of a channel and per unit area of the bed of a channel (Table 1) are expected to tend to uniformity. A modal value of central tendency between the two will lead to a longitudinal equilibrium profile of the channel.

Recently, Mangelsdorf and Scheurmann (1980) took a physical–analytical approach to the question of the equilibrium profile, giving examples and discussing the situation in streams that have almost reached or are far from their equilibrium profile. They stress that tectonics, lithology, and climate determine the longitudinal profile of each running water in a characteristic way. Thus, for example, the Rhine has three base

[2]See also Minshall et al. in this issue (Ed.).

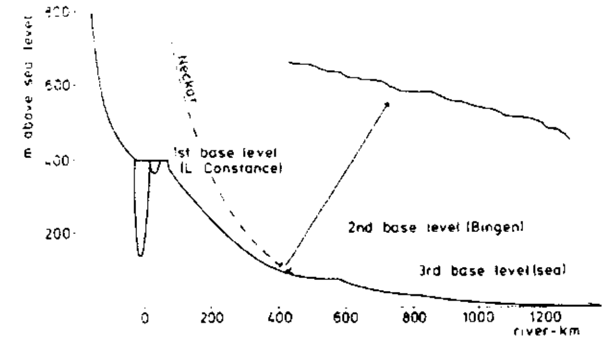


FIG. 1. Rough slope curve of the Rhine and the Neckar (according to Mangelsdorf and Scheurmann 1980). The Rhine has three base levels: lake level of Lake Constance (its depth is indicated by the two loops), slate formation at Bingen, and sea level at the mouth (indicated by the thin straight line). The arrow points to a detail in the slope curve of the Neckar above Heidelberg (according to Wilser 1937).

levels (Fig. 1): Lake Constance, Bingen (due to slate), and, finally, the sea, i.e. at present the Rhine is approaching an equilibrium profile in three sections. This is due to the very "turbulent" history of the Rhine, into which other basins were incorporated (Quitzow 1976–77). The Neckar is included in Fig. 1. If we take a closer look at its profile above Heidelberg, in an area with a high tectonic diversity, the influence of location-specific events on a stream profile can be demonstrated. These two examples show that empirical–statistical models of the physical state of a stream system cannot be used without checking if the models are valid for these streams.

System-characteristic runoff patterns, which are assumed to modify the progressive and predictable change in the physical system (Minshall et al. 1983), will further complicate the RCC. In Europe, 60 different types of runoff patterns are characterized (Grimm 1968), which can be altered on the microscale by basin shape and relief (Gregory and Walling 1973, fig. 5.10).

In principle, however, it can be stated (Mangeldorf and Scheurmann 1980, p. 148) that a stream does tend towards that profile at which, for a given discharge, the material imported will be transported. If material input and transport capacity are not in equilibrium the stream starts to erode or to accumulate. Generally, a stream with a source in the mountains and no additional base level along its course to the mouth can then be divided into three sections: an upper reach, where erosion is dominant; a middle reach, which represents a zone of transition; and a lower reach, where accumulation prevails. Since the ratio of material input to transport capacity is not constant at a given point of the stream over time — in addition to more regular annual variations, irregular episodic changes occur (Bergstrom 1982; Kelsey 1982) — the limits between these three reaches shift upstream and downstream according to discharge and material load. Hence, the reach with the highest dynamics is the middle one where the slope levels off. In this area natural streams are frequently braided at first and then start to meander. Where a stream is braided, there is a frequent decrease or increase in channel number and a variety of channel characteristics, depending on the discharge (Mosley 1982).

We are not sure whether biological consequences of the dynamic equilibrium of a stream discussed by Curry (1972, p. 13), in a paper cited in the RCC under the heading "Derivation of the concept," are implicitly included in the RCC or not. Curry considered that the energy of the physical system, which is expended as frictional heat energy, is "of great importance as energy input in biologic communities." Therefore the tendency toward uniformity of energy expenditure in river systems will help to explain the stability and diversity of stream communities. Are these ideas covered by the following RCC statement: "The tendency of the (physical) river to maximize the efficiency of energy utilization and the opposing tendency toward a uniform rate of energy use" (Vannote et al. 1980, p. 131), which is another way to express the dynamic equilibrium condition of a channel, has an analogue in the trade-off of the biological system between the tendency "to make most efficient use of energy inputs" (e.g. through resource partitioning of *temperature*) and the tendency "towards a uniform rate of energy processing throughout the year" (Vannote et al. 1980, p. 134)? And what is the meaning of "a tendency for reduced fluctuations in energy flow" of "river ecosystems" (p. 133) or a tendency of "stream ecosystems ... towards uniformity of energy flow on an annual basis" (p. 134) (Vannote et al. 1980)? Does this imply an energetic unity of the physical and biological system? If so, the annual variations in physical energy flow (e.g. discharge) must be counterbalanced by the biological energy flow in order to reach uniformity on the ecosystem level (= abiotic + biotic energy flow tend to uniformity).

Since these energy statements have a great impact on the theoretical background of stream ecology, they require clarification by its authors.

From the above it is evident that the energy expenditure of the physical system plays an important role in the RCC. However, recent contributions on the RCC have not concentrated on hydraulics. For example, only a short sentence in Minshall et al. (1983, p. 18) was devoted to this subject. Thus, we used the data from the 16 stations investigated in that study to calculate some simple physical parameters such as power expended per unit of length and area, shear stress, and Froude number, which gives an indication of turbulence in streams (streaming or shooting flow; see Table 1 for formulae). No modal value of central tendency between power/reach and power/area is indicated by the downstream pattern of these parameters (Fig. 2). Neither do Froude number and shear stress exhibit uniform tendencies (Fig. 2). The causes of this may be that (i) available discharge data are annual means and not bankfull discharges, (ii) the streams studied were not within the limits set by the dynamic equilibrium theory of streams, (iii) in three of the four study sites the lowermost stations did not receive water from the upper stations, and (iv) the location-specific lithology and geomorphology modified the general tendency expected at several stations; such a tendency is, of course, difficult to discern at only four stations over stream reaches 35–57 km long.

To demonstrate the relationship between stream geomorphology (e.g. slope), the physical properties of flow near the stream bottom, and aquatic invertebrate ecology, we will introduce another parameter here: the thickness of the laminar sublayer above the stream bottom. Distribution patterns of benthic invertebrates are related to this indicator of the actual forces acting at the stream bottom, i.e. "hydraulic stress" (Statzner 1981a, 1981b). This sublayer equation (formula 5 in Table 1) incorporates, in principle, the same parameters as the Manning formula (6 in Table 1), which can be transformed into the sublayer equation and vice versa (Smith 1975). If the Manning formula is written differently (6′) and compared with formula 5, it becomes evident that the thickness of the laminar sublayer is

TABLE 1. Formulae used for the expression of physical patterns along the course of streams (note that the Manning formula (6) is written for wide channels with a simplified roughness parameter).

(1) $P_1 = QgS\rho$ (2) $P_2 = \frac{QgS\rho}{w}$

(3) $\tau_0 = gDS\rho$ (4) $\mathrm{Fr} = \frac{U}{\sqrt{gD}}$

(5) $\delta' = \frac{11.5\nu \, 5.75 \log \left(\frac{12D}{r_p} \right)}{U}$

(6) $U = \frac{\text{const.}}{r_p} D^{2/3} S^{1/2}$ (6′) $\frac{1}{S} = \left(\frac{\frac{\text{const.}\, D^{2/3}}{r_p}}{U} \right)^2$

NOTE: D = channel depth (m), Fr = Froude number, g = acceleration due to gravity (m/s^2), P_1 = power per unit length of a channel (W/m), P_2 = power per unit area of a channel (W/m^2), Q = discharge (m^3/s), r_p = roughness of channel bottom (m), S = slope (m/m), U = mean current velocity (m/s), w = channel width (m), δ' = thickness of laminar sublayer (m), ν = kinematic viscosity (m^2/s), ρ = density of water (kg/m^3), τ_0 = shear stress (N/m^2).

also related to slope (Statzner 1981a): an increase in slope should reduce the thickness of the laminar sublayer, hence raising the hydraulic stress on the stream bottom and vice versa. We have thereby linked a central tendency of microhabitat characteristics in a reach ("hydraulic stress") to a macrohabitat characteristic ("slope"): the latter "are major determinants of the types of microhabitats," to which fish as well as invertebrates respond (Bovee 1982, p. 3). It should be noted here that these formulae (5, 6, 6′) as written in Table 1 are not applicable to all hydraulic situations found in natural streams (Bovee and Milhous 1978; Statzner 1981a), and they are used here as vehicles to elucidate some of the physical patterns one can expect along a stream course.

Summing up the above, we suggest the following characterization of an "ideal" or "standard" pristine running water course (Fig. 3) to which real streams can be compared. The source and the first part of its effluent are frequently characterized by relatively low hydraulic stress. A transition zone is followed by a reach of high hydraulic stress, which, after the next zone of transition at the break-point of the slope curve (we regard the values of bed slope, hydraulic slope, and energy slope as identical), is then followed by a zone of lower hydraulic stress. Further downstream, numerous large-scale discontinuities of the hydraulic stress occur. How the mouth of a stream system entering the sea is developed depends mainly on the material exported by the stream and the transport capacity of the marine component, including tidal amplitude and other currents (Mangelsdorf and Scheurmann 1980). The role of the stream in this context has been illustrated in "large-scale experiments": reduction of material transported by the stream due to artificial dams reduces the area of the original delta (Baxter 1977). The main types of mouths are estuaries and deltas (Fig. 3), and it is important to note that the physical characteristics of the stream influence in part the salinity at the mouth of the stream.

We conclude that the pattern of physical parameters as

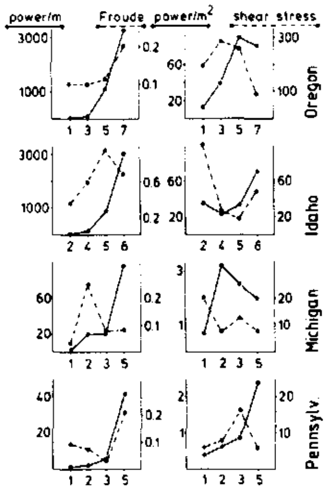


FIG. 2. Parameters for energy expenditure (see Table 1 for formulae and units) at the 16 RCC stations considered by Minshall et al. (1983). Note that no uniform patterns emerge on the way downstream (x-axes: stream orders), if the complete set of data is considered.

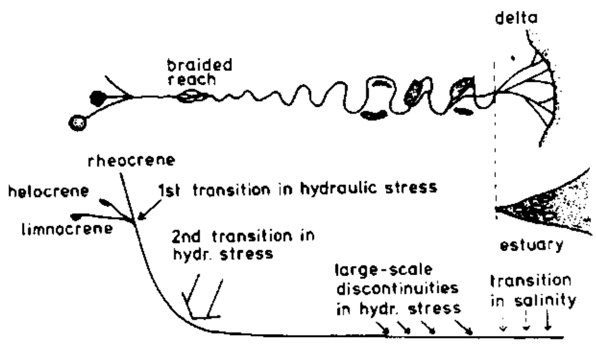


FIG. 3. Some typical changes in the central tendency of habitat characteristics from the source to the mouth in a hypothetical pristine stream. Not all of the components shown here can be or must be present in a stream system.

proposed in Fig. 3 obviously does not represent a "continuous" or "intergrading" gradient as dictated by the RCC (Vannote et al. 1980; Cushing et al. 1983), and variations on the microscale as well as lakes and other additional base levels will complicate matters much more. Thus, the analogies between the physical and the biological equilibrium of streams cannot be as simple as suggested by the RCC.

Tenet II: Entropy Patterns

In addition to energy statements discussed above, some clarification is required about a statement on entropy: from headwaters to the mouth there is a constant gain in the physical variable "entropy." Vannote et al. (1980, p. 132) postulate that "the biological organization in rivers conforms structurally and functionally to kinetic energy dissipation patterns of the physical system."

Does this imply a characteristic tendency in biological entropy from the source to the mouth of a stream? The longitudinal organization of the gross photosynthesis/respiration ratio in the stream (thermodynamic concept of entropy) or the species diversity (e.g. Shannon index: entropy concept of information theory) can serve as indicative parameters. Both are considered in the RCC (Vannote et al. 1980, fig. 2), and in contrast with the constant entropy gain in the physical system, both show increasing as well as decreasing tendencies on the way downstream.

Or does the entropy statement imply that the biological communities will adjust to the physical entropy pattern through energy consumption and processing, resulting in similar tendencies in the biological entropy in every reach of the stream? This is, of course, a usual tendency of organisms, since "living systems" are "negentropic" (Fränzle 1978).

We believe that the absence of this theoretical background will not mean a loss in significance of the RCC; thus, we suggest omitting the above statement on entropy.

Tenet III: Temporal Sequence of Species Replacement and Utilization of Energy Inputs

After a species has completed its growth "it is replaced by other species performing essentially the same function ... It is this continuous species replacement that functions to distribute the utilization of energy inputs over time" and results in a composite species assemblage tending to "maximize" energy consumption (Vannote et al. 1980, p. 134). This tenet may be applicable only to stream systems in geographical zones subject to distinct seasonal variations in abiotic factors.

A temporal sequence of species replacements, such as postulated by the RCC based on experience from North America, has already been rejected by Winterbourn et al. (1981) and Towns (1983) for streams in New Zealand. In equatorial regimes, all principal species of a stream system are present over the whole year. This is clearly demonstrated by emergence data of four insect groups from a stream situated 2°S in Zaire (Zwick 1976; Statzner 1976; Lehmann 1979; Kopelke 1981): no complete temporal replacement occurs, although several species show cyclic patterns. The terrestrial vegetation in this latitude does not exhibit a distinct phenology comparable with that of temperate zones, but periodic patterns obviously do occur (Dieterlen 1978). This suggests some seasonality in the input of course organic material into the stream communities, which is probably processed faster in the tropics than in temperate climates (Dudgeon 1982). The question is whether such stream communities near the equator have developed other possibilities to "maximize" energy consumption. Fittkau (1973) suggests that the high efficiency of energy utilization is linked to a high species number and a relatively low abundance of each species in Central Amazon streams which are scarce in nutrients.

Another question is whether the species assemblage of a stream reach really plays the role postulated by the RCC. Minimization of leakage (export of organic compounds) from a stream reach is another way to express maximization of energy consumption. Recent studies have shown that leakage is reduced under normal discharge conditions if the invertebrate fauna is destroyed in experiments or in computer simulations (Wallace et al. 1982; Webster 1983; see also Meyer and O'Hop 1983), i.e. macroinvertebrates decrease the efficiency of stream ecosystems.

Tenet IV: Time Invariance and Absence of Succession in Stream Ecosystems

Vannote et al. (1980, p. 135) stated that the temporal change of the biological system of a stream "becomes the slow process of evolutionary drift" and the community "gains and loses species in response to low probability cataclysmic events and in response to slow processes of channel development." As a result of this, succession in stream ecosystems is absent and these systems can be viewed in a time-independent fashion.

If we accept cataclysmic events as a factor that causes gains and losses of species, then we might expect that the biological community in the stream is reestablished afterwards by means of succession (see Fisher 1983) parallel to that in the terrestrial environment (e.g. after landslides, wildfires, or volcanism).

In our opinion, succession cannot, therefore, be rejected in stream communities. As a consequence, stream ecosystems cannot always be viewed in a time-independent fashion. And we have evidence from long-term studies that time invariance does not occur: this is demonstrated for insects (Illies 1978, 1982) and fish (Grossman et al. 1982). While discussing organic matter budgets for stream ecosystems, some authors of the RCC drew a similar conclusion in a recent paper (Cummins et al. 1983).

Tenet V: Pattern of Biological Diversity

This tenet of the RCC, discussed at some length, states that high environmental variation results in high biotic diversity. This concept was actually first formulated early in this century by Thienemann in one of his biocoenotic principles (see Hynes 1972, p. 234).

In Vannote et al. (1980) the variation of the environment is discussed using the example of the diel water temperature amplitude, which is certainly highest in the midreach of a natural stream in temperate climates. The RCC indicates that the biological diversity is therefore also highest in the midreach (Fig. 4D). However, if we include the annual amplitude of the water temperature (i.e. as a second environmental factor), the highest variability no longer occurs in the midreach of our stream. And it is very improbable that all other factors mentioned by the RCC, such as riparian influence, substrate, flow, and food, show their highest variability exactly in the midreaches of streams (see also the conclusion at the end of tenet I). The latter holds especially true if we include non-temperate climates. Tropical streams may have very low diel and annual temperature amplitudes in their middle and even lower reaches (e.g. Sioli 1975; Statzner 1975).

A second explanation of the RCC for the maximum of species diversity in the midreach of streams is the convergence of two vectors that illustrate shifts in spatial distribution (Vannote et al. 1980, p. 135): insects are believed to have become aquatic first in headwater streams, while molluscs and crustaceans have reached streams from the marine environment through the mouth of streams. Later, insect abundance shifted downstream and mollusc and crustacean abundance shifted upstream.

The confluence of these migratory vectors might cause high diversity (e.g. Shannon index) in the midreach only if insects shifted at the same speed downstream as molluscs and crustaceans shifted upstream, but not during the phase of complete overlap of the abundance patterns (Fig. 4A–4C). We see no evidence to suggest that these conditions are fulfilled in nature, especially not in most streams. On the other hand, existing evidence shows that, excluding effects of pollution, diversity in streams may change drastically bearing no relation to the "order" of that stream (Statzner 1981c) or that diversity is almost constant throughout different "orders" (Minshall et al. 1982).

A large part of the discussion of this topic dealt with benthic macroinvertebrates, which, of course, contribute only part of the complete community diversity. It is, for example, a well-known fact (and also shown by Vannote et al. 1980, fig. 1)

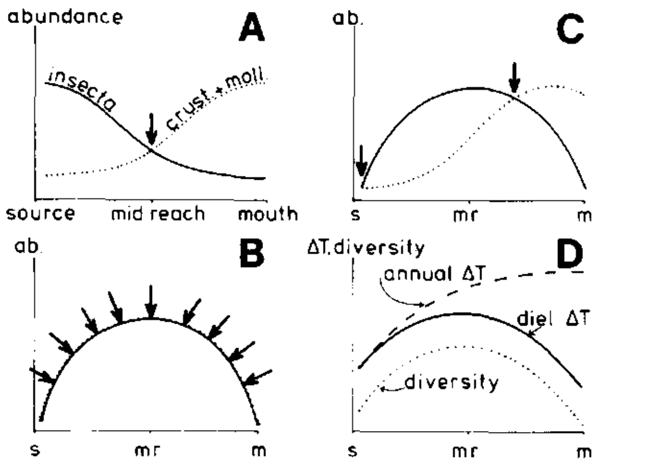


FIG. 4. (A–C) Hypothetical abundance distribution of Insecta, Crustacea, and Mollusca shifting downstream or upstream, respectively, and the consequences for a diversity index (e.g. Shannon), which is highest (arrow) where the abundance of all species is the same. (A) Beginning of shift, both groups shifting with the same speed; (B) complete overlap, both groups shifting with the same speed; (C) Insecta shifting faster downstream than Crustacea and Mollusca upstream. (D) Development of the diel and annual water temperature amplitude and the diversity, as suggested by the RCC, from the source to the mouth of a stream. See text for discussion of these patterns.

that plankton develops mainly in the lower reaches of streams, and the number of fish species increases there also. This will, of course, influence the diversity pattern of the complete community, which is probably at its highest in the lower reaches of streams, where the large-scale discontinuities in hydraulic stress occur (Fig. 3). Furthermore, the environmental variability of a particular physical structure may influence the diversity of one group (e.g. insects) in a different way than that of other groups (e.g. fish) (Schlosser 1982).

Conclusion

The five tenets of the RCC discussed above are open to various interpretations, need extension, or are unexpected or refuted by the current state of knowledge. The physical parameters in streams obviously do not exhibit a continuous or intergrading gradient (tenet I) in the downstream direction (Fig. 3). Thus, biological analogues of the energy equilibrium in the physical system are more complicated than suggested by the RCC. It is not clear how the RCC relates entropy patterns of the biological to the physical system (tenet II). Since we do not see an essential need for the statement on entropy in the RCC, we recommend its omission from the concept. This will reduce the theoretical ballast of the RCC. Maximization of yearly energy utilization through species replacement (tenet III), lack of succession and time invariance in stream communities (tenet IV), and specific mechanisms leading to high biotic diversity in midreaches of streams (tenet V) are either rejected (IV), unexpected (V), or restricted to particular geographical areas (III). We therefore suggest modifying the original RCC by excluding tenets III–V from the concept. This will result in a higher flexibility and larger applicability of the RCC.

In our opinion, these modifications will hardly conflict with projects relating to the RCC that have been realized up till now (see Minshall et al. 1983 and references therein; Cummins et al. 1983; Cushing et al. 1983; Bruns et al. 1984). These projects placed emphasis on gross photosynthesis and respiration and on the status of organic matter and the corresponding functional organization of the community, i.e. on points that we evaluate as major objectives of the RCC. None of these is directly restricted by the recommended modifications.

Acknowledgements

The "Deutsche Forschungsgemeinschaft" provided financial support for a visit of B.S. to Corvallis (Oregon), where the ideas presented in this paper were delivered in a seminar lecture in July 1983. Various proponents of the RCC as well as several other colleagues discussed several of the above ideas with us in an open and friendly atmosphere. V. H. Resh and J. Collins (Berkeley) and an anonymous reviewer gave very useful comments on an earlier draft of the manuscript. This should not imply that the ideas presented here are always accepted by the above colleagues. Liz Mole (Weinheim) provided her linguistic advice. All this help is gratefully acknowledged.

References

BARMUTA, L. A., AND P. S. LAKE. 1982. On the value of the River Continuum Concept. N.Z. J. Mar. Freshwater Res. 16: 227–229.

BAXTER, R. M. 1977. Environmental effects of dams and impoundments. Annu. Rev. Ecol. Syst. 8: 255–283.

BEHNING, A. 1928. Das Leben der Wolga. Binnengewässer 5: 1–162.

BERGSTROM, F. W. 1982. Episodic behavior in badlands: its effects on channel morphology and sediment yield, p. 59–66. *In* F. J. Swanson, R. J. Janda, T. Dunne, and D. N. Swanston [ed.] Sediment budgets and routing in forested drainage basins. U.S. Forest Service, Portland, OR.

BOVEE, K. D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. U.S. Fish and Wildlife Service (FWS/OBS-82/26), Washington, DC. 248 p.

BOVEE, K. D., AND R. T. MILHOUS. 1978. Hydraulic simulation in instream flow studies: theory and techniques. U.S. Fish and Wildlife Service (FWS/OBS-78/33), Fort Collins, CO. 143 p.

BRUNS, D. A, G. W. MINSHALL, C. E. CUSHING, K. W. CUMMINS, J. T. BROCK, AND R. L. VANNOTE. 1984. Tributaries as modifiers of the river continuum concept: analysis by polar ordination and regression models. Arch. Hydrobiol. 99: 208–220.

COLE, G. A. 1983. Textbook of limnology. 3rd ed. C. V. Mosby, St. Louis, Toronto, London. 401 p.

CULP, J. M., AND R. W. DAVIES. 1982. Analysis of longitudinal zonation and the river continuum concept in the Oldman–South Saskatchewan River system. Can. J. Fish. Aquat. Sci. 39: 1258–1266.

CUMMINS, K. W. 1974. Structure and function of stream ecosystems. Bioscience 24: 631–641.

CUMMINS, K. W., W. G. MINSHALL, J. R. SEDELL, C. E. CUSHING, AND R. C. PETERSEN. 1984. Stream ecosystem theory. Verh. Int. Ver. Limnol. 22: 1818–1827.

CUMMINS, K. W., J. R. SEDELL, F. J. SWANSON, G. W. MINSHALL, S. G. FISHER, C. E. CUSHING, R. C. PETERSEN, AND R. L. VANNOTE. 1983. Organic matter budgets for stream ecosystems: problems in their evaluation, p. 299–353. *In* J. R. Barnes and G. W. Minshall [ed.] Stream ecology. Application and testing of general ecological theory. Plenum Press, New York, NY.

CURRY, R. R. 1972. Rivers — a geomorphic and chemical overview, p. 9–31. *In* R. T. Oglesby, C. A. Carlson, and J. A. McCann [ed.] River ecology and man. Academic Press, New York, NY.

CUSHING, C. E., C. D. MCINTIRE, K. W. CUMMINS, G. W. MINSHALL, R. C. PETERSEN, J. R. SEDELL, AND R. L. VANNOTE. 1983. Relationships among chemical, physical, and biological indices along river continua based on multivariate analyses. Arch. Hydrobiol. 98: 317–326.

DIETERLEN, F. 1978. Zur Phänologie des Äquatorialen Regenwaldes im Ost-Zaire (Kivu). Diss. Bot. 47: 1–111.

DUDGEON, D. 1982. An investigation of physical and biological processing of two species of leaf litter in Tai Po Kau Forest Stream, New Territories, Hong Kong. Arch. Hydrobiol. 96: 1–32.

FISHER, S. G. 1983. Succession in streams, p. 7–27. *In* J. R. Barnes and G. W. Minshall [ed.] Stream ecology. Application and testing of general ecological theory. Plenum Press, New York, NY.

FITTKAU, E. J. 1973. Artenmannigfaltigkeit amazonianischer Lebensräume aus ökologischer Sicht. Amazoniana 4: 321–340.

FRÄNZLE, O. 1978. Die Struktur und Belastbarkeit von Ökosystemen. Amazoniana 6: 279–297.

FULLER, R. L., AND K. W. STEWART. 1977. The food habits of stoneflies (Plecoptera) in the Upper Gunnison River, Colorado. Environ. Entomol. 6: 293–302.

GRAY, L. J., J. V. WARD, R. MARTINSON, AND E. BERGEY. 1983. Aquatic macroinvertebrates of the Piceance Basin, Colorado: community response along spatial and temporal gradients of environmental conditions. Southwest. Nat. 28: 125–135.

GREGORY, K. J., AND D. E. WALLING. 1973. Drainage basin form and process. E. Arnold, London. 456 p.

GRIMM, F. 1968. Das Abflußverhalten in Europa — Typen und regionale Gliederung. Wiss. Veröff. Dtsch. Inst. Länderkd., N. F. 25/26: 18–180.

GROSSMAN, G. D., P. B. MOYLE, AND J. O. WHITAKER. 1982. Stochasticity in structural and functional characteristics of an Indiana stream fish assemblage: a test of community theory. Am. Nat. 120: 423–454.

HAUER, F. R., AND J. A. STANFORD. 1982. Ecological responses of hydropsychid caddisflies to stream regulation. Can. J. Fish. Aquat. Sci. 39: 1235–1242.

HERRMANN, K. 1930. Die Entwicklung der Oder vom Natur-zum Kulturstrom. Jahrb. Gewässerkd. Norddtschl. Bes. Mitt. 6(2): 1–75.

HORWITZ, R. J. 1978. Temporal variability patterns and the distributional patterns of stream fishes. Ecol. Monogr. 48: 307–321.

HYNES, H. B. N. 1972. The ecology of running waters. 2nd impr. University of Toronto Press, Downsview, Ont. 555 p.

ILLIES, J. 1978. Vergleichende Emergenzmessung im Breitenbach 1969–1976 (Ins.: Ephemeroptera, Trichoptera, Plecoptera). Arch. Hydrobiol. 82: 432–448.

1982. Längsprofil des Breitenbaches im Spiegel der Emergenz (Ins.: Ephemeroptera, Plecoptera, Trichoptera). Arch. Hydrobiol. 95: 157–168.

JUNK, W. J. 1982. Amazonian floodplains: their ecology, present and potential use. Rev. Hydrobiol. Trop. 15: 285–301.

KELSEY, H. M. 1982. Hillslope evolution and sediment movement in a forested headwater basin, Van Duzen River, North Coastal California, p. 86–96. *In* F. J. Swanson, R. J. Janda, T. Dunne, and D. N. Swanston [ed.] Sediment budgets and routing in forested drainage basins. U.S. Forest Service, Portland, OR.

KOPELKE, J.-P. 1981. Ökologische Studien an Eintagsfliegen am Beispiel der Emergenz des zentralafrikanischen Bergbaches Kalengo (Zaire) (Ephemeroptera). Entomol. Abh. (Dres.) 44: 9–43.

KRAUSE, W. 1976. Veränderungen im Artenbestand makroskopischer Süßwasseralgen in Abhängigkeit vom Ausbau des Rheins. Schriftenr. Vegetationskd. 10: 227–237.

LEHMANN, J. 1979. Chironomidae (Diptera) aus Fließgewässern Zentralafrikas. Teil I: Kivu-Gebiet, Ostzaire. Spixiana Suppl. (Münch.) 3: 1–144.

LEOPOLD, L. B., M. G. WOLMAN, AND J. P. MILLER. 1964. Fluvial processes in geomorphology. W. H. Freeman, San Francisco, CA. 522 p.

MANGELSDORF, J., AND K. SCHEURMANN. 1980. Flußmorphologie. R. Oldenbourg, München. 262 p.

MARTINSON, R. J., AND J. V. WARD. 1982. Life history and ecology of *Hesperophylax occidentalis* (Banks) (Trichoptera: Limnephilidae) from three springs in the Piceance Basin, Colorado. Freshwater Invertebr. Biol. 1: 41–47.

MEYER, J. L., AND J. O'HOP. 1983. Leaf-shredding insects as a source of dissolved organic carbon in headwater streams. Am. Midl. Nat. 109: 175–183.

MINSHALL, G. W., J. T. BROCK, AND T. W. LAPOINT. 1982. Characterization and dynamics of benthic organic matter and invertebrate functional feeding group relationships in the upper Salmon River, Idaho (USA). Int. Rev. Gesamten Hydrobiol. 67: 793–820.

MINSHALL, G. W., R. C. PETERSEN, K. W. CUMMINS, T. L. BOTT, J. R. SEDELL, C. E. CUSHING, AND R. L. VANNOTE. 1983. Interbiome comparison of stream ecosystem dynamics. Ecol. Monogr. 53: 1–25.

MOSLEY, M. P. 1982. Analysis of the effect of changing discharge on channel morphology and instream uses in a braided river, Ohau River, New Zealand. Water Resour. Res. 18: 800–812.

QUITZOW, H. W. 1976–77. Die erdgeschichtliche Entwicklung des Rheintals. Nat. Mus. 106: 339–342; 107: 6–12, 33–40.

ROUNICK, J. S., AND M. J. WINTERBOURN. 1983. Leaf processing in two contrasting beech forest streams: effects of physical and biotic factors on litter breakdown. Arch. Hydrobiol. 96: 448–474.

SCHLOSSER, I. J. 1982. Fish community structure and function along two habitat gradients in a headwater stream. Ecol. Monogr. 52: 395–414.

SCHRÖDER, P. 1976. Zur Nahrung der Larvenstadien der Köcherfliege *Hydropsyche instabilis* (Trichoptera: Hydropsychidae). Entomol. Ger. 3: 260–264.

SEDELL, J. R., AND J. L. FROGGATT. 1984. Importance of streamside forests to large rivers: the isolation of the Willamette River, Oregon, U.S.A., from its floodplain by snagging and streamside forest removal. Verh. Int. Ver. Limnol. 22: 1828–1834.

SEDELL, J. R., AND K. J. LUCHESSA. 1982. Using the historical record as an aid to salmonid habitat enhancement, p. 210–223. *In* N. B. Armantrout [ed.] Acquisition and utilization of aquatic habitat inventory information. Western Division American Fisheries Society, Bethesda, MD.

SIOLI, H. 1975. Tropical rivers as expressions of their terrestrial environments, p. 275–288. *In* F. B. Golley and E. Medina [ed.] Tropical ecological systems. Springer, New York, NY.

1982. Tropische Flüsse in ihren Beziehungen zur terrestrischen Umgebung und im Hinblick auf menschliche Eingriffe. Arch. Hydrobiol. 95: 463–485.

SMITH, I. R. 1975. Turbulence in lakes and rivers. Freshwater Biol. Assoc. Sci. Publ. 29: 1–79.

STANFORD, J. A., AND J. V. WARD. 1983. Insect species diversity as a function of environmental variability and disturbance in stream systems, p. 265–278. *In* J. R. Barnes and G. W. Minshall [ed.] Stream ecology. Application and testing of general ecological theory. Plenum Press, New York, NY.

STANLEY, H. M. 1874–77. Diary notes, p. 213–214. *In* H. Pleticha [ed.] Die Entdeckung des Kongos. H. Erdmann, Tübingen.

STATZNER, B. 1975. Zur Longitudinalzonierung eines zentralafrikanischen Fließgewässersystems unter besonderer Berücksichtigung der Köcherfliegen (Trichoptera, Insecta). Arch. Hydrobiol. 76: 153–180.

1976. Die Köcherfliegen-Emergenz (Trichoptera, Insecta) aus dem zentralafrikanischen Bergbach Kalengo. Arch. Hydrobiol. 78: 102–137.

1981a. The relation between "hydraulic stress" and microdistribution of benthic macroinvertebrates in a lowland running water system, the Schierenseebrooks (North Germany). Arch. Hydrobiol. 91: 192–218.

1981b. A method to estimate the population size of benthic macroinvertebrates in streams. Oecologia (Berl.) 51: 157–161.

1981c. Shannon–Weaver diversity of the macrobenthos in the Schierenseebrooks (North Germany) and problems of its use for the interpretation of the community structure. Verh. Int. Ver. Limnol. 21: 782–786.

TAYLOR, B. R., AND J. C. ROFF. 1982. Evaluation of ecological maturity in three headwater streams. Arch. Hydrobiol. 94: 99–125.

TOWNS, D. R. 1983. Life history patterns of six sympatric species of Leptophlebiidae (Ephemeroptera) in a New Zealand stream and the role of interspecific competition in their evolution. Hydrobiologia 99: 37–50.

TOWNSEND, C. R., AND A. G. HILDREW. 1984. Longitudinal pattern in detritivore communities of acid streams: a consideration of alternative hypotheses. Verh. Int. Ver. Limnol. 22: 1953–1958.

TRISKA, F. J. 1984. Role of wood debris in modifying channel geomorphology and riparian areas of a large lowland river under pristine conditions: a historical case study. Verh. Int. Ver. Limnol. 22: 1876–1892.

VANNOTE, R. L., G. W. MINSHALL, K. W. CUMMINS, J. R. SEDELL, AND C. E. CUSHING. 1980. The River Continuum Concept. Can. J. Fish. Aquat. Sci. 37: 130–137.

WALLACE, J. B., J. R. WEBSTER, AND T. F. CUFFNEY. 1982. Stream detritus dynamics: regulation by invertebrate consumers. Oecologia (Berl.) 53: 197–200.

WARD, J. V., AND J. A. STANFORD. 1983. The serial discontinuity concept of lotic ecosystems, p. 29–42. *In* T. D. Fontaine and S. M. Bartell [ed.] Dynamics of lotic ecosystems. Ann Arbor Science Publishers Inc., Ann Arbor, MI.

WEBSTER, J. R. 1983. The role of benthic macroinvertebrates in detritus dynamics of streams: a computer simulation. Ecol. Monogr. 53: 383–404.

WILLIAMS, D. D., AND N. E. WILLIAMS. 1982. Morphological and dietary variations in a riverine population of *Pycnopsyche guttifer* (Trichoptera: Limnephilidae). Aquat. Insects 4: 21–27.

WILSER, J. L. 1937. Beziehungen des Flußverlaufes und der Gefällskurve des Neckars zur Schichtenablagerung am Südrand des Odenwaldes. Akad. Wiss. Math.-Naturwiss. Kl. (Heidelberg) 37: 3–16.

WINTERBOURN, M. J. 1982. The River Continuum Concept — a reply to Barmuta and Lake. N.Z. J. Mar. Freshwater Res. 16: 229–231.

WINTERBOURN, M. J., J. S. ROUNICK, AND B. COWIE. 1981. Are New Zealand stream ecosystems really different? N.Z. J. Mar. Freshwater Res. 15: 321–328.

ZWICK, P. 1976. Neoperla (Plecoptera, Perlidae) emerging from a mountain stream in Central Africa. Int. Rev. Gesamten Hydrobiol. 61: 683–697.

APPENDIX IV

Stream hydraulics as a major determinant of benthic invertebrate zonation patterns

Freshwater Biology (1986) **16**, 127–139

OPINION

Stream hydraulics as a major determinant of benthic invertebrate zonation patterns

BERNHARD STATZNER and BERT HIGLER* Zoologisches Institut I der Universität, Karlsruhe, and *Rijksinstituut voor Natuurbeheer, Leersum

SUMMARY. 1. Studies on the zonation of benthic fauna in fourteen streams situated in a variety of latitudes from Alaska to New Zealand have been evaluated.

2. We suggest that physical characteristics of flow ('stream hydraulics') are the most important environmental factor governing the zonation of stream benthos on a world-wide scale.

3. From the source to the mouth of a stream, zones of transition in 'stream hydraulics' occur, to which the general pattern of stream invertebrate assemblages can be related. In these zones benthic community stability and resilience must be different from those upstream and downstream of the hydraulic transition zones.

1. Introduction

In 1979 Botosaneanu reviewed what had been published on longitudinal zonation patterns of benthic stream invertebrates since his last synopsis of this topic (Illies & Botosaneanu, 1963). He emphasizes the fact that major faunistic changes are generally localized in relatively short stream reaches. One explanation could be that the environment changes rather abruptly and organisms more characteristic of upstream or downstream zones reach their tolerance limits in such reaches. Whole community responses to the same natural or man-made disturbance should differ between reaches where most species live under sub-optimal conditions and reaches where most species live under optimal conditions (Balon & Stewart, 1983).

Because this topic is of fundamental and applied importance in stream ecology, we have attempted to establish some generalizations in zonation patterns in the benthic fauna and to relate them to what we regard as the major abiotic factor responsible for them: the complex of physical characteristics of flow which can be summarized under the heading 'stream hydraulics'. This is problematical, because in the hundreds of publications on invertebrate stream zones, data from which hydraulic characteristics can be derived are relatively scarce. Therefore, and even though we have included data from a wide variety of running waters from Alaska to New Zealand, the number of potential examples for this review is relatively low. Also, few of these studies considered species densities or other criteria of longitudinal organization and thus we have concentrated on the distribution of species measured merely by presence or absence. It is our main purpose in this paper, therefore, to focus upon stream hydraulics as a factor and to stimulate more interest in it.

Correspondence: Dr B. Statzner, Zoologisches Institut I der Universität, Postfach 6380, D-7500 Karlsruhe, Federal Republic of Germany.

2. Why choose 'stream hydraulics' as a major determinant?

Initially, it may seem foolish to concentrate on only one abiotic factor, because stream communities obviously are influenced by numerous other factors. Temperature, for instance, is often considered to be very important. Thus, why not give water temperature the same importance as stream hydraulics in the characterization of stream zones on a world-wide basis? A brief example shows this to be impossible.

The zonation concept of Illies (1961) is based mainly on changing current velocity and water temperature from the source to the mouth of a stream. In Fig. 3 of Illies (1961) the rhithron is shown extending to lower altitudes in higher latitudes whilst the potamon behaves conversely. Even lakes are incorporated into this system. Therefore, and because torrential streams are frequently found at low altitudes in the tropics it is evident that the Illies concept is based solely on water temperature and not, as suggested, on water temperature and current velocity. In fact, work in the tropics has shown that it is impossible to find a universally valid, constant relationship between these two factors and zonation (Hynes, 1971; Bishop, 1973; Statzner, 1975; Harrison & Rankin, 1976; Harrison, 1978). Thus, both these abiotic factors cannot be weighted similarly and hierarchical patterns must be the basis of a useful world-wide classification. We put stream hydraulics in the top position of this hierarchy for several reasons.

Although rarely stated explicitly, hydraulic properties of stream flow traditionally have been considered as valuable descriptors of the physical environment in streams. However, this usually has been deduced from more or less general considerations. Huet (1949) assumed that drag forces of stream currents were influenced by slope as well as by width. He related fish zonation to these two parameters. Gessner (1955) discussed in detail some hydraulic factors which affect the ecology of plants in running waters. The longitudinal zonation of benthic invertebrates was related to stream slope and consequent bed stability by Hesse (1924). The 'erosion-deposition' (Moon, 1939) and the 'riffle-pool' (Kani, 1944) concepts also reflect stream hydraulics. The same holds for the zonation concept of Illies (1961) who speculated on the importance of 'current velocity at the stream bottom' which can probably best be translated into the hydraulic term 'friction velocity'. Two years earlier, Ambühl (1959) evaluated a similar parameter, the thickness of the boundary layer above the stream bottom, as a determinant of benthic invertebrate distribution.

Recent analyses have described microdistribution of the benthos in relation to various hydraulic parameters (Décamps, Larrouy & Trivellato, 1975; Gore, 1978; Statzner, 1981a, b). Since the physical qualities of microhabitats are

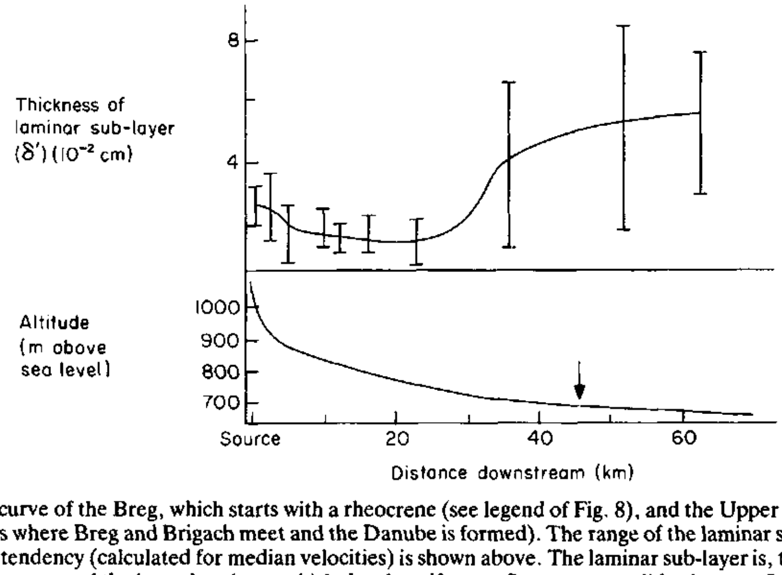


FIG. 1. Slope curve of the Breg, which starts with a rheocrene (see legend of Fig. 8), and the Upper Danube (the arrow indicates where Breg and Brigach meet and the Danube is formed). The range of the laminar sub-layer (δ') and its central tendency (calculated for median velocities) is shown above. The laminar sub-layer is, theoretically, the bottom-most zone of the boundary layer which develops if water flows over a solid substrate. It is calculated from replicated measurements conducted during non-flood conditions, its reciprocal value is used as an indicator of the hydraulic stress. δ' is calculated by $\delta' = U^{-1}\,11.5\,\nu\,5.75 \log(12D\,r_p^{-1})$. U: current velocity (cm s^{-1}); ν: kinematic viskosity ($cm^2\,s^{-1}$); D: depth (cm); r_p: substrate roughness (estimated from particle size, cm). Calculated after data from Backhaus & Sander (1967).

determined by downstream trends in macro-hydraulics (Bovee, 1982), it is logical to postulate they will have a major effect on the zonation of the benthos (Statzner, 1981a; Higler & Mol, 1984; Newbury, 1984).

Another reason to suspect that stream hydraulics is the critical factor bringing about biological zonation is that, from the source to the mouth of a stream, hydraulics often exhibits distinct changes localized within relatively short stretches (Fig. 1). Using the thickness of the laminar sub-layer and the slope as a descriptor of the hydraulic stress at the stream bottom, a 'standard' pristine running water course, to which real streams can be compared, has the following properties (see Statzner & Higler, 1985, and top of Fig. 8): the source and the first part of the headwater are frequently characterized by relatively low hydraulic stress. A transition zone is followed by a reach of high slope and high hydraulic stress. Another zone of transition where the slope levels off, is followed by a zone of lower hydraulic stress. Further downstream, numerous large-scale discontinuities of the hydraulic stress may occur. The character of the mouth of the stream is determined through the material exported by the stream and the transport capacity of the marine component (delta or estuary). The upper two zones of transition of hydraulic stress may shift up- and downstream with fluctuating discharge.

It is not easy to describe the above pattern from physical data published in zonation studies. Sometimes the power of the water expended per unit length (Watt m^{-1}) or per unit area (Watt m^{-2}) of the channel and the Froude-Number (streaming or shooting flow) could be calculated (see Statzner & Higler, 1985, for formulae).

TABLE 1. Short characterization of the zonation studies reviewed here. Latitudes, altitudes, and lengths approximations

Stream	Geographical latitude	Country	Length of reach studied (km)	Altitude (m.a.s.l.) of highest-lowest station	Fauna studied	Author
Atigun	68°N	U.S.A.	75	1375–700	Zoobenthos	Slack, Naumann & Tilley, 1979
Endrick	56°N	Scotland	49	500–10	Macrozoobenthos	Maitland, 1966
Hierden	52°N	Netherlands	20	26–0	Macrozoobenthos	Higler, 1979, 1980; Higler & Repko, 1981
Fulda	51°N	F.R.G.	220	850–120	Macrozoobenthos, mainly Insecta	Illies, 1953; physiography: Marten, 1983
Schwechat	48°N	Austria	68	700–154	Macrozoobenthos	Starmühlner, 1969
Issyk	43°N	U.S.S.R.	29	4000–700	Mainly Insecta	Brodsky, 1980, Fig. 91, Table 62
Tiber	43°N	Italy	150	1279–175	Trichoptera	Moretti & Cianficconi, 1984
St Vrain	40°N	U.S.A.	54	3414–1544	Ephemeroptera, Plecoptera, Trichoptera	Ward & Berner, 1980; Ward, 1981, 1982
Arima	11°N	West Indies	15	365–17	Mainly Insecta	Hynes, 1971
Bandama	10°N -5°N	Ivory Coast	1000	500–0 (400)	Decapoda, Simuliidae, Hydropsychidae, Philpotamidae	Lévêque, Dejoux & Iltis, 1983; Gibon & Statzner, 1985
Tshinganda/ Luhoho	2°S	Zaire	64	2450–850	Trichoptera	Statzner, 1975
Luanza	10°S	Zaire	58	1690–975	Trichoptera	Malaisse, 1976; Marlier, 1981
Vaal Dam Catchment	27°S	South Africa	Up to 400	2000–1500	Macrozoobenthos	Chutter, 1970
Cascade/ Waitakere	37°S	New Zealand	6	120–5	Macrozoobenthos	Towns, 1979

Sometimes only substrate characteristics or the slope of the valley are available. These characteristics of flow are evaluated by biologists and generally not measured as hydrologists would do. Nevertheless, we have been able to show where the hydraulic stress in the channel undergoes a distrinct change on the way downstream. Our results indicate that these transition zones are the critical determinants of species association change.

3. Examples of faunistic zonation patterns in a variety of streams

Natural zonation patterns over long stream reaches are usually obscured by the fact that more or less intensive human influences on the stream or its valley have long been established. Most studies accordingly have been more or less restricted to the upper parts of streams, and we have rather little information on what constituted the original fauna of large pristine rivers. Therefore, only some general remarks on the latter are possible.

3.1. *Upper parts of streams*

In a series of figures and short characterizations we will relate faunistic zonation to downstream changes in hydraulic properties. We have included information on water temperature as well in order to demonstrate that its role in defining general species distribution patterns along running water courses has been overestimated in the past.

Some simplifications are necessary in the way that faunistic zonation patterns are shown. Thus, for each species considered, it will be assumed that it is distributed in all stream reaches between the highest and lowest station it was found, even if it was not actually present in samples from all stations between these points. Single specimens of species found at only one station frequently are omitted from the analyses. For each station a curve is drawn, showing how the particular assemblage of species found at that station decrease in an upstream and (or) a downstream direction (see further details in legend to Fig. 2). A set of such curves covering the whole reach under study are used to deter-

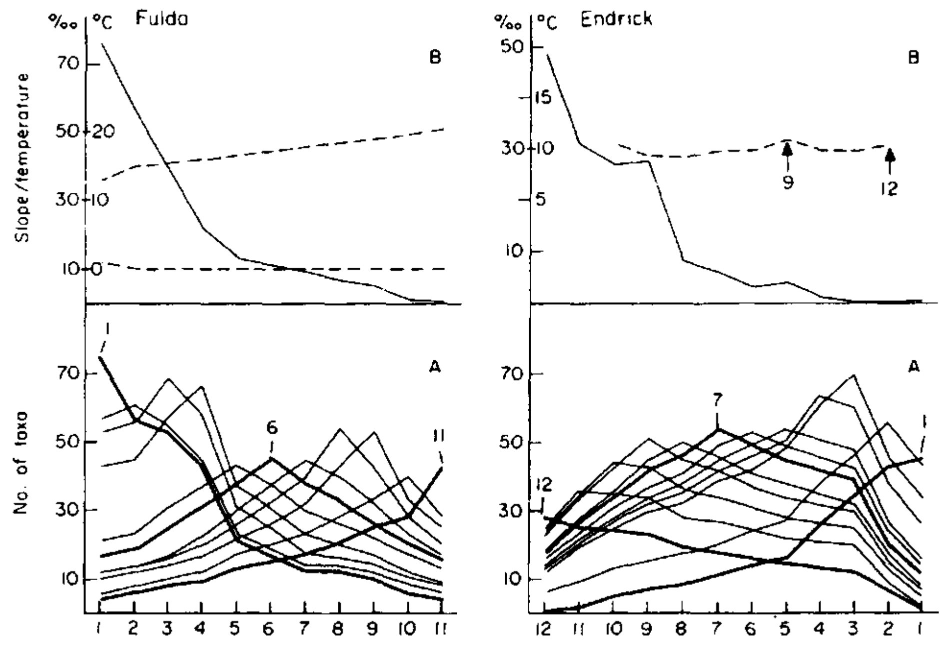


FIG. 2. Fulda (F.R.G.) and Endrick (Scotland). (A) Species congruity curves demonstrating species replacement along the downstream gradient. In each set of curves, the curve for the highest station as well as that representative of a reach of relatively little faunistic change and of the lower reach are emphasized by thicker lines. (B) Fulda: ——: slope; ----: annual maximum and minimum water temperature. Endrick: ——: slope; ----: annual mean water temperature, number below arrow: maximal weekly amplitude of water temperature.

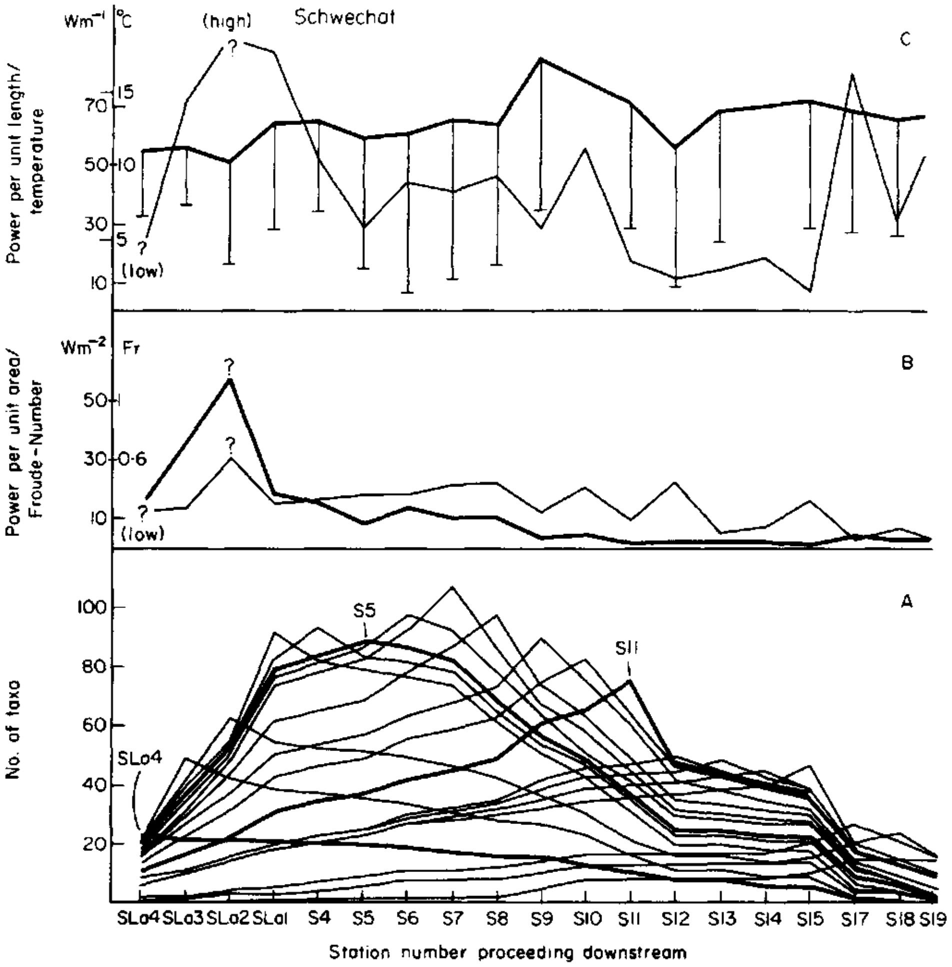


FIG. 3. Schwechat (Austria): (A) species congruity curves; (B) thick line: power per unit area; thin line: Froude-Number; (C) thin line: power per unit length; thick line: mean annual water temperature—half of the maximal annual amplitude. See Fig. 2 for further details.

mine stream zones (Illies, 1953). This method of presenting the data is perhaps more complicated than, for example, cluster analyses, but the total number of species at each station, and reaches with high and low overlap from upstream and downstream stations, are indicated clearly.

The studies considered here are characterized briefly in Table 1. Figs. 2–7 show the distribution pattern discovered in nine of them.

The species congruity curves of Fulda (Fig. 2), Endrick (Fig. 2), Schwechat (Fig. 3), and Tshinganda/Luhoho (Fig. 4) are rather similar in their general shape. Generally few species appear at the spring sources. The deviation from this pattern in the Fulda, with many species at the uppermost station, is caused by the combined sampling of the source and the spring brook. Further downstream, a zone of rapid change in species is followed by a zone with a rather stable set of species, then there is a second zone of rapid change in species. Apparently, a change in water temperature cannot explain these patterns in any case. Nor is it probable that pollution and weirs, both observed in Fulda, Endrick and Schwechat, would shape the patterns of congruity curves in such a similar way. In the Schwechat obvious industrial pollution and increased hydraulic engineering start upstream of station S9, the reach downstream of station S11 is highly perturbed. Thus, in this stream the

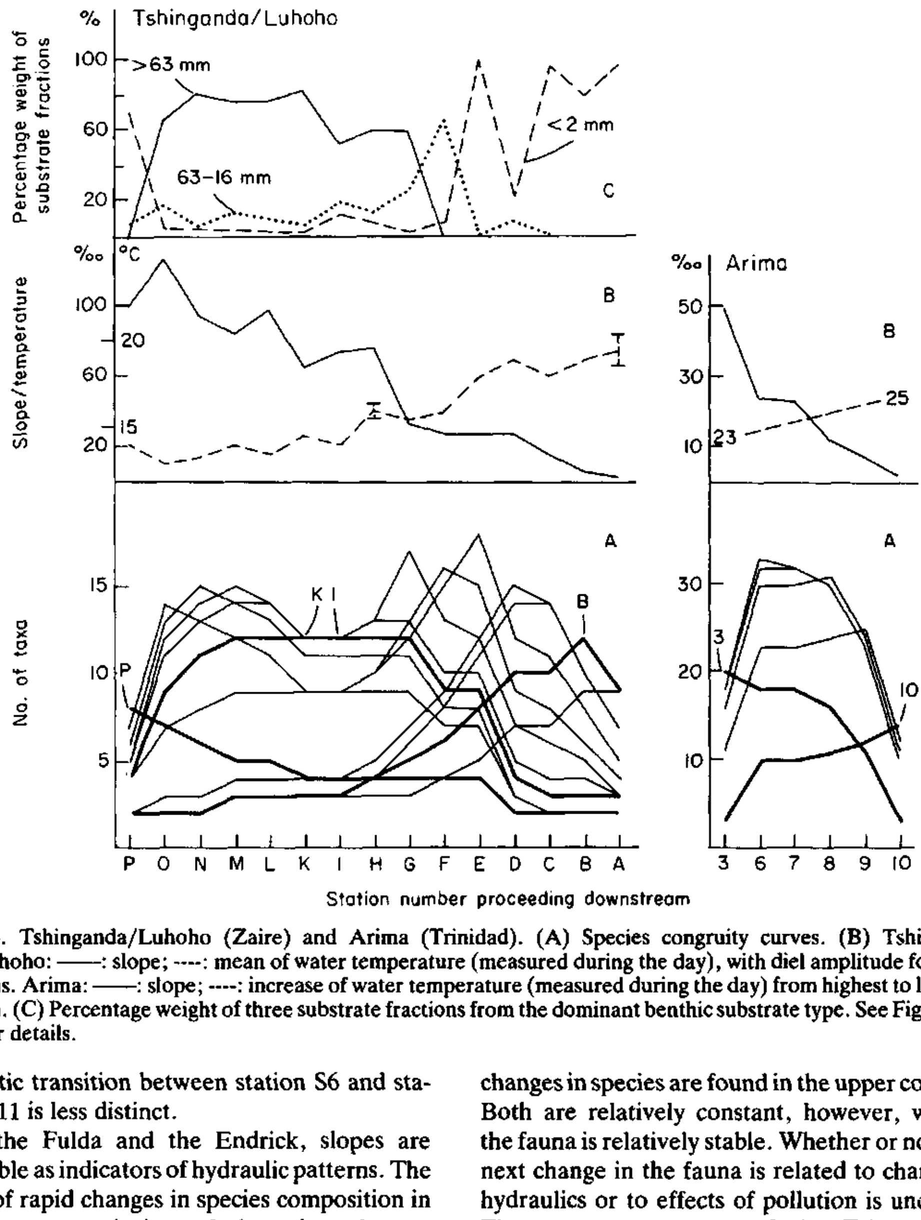


FIG 4. Tshinganda/Luhoho (Zaire) and Arima (Trinidad). (A) Species congruity curves. (B) Tshinganda/Luhoho: ——: slope; ----: mean of water temperature (measured during the day), with diel amplitude for two stations. Arima: ——: slope; ----: increase of water temperature (measured during the day) from highest to lowest station. (C) Percentage weight of three substrate fractions from the dominant benthic substrate type. See Fig. 2 for further details.

faunistic transition between station S6 and station S11 is less distinct.

In the Fulda and the Endrick, slopes are available as indicators of hydraulic patterns. The zone of rapid changes in species composition in the upper course is situated where slope changes distinctly. A rather stable set of species is found where the slope is relatively constant. The second rapid change in species is observed beween the stable zone and the flood-plain, in which the lowest sampling stations were established. In the Schwechat, as in other examples given later, the power expended per unit reach of channel is less helpful in explaining distribution patterns of benthic macroinvertebrates. Froude-Number or power expended per unit area show distinct changes where rapid changes in species are found in the upper course. Both are relatively constant, however, where the fauna is relatively stable. Whether or not the next change in the fauna is related to changing hydraulics or to effects of pollution is unclear. The uppermost course of the Tshinganda/Luhoho demonstrates that slope is only a rough predictor of stream hydraulics: it failed to indicate the very different conditions in the source and in the following reach (see also Fig. 1), as indicated by substrate characteristics. Changes in the latter induce distinct faunistic changes, and the relative stable faunistic zone is situated in the stony reach.

In all four streams, species occurred which were restricted to the zones of distinct faunistic changes. Descriptors of the hydraulic situation

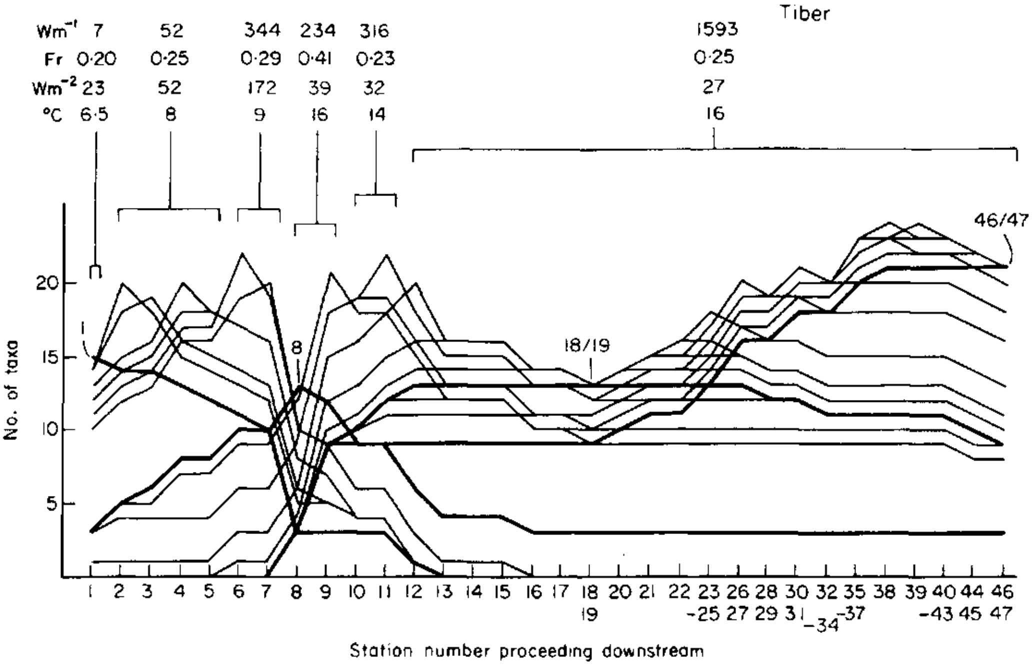


FIG. 5. Tiber (Italy). Species congruity curves and physical parameters. Power per unit length (Watt m^{-1}), power per unit area (Watt m^{-2}), Froude-Number (Fr) and mean annual water temperature (°C) are available only as a mean for several stations. Stations with identical species assemblages are plotted together. See Fig. 2 for further details.

used above indicate similar conditions at the source and further downstream in Schwechat and Tshinganda/Luhoho, but their assemblages of species are rather different. This may be because water temperatures (Schwechat: amplitude; Tshinganda: mean) differ between upstream and downstream reaches.

In addition to stream types represented by the Tshinganda/Luhoho another type characterized by a zone or large waterfalls occurs in the Zaire. Such a stream is the Luanza (not figured). Its source discharges into a pond, below which is a reach of rapid changes in slope and species composition. The Luanza then enters a high plateau, where few changes in species are observed. Some species changes occur where the water falls to a lower plateau, and some species are found only around the falls. The effect of the falls on the distribution patterns of fish is much more distinct than on insects. Water temperature was almost constant over the whole length under study.

A similar low significance of water temperature on faunal zonation was found in the Vaal Dam Catchment (not figured). There streams enter a high plateau and accumulate much silt and sand in the lower reaches. The presence or absence of this fine material which is generally determined by stream hydraulics appears to be the major factor correlated with species distribution.

Arima (Fig. 4) and Cascade/Waitakere (Fig. 6) are short streams. Samples from the uppermost courses were not available and only one zone of faunistic overlap could be discerned. This was situated between the uppermost station and the flood-plain. In the Cascade/Waitakere, species richness decreased distinctly in the lowest reach, close to the mouth. The difference in water temperature was low (0.2°C) between station 9 and 10 in the Arima; in the Cascade/Waitakere the upper stations were about 5°C cooler than the lower ones during summer.

The Tiber (Fig. 5) is included in our review since results are based on a long-term study at a large number of stations. The source is an artificial basin, the river bed is further modified downstream, and pollution is recorded. Physiographical data are available only as means

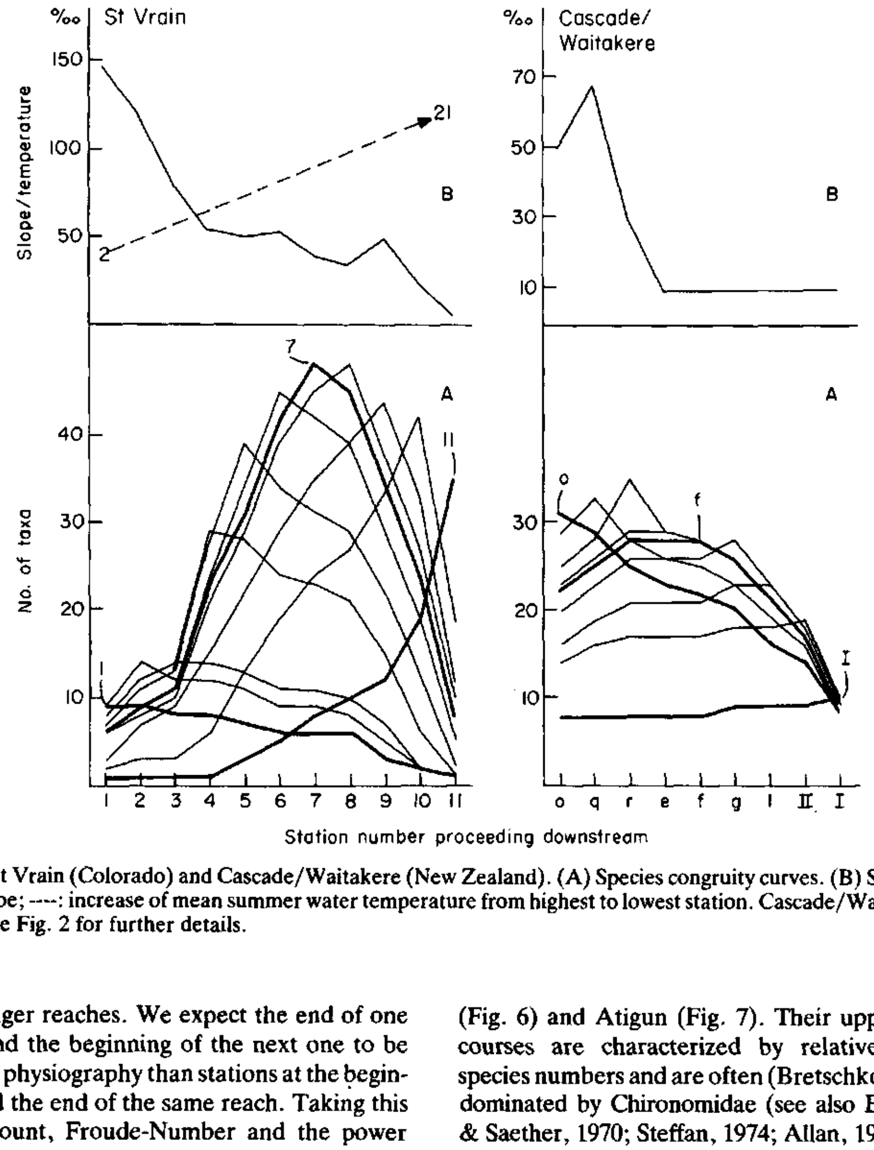


FIG. 6. St Vrain (Colorado) and Cascade/Waitakere (New Zealand). (A) Species congruity curves. (B) St Vrain: ——: slope; ----: increase of mean summer water temperature from highest to lowest station. Cascade/Waitakere: slope. See Fig. 2 for further details.

over longer reaches. We expect the end of one reach and the beginning of the next one to be closer in physiography than stations at the beginning and the end of the same reach. Taking this into account, Froude-Number and the power expended per unit area indicate an increase in hydraulic stress from the source to the reach around station 8 and a decrease in this parameter further downstream. Water temperature rises distinctly around station 8. Due to a lack of data we can only speculate that the hydraulic stress is distinctly reduced in the lower reach of the Tiber (an artificial lake is situated 5 km downstream of station 36). Abrupt faunistic changes were observed around station 8 and, less pronounced ones, above the reservoir (upstream of station 47).

The next three streams we will deal with are fed by glaciers: Issyk (not figured), St Vrain (Fig. 6) and Atigun (Fig. 7). Their uppermost courses are characterized by relatively low species numbers and are often (Bretschko, 1969) dominated by Chironomidae (see also Elgmork & Saether, 1970; Steffan, 1974; Allan, 1975).

In the Issyk the highest species numbers were recorded in a zone with two transitions: the first where coniferous forest is replaced by hardwood forest and the second between the torrent zone and the debris cone zone. The Issyk is an example of a stream in which discharge decreases on the way down: it enters a steppe and then a semi-desert in the plain, where it disappears (water is used for irrigation). In the lower reaches, the number of torrential benthic species gradually decreases. In the St Vrain a distinct increase in numbers of species was observed until the slope was almost uniform around station 7, and a clear change in the fauna occurred where the slope

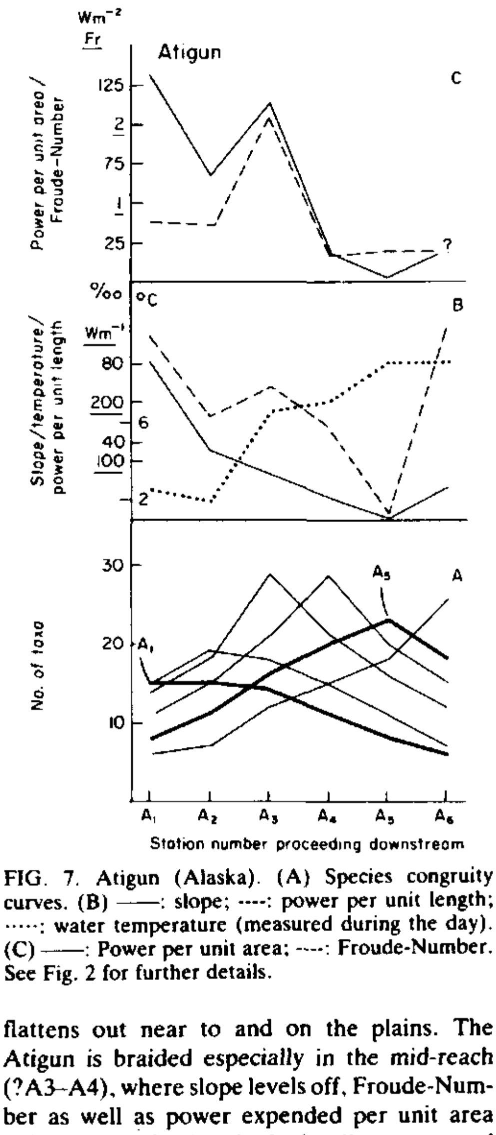


FIG. 7. Atigun (Alaska). (A) Species congruity curves. (B) ——: slope; ----: power per unit length; ·····: water temperature (measured during the day). (C) ——: Power per unit area; ----: Froude-Number. See Fig. 2 for further details.

flattens out near to and on the plains. The Atigun is braided especially in the mid-reach (?A3–A4), where slope levels off, Froude-Number as well as power expended per unit area indicate a reduction in hydraulic stress, and water temperature rises. In this mid-reach species richness is highest. Below station A5 the stream is influenced by lake drainage.

The last two streams considered lack well-defined sources. In the Hierden stream (not figured), stations near bridges or weirs with stony substrata and high velocities are inhabited by a unique set of species in addition to species present over the largest part of the stream. The Bandama River system (not figured) runs from north to south and lacks well-defined changes in its gentle slope. Discharge is very variable and the northern parts are temporary stream reaches. A north–south gradient in the length of the period without flow exists, while the differences in water temperature are insignificant between northern and southern reaches. Additional species are added to the fauna in the south, without the loss of northern species. The lowest reach lacks riffles, and a sharp decrease in lotic species is observed there.

3.2. *Large rivers*

Fittkau & Reiss (1983) recently attempted to reconstruct the ecological characteristics that occurred in large pristine rivers and their flood-plains. Besides the main channel 'lotic and lentic, static and astastic, summer-cold and summer-warm, small and large' freshwaters occurred in a relatively restricted area, which contained a rich fauna. This species richness is also well documented by observations from the Rhone (Richardot-Coulet, Richoux & Roux, 1983) as well as by a palaeo-limnological study in the Rhine (Klink, 1983). In the main channel, various species assemblages occur in different habitats (Mordukhai-Boltovskoi, 1979), some of these are extremely specialized, for instance, to shifting sand (Barton & Smith, 1984). The large debris dams and the resulting lacustrine conditions (Sedell & Froggatt, 1984; Triska, 1984) created numerous 'lake out-flows' and, presumably, lake out-flow communities (Müller, 1955; Illies, 1956), which are overlap communities between lentic and lotic aquatic systems (Statzner, 1978).

Thus we assume that the species richness of the benthic fauna in the pristine large river, which in our view includes the adjacent freshwaters of the flood-plain, is much higher than in the upper parts of the same stream. Again it is primarily the physics of the flow which creates the richness of habitats and thereby the high biological diversity in large rivers. Running waters like the Issyk, which ends in a desert, or the Bandama, which builds up high dams from material deposited at the bank (due to high turbidity under a seasonally dry climate), represent exceptions from the above picture of a large pristine river.

3.3. *Mouths of streams*

Stream hydraulics determine in part the geomorphological features of the mouth (whether a delta or estuary is formed). These

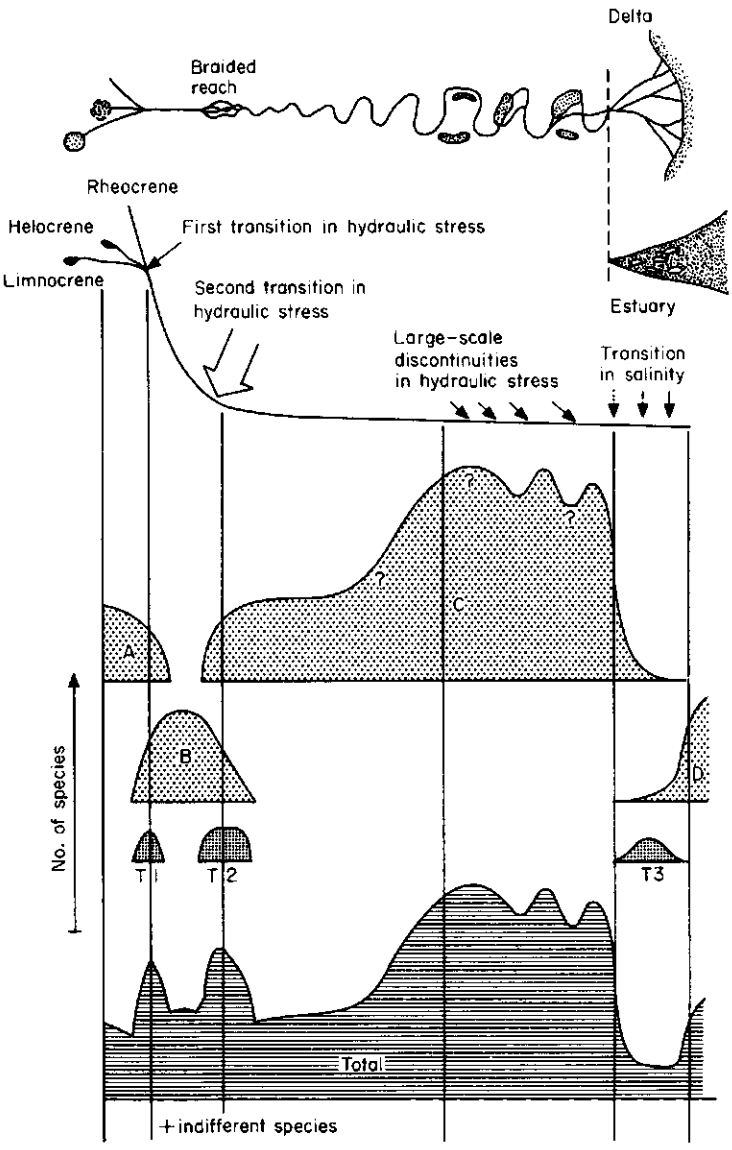


FIG. 8. Proposal for a general faunistic zonation pattern of the benthos in pristine streams (aerial view and slope) with 'standard' flow characteristics. Source types: rheocrene—source discharges directly into a channel; helocrene: source discharges into a marshy pond; limnocrene—source discharges into a pond. Not all of the components shown here can be or must be present in a stream. The species distribution in a running water that starts with a helocrene and ends with an estuary is indicated in our example. Species occurring in the spring (A) and in the reach of high slope (B) overlap at the first transition in hydraulic stress. Species of group B and species occurring in the stream after it has entered the flood-plain (C) overlap at the second transition in hydraulic stress, where pristine streams are frequently braided. Patterns in the large river are rather speculative due to sparse information. In the brackish zone a third overlap is found between species of group C and the marine fauna (D). In all three zones of species overlap few species occur which are solely found in these reaches of transition (T1, T2, T3). Species which do not characterize a zone are omitted.

features in turn are largely responsible for the pattern of species present through the resulting salinity gradient: it is a well-known fact that a relative scarcity of species exists in the lowest reaches of streams under brackish conditions (Remane & Schlieper, 1958; Wolff, 1983). This transition zone in salinity once more shows a distinct overlap of species: freshwater species disappear and marine species show up, and few specialists of brackish conditions are found here.

4. Conclusions

Although patterns of faunistic stream zonation and abiotic parameters are relatively diverse, one general aspect emerges: distinct changes in species assemblages are often linked to changes in parameters associated with stream hydraulics. In a 'stereotyped' stream such as that described at the end of part 2 the faunistic zonation pattern should be like that depicted in Fig. 8. It is evident that this pattern has to be modified if additional base levels, for example lakes, in the stream's course occur or if single components in the order of reaches shown in Fig. 8 do not exist. Streams which lack well-defined sources and abrupt changes in the slope are such examples. Because no distinct faunal zones were observed in these type of streams (Hierden stream; Bandama River; see Table 1 for references) they represent a null model against which zonation patterns linked to changes in hydraulics can be tested.

Under similar hydraulic conditions but different water temperature regimes different faunistic communities are found even in the same geographical area (Stoneburner, 1977). Other abiotic and biotic variables will complicate the picture even more. Faunistic differences in stream reaches with similar hydraulics situated in upper and lower courses should be related to these non-hydraulic environmental factors. But on a world-wide scale stream hydraulics are the major factor affecting stream zonation, i.e. the pattern shown in Fig. 8 is applicable in the humid tropics as well as in high latitudes because water temperature plays only an inferior role in defining invertebrate zones.

Our approach differs clearly from the crenon-rhithron-potamon concept (see Illies & Botosaneanu, 1963), although in a highland stream of Mid Europe species of group A (Fig. 8) should represent the crenon, group B the rhithron, and group C the potamon. However, we were not able to discern the division of rhithron as well as of potamon into three biocoenoses, i.e. into components of the same level of organization. Nor did we discover a pattern of species distribution as postulated by Vannote *et al.* (1980) and Stanford & Ward (1983) who predict the highest faunal diversity in mid-reaches of streams.

The patterns elaborated in this paper reflect what is predicted by Thienemann (1918, 1920) who linked species richness to environmental harshness and variability, ideas represented more recently in the 'intermediate disturbance' hypothesis (see Stanford & Ward (1983) and Reice (1984)). Under ecologically extreme conditions, such as the headwaters of glacier-fed streams or in a brackish river mouth, species numbers are relatively low. Under less extreme conditions high species richness is found in the zones of transition of hydraulic stress, where we expect a considerable inconstancy of this factor (Statzner & Higler, 1985). In these transition zones species assemblages overlap and a relatively large number of species live near the limits of their ecological tolerance. Thus in these zones of major hydraulic and faunistic change (transition zones) the potentials of community stability and resilience must be different from those in zones upstream and downstream.

In conclusion, we suggest that more emphasis should be placed on hydraulics in future stream studies. They should include measurements of current velocity, depth, substrate roughness, surface slope, and hydraulic radius (see Gore, 1978, and Newbury, 1984, for methods). From these simple parameters hydraulic characteristics can be calculated according to formulae given, for example, in Smith (1975), Mangelsdorf & Scheurmann (1980), Newbury (1984) or Statzner & Higler (1985).

Acknowledgments

We thank Liz Mole (Weinheim), Professor Mike Dickman (Ontario), Dr Alan G. Hildrew (London) and an anonymous referee for comments on the content and linguistic advice.

References

Allan J.D. (1975) The distributional ecology and diversity of benthic insects in Cement Creek, Colorado. *Ecology*, **56**, 1040–1053.

Ambühl H. (1959) Die Bedeutung der Strömung als ökologischer Faktor. *Schweizerische Zeitschrift für Hydrologie*, **21**, 133–264.

Backhaus F. & Sander U. (1967) Zur Chemie der Donauquellflüsse Breg und Brigach und des obersten Donauabschnittes bis zur Versickerung bei Immendingen. *Archiv für Hydrobiologie, Supplement*, **30**, 228–305.

Balon E.K. & Stewart D.J. (1983) Fish assemblages in a river with unusual gradient (Luongo, Africa-Zaire system), reflections on river zonation, and description of another new species. *Environmental Biology of Fishes*, **9**, 225–252.
Barton D.R. & Smith S.M. (1984) Insects of extremely small and extremely large aquatic habitats. *The Ecology of Aquatic Insects* (Eds V. H. Resh and D. M. Rosenberg), pp. 456–483. Praeger, New York.
Bishop J.E. (1973) Limnology of a small Malayan river Sungai Gombak. *Monographiae Biologicae*, **22**. Junk, The Hague.
Botosaneanu L. (1979) Quinze années de recherches sur la zonation des cours d'eau: 1963–1978. *Bijdragen tot de Dierkunde*, **49**, 109–134.
Bovee K.D. (1982) A guide to stream habitat analysis using the instream flow incremental methodology. U.S. Fish and Wildlife Service (FWS/OBS-82/26), Washington.
Bretschko G. (1969) Zur Hydrobiologie zentralalpiner Gletscherabflüsse. *Verhandlungen der Deutschen Zoologischen Gesellschaft in Innsbruck*, **1968**, 741–750.
Brodsky K.A. (1980) Mountain torrent of the Tien Shan. *Monographiae Biologicae*, **39**. Junk, The Hague.
Chutter F.M. (1970) Hydrobiological studies in the catchment of Vaal Dam, South Africa. Part 1. River zonation and the benthic fauna. *Internationale Revue der Gesamten Hydrobiologie*, **55**, 445–494.
Décamps H., Larrouy G. & Trivellato D. (1975) Approche hydrodynamique de la microdistribution d'invertébrés benthiques en eau courante. *Annales de Limnologie*, **11**, 79–100.
Elgmork K. & Saether O.A. (1970) Distribution of invertebrates in a high mountain brook in the Colorado Rocky Mountains. *Studies of the University of Colorado (Series Biology)*, **31**, 1–51.
Fittkau E.J. & Reiss F. (1983) Versuch einer Rekonstruktion der Fauna europäischer Ströme und ihrer Auen. *Archiv für Hydrobiologie*, **97**, 1–6.
Gessner F. (1955) *Hydrobotanik I*. VEB Deutscher Verlag der Wissenschaften, Berlin.
Gibon F.M. & Statzner B. (1985) Longitudinal zonation of lotic insects in the Bandama system (Ivory Coast). *Hydrobiologia*, **122**, 61–64.
Gore J.A. (1978) A technique for predicting in-stream flow requirements of benthic macroinvertebrates. *Freshwater Biology*, **8**, 141–151.
Harrison A.D. (1978) Freshwater invertebrates (except molluscs). *Biogeography and Ecology of Southern Africa* (Ed. M. J. A. Werger), pp. 1139–1152. Junk, The Hague.
Harrison A.D. & Rankin J.J. (1976) Hydrobiological studies of Easter Lesser Antillean Islands. II. St. Vincent: Freshwater fauna—its distribution, tropical river zonation and biogeography. *Archiv für Hydrobiologie, Supplement*, **50**, 275–311.
Hesse R. (1924) *Tiergeographie auf ökologischer Grundlage*. G. Fischer, Jena.
Higler L.W.G. (1979) *Faunistische gegevens van de Hierdense Beek 1907–1970*. Rijksinstituut voor Natuurbeheer, Leersum.
Higler L.W.G. (1980) *Hydrologische, fysische en chemische gegevens van de Hierdense Beek*. Rijksinstituut voor Natuurbeheer, Leersum.
Higler L.W.G. & Repko F.F. (1981) The effects of pollution in the drainage area of a Dutch lowland stream on fish and macro-invertebrates. *Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie*, **21**, 1077–1082.
Higler L.W.G. & Mol A.W.M. (1984) Ecological types of running water based on stream hydraulics in The Netherlands. *Hydrobiological Bulletin*, **18**, 51–57.
Huet M. (1949) Aperçu des relations entre la pente et les populations piscicoles des eaux courantes. *Schweizerische Zeitschrift für Hydrologie*, **11**, 332–351.
Hynes H.B.N. (1971) Zonation of the invertebrate fauna in a West Indian stream. *Hydrobiologia*, **38**, 1–8.
Illies J. (1953) Die Besiedlung der Fulda (insbes. das Benthos der Salmonidenregion) nach dem jetzigen Stand der Untersuchung. *Berichte der Limnologischen Flußstation Freudenthal*, **5**, 1–28.
Illies J. (1956) Seeausfluß-Biozönosen lappländischer Waldbäche. *Entomologisk Tidskrift*, **77**, 138–153.
Illies J. (1961) Versuch einer allgemeinen biozönotischen Gliederung der Fliessgewässer. *Internationale Revue der Gesamten Hydrobiologie*, **46**, 205–213.
Illies J. & Botosaneanu L. (1963) Problèmes et méthodes de la classification et de la zonation écologique des eaux courantes, considerées surtout du point de vue faunistique. *Mitteilungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie*, **12**, 1–57.
Kani T. (1944) Stream classification in 'Ecology of torrent-inhabiting insects' (1944): an abridged translation. *Physiological Ecology Japan*, **18** (1981), 113–118.
Klink A. (1983) Studie over de toepasbaarheid van palaeolimnologisch onderzoek in riviersedimenten. Een middel om biologische beoordeling van rivieren te onderbouwen? *Rapporten en Mededelingen Hydrobiologisch Adviesburo*, **7**, Wageningen.
Lévêque C., Dejoux C. & Iltis A. (1983) Limnologie du Fleuve Banadama, Côte d'Ivoire. *Hydrobiologia*, **100**, 113–141.
Maitland P.S. (1966) The fauna of the River Endrick. *Studies on Loch Lomond. II*. The University of Glasgow & Blackie, Glasgow.
Malaisse F. (1976) Écologie de la Rivière Luanza. *Exploration hydrobiologique du Bassin du Lac Bangweolo et du Luapula, Resultats Scientifique*, **17** (2). Cercle Hydrobiologique, Bruxelles.
Mangelsdorf J. & Scheurmann K. (1980) *Flussmorphologie*. Oldenbourg, München.
Marlier G. (1981) Trichoptères. *Exploration hydrobiologique du Bassin du Lac Bangweolo et du Luapula, Resultats scientifique*, **14** (7). Cercle Hydrobiologique, Bruxelles.
Marten M. (1983) Die Ephemeropteren, Plecopteren, Heteropteren und Coleopteren der Fulda.

Diplomarbeit, Freie Universität Berlin.

Moon H.P. (1939) Aspects of the ecology of aquatic insects. *Transactions of the Society for British Entomology*, **6**, 39–49.

Mordukhai-Boltovskoi P.D. (1979) Zoobenthos and other invertebrates living on substrata. *The River Volga and its Life* (Ed. P. D. Mordukhai-Boltovskoi), pp. 235–268. Junk, The Hague.

Moretti G.P. & Cianficconi F. (1984) Zonation of Trichoptera populations from the source to the mouth of the Tiber River (Central Italy, Rome). *Proceedings of the 4th International Symposium on Trichoptera, Clemson 1983* (Ed. J. C. Morse), pp. 243–252. Junk, The Hague.

Müller K. (1955) Produktionsbiologische Untersuchungen in Nordschwedischen Fließgewässern. Teil 3. Die Bedeutung der Seen und Stillwasserzonen für die Produktion in Fließgewässern. *Report of the Institute for Freshwater Research Drotningholm*, **36**, 148–162.

Newbury R.W. (1984) Hydrologic determinants of aquatic insect habitats. *The Ecology of Aquatic Insects* (Eds V. H. Resh and D. M. Rosenberg), pp. 323–357. Praeger, New York.

Reice S.R. (1984) The impact of disturbance frequency on the structure of aotic riffle community. *Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie*, **22**, 1906–1910.

Remane A. & Schlieper C. (1958) Die Biologie des Brackwassers. *Die Binnengewässer*, **22**. Schweizerbart, Stuttgart.

Richardot-Coulet M., Richoux P. & Roux C. (1983) Structure et fonctionnement des écosystèmes du Haut-Rhône français. 29. Structure des peuplements de macroinvertebrés benthiques d'un ancien méandre. *Archiv für Hydrobiologie*, **96**, 363–383.

Sedell J.R. & Froggatt J.L. (1984) Importance of streamside forests to large rivers: the isolation of the Willamette River, Oregon, USA, from its floodplain. *Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie*, **22**, 1828–1834.

Slack K.V., Naumann J.W. & Tilley L.J. (1979) Benthic invertebrates in a north-flowing stream and a south-flowing stream, Brooks Range, Alaska. *Water Resources Bulletin*, **15**, 108–135.

Smith I.R. (1975) Turbulence in lakes and rivers. Scientific Publication No. 29, Freshwater Biological Association, Ambleside.

Stanford J.A. & Ward J.V. (1983) Insect species diversity as a function of environmental variability and disturbance in stream systems. *Stream Ecology* (Eds J. R. Barnes and G. W. Minshall), pp. 265–278. Plenum Press, New York.

Starmühlner F. (1969) *Die Schwechat*. Notring, Wien.

Statzner B. (1975) Zur Longitudinalzonierung eines zentralafrikanischen Fließgewässersystems unter besonderer Berücksichtigung der Köcherfliegen (Trichoptera, Insecta). *Archiv für Hydrobiologie*, **76**, 153–180.

Statzner B. (1978) Factors that determine the benthic secondary production in two lake outflows—a cybernetic model. *Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie*, **20**, 1517–1522.

Statzner B. (1981a) The relation between 'hydraulic stress' and microdistribution of benthic macroinvertebrates in a lowland running water system, the Schierenseebrooks (North Germany). *Archiv für Hydrobiologie*, **91**, 192–218.

Statzner B. (1981b) A method to estimate the population size of benthic macroinvertebrates in streams. Oecologia, **51**, 157–161.

Statzner B. & Higler B. (1985) Questions and comments on the River Continuum Concept. *Canadian Journal of Fisheries and Aquatic Sciences*, **42**, 1038–1044.

Steffan A.W. (1974) Die Lebensgemeinschaft der Gletscherbach-Zuckmücken (Diptera: Chironomidae)—eine Extrembiozönose. *Entomologisk Tidskrift, Supplement*, **95**, 225–232.

Stoneburner D.L. (1977) Preliminary observations of the aquatic insects of the Smoky Mountains: altitudinal zonation in the spring. *Hydrobiologia*, **56**, 137–143.

Thienemann A. (1918) Lebensgemeinschaft und Lebensraum. *Naturwissenschaftliche Wochenschrift*, Neue Folge, **17**, 281–290, 297–303.

Thienemann A. (1920) Die Grundlagen der Biozönotik und Monards faunistische Prinzipien. *Festschrift für Zschokke*, **4**, 1–14.

Towns D.R. (1979) Composition and zonation of benthic invertebrate communities in a New Zealand kauri forest stream. *Freshwater Biology*, **9**, 251–262.

Triska F.J. (1984) Role of wood debris in modifying channel geomorphology and riparian habitats of a large lowland river under pristine conditions: a historical study. *Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie*, **22**, 1876–1892.

Vannote R.L., Minishall G.W., Cummins K.W., Sedell J.R. & Cushing C.E. (1980) The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences*, **37**, 130–137.

Ward J.V. (1981) Altitudinal distribution and abundance of Trichoptera in a Rocky Mountain stream. *Series Entomologica*, **20**, 375–381.

Ward J.V. (1982) Altitudinal zonation of Plecoptera in a Rocky Mountain stream. *Aquatic Insects*, **4**, 105–110.

Ward J.V. & Berner L. (1980) Abundance and altitudinal distribution of Ephemeroptera in a Rocky Mountain stream. *Advances in Ephemeroptera Biology* (Eds J. F. Flannagan and K. E. Marshall), pp. 169–177. Plenum Press, New York.

Wolff W.J. (1983) Estuarine benthos. *Estuaries and Enclosed Seas* (Ed. B. H. Ketchum), pp. 151–182. Ecosystems of the World, 26. Elsevier, Amsterdam.

(Manuscript accepted 5 September 1985)

APPENDIX V

Flora and fauna of European running waters

A. Mol (consultant)
Council of Europe (EXP/Eau/ff (78) 4

CONTENTS

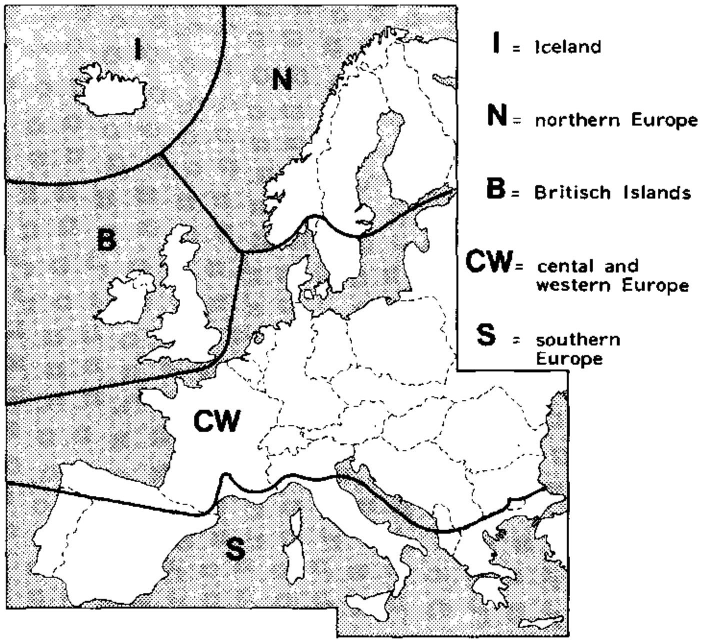
I. INTRODUCTION

In report EXP/Eau/ff (77) 15 rev. a division of Europe into four zones was adopted, basically on climatical differences. It was agreed that this division was necessary as a first step to the classificaton of European running waters. A more precise delimitation of the areas is given in fig. V 1. Some investigations in Spain, France and Norway showed that the borderlines between zones of terrestrial vegetation (viz. mediteranean zone in the south and coniferous zone in the north) were very suitable as hydrobiological demarcation lines. The difference between "CW" and "B" (fig. V 2) is more subtle and does not show in the terrestrial vegetation. In Iceland many important groups of aquatic organisms are lacking or very poorly represented. A classification and description of its freshwater communities will not be comparable to any other part of Europe. With respect to biological character, the European streams can readily be divided in three main categories. Every category is in fact a separate sequence of stream system development with temperature (general level and annual fluctations) as the principal differentiating factor:

a) the high altitude series (KRYON).

- water originating from melting snow or glacier-ice,
- maximum temperature (monthly mean) very low (0-8 °C),
- water oligotrophic, primary production very low,
- no surrounding vegetation.

Theoretically a stream system of this type can develop from small, steep torrent to large slow-flowing stream (a "cold potamon"). In the temperate climatical region the last possibility is never realized, because this streamtype is necessarily high up in the mountains. At higher latitudes a diversification of the Kryon-series can be seen, caused by breakdown of the correlation between the parameters cold-small-steep-torrential.



CW = central and western Europe,
B = British Islands,
N = Northern Europe,
S = Southern Europe, (I = Iceland).
Fig. V 1. Hydrobiological regions of Europe.

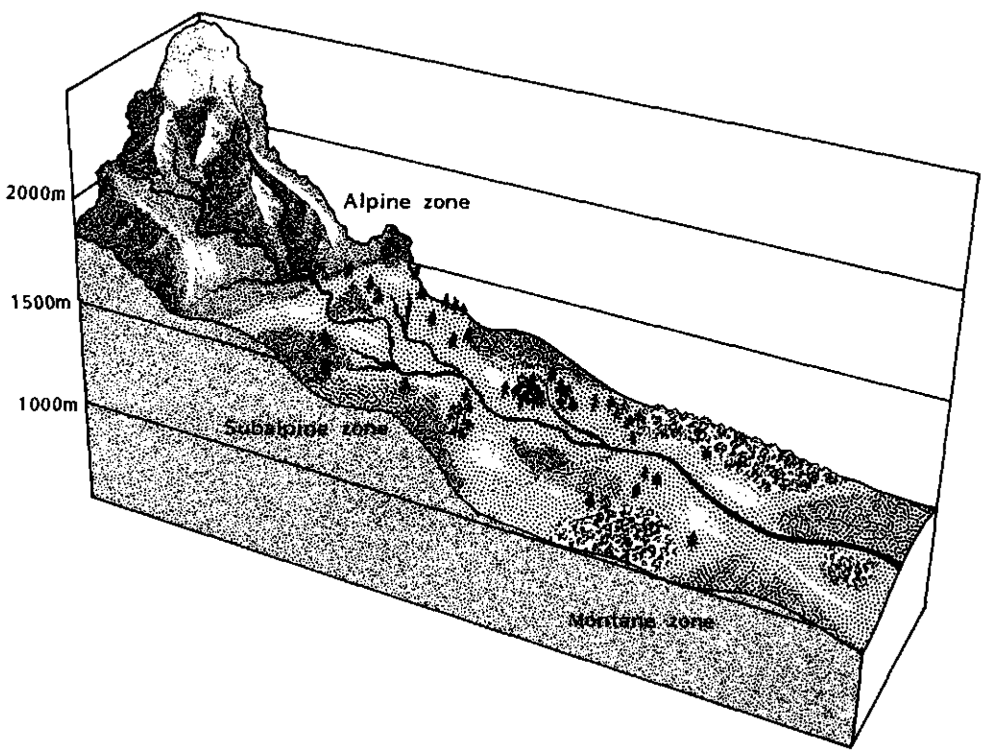


Fig. V 2. Generalized Central European stream. (includes types I, (II), IV (V), VI).

b) medium-altitude series (RHITHRON and POTAMON),

- water originating from sources (or continuation of previous type),
- temperature regime evolves from cold/stable to warm/instable,
- upper reaches oligotrophic, lower reaches eutrophic,
- streamside vegetation ranging from pasture to deciduous forest. Allochthonous input important.

Zonation of flora and fauna is relatively clear in series a) and b). A generalized scheme is given in fig. V 2.

c) lowland series,

- water originating from sources or direct surface runoff. First order streams of the system on lower altitudes,
- temperatures depending on origin of water and insolation. Generally high as compared to previous types.

From a biological point of view streamsystems of this type can hardly be fitted into the rhithron potamon-scheme.

	Kryon	Rhithron	Potamon
maximum monthly mean temperature	8^{o}	8^{o}-20^{o}	more than 20^{o}
gradient ($_{o}$/oo)	>100	100-2	<2
width	0-1 m	1-5 m	5-100 m
current velocity	<1 m/sec	0,5-1 m/sec	<0,5 m/sec
dominant microflora	attached algae	attached algae	plankton
dominant macroflora	-	mosses, liverworts	phanerogams
dominant invertebrate	Diamesinae, Plecoptera	Plecoptera, Ephemeroptera Trichoptera, Elminthidae	Ephemeroptera, Trichoptera, Coleoptera, Heteroptera Mollusca
dominant fish	-	Salmonidae	Cyprinidae

II BIOLOGICAL SECTION.

II.1 Some notes on the interpretation of the listed data.

Origin of water. Only the most typical form of stream system initiation is given. There are always other contributions like direct surface-runoff or melting snow in spring.

Average gradient, i.e. averaged over at least several hundreds of metres stream length.

Current velocity. Indicated for centre of stream, that is halfway between the banks and halfway between surface and bottom.

Organisms are listed in four major groups:

PLANKTON (true plankton, free-floating and normally growing and reproducing in free water)

STREAMBED VEGETATION
(includes only truly aquatic forms)

INVERTEBRATE BENTHIC FAUNA

FISH

Within each major group the higher taxa ("mosses", "Plecoptera") are roughly listed in descending order of importance, being the amount of genera or species they contribute to the total biocoenosis. Only genera and species are given that occur most frequently in a watertype. The presence of vegetation is very dependent on light exposure. Plants can be quite naturally absent from shaded parts of a stream.

II.2 Central and Western Europe.

Central and western Europe, type 1. Glaciertorrent.

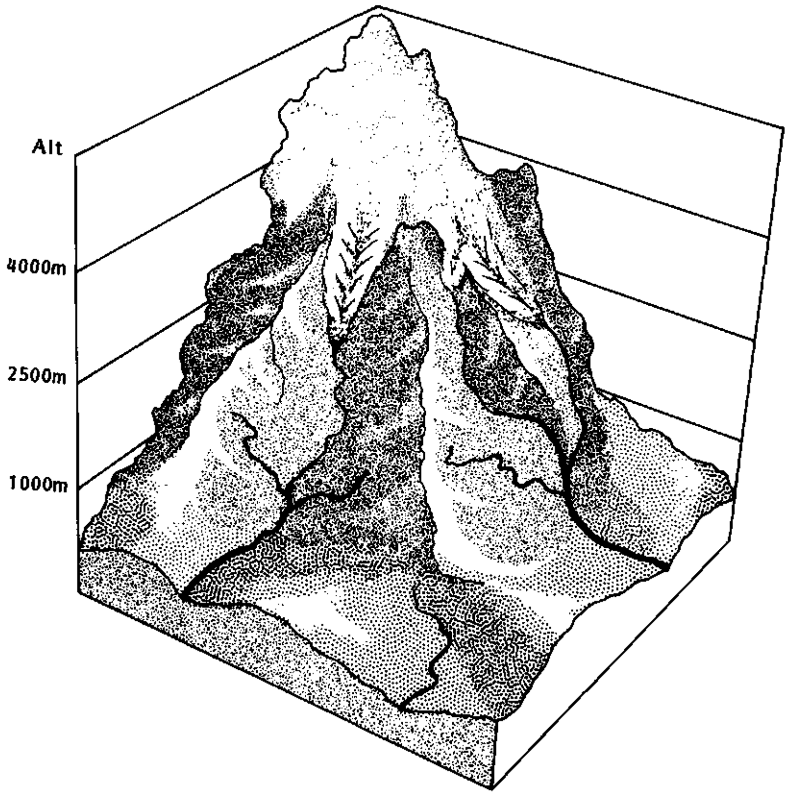


Fig. V 3.

origin of water:	melting ice of glacier.
average gradient:	>200^{o}/oo
current velocity:	> 0,5 m/sec.
Maximum temperature amplitude (monthly mean):	8^{o}C
width:	0 - 3 m
dominant substrate:	rock, pebbles
nutrient status:	oligotrophic
energetic type:	autotrophic
substrate activity:	eroding
oxygen content:	around 100% saturation

PLANKTON	-
STREAMBED VEGETATION	attached algae (e.g. Chamaesiphon sp., Diatoma hiemale var. mesedon,

	Achnantes sp. etc.)
	mosses (Fontinalis sp. and others).
INVERTEBRATE FAUNA	some insect-larvae only (most characteristic species underlined):
	Diamesa steinböcki, Diamesa gr. latitarsis
	Eukiefferiella sp.
	Prosimilium sp.
	Nemoura sp.
	Drusus sp., Rhyacophila sp.
	additionally other Trichoptera
	other Simuliidae
	other Plecoptera
	Blepharoceridae
	Total amount of species: 10 - 15
FISH	-

Central en Western Europe, type II. high altitude torrent.

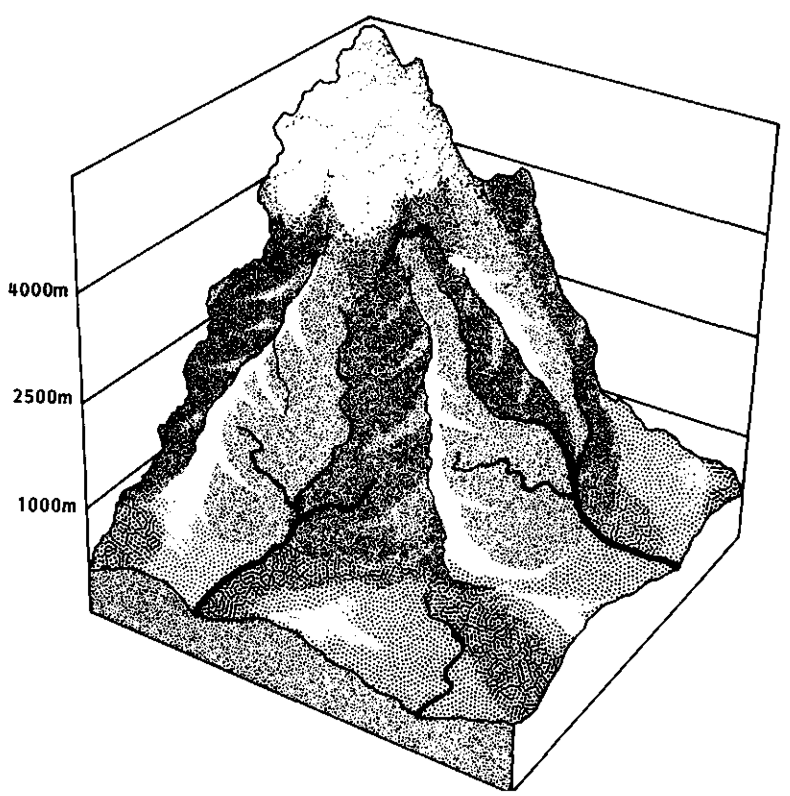


Fig. V 4.

origin of water: melting snow or source

average gradient: >200^{o}/oo

current velocity:	> 0,5 m/sec.
max. annual temp. ampl. (monthly mean):	8°C
width:	0 - 3 m
dominant substrate:	rock, pebbles
nutrient status:	oligotrophic
energetic type:	autotrophic
substrate activity:	eroding
oxygen content:	around 100% saturation

PLANKTON		
STREAMBED VEGETATION	attached algae	(Cyanophyceae Chlorophyceae Diatomae, Desmidiaceae)
	mosses	
INVERTEBRATE FAUNA	Plecoptera:	*Protonemura* sp.
		Amphinemura standfussi
		Perlidae, *Leuctra* sp.
	Ephemeroptera:	*Ecdyonurus* sp.
		Rhithrogena sp., *Baetis* sp.
	Diptera	Simuliidae
		Chironomidae (Diamesini, *Eukiefferiella* sp.)
		Dicranota sp.
		Atherix sp.
		Tipulidae, Tabanidae
	Tricladida:	*Crenobia alpina*
	Tubificidae:	div. sp.
	Total amount of species 10 - 25.	
FISH		

Central and Western Europe, type III. High-altitude lake outflows.

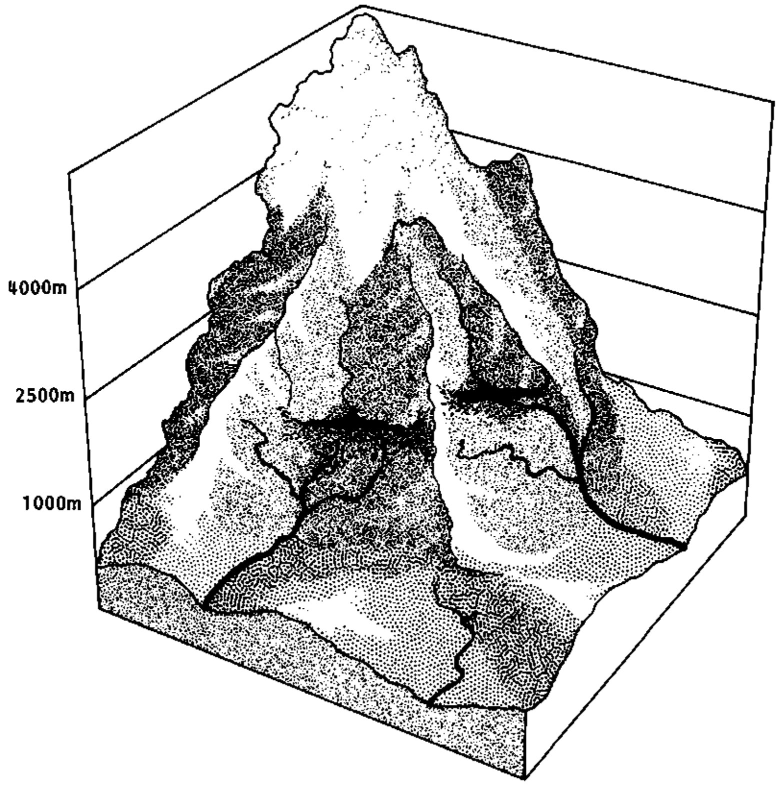


Fig. V 5.

origin of water:	high-altitude lake
average gradient:	>200°/oo
current velocity:	> 0,5 m/sec.
max. annual temp. ampl. (monthly mean):	15°C
width:	0 - 10 m
dominant substrate:	rock, pebbles
nutrient status:	oligotrophic
energetic type:	allotrophic
substrate activity:	eroding
Oxygen content:	around 100% saturation

PLANKTON	phytoplankton	Chlorophyceae
		Scenedesmus sp.
		Pediastrum sp.
		Cosmarium sp.
		Chrysophyceae
		Mallomonas sp.
		Chromulina sp.
		Bacillariaophyceae
	zooplankton	Cladocera
		Copepoda
		Ostracoda
STREAMBED VEGETATION:	similar to type II.	
INVERTEBRATE BENTHIC FAUNA:	Trichoptera	*Hydropsyche pellucidula*
		Rhyacophila div. sp.
		Philopotamus montanus
		Potamophylax sp.
	Diptera	Simuliidae
		Diamesini
		Orthocladiinae
		Blepharoceridae
	Ephemeroptera	*Baetis* sp.
		Ecdyonurus sp.
		Rhithrogena sp.
	Tricladida	*Crenobia alpina*
	Oligochaeta	Tubificidae
		Lumbriculidae
	total amount of species: 20 -30	
	note: directly after lake-outflow high biomass of Simuliidae and net-spinning Caddisflies. Back to normal numbers within the first several hundreds of meters of the stream.	
FISH	-	

Central and Western Europe <u>type IV</u>. Small mountain- and hillstreams (soft water).

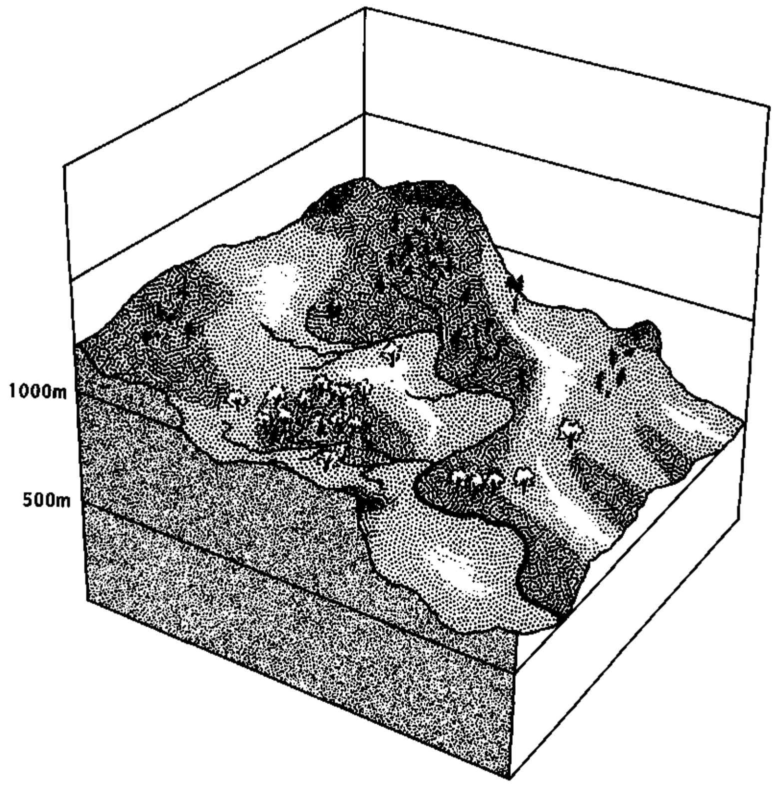


Fig. V 6.

origin of water:	sources
average gradient:	100 - 2°/oo
current velociy:	>0,5 m/sec.
maximum temperature amplitude (monthly mean):	20°C
width:	0,5 - 5 m
dominant substrate:	pebbles, gravel (of igneous rock types)
water hardness:	<2°d
nutrient status:	oligotrophic
energetic type:	autotrophic with variable allochthonous input.
substrate activity:	eroding
oxygen content:	around 100% saturation

PLANKTON	none
STREAMBED VEGETATION	dominated by attached algae and mosses. attachted algae: *Diatoma hiemale* var. *mesodon* *Ceratoneis arcus* *Achnantes* sp. *Lemanea fluviatilis* *Hildenbrandia rivularis* *Ulothrix zonata* *Cladophora glomerata* mosses: *Fontinalis antipyretica* *Chiloscyphus rivularis* Additionally liverworts (*Pellia* sp.) and in the lower reaches higher plants (*Callitriche* sp., *Myriophyllum* sp., *Potamogeton* sp.)
INVERTEBRATE FAUNA	dominated by insect orders Plecoptera Ephemeroptera, Trichoptera and Diptera + Gammaridae (Crustacea) Plecoptera: *Nemoura* div. sp. *Protonemura* sp. *Brachyptera risi* Perlidae Ephemeroptera: *Ecdyonurus* sp. *Baetis* sp. *Rithrogena* sp. *Ephemerella ignita* Trichoptera: *Hydropsyche* sp. *Rhyacophila* sp. *Ephemerella ignita*

	Diptera	Simuliidae
		Liponeura sp.
		Atherix sp.
		Dicranota sp.
		Prodiamesa olivacea
		Brillia modesta
	Gammaridae:	*Gammarus* sp. or div. sp.

Additionally some species of the groups Platyhelminthes, Mollusca, Oligochaeta, Heteroptera, Coleoptera and Chironomidae may be present.

Total amount of species 50 - 100

FISH — Characteristically:
Cottus gobio, *Salmo trutta fario*, *Phoxinus phoxinus*, *Noemacheilus barbatulus*, *Leuciscus leuciscus*, *Lota lota*, *Gobio gobio*, *Leuciscus cephalus*, *Chrondrostoma nasus*, *Thymallus thymallus*

Central and Western Europe, type V. Mountain- and hillstreams (hard water)

origin of water:	sources
average gradient:	200 - 2^{o}/oo
current velocity:	> 0,5 m/sec.
max. temp. amplitude (monthly mean):	20^{o}C
width	0,5-5 m
dominant substrate:	pebbles, gravel (of calcareous type)
water hardness:	> 2^{o}D
nutrient status:	meso- to eutrophic
energetic type:	autotrophic with variable allochthonous input
substrate activity:	eroding
oxygen content:	arond 100% saturation

PLANKTON:	-	
STREAMBED VEGETATION	attached algae:	*Vaucheria sessilis* *Cladophora glomerata* *Cocconeis pediculus* *Diatoma vulgare* *Synedra ulna*
	mosses:	*Rhynchostegium rusciforme*
	higher plants	(only in lower parts, where the current is weak enough to allow growth of phanerogams) *Zannichellia palustris* *Sium erectum* *Ranunculus* sp. *Veronica* sp.
INVERTEBRATE BENTHIC FAUNA:	similar to type IV.	
FISH:	similar to type IV.	

Central and Western Europe, TYPE VI. Upland rivers.

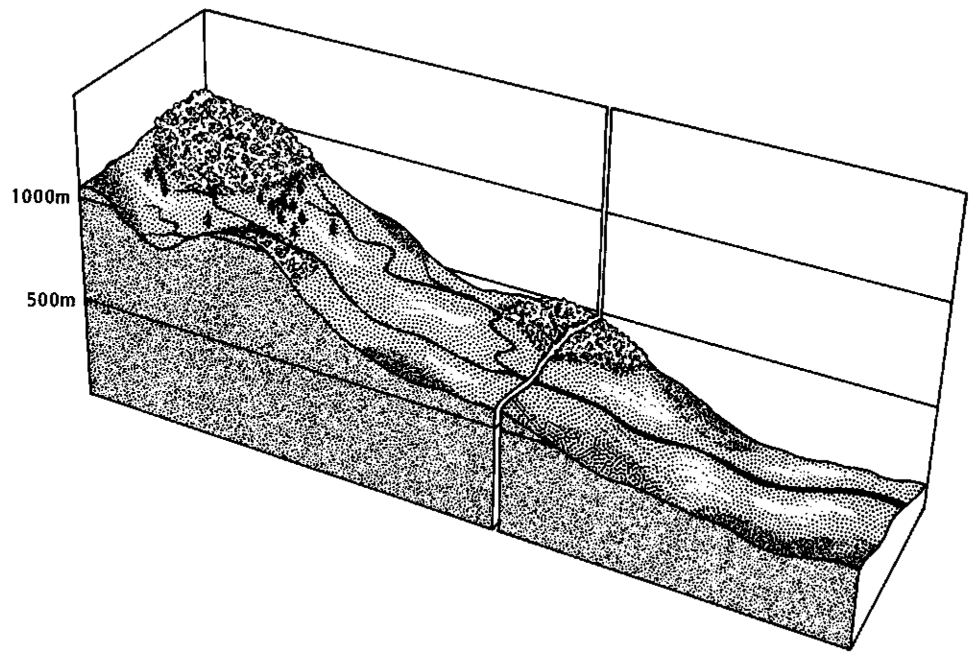


Fig. V 7.

Origin of water:	smaller streams
average gradient:	< 2°/oo
current velocity:	< 0,5 m/sec
max. temp. ampl. (monthly mean):	> 20°C
width:	5 - 50 m
dominant substrate:	pebbles, sand, mud
nutrient status:	eutrophic
energetic type:	autotrophic with variable allochthonous input

substrate activity:	depositing
oxygen content:	50 - 150% saturation
PLANKTON:	Phyto- and zooplankton present. Phytoplankton: *Asterionella* sp. *Stephanodiscus* sp. *Fragillaria* sp. *Botryococcus* sp. *Anabaena* sp. zooplankton: *Dinobryon* sp. *Ceratium hirundinella* *Notholca longispina* *Asplanchna* sp. *Leptodora kindtii* *Diaphanosoma* sp. *Daphnia* sp., *Bosmina* sp., *Diaptomus* sp. *Cyclops* sp.
STREAMBED VEGETATION	higher plants more important, but algae and mosses (as in type V) still present. Higher plants: *Sparganium* sp. *Potamogeton* div. sp., *Butomus umbellatus* and others.
INVERTEBRATE FAUNA	many groups represented Ephemeroptera: *Pothamanthus luteus*, *Epheron virgo* *Rhithrogena* div. sp. *Heptagenia sulphurea* *Baetis* div. sp., *Caenis* div. sp., *Ephemerella ignita* Plecoptera: *Taeniopteryx nebulosa* *Brachyptera risi* *Isoperla grammatica* Trichoptera: *Rhyacophila* sp. *Hydropsyche* sp. *Leptocerus* sp.

	Neureclipsis bimaculata
Heteroptera:	Aphaelocheirus aestivalis, Corixidae, Notonectidae
Coleoptera:	Elminthidae, Dytiscidae
Diptera:	Simuliidae Chironomidae
Odonata:	div. sp.
Oligochaeta:	div. sp.
Tricladida:	div. sp.
Hirudinea:	div. sp.
Mollusca:	Gastropoda div. sp. Lamellibranchia div.sp.
Crustacea:	Gammarus sp., Asellus aquaticus, Asellus meridianus, Astacus sp.

Total amount of species more than 100.

FISH

Characteristic and dominant are the Cyprinidae, e.g. Barbus barbus, Chondrostoma nasus, Rhodeus sericeus amarus, Leuciscus leuciscus, Rutilus rutilus, Scardinius erythrophthalmus, Tinca tinca, Abramis brama
Additionally: Lota lota, Perca fluviatilis, Esox lucius, Blicca bjoerkna + anadromous fish (Petromyzon marinus, Lampetra fluviatilis, Salmo salar, Salmo trutta, Alosa alosa, Osmerus eperlanus)

Central and Western Europe, type VII. Rain-fed lowlandstreams.

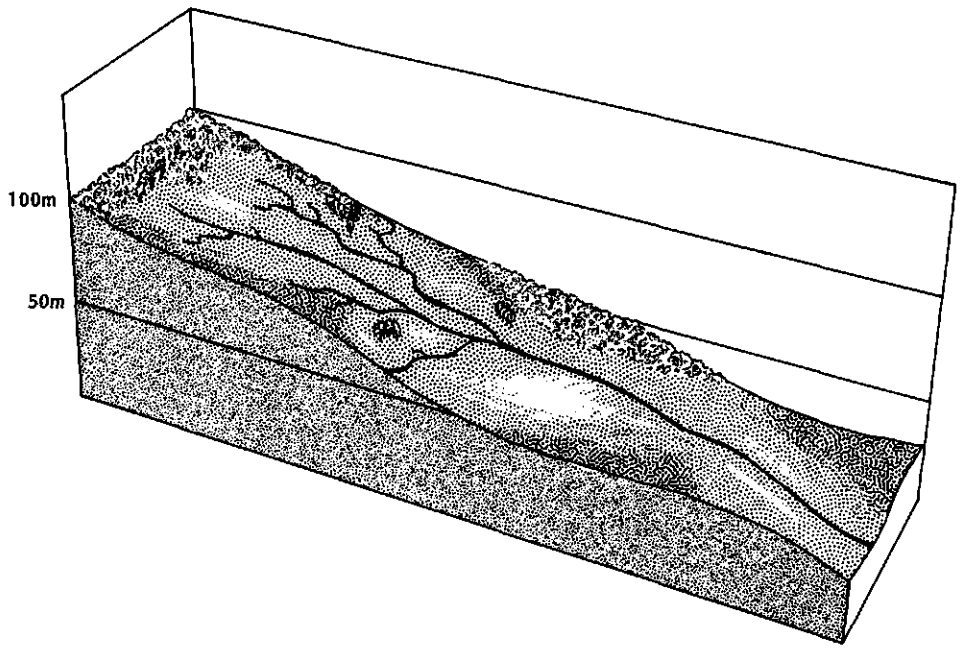


Fig. V 8.

Origin of water:	surface run-off
average gradient:	< 2^o/oo
current velocity:	< 0,5 m/sec.
maximum temperature amplitude (monthly mean):	> 20^oCB
width:	0,5 - 20 m
dominant substrate:	sand, mud
nutrient status:	oligotrophic --> eutrophic
energetic type:	autotrophic with variable allochthonous input
substrate activity:	depositing
oxygen content:	50 - 150% saturation

PLANKTON	-
STREAMBED VEGETATION	higher plants Callitriche hamulata, Sium erectum f. submersum, Veronica

	anagallis aquatica, *Myriophyllum alternifolorum*	
	mosses	*Fontinalis antipyretica*
INVERTEBRATE BENTHIC FAUNA	Ephemeroptera	*Baetis* sp. *Centroptilum luteolum* *Procloeon pseudorufulum*, *Cloeon* sp., *Brachycercus harrisella*
	Trichoptera	*Hydropsyche* sp. *Halesus* sp., *Anabolia nervosa*, *Plectrocnemia* sp.
	Diptera	Simuliidae Orthocladiinae Chironominae Tipulidae, Tabanidae
	Odonata	*Calopteryx splendens* Coenagrionidae
	Heteroptera	Corixidae *Velia caprai*, *Gerris najas*
	Coleoptera	Dytiscidae, Dryopidae Elminthidae
	Crustacea	*Gammarus* sp., *Asellus* sp.
	Oligochaeta	Tubificidae Lumbriculidae
	Hirudinea	div. sp.
	Mollusca	*Ancylus fluviatilis* *Acroloxus lacustris* *Lymnea* sp., *Planorbis* sp., *Pisidium* sp. *Sphaerium* sp.
	Hydracarina	*Lebertia* sp., *Sperchon* sp.
FISH		*Salmo trutta fario* *Cottus gobio* *Noemacheilus*

		barbatulus, Lampetra planeri, Leuciscus idus, Gobio gobio, Umbra pygmaea, Perca fluviatilis, Esox lucius, Cobitis taenia, Gasterosteus aculeatus, Pungitius pungitius

Central and Western Europe, type VIII. source-fed lowlandstreams

Origin of water:	sources
average gradient:	< 2^{o}/oo
current velocity:	< 0,5 m/sec.
maximum temperature amplitude (monthly mean):	< 20^{o}C
width:	0,5 - 5 m
dominant substrate:	pebbles, sand, mud
nutrient status:	eutrophic
energetic type:	autotrophic with variable allochthonous input
substrate activity:	depositing
oxygen content:	around 100% saturation

PLANKTON	-	
STREAMBED VEGETATION	higher plants	Ranunculus fluitans, R. circinatus, R. tricho-phyllus Zannichellia palustris Potamogeton div. sp. Sium erectum f. submersum
	attached algae	
INVERTEBRATE BENTHIC FAUNA	Ephemeroptera	Ephemerella ignita

	Baetis div. sp.
	Heptagenia sulphurea
	Centroptilum sp.
	Cloeon sp., *Caenis* sp.
Odonata	*Calopteryx virgo*, *C. splendens*, *Ischnura elegans*
	Coenagrionidae
	Libellula sp.
Plecoptera	*Nemoura* sp., *Leuctra* sp., Perlidae
Mollusca	*Lymnea* div. sp.
	Planorbis div. sp.
	Physa fontinalis
	Ancylus fluviatilis
	Sphaerium sp., *Pisidium* sp., *Anodonta* sp.
	Dreissena sp.
Coleoptera	Dytiscidae, Gyrinidae, Haliplidae, Elminthidae
Diptera	Chironomidae
	Orthocladiinae
	Tanypodinae
	Simuliidae, *Dicranota* sp., *Atherix* sp.
Trichoptera	*Rhyacophila* sp.
	Agapetus fuscipes
	Polycentropidae
	Hydropsyche sp.
	Limnephilidae
Hydracarina	*Sperchon* sp., *Lebertia* sp., *Limnesia* sp.
	Hygrobates sp.
Crustacea	*Gammarus* sp., *Asellus* div. sp.
Tricladida	*Polycelis* sp., *Dugesia* sp., *Dendrocoelum lacteum*
Hirudinea	*Piscicola geometra*

	Erpobdella div. sp.
	Helobdella stagnalis
	Glossiphonia div. sp.
FISH	*Lampetra planeri*, *Salmo trutta fario*, *Gobio gobio*, *Rutilus rutilus*, *Noemacheilus barbatulus*, *Cottus gobio*, *Cobitis taenia*, *Anguilla anguilla*, *Gasterosteus aculeatus*, *Pungitius pungitius*, *Esox lucius*, *Perca fluviatilis*

Central and Western Europe, type IX. Lowland rivers

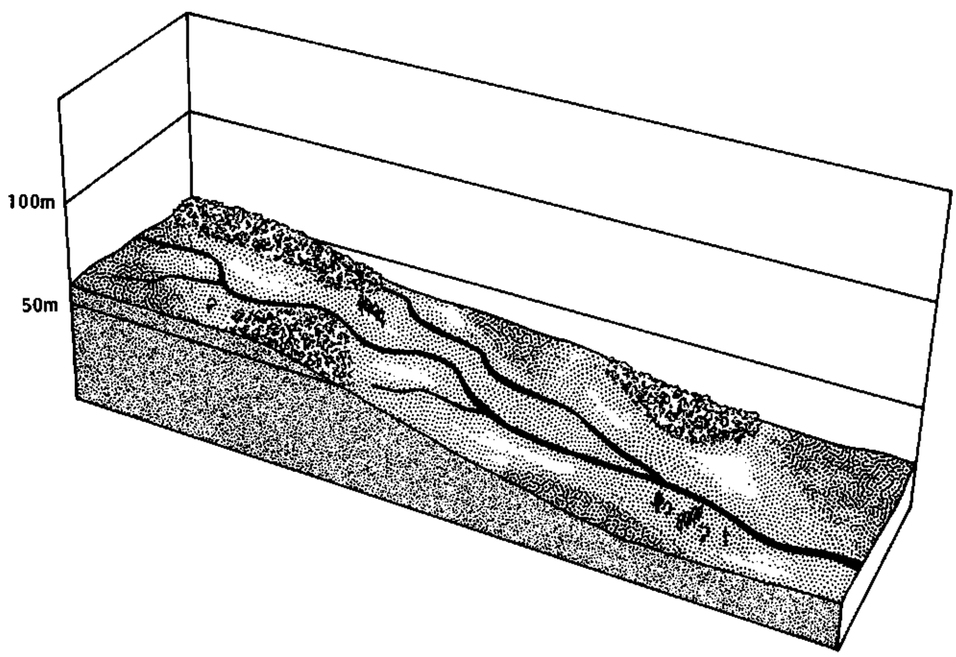


Fig. V 9.

Origin of water:	smaller streams
average gradient:	< 2°/oo

current velocity:	< 0,5 m/sec.
maximum temperature amplitude (monthly mean):	> 20°C
width:	0,5 - 20 m
dominant substrate:	sand, mud
nutrient status:	eutrophic
energetic type:	autotrophic
substrate activity:	depositing
oxygen content:	50 - 150% saturation

PLANKTON	some phyto- and zooplankton	
STREAMBED VEGETATION	higher plants	*Glyceria maxima* *Phragmites australis* *Nymphaea alba*, *Caltha palustris*, *Elodea canadensis*
	attached algae	*Cladophora* sp.
INVERTEBRATE BENTHIC FAUNA	Mollusca	*Physa fontinalis* *Viviparus* div. sp. *Lymnea* sp., *Planorbis* sp., *Valvata* sp. *Bithynia* sp., *Acroloxus lacustris*, *Unio* div. sp., *Anodonta* div. sp. *Dreissena* sp. *Sphaerium* sp., *Pisidium* sp.
	Ephemeroptera	*Cloeon* sp., *Caenis* div. sp.
	Trichoptera	Leptoceridae, *Anabolia nervosa*, *Molanna angustata* Polycentropidae
	Diptera	Chironomidae, Simuliidae, Chaoboridae
	Crustacea	*Gammarus* sp. *Asellus* div. sp.

		<u>Astacus</u> <u>astacus</u>
	Hirudinea	<u>Erpobdella</u> div. sp.
		<u>Helobdella</u> <u>stagnalis</u>
		<u>Piscicola</u> <u>geometra</u>
		<u>Glossiphonia</u> div. sp.
	Coleoptera	Dytiscidae, Gyrinidae
		Elminthidae
	Heteroptera	Corixidae, Gerridae
FISH	<u>Lampetra</u> <u>planeri</u>, <u>Noemacheilus</u> <u>barbatulus</u>, <u>Gobio</u> <u>gobio</u>, <u>Rutilus</u> <u>rutilus</u>, <u>Cottus</u> <u>gobio</u>, <u>Cobitis</u> <u>taenia</u>, <u>Anguilla</u> <u>anguilla</u>, <u>Gasterosteus</u> <u>aculeatus</u>, <u>Pungitius</u> <u>pungitius</u>, <u>Esox</u> <u>lucius</u>, <u>Perca</u> <u>fluviatilis</u>	

II. 3.

British Isles - <u>type I</u>. mountain- and hillstreams (soft water)

Origin of water:	sources
average gradient:	200 - 2°/oo
current velocity:	0,5 m/sec.
maximum temperature amplitude (monthly mean):	15°C
width:	0,5 - 5 m
dominant substrate:	rock, pebbles, gravel
flow regime:	instable
nutrient status:	oligotrophic
energetic type:	autotrophic with variable allochthonous input
substrate activity:	eroding
oxygen content:	around 100% saturation

PLANKTON	-
STREAMBED VEGETATION	attached algae <u>Diatoma</u> <u>hiemale</u>
	<u>Ceratoneis</u> <u>arcus</u>

		Achnantes sp., *Eunotia* div. sp., *Tabellaria* div. sp.
	mosses	*Eurhynchium* sp.
		Hygroamblystegium fluviatile
	liverworts	*Pellia epiphylla*
		Conocephalum conicum
INVERTEBRATE BENTHIC FAUNA	Plecoptera	*Nemoura* sp.
		Brachyptera risi
		Amphinemura sp.
		Protonemura sp.
		Leuctra div. sp.
		Perlidae
	Ephemeroptera	*Baetis* div. sp.
		Ephemerella ignita
		Rhithrogena sp.
		Ecdyonurus sp.
		Heptagenia sp.
	Trichoptera	*Rhyacophila* sp.
		Hydropsyche instabilis
		Plectrocnemia div. sp.
		Wormaldia sp.
	Diptera	Simuliidae
		Orthocladiinae
		Tipulidae, *Atherix* sp.
		Dicranota sp.
	Coleoptera	*Velia caprai*, *Gerris* sp.
	Mollusca	*Ancylus fluviatilis*
	Hydracarina	*Lebertia* sp., *Sperchon* sp.
	Tricladida	*Crenobia alpina*
		Polycelis felina
	Crustacea	Gammaridae
FISH	*Salmo trutta fario*, *Phoxinus phoxinus*, *Noemacheilus barbatulus*, *Gobio gobio*	

British Isles - type II, mountain- and hill streams (hard water)

Origin of water:	sources
average gradient:	200 - 2°/oo
current velocity:	< 0,5 m/sec.
maximum temperature amplitude (monthly mean):	15°C
width:	0,5 - 5 m
dominant substrate:	rock, pebbles, gravel
flow regime:	instable
nutrient status:	eutrophic
energetic type:	autotrophic with variable allochthonous input
substrate activity:	eroding
oxygen content:	around 100% saturation

PLANKTON	-
STREAMBED VEGETATION	attached algae *Cocconeis placentula*, *Ulvella frequens*, *Chamaesiphon* sp., *Synedra ulna*, *Navicula viridula*, *Surirella ovalis*, *Cymbella* sp., *Gomphonema* sp.
	mosses
	liverworts
INVERTEBRATE BENTHIC FAUNA	similar to type I
	similar to type I

British Isles - type III, Intermediate type

Origin of water:	smaller streams
average gradient:	20 - 1°/oo
current velocity:	< 0,5 m/sec.

maximum temperature amplitude (monthly mean):	> 15°C
width:	5 - 20 m
dominant substrate:	pebbles, gravel
flow regime:	relatively stable
nutrient status:	eutrophic
energetic type:	autotrophic
substrate activity:	eroding
oxygen content:	around 100% saturation

PLANKTON	-	
STREAMBED VEGETATION	attached algae, mosses as in type I	
	higher plants	*Apium nodiflorum* *Callitriche* div. sp. *Berula erecta*, *Mentha aquatica*, *Groenlandia densa*, *Zannichellia palustris*, *Potamogeton crispus*
INVERTEBRATE BENTHIC FAUNA	Plecoptera	*Leuctra* sp., *Dinocras cephalotes*, *Chloroperla* sp.
	Ephemeroptera	*Habrophlebia fusca* *Baetis* div. sp. *Ecdyonurus* sp. *Ephemerella ignita* *Caenis* sp.
	Trichoptera	*Tinodes waeneri* *Agapetus fuscipes* *Lepidostoma hirtum* *Cyrnus trimaculatus* *Hydropsyche* sp. *Rhyacophila* sp.
	Diptera	Simuliidae Chironomidae Tipulidae, Tabanidae *Atherix* sp., *Dicranota*

		sp.
	Tricladida	*Crenobia alpina*
		Dendrocoelum lacteum
	Hirudinea	*Glossiphonia complanata*, *Erpobdella* sp., *Helobdella stagnalis*
	Mollusca	*Potamopyrgus jenkinsi*
		Ancylus fluviatilis
		Planorbis sp., *Lymnea* sp.
	Oligochaeta	*Eiseniella tetraedris*
		Tubificidae
	Hydracarina	*Lebertia* sp.
		Hygrobates sp.
	Coleoptera	Elminthidae, Dytiscidae
FISH	*Salmo trutta fario*, *Lampetra planeri*, *Phoxinus phoxinus*, *Noemacheilus barbatulus*, *Anguilla anguilla*, *Gasterosteus aculeatus*	

British Isles - type IV, main rivers.

Origin of water:	smaller streams
average gradient:	< 2o/oo
current velocity:	< 0,5 m/sec.
maximum temperature amplitude (monthly mean):	> 15oC
width:	20 - 100 m
dominant substrate:	gravel, sand, mud
flow regime:	relatively stable
nutrient status:	eutrophic
energetic type:	autotrophic
substrate activity:	depositing
oxygen content:	50 - 150% saturation

PLANKTON	phytoplankton	*Asterionella* sp.
		Cyclotella sp.
		Stephanodiscus sp.
		Synedra sp.
		Dinobryon sp., *Ceratium* sp.
	zooplankton	*Asplanchna* sp.
		Leptodora kindtii
		Daphnia sp., *Bosmina* sp.
STREAMBED VEGETATION	higher plants	*Sagittaria sagittifolia*, *Scirpus lacustris*, *Rorippa amphibia*, *Sparganium emersum*, *Nuphar lutea*
	algae	*Enteromorpha* sp.
INVERTEBRATE BENTHIC FAUNA	Ephemeroptera	*Baetis* div. sp.
		Habrophlebia fusca
		Cloeon sp., *Caenis* sp.
		Centroptilum pennulatum
	Trichoptera	*Polycentropus flavomaculatus*
		Phryganea sp.
		Hydroptilidae
		Leptoceridae
	Odonata	*Ischnura elegans*
		Cordulegaster boltonii
	Plecoptera	*Nemoura cinerea*
		Taeniopteryx nebulosa
		Leuctra fusca, *Isoperla grammatica*
	Coleoptera	Dytiscidae, Gyrinidae
	Heteroptera	Corixidae
		Notonectidae, Nepidae
	Mollusca	*Lymnea* sp., *Planorbis* sp., *Bithynia* sp.
		Physa fontinalis
		Acroloxus lacustris

	Crustacea	Gammaridae, *Asellus aquaticus*, *Asellus meridianus*
	Oligochaeta	Tubificidae, Naididae
	Hirudinea	
FISH	*Gobio gobio*, *Perca fluviatilis*, *Esox lucius*, *Lampetra planeri*, *Tinca tinca*, *Rutilus rutilus*, *Scardinius erythrophthalmus*, *Abramis brama*, *Anguilla anguilla* (anadromous: *Petromyzon marinus*, *Lampetra fluviatilis*, *Alosa alosa*, *Alosa fallax*, *Salmo salar*, *Salmo trutta*, *Osmerus eperlanus*)	

British Isles - type V, Chalk streams

Origin of water:	sources
average gradient:	< 2°/oo
current velocity:	< 0,5 m/sec.
maximum temperature amplitude (monthly mean):	> 15°C
width:	1 - 20 m
dominant substrate:	gravel, silt, mud
flow regime:	relatively stable
nutrient status:	mesotrophic
energetic type:	autotrophic
substrate activity:	depositing
oxygen content:	50 - 150% saturation

PLANKTON	-	
STREAMBED VEGETATION	higher plants	*Ranunculus penicillatus* var. *calcareus*, *Apium nodiflorum*, *Rorippa nasturtium aquaticum*,

		Batrachium sp.
		Potamogeton div. sp.
INVERTEBRATE BENTHIC FAUNA	Ephemeroptera	*Baetis* div. sp., *Cloeon* sp., *Ephemera danica*, *Paraleptophlebia submarginata*
		Heptagenia sulphurea
		Ephemerella ignita
	Trichoptera	*Rhyacophila* sp.
		Agapetus sp.
		Plectrocnemia conspersa, *Hydropsyche* sp., *Polycentropus* sp.
		Molanna angustata
	Plecoptera	*Nemoura cinerca*
		Leuctra div. sp.
		Isoperla grammatica
		Perla microcephala
	Odonata	*Calopteryx splendens*
		Pyrrhosoma nymphula
		Ischnura elegans
		Sympetrum sp.
	Coleoptera	Dytiscidae, Haliplidae
		Gyrinidae, Elminthidae
	Heteroptera	Corixidae
		Aphelocheirus montandoni
	Diptera	Simuliidae
		Chironomidae
	Hydracarina	*Eylais* sp., *Sperchon* sp., *Lebertia* sp.
		Hygrobates sp.
		Atractides sp.
	Crustacea	*Gammarus pulex pulex*
		Asellus aquaticus
		Asellus meridianus
	Tricladida	*Dugesia lugubris*
		Polycelis sp.
FISH	upper parts:	*Cottus gobio*, *Salmo*

		trutta fario, Phoxinus phoxinus, Noemacheilus barbatulus, Thymallus thymallus
	lower parts:	Rutilus rutilus, Gobio gobio, Leuciscus leuciscus, Anguilla anguilla

British Isles, type VI, winterbournes

In all respects winterbournes are very much like normal chalk streams (type V), only the flow regime is very unstable. Due to the porous substrate and the sinking groundwater level in summer, Winterbournes are stagnant or dry during a considerable part of the year. Some of them only carry water from March to July.

A few weeks after flow starts, flora and fauna are a fragment of a chalkstream-biocoenosis:

PLANKTON	-	
STREAMBED VEGETATION	higher plants	Oenanthe crocata
	attached algae	Tribonema sp., Melosira sp., Fragillaria sp.
INVERTEBRATE BENTHIC FAUNA	Eiseniella tetraedra, Planorbis leucostoma, Zonitoides nitidus, Baetis vernus, Stenophylax sequax, Haliplus lineatocollis, Agabus sp., Dytiscidae, Lymnea truncatula	

Of the most stable winterbournes (3 to 4 months of continuous flow, never completely dry) flora and fauna are comparable to those of a chalkstream (type V).

British Isles, type VII. Rainfed lowlandrivers

Origin of water:	surface run-off
average gradient:	$< 2^{o}/oo$
current velocity:	< 0,5 m/sec.
maximum temperature amplitude (monthly mean):	$> 15^{o}C$
width:	0,5 - 10 m
dominant substrate:	sand, mud
fluctuations in flow:	strong
nutrient status:	oligo- ---> eutrophic
energetic type:	autotrophic with variable allochthonous input
substrate activity:	depositing
oxygen content:	50 - 150% saturation
PLANKTON	-
STREAMBED VEGETATION	upper reaches: Apium nodiflorum, Callitriche sp., Phalaris arundinacea, Sparganium erectum, Veronica beccabunga lower reaches: Elodea canadensis, Sagittaria sagittifolia, Scirpus lacustris, Sparganium emersum, Sp. erectum, Lemna minor, Nuphar lutea
INVERTEBRATE FAUNA and FISH	see type VII, central & western Europe

II. 4. Northern Europe

General differences with central European streams:

- water temperatures generally much lower; no correlation between low temperature and high altitude (c.q. high gradient and current velocity).

- the great majority of waters is soft-oligotrophic,
- allochthonous input as an energy source is much more important than primary production,
- insect larvae are the most important component of the benthic fauna.

Suggested classification:

a. Glacier streams.
b. Mountain streams above birch-zone.
c. Streams in birch- or coniferous zone.
d. Large rivers.

N-Europe, type a. Glacierstreams.

Origin of water:	melting glacier
average gradient:	very variable, depending on latitude, c.q. altitude of glacier and stream
current velocity:	very variable, depending on gradient
maximum temperature amplitude (monthly mean):	4°C
width:	0,5 - 20 m
dominant substrate:	rock, pebbles
nutrient status:	oligotrophic
energetic type:	allotrophic
substrate activity:	eroding
oxygen content:	around 100% saturation

PLANKTON	-
STREAMBED VEGETATION	attached algae, mosses
INVERTEBRATE BENTHIC FAUNA	one to several species of Orthocladiinae (Diamesa sp., Diamesa lindrothi, Eukiefferiela sp. Simuliidae (lower parts)
FISH	Salvelinus alpinus

N-Europe, type b, mountainstreams above the Birchzone.

Origin of water:	melting snow, rain
average gradient:	200 - 2^{o}/oo
current velocity:	> 0,5 m/sec.
width:	0,5 - 10 m
dominant substrate:	rock, pebbles
nutrient status:	oligotrophic
energetic type:	autotrophic
substrate activity:	eroding
oxygen content:	around 100% saturation

PLANKTON	-	
STREAMBED VEGETATION	Cyanophyceae (Lyngbya sp., Stigonema sp.)	
	Bacillariophyceae (Achnantes sp., Ceratoneis arcus)	
	Chlorophyceae (Ulothrix zonata, Oedogonium sp.)	
	mosses (Fontinalis sp., Aulacomnium sp.)	
INVERTEBRATE BENTHIC FAUNA	Plecoptera	Nemoura sp., Leuctra div. sp., Nemurella picteti, Perlidae
	Ephemeroptera	Heptagenia sp., Baetis sp.
	Trichoptera	Rhyacophila sp. Hydropsyche sp.
	Diptera	Orthocladiinae
FISH	Salmo trutta fario, Phoxinus phoxinus, Lota lota	

N-Europe. type c., Streams in the Birch- or coniferous zone

Origin of water:	melting snow or sources/ surface run-off (depending on season)
average gradient:	200 - 2°/oo
current velocity:	30 - 70 cm/sec.
width:	0,5 - 50 m
dominant substrate:	pebbles, gravel
nutrient status:	oligotrophic
energetic type:	mainly allotrophic + some primary production
substrate activity:	eroding
oxygen content:	around 100% saturation

PLANKTON	-	
STREAMBED VEGETATION	attached algae	*Ulothrix zonata*
		Achnantes sp.
		Ceratoneis arcus
		Hydrurus foetidus
		Lemanea fluviatilis
		Nostoc sp.
	mosses	*Fontinalis* div. sp.
		Scapania undulata
	higer plants	*Callitriche* sp.
		Ranunculus peltatus
		Potamogeton sp.
INVERTEBRATE BENTHIC FAUNA	Plecoptera	Perlidae, *Leuctra* div. sp., *Capnia* sp.
		Nemoura div. sp.
	Ephemeroptera	*Baetis* div. sp.
		Heptagenia sp.
		Siphlonurus sp.
		Leptophlebia sp.
		Ephemerella ignita
	Trichoptera	*Hydropsyche* sp.
		Rhyacophila sp.

		Sericostoma personatum
		Drusus sp.
		Limnephilidae
	Diptera	Simuliidae
		Orthocladiinae
	Hydracarina	div. sp.
	Mollusca	*Ancylus fluviatilis*
	Tricladida	*Crenobia alpina*

FISH — *Salmo trutta fario*, *Cottus gobio* (not Norway), Phoxinus phoxinus, Leuciscus div. sp., *Lota lota*, *Thymallus thymallus*, *Lampetra planeri* (not Finland), *Salmo salar*, *Salmo trutta*, *Salvelinus alpinus*

Northern-Europe *type d.*, Large rivers

Origin of water:	smaller streams
average gradient:	< 2^{o}/oo
current velocity:	< 0,5 m/ sec.
width:	> 50 m
dominant substrate:	pebbles, gravel, mud
nutrient status:	meso- eutrophic
energetic type:	autotrophic
substrate activity:	depositing
oxygen content:	around 100% saturation

PLANKTON	some phyto- and zooplankton	
STREAMBED VEGETATION	higher plants	*Potamogeton* div. sp. *Sparganium angustifolium*, *Scirpus* sp., *Sagittaria sagittifolia* *Callitriche* sp.

		Ranunculus div. sp.
	mosses	Fontinalis dalecarlica
		Calliergonella sp.
	attached algae	
INVERTEBRATE BENTHIC FAUNA	Plecoptera	Amphinemura borealis
		Leuctra div. sp., Diura nanseni, Perlidae
		Brachyptera risi
	Ephemeroptera	Baetis div. sp.
		Siphlonurus lacustris
		Heptagenia sulphurea
		Nemurella picteti
		Ephemerella ignita
	Trichoptera	Polycentropus sp.
		Limnophilidae
		Stenophylax sp.
		Rhyacophila sp.
		Hydropsyche sp.
		Halesus sp.
	Diptera	Orthocladiinae
		Simuliidae, Tipulidae
		Tabanidae
	Hydracarina	div. sp.
	Mollusca	Lymnea peregra
		Pisidium sp.
FISH	Esox lucius, Leuciscus div. sp., Rutilus rutilus, Abramis brama, Alburnus alburnus, Anguilla anguilla, Lota lota, Perca fluviatilis, Acerina cernua, Petromyzon marinus, Lampetra fluviatilis, Accipenser sturio, Alosa alosa, A. fallax, Salmo salar, S. trutta, Salvelinus alpinus, Osmerus eperlanus	

II. 5 Southern Europe

Most mediterranean streams are biologically comparable to Central European types, provided that they carry water for more than half a year continuously. Owing to the very dry climate this is often not the case. Accordingly, many mediterranean streams are intermittent or very irregular.

Suggested classification:

A. High-altitude torrents.
B. High-altitude lake outflows.
C. Mountain- and hillstreams (rhithron).
D. Main rivers (Potamon)
E. Intermittent or highly irregular streams

Southern Europe, types A & B.

A. High altitude stream

Origin of water:	melting snow
average gradient:	> 200°/oo
current velocity:	> 1 m/sec.
maximal annual temperture ampl. (monthly mean)	8°C
width	0-3 m
dominant substrate:	rock, pebbles
flow regime	very low to dry in summer
nutrient status:	oligotrophic
energetic type:	autotrophic
substrate activity:	eroding
oxygen content:	around 100% saturation

PLANKTON -

STREAMBED VEGETATION	attached algae	_Hydrurus foetidus_
		Ceratoneis arcus
		Hydrococcus sp.
		Chamaesiphon sp.
		Hildenbrandia sp.
INVERTEBRATE BENTHIC FAUNA	_Diamesa_ gr. _latitarsis_, Simuliidae, _Protonemura_ sp., _Rhyacophila_ sp., _Drusus_ sp., _Leuctra_ sp., Perlidae	
FISH	-	

B. Lake Outflows

Origin of water:	high or medium altitude lake
average gradient:	> 200°/oo
current velocity:	> 1 m/sec.
maximal annual temperture ampl. (monthly mean)	15°C
width:	0 - 10 m
dominant substrate:	rock, pebbles
flow regime:	relatively stable
nutrient status:	eutrophic
energetic type:	allotrophic
substrate activity:	eroding
oxygen content:	around 100% saturation

PLANKTON	phytoplankton	_Scenedesmus_ sp.
		Pediastrum sp.
		Cosmarium sp.
		Mallomonas sp.
		Chromulina sp.
		Diatomaceae
	zoöplankton	Cladocera, Copepoda, Ostracoda
STREAMBED VEGETATION	similar to type A.	

INVERTEBRATE BENTHIC FAUNA	Simuliidae, *Hydropsyche* sp., Plecoptera, Ephemeroptera, Trichoptera, *Crenobia alpina*, Oligochaeta
FISH	-

Southern-Europe, types C., D., and E.

C. Mountain- and hillstreams

Origin of water:	sources
average gradient:	200 - 2°/oo
current velocity:	> 0,5 m/sec.
width:	0,5 - 10 m
dominant substrate:	pebbles, gravel
nutrient status:	eutrophic
energetic type:	autotrophic
substrate activity:	eroding
oxygen content:	around 100% saturation

PLANKTON	-	
STREAMBED VEGETATION	attached algae	*Diatoma hiemale*
		Meridion circulare
		Achnantes lanceolata
		Gomphonema sp.
		Hildenbrandia sp.
		Cladophora sp.
	mosses	*Fontinalis* sp.
		Platyhypnidium sp.
	higher plants	(lower reaches only) *Callitriche* sp., *Apium* sp., *Myriophyllum* sp.
INVERTEBRATE BENTHIC FAUNA	similar to central-European rhithron	
FISH	*Cottus gobio*, *Salmo trutta* subsp., *Phoxinus phoxinus* (only Iber.), *Lampetra planeri*	

D. Main rivers

Origin of water:	smaller streams
average gradient:	< 2^{o}/oo
current velocity:	< 0,5 m/sec.
width:	10 - 100 m
dominant substrate:	pebbles, sand, mud
nutrient status:	eutrophic
energetic type:	autotrophic
substrate activity:	depositing
oxygen content:	50 - 150% saturation
PLANKTON	general European potamoplankton
STREAMBED VEGETATION	similar to central-European potamon
INVERTEBRATE BENTHIC FAUNA	similar to central-European potamon, with the exception of _Aphelocheirus aestivalis_
FISH	_Perca fluviatilis_ (not Iber.), _Tinca tinca_, _Rutilus rubilio_ (not Iber.), _Scardinius erythrophthalmus scardafa_ (not Iber.), _Blennius fluviatilis_, _Anguilla anguilla_ anadromous: _Petromyzon marinus_, _Lampetra fluviatilis_, _Alosa alosa_, _Alosa fallax nilotica_, _Salmo salar_ (only Iber.), _Salmo trutta_ (only Iber.), _Osmerus eperlanus_ (only Iber.)

Type E., Intermittent streams.
no plankton and no aquatic vegetation; fauna a fragment of the rhitron-fauna (type C.)

III. CLASSIFICATION OF EUROPEAN RUNNING WATERS - SURVEY

Central & Western Europe	British Isles	S-Europe	N-Europe
1. glacier torrent			a. glacier streams
2. high-altitude streams		A. high-altitude streams	b. streams above birch-zone
			c. mountainstreams in birch- or coniferous zone
3. lake-outflows		B. lake-outflows	
4. mountain- and hill-streams (soft water)	I. mountain- and hill-streams (soft water)		
5. mountain- and hill-streams (hard water)	II. mountain- and hill-streams (hardwater)	C. mountain- and hill-streams	
	III. interme-diary type		
6. upland rivers (potamon)	IV. main rivers	D. main rivers	
	V. chalk streams		
	VI. winterbournes	E. intermittent streams	
7. rainfed lowland-streams	VII. rainfed low-land streams		
8. source-fed low-land streams			
9. lowland rivers			

REFERENCES

Albrecht,M.L. 1953. Die Plane und andere Flämingbäche. Z. Fisch., N.F. 1: 389-476.

Arnold,F. & T.T. Macan 1969. Studies on the fauna of a Shropshire hill stream. Field Studies 3: 159-184.

Badcock,R.M. 1953. Comparative studies on the populations of streams. Rep. Inst. Fresh. Res., Drottningholm 35: 38-50.

Berg,K. 1948. Biological studies on the river Susaa. Folia Limn. Scand 4: 1-318.

Beyer,H. 1932. Die Tierwelt der Quellen und Bäche des Baumbergegebietes. Abh. Westfäl. Prov. Mus. f. Naturk. 3: 1-185.

Carpenter,K.E. 1928. Life in inland waters. Sidgwick and Jackson, London.

Castenholz,R.W. & C.E. Wickstrom 1975. Thermal streams. In: B.A. Whitton (ed.), River Ecology. Blackwell, Oxford.

Décamps,H. 1967. Ecologie des Trichoptères de la vallée d'Aure (Hautes Pyrénées). Annls. Limnol. 3: 399-577.

Dittmar,H. 1955. Ein Sauerlandbach. Arch. Hydrobiol. 50: 305-552.

Dorier,A. 1937. La faune des eaux courantes alpines. Verh. Internat. Verein. Limnol. 8: 31-41.

Egglishaw,H.J. & N.C. Morgan 1965. A survey of the bottom fauna of streams in the Scottish Highlands, part II, the relationship of the fauna to the chemical and geological conditions. Hydrobiologia 26: 173-183

Eidel,K. 1933. Beiträge zur Biologie einiger Bächer des Schwarwaldes mit besonderer Berücksichtigung der Insektenfauna der Elz und Kinzig. Arch. Hydrobiol. 25: 543-615.

Fahy,E. 1975. Quantitative aspects of the distribution of invertebrates in the benthos of a small stream system in Western Ireland. Freshw. Biol. 5: 167-182.

Flanagan,P.J. & P.F. Toner 1972. Notes on the chemical and biological analysis of Irish River waters. An Foras Forbarther - water resources division.

Furse,M.T. 1977. The ecology of the Gussage, a lined winterbourne. Ann. Rep. Freshw. Biol. Ass. 45: 30-36.

Geijskens,D.C. 1935. Faunistisch-ökologische Untersuchungen am Röserenbach bei Liestal im Basler Tafeljura. Tijdschr. Entom. 78: 249-382.

Ghetti,P.F. 1974. L'acqua nell' ambiente umano di Val Parma. "Studium Parmense", Parma.

Harrison Church,R.J. et al. 1967. An advanced geography of Northern and Western Europe. Hulton Educational Publications, London.

Hawkes,H.A. 1975. River zonation and classification. In: B.A. Whitton (ed.), River Ecology. Blackwell, Oxford.

Hawkes,H.A. 1976. Determinants in freshwater ecosystems and man-modifiable factors inducing change in hydrobiocoenoses. In: R.Amavis & J.Smeets (eds.), Principles and methods for determining ecological criteria on hydrobiocoenoses. Pergamon Press, Oxford.

Hynes,H.B.N. 1958. The effect of drought on the fauna of a small mountain stream in Wales. Verh. Internat. Verein. Limnol. 13: 826-833.

Hynes,H.B.N. 1961. The invertebrate fauna of a Welsh mountain stream. Arch. Hydrobiol. 57: 344-388.

Hynes,H.B.N. 1970. The ecology of running waters. Liverpool University Press.

Illies,J. 1958. Die Barbenregion mitteleuropäischer Fliessgewässer. Verh. Internat. Verein. Limnol. 13: 834-844.

Illies,J. 1961. Gebirgsbäche in Europa und in Südamerika; ein limnologischer Vergleich. Verh. Internat. Verein. Limnol. 14: 517-523.

Illies,J. 1963. Limnofauna Europaea. Fischer, Stuttgart.

Illies,J. & L. Botosaneanu 1963. Problèmes et méthodes de la classification et de la zonation écologique des eaux courantes, considérées surtout du point de vue faunistique. Mitt. Internat. Verein. Limnol. 12: 1-57.

Jones,H.R. & J.C. Peters (undated). Physical and biological typing of unpolluted rivers. (reproduced in doc. EXP/Eau/ff (76) Misc. 1 Council of Europe 1976)

Kawecka,B. et al. 1971. General characteristics of the biocoenoses in the streams of the Polish High Tatras. Acta Hydrobiol. 13: 465-476.

Kownacka,M. & A.Kownacki 1972. Vertical distibution of the zoocoenoses in the streams of the Tatra, Caucasus and Balkan Mts. Verh. Internat. Verein. Limnol. 18: 742-750.

Klein,L. 1957. Aspects of River Pollution. Butterworth, London. 821 p.

Lauterborn,R. 1916, 1917, 1918. Die geographische und biologische Gliederung des Rheistroms I, II, III. Teil. Sitzungsber. Heidelb. Adak. wiss. Bd. VII B, VIII B, IX B.

le Grand,H.E. 1973. Hydrological and ecological problems of Karst regions. Science 179 (4076): 859-864.

Lehmann,J. 1971. Die Chironomiden der Fulda. Arch. Hydrobiol. suppl. Bd. 37: 466-555.

Liebmann,H. 1960. Handbuch der Frischwasser und Abwasserbiologie. Bd I, II. Oldenbourg, München.

Macan,T.T. 1961. A review of running water studies. Verh. Internat. Verein. Limnol. 14: 587-602.

Macan,T.T. 1974. Running water. Mitt. Int. Ver. Limnol. 20: 301-321.

Maitland,P.S. 1966. Studies on Loch Lomond II. The fauna of the river Endrick. Blackie, Glasgow.

Marlier,G. 1951. La biologie d'un ruisseau de plaine: Le Smohain. Mém. Inst. r. Sci. nat. Belg. 114: 1-98.

Minshall,G.W. & R.A. Kuehne 1969. An ecological study of invertebrates of the Duddon, an English mountain stream. Arch. Hydrobiol. 66: 169-191.

Möller,L. 1955. Geographische Verteilung der Konzentration gelöster Substanzen von Grund und Oberflächengewässern Südwestdeutschlands in Limnologischer Sicht. Verh. Internat. Verein. Limnol. 12: 351-359.

Moller Pillot,H.K.M. 1971. Thesis: Faunistische beoordeling van de verontreiniging in laaglandbeken. Pillot-Standaardboekhandel, Tilburg.

Moretti,G. 1953. I fattori ecologici che regolano la vita nelle acque correnti delle Alpi e degli Apennini. Mem. Ist. Ital. Idrobiol 7: 229-316.

Moretti,G. 1955. Idrobiologia comparata delle acque correnti sudalpine ed appenniniche. Verh. Internat. Verein. Limnol. 12: 588-592.

Morgan,N.C. & H.J. Egglishaw 1965. A survey of the bottom fauna of streams in the Scottish Highlands, part I, Composition of the fauna. Hydrobiologia 25: 181-211.

Müller,K. 1955. Die regionale Gliederung lappländischer Fliessgewässer. Arch. Hydrobiol. suppl. Bd 22: 439-441.

Nietzke,G. 1938. Die Kossau. Hydrobiologisch-faunistische Untersuchungen an Schleswig-holsteinischen Fliessgewässer. Archiv Hydrobiol. 32: 1-74.

Nisbet,M. & J. Verneaux 1970. Composantes chimiques des eaux courantes. Annls. Limnol. 6: 161-190.

Pennak,R.W. 1971. Towards a classification of lotic habitats. Hydrobiologia 38: 321-334.

Pinder,L.C.V. 1977. The Chironomidae and their ecology in chalk streams.

Ann. Rep. Freshw. Biol. Ass. 45: 62-69.

Pomeisl,E. 1961. Ökologisch-biologische Untersuchungen an Plecopteren im Gebiet der nieder-österreichischen Kalkalpen und des diesem vorgelagerten Fliessgebietes. Verh. Internat. Verein. Limnol. 14: 351-354.

Redeke,H.C. 1948. Hydrobiologie van Nederland. De Boer, Amsterdam.

Ricker,W.E. 1934. An ecological classification of certain Ontario streams. Univ. Toronto Studies, Biol. series 37: 7-114.

Scheele,M. 1952. Systematisch-ökologische Untersuchungen über die Diatomeenflora der Fulda. Arch. Hydrobiol. 46: 305-423.

Schmitz,W. 1957. Die Bergbach-Zoozönosen und ihre Abgrenzung, dargestelt am Beispiel der oberen Fulda. Arch. Hydrobiol. 53: 465-498.

Sládeĉek,V. 1973. System of water quality from the biological point of view. Arch. Hydrobiol. Beiheft 7: 1-218.

Smissaert,H.R. 1959. Limburgse beken. Natuurh. Maandblad 48: 7-78.

Steinböck,O. 1938. Arbeiten über die Limnologie der Hochgebirgsgewässer. Int. Rev. ges. Hydrobiol. u. Hydrogr. 37: 467-509.

Thiel,K.D. & H.J. Subklew 1976. Der Bierbach im Naturschutzgebiet "Eldena" bei Greifswald. Limnologica (Berlin) 11, 1: 101-123.

Thienemann,A. 1925. Die Binnengewässer, Bd. 1.

Thienemann,A. 1942. Lappländische Chironomiden und ihre Wohngewässer. Arch. Hydrobiol. supppl. Bd 17: 1-253.

Thorup,J. 1963. Growth and life cycles of invertebrates from Danish springs. Hydrobiologia 22: 55-84.

Tittizer,T.G. 1976. Comparison of biological-ecological procedures for assessment of water quality. In: R.Amavis & J.Smeets (eds.), Pinciples and methods for determining ecological criteria on hydrobiocoenoses. Pergamon Press, Oxford.

Verneaux,J. 1973. Cours d'eau de Franche-Comté (Massif du Jura). Faculté des Sciences de Besançon. 257 p.

Verneaux,J. 1976, 1977. Biotypologie de l'écosystème "eau courante". C.R. Acad. Sc. Paris t. 283/284, série D. 1663, 1791, 77, 675.

APPENDIX VI

Tables with data on morphometry of large water bodies

Unesco 1978

2.6. Major rivers

The development of a drainage network depends on climate, relief and geological formations. The distribution of networks over the globe is closely related to the degree to which the land surface of the earth has been disturbed.

Conventionally, rivers are classified as large, medium or small, according to the size of their catchment areas, their lengths and the volume of their discharge.

Table 6 includes data on large- and medium-sized rivers that flow into the seas and oceans, and also on large rivers that flow into closed inland seas (Volga, Amu Darya, Syr Darya, etc.); it also includes data on lakes (Ili, Chari, Cooper's Creek, etc.) and other depressions without external run-off (Sarysu, Okovango, etc.) [5, 13, 16 to 18, 23 to 25, 27, 30].

Table 6. Basic morphometric data on large- and medium-sized rivers that flow into oceans, seas and inland water bodies

River	Area of basin (10^3 km²)	Length (km)	River	Area of basin (10^3 km²)	Length (km)
Europe					
Volga	1 360	3 350	Dal	29.0	520
Danube	817	2 860	Kem	27.7	191
Dnepr	504	2 200	Jucar	22.4	506
Don	422	1 870	Severn	21.0	390
Northern Dvina	357	744	Miño	17.7	340
Pechora	322	1 810	Tiber	17.2	405
Neva	281	74	Tana	16.2	344
Ural	237	2 430	Segura	16.1	341
Rhine	224	1 360	Shannon	15.7	368
Vistula	198	1 090	Thames	15.3	405
Elbe	148	1 110			
Loire	120	1 110	**Asia**		
Oder	112	907	Ob (with Irtysh)	2 990	3 650
Rhône	99.0	810	Yenisei	2 580	3 490
Neman	98.2	937	Lena	2 490	4 400
Duero	95.0	925	Amur	1 855	2 820
Western Dvina	87.9	1 020	Yangtze	1 800	5 520
Garonne	86.0	650	Gangas (with Brahmaputra)	1 730	3 000
Ebro	86.8	930	Indus	960	3 180
Tagus	80.9	1 010	Mekong	810	4 500
Seine	78.6	780	Shatt-al-Arab(1) (Tigris and Euphrates)	750	2 760
Mezen	78.0	966	Hwang Ho	745	4 670
Po	75.0	650	Kolyma	647	2 130
Dnestr	72.1	1 350	Tarim (Yarkend)	446	2 000
Guadiana	72.0	800	Chutsyan	437	2 130
Kuban	57.9	870	Irrawaddy	410	2 300
Guadalquivir	57.1	560	Khatanga	364	1 636
Onega	56.9	416	Indigirka	360	1 726
Narva	56.2	77	Salween	325	2 820
Maritsa	53.8	630	Godavari	314	1 500
Kemi	52.0	550	Amu Darya	309 (2)	1 415
Weser	46.0	724	Krishna (Kistna)	256	1 290
Terek	43.2	623	Helmand	250	1 150
Glama	40.5	611			
Tornio	39.5	510			
Kiumi	37.8	600			

(1) The length of the Shatt-al-Arab proper (below the junction of the Tigris and Euphrates rivers) is about 145 km.

(2) Extent of the catchment area as far as Kerki.

Table 6 (contd.)

River	Area of basin (10^3 km^2)	Length (km)
Asia (contd.)		
Yana	238	872
Liao Ho	231	1 350
Hwai Ho	220	900
Olenek	219	2 270
Syr Darya[1]	219	2 210
Anadyr	191	1 150
Kura	188	1 360
Pyasina	182	818
Menam (Chao Phraya)	160	1 200
Taz	150	1 400
Hong Ha (Red River)	145	1 200
Ili	140	1 000
Mahanadi	133	858
Taimyra	124	754
Kerulen	120	1 264
Pur	112	389
Narmada	102	1 300
Anabar	100	939
Sarysu	81.6	761
Kyzyl Irmak	75.8	1 151
Penzhina	73.5	713
Tedzhen	70.6	1 124
Alazea	64.7	498
Nadym	64.0	545
Yalu	62.6	1 500
Uda	61.3	457
Chu	60.8	1 190
Sakarya	56.5	790
Kamchatka	55.9	704
Africa		
Congo	3 820	4 370
Nile (with Kagera)	2 870	6 670
Niger	2 090	4 160
Zambezi	1 330	2 660
Orange	1 020	1 860
Chari	880	1 400
Okavango (Cubango)	785	1 800
Juba (with Shaballe)	750	1 600
Senegal	441	1 430
Limpopo	440	1 600
Volta	394	1 600
Ogowe	203	850
Gambia	180	1 200
Rufiji	178	1 400
Cuanza	149	630
Ruvuma	145	800
Cunene	137	830
Sanaga	135	860
Save	107	680
Bandoma	97.0	780
Dra	95.0	1 150
Tana	91.0	720
Kam	76.5	1 160
Sassandra	72.0	660
Kouilou	62.0	600
Lurio	57.6	560
Moulouya	52.0	450
Omo	46.7	800
Gourits	44.0	310
Sebu	40.0	460
Chélif	35.0	700
Oum-er-Rbia	34.4	556
Pangani	33.8	480
Kovali	28.8	480
Medjerda	22.0	460
Mono	21.0	360
North America		
Mississippi (with Missouri)	3 220	5 985
Mackenzie (with Athabaska)	1 800	4 240
St. Lawrence	1 290	3 060
Nelson (with Saskatchewan)	1 070	2 600
Yukon	852	3 000
Columbia	669	1 950
Colorado (State of Arizona)	635	2 180
Bravo del Norte (Río Grande)	570	2 880
Churchill	281	1 600
Fraser	220	1 110
Telon	142	—
Albany	134	975
Koksoak	133	1 300
Río Grande de Santiago	125	960
Grijalva (with Usumacinta)	122	—
Mobile (Alabama)	115	1 064
Brazos	114	1 400
Moose	108	—
Hayes	108	—
Back	107	960
Balsas	106	—
Severn	101	976
Colorado (State of Texas)	100	1 450
Fort George	97.7	—
Saguenay	90.1	—
Panuco	84.0	—
San Joaquin	80.1	560
Churchill (Hamilton)	79.8	560
Sacramento	73.0	610
Susquehanna	72.5	733
Kazan	71.5	—
Winisk	67.3	740
Nottaway	65.0	—
Copper	61.8	360
Saint John	55.4	640
Skeena	54.9	510
Apalachicola	51.8	880

[1] Extent of the catchment area as far as Tyumen-Aryk station.

Table 6 (contd.)

River	Area of basin (10^3 km²)	Length (km)
North America (contd.)		
Attawapiskat	50.2	810
Stikine	49.2	520
Eastmain	46.4	680
Manicouagan	45.6	520
George	44.8	550
Humboldt	43.9	465
Rupert	43.2	—
Great Whale	43.2	700
Leaf	43.0	200
St. Maurice	42.7	—
Papaloapan	37.4	350
Hudson	35.0	490
Weiss	31.3	—
Penobscot	30.0	340
Potomac	30.0	460
Harricanaw	29.3	460
Connecticut	29.0	552
Savannah	27.2	505
South America		
Amazon (with Ucayali)	6 915	6 280
La Plata (with Paraná and Uruguay)	2 970	4 700
Orinoco	1 000	2 740
São Francisco	600	2 800
Parnaiba	325	1 450
Magdalena	240	1 530
Essequibo	155	970
Chubut	138	850
Rio Negro	130	~1 000
Mearim	89.7	~800
Doce	81.3	~600
Colorado	65.0	~1 000
Paraiba	59.0	800
Atrato	32.2	644
Bio Bio	24.3	380
Australia and Oceania		
Murray (with Darling)	1 060	3 490
Cooper's Creek	285	2 000
Diamantina	156	896
Fitzroy (Eastern)	143	960
Burdekin	131	680
Flinders	108	830
Fitzroy (Northwest)	86.5	520
Ashburton	82.0	640
Sepik (*in* New Guinea)	81.0	700
Gascoyne	79.0	770
Victoria	77.5	570
Mitchell	69.3	520
Murchison	68.3	700
Fly (in New Guinea)	64.4	620
Fortescue	55.0	670
Clutha (in New Zealand)	22.0	338

Table 14. Water reserves in large lakes of the world

Continent	Number of lakes with a water surface area >100 km²		Total area (10^3 km²)	Water reserves (km³)	
	Total	Investigated		Fresh water	Salt water
Europe	34	30	430.4	2 027	78 000
Asia	43	24	209.9	27 782	3 165
Africa	21	15	196.8	30 000	—
North America	30	20	392.9	25 623	19
South America	6	2	27.8	913	2
Australia and New Zealand	11	1	41.7	154	174
Total	145	92	1 300	86 500	81 360

Table 7. Basic morphometric data on larger lakes(1)

Lake	Country	Area (km²)	Max. depth (m)	Volume (km³)
	Europe			
Caspian Sea*	U.S.S.R., Iran	374 000	1 025	78 200
Ladoga	U.S.S.R.	17 700	230	908
Onega	"	9 630	127	295
Vänern	Sweden	5 550	100	180
Chudskoye with Pskovskoe	U.S.S.R.	3 550	15	25
Vättern	Sweden	1 900	119	72
Saimaa	Finland	1 800	58	36
Beloye	U.S.S.R.	1 290	20	5.2
Vygozero	"	1 140	18	7.1
Mälaren	Sweden	1 140	64	10
Ilmen	U.S.S.R.	1 100	10	12
Päijänne	Finland	1 065	93	—
Inari	"	1 000	80	28
Imandra	U.S.S.R.	900	67	11
Balaton	Hungary	596	12	1.9
Geneva (Leman)	Switzerland, France	581	310	90
Constance	Germany, Fed. Rep., Switzerland, Austria	538	252	48
Hjälmaren	Sweden	484	22	—
Storsjön	"	464	74	8.0
Kubena	U.S.S.R.	407	13	1.7
Lough-Neagh	N. Ireland	396	31	—
Garda	Italy	370	346	50
Mjösa	Norway	363	434	56
Scutari	Albania, Yugoslavia	362	10	2.2
Ohrid	" "	350	256	61
Sniardwy	Poland	331	47	2.8
Torneträsk	Sweden	330	168	17
Neusiedler See	Austria, Hungary	323	2	—
Prespansko	Greece, Albania, Yugoslavia	288	54	4.0
Neuchâtel	Switzerland	216	152	—
Maggiore	Italy, Switzerland	214	372	—
Femunden	Norway	202	131	6.0
Como	Italy	146	410	—
	Asia			
Aral Sea*	U.S.S.R.	64 100	68	1 020
Baikal	"	31 500	1 741	23 000
Balkhash*	"	18 200	26	112
Tonlé Sap	Cambodia	10 000 (2)	12	40
Issyk-Kul	U.S.S.R.	6 200	702	1 730
Tung Ting	China	6 000 (3)	10	—
Rezaiyeh (Urmia)*	Iran	5 800	16	45
Zaisan	U.S.S.R.	5 510	8.5	53
Taimyr	"	4 560	26	13
Koko Nor*	China	4 220	38	—
Khanka	U.S.S.R., China	4 190	10.6	18.5
Van*	Turkey	3 760	145	—
Lop Nor*	China	3 500	5	(5)
Ubsa Nor*	Mongolia	3 350	—	—
Poyang	China	2 700	20	—
Alakol*	U.S.S.R.	2 650	54	58.6
Khubsugul	Mongolia	2 620	270	480
Chany*	U.S.S.R.	2 500	10	4.3
Tuz*	Turkey	2 500	—	—
Nam Tso*	China	2 460	—	—
Tai Hu	China	2 210	—	—
Kara-Ussu-Nor	Mongolia	1 760	—	—

Table 7 (contd.)

Lake	Country	Area (km²)	Max. depth (m)	Volume (km³)
	Asia (contd.)			
Tengiz*	U.S.S.R.	1 590	8	—
Ebi Nor	China	1 420	—	—
Kirgiz Nor	Mongolia	1 480	—	—
Sevan	U.S.S.R.	1 230	86	38
Dalai Nor	China	1 100	—	—
Uliungur	China	1 000	—	—
Dead Sea*	Israel, Jordan	940	400	188
Seletyteniz	U.S.S.R.	777	3.2	1.5
Sasykkol*	„	736	—	—
Pyasina	„	735	10	—
Kulunda*	„	728	4.9	—
Biwa	Japan	688	103	27.5
Gandhi	India	663	64	39.2
Karnaphuli	Bangladesh, India	656	33	13.8
Buir Nor	Mongolia	610	11	—
Markakol	U.S.S.R.	449	30	—
Ubinsk	„	440	3	—
Karakul	„	380	238	—
Tungabhadra	India	378	47	12.4
Phumiphol	Thailand	300	123	29.7
Kronotskoye	U.S.S.R.	245	128	—
Teletskoye	„	223	325	40
	Africa			
Victoria	Tanzania, Kenya, Uganda	69 000	92	2 700
Tanganyika	Tanzania, Zaïre, Zambia, Rwanda, Burundi	32 900	1 435	18 900
Nyasa	Malawi, Mozambique, Tanzania	30 900	706	7 725
Chad	Chad, Niger, Nigeria	16 600 (4)	~ 12	44.4
Rudolf	Kenya	8 660	73	—
Albert	Uganda, Zaïre	5 300	57	64.0
Mweru	Zambia, Zaïre	5 100	15	32.0
Bangweulu	Zambia	4 920 (5)	5	5.00
Rukwa	Tanzania	4 500	—	—
Tana	Ethiopia	3 150	14	28.0
Edward	Zaïre, Uganda	2 500	131	78.2
Kivu	Zaïre, Rwanda	2 370	496	569
Leopold II	Zaïre	2 325	6	—
Katnit	Nigeria	1 270	60	14.0
Abaya	Ethiopia	1 160	13	8.20
Shirwa	Malawi	1 040	2.6	45.0
Tumba	Zaïre	765	—	—
Faguibini	Mali	620	14	3.72
Gabel Auliya	Sudan	600	12	—
Chamo	Ethiopia	551	12.7	—
Upemba	Zaïre	530	3.5	0.90
Zwai	Ethiopia	434	7	1.10
Shala	„	409	266	37.0
Langana	„	230	46.2	3.82
Guiers	Senegal	213	7	0.64
Hora Abiata	Ethiopia	205	14.2	1.56
Naivasha	Kenya	140	—	—
Awasa	Ethiopia	130	21	1.34
	North America			
Superior	Canada, U.S.A.	82 680	406	11 600
Huron	„ „	59 800	229	3 580
Michigan	U.S.A.	58 100	281	4 680

Table 7 (contd.)

Lake	Country	Area (km²)	Max. depth (m)	Volume (km³)
	North America (contd.)			
Great Bear	Canada	30 200	137	1 010
Great Slave	„	27 200	156	1 070
Erie	Canada, U.S.A.	25 700	64	545
Winnipeg	Canada	24 600	19	127
Ontario	Canada, U.S.A.	19 000	236	1 710
Nicaragua	Nicaragua	8 430	70	108
Athabasca	Canada	7 900	60	110
Reindeer	„	6 300	—	—
Winnipegosis	„	5 470	12	16
Nipigon	„	4 800	162	—
Manitoba	„	4 720	28	17
Great Salt*	U.S.A.	4 660	14	19
Lake ot the Woods	Canada, U.S.A.	4 410	21	—
Dubawnt	Canada	4 160	—	—
Mistassini	„	2 190	120	—
Managua	Nicaragua	1 490	80	—
Saint Clair	Canada	1 200	7.2	5.3
Lesser Slave	„	1 190	3	—
Chapala	Mexico	1 080	10	10.2
Winnebago	U.S.A.	818	6	4.1
Marion	„	465	—	2.8
Winnipesaukee	„	181	55	3.8
	South America			
Maracaibo	Venezuela	13 300	35	—
Titicaca	Peru, Bolivia	8 110	230	710
Poopó*	Bolivia	2 530	3	2
Buenos Aires	Chile, Argentina	2 400	—	—
Lago Argentino	Argentina	1 400	300	—
Valencia	Venezuela	350	—	—
	Australia			
Eyre*		15 000 (max.)	20	—
Amadeus*		8 000	—	—
Torrens*		5 800	—	—
Gairdner*		4 780	—	—
George		145	3	0.3
	New Zealand			
Taupo		611	159	—
Te Anau		352	276	—
Wakatipu		293	378	—
Wanaka		194	—	—
Manapouri		130	—	—
Hawea		119	—	—

(1) The asterisk (*) next to the name of a water body indicates that it is a salt lake.
(2) At low levels, 3,000 km², at high levels, 30,000 km².
(3) At low levels, 4,000 km², at high levels, 12,000 km².
(4) At low levels, 7,000—10,000 km², at high levels, 18,000—22,000 km².
(5) At low levels, 4,000 km³, at high levels, 15,000 km².

Table 8. Larger reservoirs of the world

Reservoir	Country	River, Lake	Volume (km³)		Surface area (km²)	Head (m)	Year reservoir reached full capacity
			Total	Useable			
			Europe				
Kuibyshev	U.S.S.R.	Volga	58.0	34.6	6 450	25	1957
Volgograd	U.S.S.R.	Volga	33.5	8.65	3 500	27	1962
Kanevsk	U.S.S.R.	Dnepr	28.1	6.00	—	15	1963
Rybinsk	U.S.S.R.	Volga	25.4	16.6	4 550	18	1947
Tsimlyansk	U.S.S.R.	Don	23.8	11.5	2 320	27	1954
Kakhovka	U.S.S.R.	Dnepr	18.2	6.80	2 160	16	1956
Upper Svir	U.S.S.R.	Svir	—	17.5	9 700	17	1952
Cheboksary	U.S.S.R.	Volga	14.2	5.70	2 295	19	U.C.
Kremenchug	U.S.S.R.	Dnepr	13.5	9.07	2 250	17	1960
Kuma	U.S.S.R.	Kuma Kovda	13.3	8.68	1 910	38	1962
Lower Kama	U.S.S.R.	Kama	13.0	4.40	2 850	19	1970
Saratov	U.S.S.R.	Volga	12.9	1,75	1 950	15	1970
Upper Tuloma	U.S.S.R.	Tuloma	11.5	3.86	745	62	1965
Imandrovsk	U.S.S.R.	Niva	11.2	2.80	876	—	1953
Kama (Perm)	U.S.S.R.	Kama	10.7	9.20	1 570	21	1957
Votkinsk	U.S.S.R.	Kama	9.36	3.70	1 130	23	1963
Gorki	U.S.S.R.	Volga	8.70	2.80	1 500	17	1957
Tainionkoski	Finland	Vuoksa	7.20	—	—	8	1949
Vygozero	U.S.S.R.	Lower Vyg.	7.10	1.14	1 159	—	1933
Sheksna	U.S.S.R.	Sheksna	6.51	1.85	1.670	—	1968
Randsfjord	Norway	Etna	5.97	—	136	—	—
King Paul (Kremasta)	Greece	Achelous	4.70	3.30	81	136	1966
			Asia				
Bratsk	U.S.S.R.	Angara	169	48.2	5 500	106	1966
Pa Mong	Laos	Mekong	107	40.0	—	115	U.C.
Krasnoyarsk	U.S.S.R.	Yenisei	73.3	30.4	2 000	100	1970
Zeya	U.S.S.R.	Zeya	68.4	32.1	2 420	90	U.C.
Sansia	China	Yangtze	67.8	—	—	154	—
Badi Tartar	Iraq	Tigris	67.0	—	2 000	—	1956
Sanmensia	China	Hwang Ho	65.0	55.0	3 500	80	1962
Sanmen	China	Yangtze	64.1	—	—	100	U.C.
Ust Ilimsk	U.S.S.R.	Angara	59.4	2.8	1 870	88	U.C.
Bukhtarminsk	U.S.S.R.	Irtysh, Lake Zaisan	53.0	31.0	5 500	67	1967
Irkutsk	U.S.S.R.	Angara, Lake Baikal	48.5**	46.4	32 970	31	1959
Dantsianhow	China	Hanshui	51.6	38.5	1 020	130*	1962
Vainganga	India	Hanshui	40.7	—	—	—	—
Tabka	Syria	Euphrates	40.0	11.0	830	60	U.C.
Kalabagh	Pakistan	Indus	36.6	—	—	—	—
Vilyuisk	U.S.S.R.	Vilyui	35.9	14.8	2 180	68	1968
Keban	Turkey	Euphrates	30.5	22.0	750	160	1971
Sayan	U.S.S.R.	Yenisei	29.1	14.7	583	220	U.C.
Kapchagai	U.S.S.R.	Ili	28.1	6.60	1 850	40	1970
Toktogul	U.S.S.R.	Naryn	19.5	14.0	265	180	U.C.
Tsintian	China	Autsian	19.5	—	—	135*	1961
Sinantsian	China	Sinantsian	17.8	8.8	580	106*	1964
Mangla	India, Pakistan	Jhelum	16.7	—	256	116*	1973
Mingechaura	U.S.S.R.	Kura	16.1	7.50	525	62	1954
Tarbela	Pakistan	Indus	13.6	6.00	260	148*	U.C.
Kolyma	U.S.S.R.	Kolyma	13.0	4.40	—	—	U.C.
Phumiphol (Yanhi)	Thailand	Pong Chao Praiya	12.2	—	—	152*	1964
Suifun	Korea	Yalu	11.6	7.50	180	107*	1966
Nagarjuna Sagar	India	Kistna	11.5	5.45	285	123*	1966
Sinfintsian	China	Duntsian	11.5	0.39	390	102*	U.C.
Khaishansia	China	Hwang Ho	11.4	—	101	140*	U.C.
Rikhand	India	Rikhand	10.6	8.97	466	91*	U.C.
Nureka	U.S.S.R.	Vaksh	10.5	4.50	400	275	U.C.
Bhakra Nangal	India	Sutlej	9.87	7.77	226	168	1967
Finman	China	Sungari	9.70	5.60	487	92*	1956
Lunyantsia	China	Hwang Ho	9.00	—	—	176*	1963
Novosibirsk	U.S.S.R.	Ob	8.85	4.40	1 070	20	1959
Srisailem	India	Krishna	8.75	4.25	700	122*	1971

** The volume of the lake up to the level of the backwater has not been calculated.

Table 8 (contd.)

Reservoir	Country	River, Lake	Volume (km³) Total	Volume (km³) Useable	Surface area (km²)	Head (m)	Year reservoir reached full capacity
Asia (contd.)							
Ukai	India	Tapti	8.51	7.10	—	69	1971
Gandhisagar	India	Chambal	8.45	7.68	663	64*	1962
Huanshen	China	Huantsian	8.30	5.90	435	102*	1958
Bias	India	Bias	8.14	6.90	—	134*	U.C.
Hirakud	India	Mahanadi	8.10	5.80	637	66*	1959
Dokan	Iraq	Little Zab	6.80	5.40	270	117*	1961
Hirfanlar	Turkey	Kyzyl Irmak	6.00	2.00	277	81*	1960
Chardarinsk	U.S.S.R.	Syr Darya	5.70	4.70	900	25	1966
Liudziasia	China	Hwang Ho	5.70	4.10	130	146*	1961
Giumiusha	U.S.S.R.	Razdan	5.60	4.10	—	297	1953
Africa							
Owen Falls	Tanzania, Kenya, Uganda	Victoria River Nile, Lake Victoria	205**	68.0	69 000	22	1968
Murchison Falls	Tanzania, Kenya, Uganda	Lake Albert, Nile	195	—	5 300	—	U.C.
Kariba	Zambia, Southern Rhodesia	Zambezi	160	46.0	4 450	100	1963
Nasser	Egypt, Sudan	Nile	157	74.0	5 120	95	1971
Volta	Ghana	Volta	148	90.0	8 480	70	1967
Cabora Bassa	Mozambique	Zambezi	66.4	51.7	2 700	100	U.C.
Roseires	Sudan	Blue Nile	36.3	—	290	70*	1966
Sunda	Congo	Niari	35.0	35.0	1 600	100	1961
Kossu	Ivory Coast	Bandama Blanc	30.0	25.9	1 740	60	U.C.
Kainji	Nigeria	Niger	15.1	11.5	1 240	66*	1971
Suapiti	Guinea	Conkoure	11.0	—	—	118*	—
Hendrik Verwoerd	South Africa	Orange	5.67	1.62	372	87*	1971
North America							
Daniel Johnson (Manicouagan-5)	Canada	Manicouagan River and Lake; Mushalagan Lake	142	36.0	1 940	195	1968
Gordon Croome (Bennet)	Canada	Peace River	108	37.0	1 660	165	1968
Kanuti	U.S.A.	Yukon	46	—	—	58	—
Lake Mead (Hoover)	U.S.A.	Colorado	37.5	34.0	637	159	1938
Winar Grue	Canada	Peace River	37.0	37.0	—	2 300	1952
Nechako-Kemalo	Canada	Nechako	35.0	24.8	860	783	1966
Lake Powell (Glen Canyon)	U.S.A.	Colorado	34.5	31.1	664	200	1966
Churchill Falls	Canada	Churchill, Lake Michikamo and others	31.1	28.0	6 650	33	1968
Ontario (Iroquois)	Canada	St. Lawrence, Lake Ontario	30.0	30.0	19 470	21	1959

** The volume of the lake up to the level of the backwater has not been calculated.

Table 8 (contd.)

Reservoir	Country	River, Lake	Volume (km³) Total	Volume (km³) Useable	Surface area (km²)	Head (m)	Year reservoir reached full capacity
		North America (contd.)					
Garrison Dam (Lake Sakajawea)	U.S.A.	Missouri	30.6	24.5	1 560	46	1954
Oahe	U.S.A.	Missouri	29.1	22.2	1 500	61	1963
Fort Peck	U.S.A.	Missouri	24.8	21.1	1 000	62	1943
Mica (Mica Creek)	Canada	Columbia	24.4	14.8	—	183	U.C.
Baie de l'Estuaire	Canada	Salmon Grey	—	—	15.5	183	1969
Netsaualcoitl (Presa de Malpaso)	Mexico	Grijalva	13.0	—	238	100	1964
Lake Portage	Canada	Lake Nipigon	12.4	—	4 960	32	1954
Infiernillo	Mexico	Balsas	12.0	9.75	400	101	1966
Franklin Roosevelt (Grand. Coulee)	U.S.A.	Columbia	11.7	6.44	321	107	1942
Bersimis I	Canada	Bersimis	11.7	4.74	—	267	1958
Sardis	U.S.A.	Little Takahechi	11.7	—	230	—	1940
Grand Rapids	Canada	Saskatchewan	11.0	8.00	4 100	39	1968
Gardner	Canada	South Saskatchewan	10.0	—	—	47	1969
Manicouagan-3	Canada	Manicouagan	10.0	0.7	—	95	U.C.
Rapid Ile	Canada	Ottawa	9.83	—	—	27	1967
Gouin (La Lioutre)	Canada	St. Maurice	—	8.00	1 295	—	—
Arrow Lake	Canada	Arrow Columbia	8.76	7.80	—	—	—
Miguel Aleman	Mexico	Papaloapan	8.00	—	—	—	1955
Lake of the Woods	U.S.A.	Winnipeg	7.60	7.60	3 820	—	1905
Fort Randall	U.S.A.	Missouri	7.60	5.80	415	40	1956
Wolf Creek	U.S.A.	Lake Cumberland	7.50	2.65	257	49	1955
Kentucky	U.S.A.	Tennessee	7.40	4.95	690	15	1945
Lake Texoma (Denison)	U.S.A.	Red River	7.24	2.20	370	31	1945
Amistad	Mexico	Río Bravo del Norte	7.05	5.89	—	80	1968
Boundary	U.S.A.	Pend Oreille	6.80	0.12	—	76	1967
Bull Shoals	U.S.A.	White	6.65	5.60	290	73	1953
Lake Shasta	U.S.A.	Sacramento	5.55	5.37	120	146	1948
Shipshaw 2	Canada	Peribonca	5.50	—	—	63	1943
Sam Rayburn (MacGee Bend)	U.S.A.	Angelica	5.50	—	296	—	U.C.
Ile Maline	Canada	Saguenay	5.30	—	—	51	1937
Chutes des Passes	Canada	Peribonco	5.20	—	—	165	1960
Lake Okeechobee	U.S.A.	Lake Okeechobee	5.16	1.00	1 820	—	1958
Falcon	Mexico	Río Grande (Bravo del Norte)	5.04	—	—	—	1953
		South America					
El Manteco (Guri)	Venezuela	Caroni	111	55.0	—	136	1968
Cerros Colorados	Argentina	Neuquén	43.5	5.60	620	79	U.C.
Ilha Solteiri	Brazil	Paraná	21.2	12.9	1 230	43	1965
Furnas	Brazil	Grande	21.0	18.7	1 600	95	1965

Table 8 (contd.)

Reservoir	Country	River, Lake	Volume (km³) Total	Useable	Surface area (km²)	Head (m)	Year reservoir reached full capacity
			South America (contd.)				
Tres Marías	Brazil	São Francisco ..	21.0	18.0	1 350	55	1965
El Chocon	Argentina	Limay-Rio Negro	20.0	2.35	825	62	U.C.
Silto Grande	Uruguay	Uruguay	20.0	—	—	33	—
Van Blanstein	Surinam	Surinam	12.4	—	1 500	—	U.C.
Rincon del bonete	Uruguay	Río Negro	11.00	6.60	1 400	32	1946
Boa Esperanza	Brazil	Parnaiba	5.00	4.00	—	35	—
			Australia and Oceania				
Ord	Australia	Ord	19.0	5.67	720	100*	1972
Main Gordon	Australia	Gordon	11.8	—	167	142*	U.C.
Eucumbene	Australia	Eucumbene	6.90	4.30	—	119*	1958

Note. Figures with an asterisk (*) indicate the height of the dam U.C. indicates under construction.

The United States has over 1,560 reservoirs, with a useful capacity of about 450 km³ and a water-surface area equal to 60,000 km² [6, 27].

Asia, Africa and Australia have about 3,700 reservoirs, the larger of which are situated in the U.S.S.R., Egypt, Ghana, China, Rhodesia and Iraq. Details of large reservoirs of the world, which fulfil various needs (hydro-power, water supply, irrigation, navigation) and the full volume of which exceeds 5 km³, were listed by continents in Table 8 [1 to 3, 6 to 10, 19, 21, 23, 25, 27, 28, 30].

Table 16. Basic information on the reservoirs of the world in 1972

Continent	Reservoirs with a volume >5 km³ Total number	Total volume (km³)	Useful volume (km³)	Total annual run-off of rivers (km³)	Ratio of volume of reservoir to volume of river run-off (%)
Europe	25	422	170	3 210	13.1
Asia	48	1 350	493	14 410	9.4
Africa	12	1 240	432	4 570	27.1
North America	45	950	210	8 200	11.6
South America	10	286	123	11 760	2.4
Australia & Oceania	3	38	10	2 390	1.6
Total	143	4 286	1 438	44 540	9.6

The total capacity of the 10,000 reservoirs of the world now in operation, or under construction, amounts to about 5,000 km³ and the useful capacity to about 2,000 km³. The total water-surface area of the reservoirs is approximately 400,000 km², and, taking into account the lakes included in the backwater, the area amounts to 600,000 km² [1, 2]. Most of the water reserves are concentrated in the larger reservoirs, each with a capacity exceeding 5 km³ (Table 16).

The total capacity of reservoirs controls approximately 14% of total annual river run-off while the useful capacity controls about 7%.

Table 12. Natural amounts of ground water in the upper part of the earth's crust, by hydrogeological zones

Continent	Total area with islands (10^6 km²)	Mean altitude above sea level (m)	Zone classification	Thickness of zone (m)	Effective porosity (%)	Amounts of ground water by zones (10^6 km³)	Total amounts of ground water (10^6 km³)
Europe	10.5	300	1st	100	15	0.2	
			2nd	200	12	0.3	
			3rd	2 000	5	1.1	1.6
Asia	43.5	950	1st	200	15	1.3	
			2nd	400	12	2.1	
			3rd	2 000	5	4.4	7.8
Africa	30.1	650	1st	200	15	1.0	
			2nd	400	12	1.5	
			3rd	2 000	5	3.0	5.5
North America	24.2	700	1st	200	15	0.7	
			2nd	400	12	1.2	
			3rd	2 000	5	2.4	4.3
South America	17.8	580	1st	100	15	0.3	
			2nd	400	12	0.9	
			3rd	2 000	5	1.8	3.0
Australia and Oceania	8.9	350	1st	100	15	0.1	
			2nd	200	12	0.2	
			3rd	2 000	5	0.9	1.2
						Total	23.4

Table 13. Natural ground-water resources renewed annually, by continents

Continent	Annual volume of river run-off (km³)	Ground-water run-off in % of river run-off	Ground-water run-off into rivers (km³ yr⁻¹)
Europe	3 210	35	1 120
Asia	14 410	26	3 750
Africa	4 570	35	1 600
North America ..	7 450[1]	29	2 160
South America ..	11 760	35	4 120
Australia	2 390	24	575
Total	43 790	30	13 320

[1] Excluding polar regions.

The average proportion of ground water in the river run-off of the world is close to 30%. It follows that the total quantity of annually recharged ground water in the active and relatively active zones of water exchange amounts to about 13,000 km³ per year.

Table 11. Water reserves in surface ice

Territory	Area of ice (km^2)	Water reserves (km^3)
Antarctica	13 980 000	21 600 000
Greenland	1 802 400	2 340 000
Arctic islands	226 090	83 500
Franz Josef Land	13 735	2 530
Novaya Zemlya	24 420	9 200
Severnaya Zemlya	17 470	4 620
Spitsbergen (Western)	21 240	18 690
Small islands	400	60
Canadian Arctic archipelago	148 825	48 400
Europe	21 415	4 090
Iceland	11 785	3 000
Scandinavia	5 000	645
Alps	3 200	350
Caucasus	1 430	95
Asia	109 085	15 630
Pamir Alai	11 255	1 725
Tien Shan	7 115	735
Dzungarian Alatau, Altai, Sayan Mountains	1 635	140
Eastern Siberia	400	30
Kamchatka, Koryak Range	1 510	80
Hindu Kush	6 200	930
Karakoram Range	15 670	2 180
Himalayas	33 150	4 990
Tibet	32 150	4 820
North America	67 522	14 062
Alaska (Pacific Coast)	52 000	12 200
Inland Alaska	15 000	1 800
U.S.A.	510	60
Mexico	12	2
South America		
Venezuela, Colombia, Andes of Ecuador, Andes of Peru, Andes of Chile and Argentina, Tierra del Fuego	7 100	2 700
Andes of Patagonia	17 900	4 050
Africa (Kenya, Kilimanjaro, Ruwenzori mountains)	22.5	3
New Zealand	1 000	100
New Guinea	14.5	7
Total	16 227 500	24 064 100

Table 9. World water reserves

Form of water	Area covered (km^2)	Volume (km^3)	Depth of run-off (m)	Share of world reserves (%)	
				of total water reserves	of reserves of fresh water
World ocean	361 300 000	1 338 000 000	3 700	96.5	—
Ground water (gravitational and capillary)	134 800 000	23 400 000(1)	174	1.7	—
Predominantly fresh ground water	134 800 000	10 530 000	78	0.76	30.1
Soil moisture	82 000 000	16 500	0.2	0.001	0.05
Glaciers and permanent snow cover:	16 227 500	24 064 100	1 463	1.74	68.7
Antarctica	13 980 000	21 600 000	1 546	1.56	61.7
Greenland	1 802 400	2 340 000	1 298	0.17	6.68
Arctic islands	226 100	83 500	369	0.006	0.24
Mountainous areas	224 000	40 600	181	0.003	0.12
Ground ice in zones of permafrost strata	21 000 000	300 000	14	0.022	0.86
Water reserves in lakes	2 058 700	176 400	85.7	0.013	—
Fresh water	1 236 400	91 000	73.6	0.007	0.26
Salt water	822 300	85 400	103.8	0.006	—
Marsh water	2 682 600	11 470	4.28	0.0008	0.03
Water in rivers	148 800 000	2 120	0.014	0.0002	0.006
Biological water	510 000 000	1 120	0.002	0.0001	0.003
Atmospheric water	510 000 000	12 900	0.025	0.001	0.04
Total water reserves	510 000 000	1 385 984 610	2 718	100	—
Fresh water	148 800 000	35 029 210	235	2.53	100

(1) Not taking into account ground-water reserves in Antarctica, broadly estimated at 2 million km^3 (including about 1 million km^3 of predominantly fresh water).

APPENDIX VII

Appendices with data on saline lakes in the world

Hammer 1986

Appendix A Climatic data for centres representative of dry climates.

Locality	Latitude	Longitude	Altitude (ASL, m)	Temperature (°C)		Precipitation (mm)	Annual potential evaporation (mm)	Annual sunshine (h)	Annual radiation (kcal m⁻²)
				Mean daily	Mean monthly range				
Africa									
Biskra, Algeria	34°51′ N	5°44′ E	122	21.8	33.3–11.2	148	2592	3468	160*
Faya Largeau, Chad	18°00′ N	19°10′ E	233	28.6	34.2–20.6	504	5000*	3800*	210*
Addis Ababa, Ethiopia	09°02′ N	38°45′ E	2450			1256	1861	2336	170*
Nairobi, Kenya	01°18′ S	36°45′ E	1798			1066	1502	2503	160*
Kimberley, S.A.	28°48′ S	24°46′ E	1197			431	2968	3468	184.7
Cairo, Egypt	30°08′ N	31°34′ E	95	20.8	27.7–12.3	24	3613	3504	190*
Salisbury, Zimbabwe	17°50′ S	31°01′ E	1470	18.6	21.4–13.8	868	2040	2884	188.7
Asia									
China									
Beijing	39°57′ N	116°19′ E	52	12.1	− 4.7–26.1	623	2705	925	–
Urumchi	43°47′ N	87°37′ E	913	5.3	− 15.8–23.9	276	2607	–	–
Xining	36°35′ N	101°55′ E	2244	6.9	− 6.4–18.3	377	2619	700	–
India									
Jodpur	26°18′ N	73°01′ E	224	26.7	17.1–34.5	380.1	3322	2847	–
Sprinigar	34°05′ N	74°50′ E	1586	13.3	1.1–23.9	564	2190	–	–
Iran									
Shiraz	29°36′ N	52°32′ E	1491	16.6	5.8–27.5	350.3	–	–	–
Tabriz	38°08′ N	46°15′ E	1362	12.7	1.2–26.1	296.2	–	–	–
Jordan, Wadi Husban	31°49′ N	35°39′ E	− 185	23.5	14.5–30.9	150–250	–	–	–
Turkey, Ankara	39°57′ N	32°53′ E	902	11.7	− 2.7–19.7	358.5	–	–	–
U.S.S.R.									
Balkhash	46°54′ N	75°00′ E	423	5.1	− 15.6–23.9	115	–	800	–
Minusinsk	53°42′ N	91°42′ E	251	− 0.1	− 20.3–19.7	316	1716	400	–
Turgay	49°38′ N	63°30′ E	123	4.2	− 17.2–24.2	177	2491	700	–
Antarctica									
McMurdo	77°35′ S	166°44′ E	24	− 17.4	− 3.4 to − 27.8	200*	–	–	–
Australia									
Mildura, N.S.W.	34°11′ S	142°12′ E	54	17.4	10.1–24.4	264	1511	3000*	–
Alice Springs, N.T.	23°38′ S	132°35′ E	579	20.6	11.6–28.1	252	2388	3468	190.5
Cloncurry, Qld.	20°43′ S	140°30′ E	193	25.5	17.8–31.3	429	2743	–	–
Launceston, Tas.	41°27′ S	147°10′ E	81	11.2	9.0–13.2	740	800	2400*	–
Melbourne, Vic.	37°49′ S	144°58′ E	35	14.8	9.6–19.9	500	1000	2035	129.6
Port Augusta, S.A.	32°29′ S	137°45′ E	5.5	19.0	11.8–25.4	236	2507	3000*	
Merridin, W.A.	31°29′ S	118°18′ E	319	17.5	10.1–25.1	320	2109	3000*	
Alexandra, N.Z.	45°15′ S	169°24′ E	158	11.7	9.1–12.8	335	676	2081	
North America									
Canada,									
Leth bridge, Alta.	49°38′ N	112°48′ W	280	5.4	− 8.2–18.9	439	2384	910	–
Saskatoon, Sask.	52°08′ N	106°38′ W	157	2.0	− 17.6–19.3	352	2381	710	–
United States									
San Diego, Calif.	32°44′ N	117°10′ W	4	17.2	13.1–21.5	264	3200	1200	–
Reno, NE	39°30′ N	119°47′ W	1342	21.2	16.3–26.5	180	3000	1100	–
Bismarck, N.Dat.	46°46′ N	100°45′ W	502	5.4	− 12.8–22.3	385	2750	850	133.96
Salt Lake City, Utah	40°46′ N	111°48′ W	1286	10.7	− 2.1–24.7	354	3000	1000	149.29
Walla Walla, Wash.	46°02′ N	118°20′ W	289	12.3	0.7–24.4	395	2700	1000	–

Appendix A (Continued).

Locality	Latitude	Longitude	Altitude (ASL, m)	Temperature (°C)		Precipitation (mm)	Annual potential evaporation (mm)	Annual sunshine (h)	Annual radiation (kcal m⁻²)
				Mean daily	Mean monthly range				
South America									
Argentina									
Cordoba	31°24′S	64°11′W	425	17.4	10.6–24.2	680	1287	2701	
LaPampa	37°08′S	63°41′W	142	15.2	7.4–23.7	608	1522	2665	
Sarmiento	45°35′S	69°08′W	266	10.8	3.9–17.3	153	–	2336	
Brazil									
Quixeramobim	5°12′S	39°18′W	198	27.5	26.2–28.8	763	1513*	2800	
Bolivia									
La Paz	16°30′S	68°08′W	3642	18	16–19	488	1480*		
Chile									
Iquique	20°22′S	70°11′W	9	17.9	15.4–20.9	2.1			
Europe									
U.S.S.R.									
Astrakhan	46°16′N	48°02′E	18	9.3	−6.9–25.1	190	900	2441	111
Hungary									
Szeged	46°15′N	20°09′E	79	11.5	−1.4–23.0	558	573	2102	
Spain									
Madrid	40°25′N	3°41′E	667	13.9	4.9–24.2	435	1059	2824	110.6

Appendix B World saline lakes: their location, altitude, morphometry and origin, # (ASL = above sea level; S = surface area; z_m = maximum depth; $\bar{z}$ = mean depth).

Lake	Lat	Long	ASL (m)	S (km²)	z_m (m)	$\bar{z}$ (m)	V (× 10⁶ m³)	Origin
Africa								
Chad								
Bodou	13°53′N	14°15′E	–	0.75	1.5	–	–	Interdunal
Rombou	14°05′N	15°13′E	–	0.125	1	–	–	Interdunal
Yoan	19°17′N	20°45′E	–	–	25	–	–	Interdunal
Egypt								
Hydredrome	31°30′N	29°40′E	−3.6	5	7	3	18	Dune, reservoir
Mariut	31°07′N	29°57′E	−2.85	84	1.15	1	84	Dune
Qarun	29°30′N	30°41′E	−44	200	8.5	4	824	Tectonic, deflation
Ethiopia								
Abiata	03°37′N	38°55′E	1573	204.7	14.2	–	–	Rift fault
Aranguadi	03°54′N	39°07′E	1900	0.54	32	18.5	10	Maar
Kilotes	03°54′N	39°07′E	2000	0.77	6.4	2.6	2	Maar
Shala	03°26′N	38°51′E	1567	409.4	266	–	–	Rift fault
Kenya								
Bogoria	00°15′N	36°07′E	963	33	12	7.0	231	Rift fault
Elmenteita	00°27′S	36°05′E	1776	18	1.9	1.33	24	Rift fault
Nakuru	00°24′S	36°05′E	1758	42	3.3	3.58	150	Rift fault
Tanzania								
Big Momela	03°13′S	36°54′E	1448	0.9	31	–	–	Volcanic lahar
Manyara	03°35′S	35°50′E	960	413	3.7	–	–	Fault scarp
Madagascar								
Ihotry	21°50′S	43°30′E	50	8.65–94.2	2.5–3.8	–	–	Dunes, tectonic
Malawi								
Chilwa	15°30′S	35°30′E	630	1400	5	–	–	Tectonic

Appendix B (Continued).

Lake	Lat	Long	ASL (m)	S (km^2)	z_m (m)	$\bar{z}$ (m)	V ($\times 10^6 m^3$)	Origin
South Africa								
Blaauwater 1	26° 16′ S	30° 14′ E	–	0.4	6	–	–	Deflation?
Banagher 3	26° 23′ S	30° 18′ E	–	0.2	0.3	–	–	Deflation?
Ronde	34° 12′ S	18° 30′ E	–	1.3	shallow	–	–	Estuary-dune
Zeekoe	34° 12′ S	18° 32′ E	–	6.0	several	–	–	Estuary-dune

Chad lakes (Iltis 1969, 1971); Hippodrome (Elster & Vollenweider 1961); Mariut (El-Wakeel *et al.* 1970); Qarun (Naguib 1958); Abiata, Aranguadi, Shala (Barker *et al.* 1965); Kilotes (Prosser *et al.* 1968); Bogoria (Hannington) (Melack 1981, Nogrady 1983); Elmenteita, Nakuru, Big Momela, Manyara (Melack & Kilham 1974); Chilwa (Morgan & Kalk 1969); Ihotry (Mars & Richard-Vindard 1972); Blaauwater, Banagher, Ronde, Zeekoe (Hutchinson *et al.* 1932); Rocher (Coetzer 1981).

Antarctica								
Don Juan	77° 34′ S	161° 10′ E	122	0.14	<1.5	0.11	0.15	Glacial
Fryxell	77° 35′ S	163° 35′ E	–	–	18	10	–	Glacial

Don Juan (Meyer *et al.* 1962, Tedrow & Ugolini 1963); Fryxell (Angino *et al.* 1962, Torii *et al.* 1977)

Asia								
China								
Chen-Chuan	35° 65′ N	86° 58′ E	4784	84				
Qinghai	36° 50′ N	100° 10′ E	3196	4635	28.7	19.2	854500	Tectonic
India								
Kar	33° 18′ N	78° 00′ E	4527	15.6	2.0	–	–	Tectonic
Khyagar	33° 06′ N	78° 18′ E	4672	6.2	21.2	–	–	Kettle
Panggong	33° 42′ N	78° 45′ E	4241	279.2	51	26.1	7.287	Tectonic, glacial
Sambhar	26° 58′ N	75° 55′ E	–	190	3.75	–	–	Erosion, dunes
Iran								
Maharlu	29° 26′ N	52° 48′ E	1520	220	0.5	–	–	
Nargiz-Niriz	29° 30′ N	53° 40′ E	1525	1210	1.1	0.5	0.605	
Urmia	35° 30′ N	40° 30′ E	1273	4000	16	4.9	19.5	
Mongolia								
Orog	50° 10′ N	91° 00′ E	1425	237.6	42	15	3564	
Turkey								
Burdur	37° 45′ N	30° 11′ E	845	180	50	–	–	
Krater Aci	38°47′ N	33°25′ E	950	1	76.5	–	–	Crater
Tuz	37° 42′ N	33°07′ E	900	1600	2	0.61	976	Deflation playa
Van	38° 00′ N	42° 30′ E	1720	3600	550	53	190800	Graben
U.S.S.R.								
Balkhash	46° 30′ N	75° 00′ E	342	17575	26.5	6.13	·107735	Graben, erosion
Bolshoy Shantropy			187	5.23	4.6	3.4	17.78	Glacial
Butash			192	37.7	2.2	1.6	60.32	Glacial
Issyk-Kul	42° 20′ N	77° 00′ E	1609	6206	668	320	1986920	Graben
Karakul	39° 00′ N	73° 30′ E	3952	370	240	210	77700	Graben

Chen-Chuan (Wei, pers. comm.); Qinghai (Koko Nor) (Academia Sinica 1979); Kar, Khyagar, Panggong (Hutchinson 1937a); Sambhar (Bhagarva & Alaam 1979); Maharlu (Löffler 1961a), Nargiz-Niriz (Löffler 1959a), Urmia (Resaieh) (Greer 1977); Dead (Neev & Emery 1967, Nissenbaum 1975); Orog (Dulma 1979); Burdur (Numann 1960), Krater Aci (Dumont 1981), Tuz (Irion 1973), Van (Gessner 1957, Irion 1963, Langbein 1961); Balkhash (Ergashev 1979, Greer 1977, Hutchinson 1957), Bolshoy Shantropy and Butash (Letanskaya 1980, Drabkova *et al.* 1978b), Issyk-Kul (Ergashev 1979, Hutchinson 1957), Karakul (Ergashev 1979, Melack 1983).

Appendix B (Continued).

Lake	Lat	Long	ASL (m)	S (km²)	z_m (m)	$\bar{z}$ (m)	V ($\times 10^6 m^3$)	Origin
Australia								
Eyre (North)	28° 35′ S	137° 14′ E	– 15*	8030	6.1	3.99	32000	Subsidence &
Eyre (South)	29° 21′ S	137° 21′ E	– 13*	1300	–	–	–	deflation
Eliza	37° 12′ S	139° 53′ E		38.2				Eustasis-dunes
Robe	37° 15′ S	139° 58′ E		3.25				Eustasis-dunes
Folly	42° 07′ S	147° 23′ E	–	0.18	0.51	0.4	0.072	
Tunbridge 2a	42° 08′ S	147° 31′ E	–	0.03	0.05	0.05	0.0002	
Bullenmerri	38° 11′ S	143° 04′ E	146	4.88	66	39.3	192	Maar
Corangamite	38° 13′ S	143° 25′ E	116	233	4.9	2.9	676	Volcanic, tectonic
Gnotuk	38° 09′ S	143° 03′ E	102	2.08	18.5	15.3	32	Maar
Pink	38° 01′ S	143° 33′ E	115	0.134	0.7	0.5	0.007	Deflation?
Red Rock	38° 14′ S	143° 30′ E	164	0.008	2.0	1.4	0.011	Maar
Werowrap	38° 14′ S	143° 30′ E		0.216	1.64	1.35	0.291	Maar
Eganu	30° 03′ S	116° 02′ E		0.9	2.2			
Pinjarrega	30° 03′ S	116° 02′ E		6.5	1.3			

Eliza (Bayly 1970), Eyre (Dulhunty 1977; * lowest point in basin), Robe (Bayly & Williams 1966); Folly, Tunbridge 2a (Buckney & Tyler 1976); Bullenmerri, Gnotuk (Timms 1976); Corangamite (Williams 1981b); Pink, Red Rock (Hammer 1981); Werowrap (Walker 1973); Eganu, Pinjarrega (Halse 1981). Latitude and longitude estimated by Hammer.

Europe								
Spain								
Gallocanta	40° 50′ N	02° 11′ W	1000	19	2.5	–	–	Tectonic depression
U.S.S.R.								
Elton	49° 09′ N	46° 38′ E	– 14.7	152	1.0	0.7	106.6	Fault

Gallocanta (Comin *et al.* 1983), Elton (Greer 1977).

North America								
Canada								
Barnes	52° 01′ N	.122° 27′ W	945	0.17	4.5	2.0	0.348	Glacial
Boitano	51° 57′ N	122° 10′ W	975	0.81	4.5	2.7	2.19	Glacial
Goodenough	51° 17′ N	121° 38′ W	1095	0.15	1.5	0.8	0.127	Glacial
Fleeinghorse	52° 19′ N	110° 11′ W	652	2.64	1.2			Glacial
Big Quill	51° 55′ N	104° 22′ W	519	307	2.6	1.5	449	Glacial
Goose	53° 37′ N	102° 30′ W	265	12.67	0.8	0.7	0.089	Glacial
Humboldt	52° 09′ N	105° 06′ W	552	17.2	8.0	4.8	81.9	Glacial river
Little Manitou	51° 48′ N	105° 30′ W	495	13.3	5.2	3.6	48.1	Glacial river
Manito	52° 43′ N	109° 43′ W	601	21.5	21.5	7.9	627	Glacial, deflation
Patience	52° 07′ N	106° 20′ W	515	5.63	1.6	1.0*	5.63	Glacial
Redberry	52° 43′ N	107° 09′ W	515	54.4	18	9.3	506	Glacial
Wakaw	52° 40′ N	105° 35′ W		10.4	14	4.7	48.7	Glacial river
721	50° 49′ N	100° 25′ W*	550*	0.065	3.0	1.6	0.104	Glacial
United States								
Borax	38° 59′ N	122° 40′ W	406	0.4	1.45			Lava dam
Mono	38° 00′ N	119° 15′ W	1979	199.5	51.5	19	3790	Tectonic, volcanic
Owens	36° 20′ N	118° 00′ W		271.8	–	7.3	1984.4	Deflation
Salton	33° 20′ N	115° 50′ W	– 71.6	880	12.5	7.9	6933.5	Tectonic
S. Panamin	36° 05′ N	117° 14′ W	315	50.84	>1			Deflation
Pyramid	40° 00′ N	119° 35′ W	1157	446.4	103	59	26400	Graben
Walker	38° 43′ N	118° 43′ W	1210	150	33	20	3000*	Fault block
Zuni Salt	34° 49′ N	111° 56′ W	1938	0.604	1.0	0.7	0.422	Maar
Devils	48° 00′ N	98° 59′ W	433	130	5	3	390	Riverine
Stump	47° 52′ N	98° 22′ W	423	13.6			20	Riverine
Abert	42° 40′ N	120° 15′ W	1299	165	5.2	3.7	611.8	Fault
Summer	42° 50′ N	120° 45′ W	1265	77.6	1.5	0.91	70.6	Tectonic
Lenore	47° 29′ N	119° 30′ W		5.56	11.0	6.5	36	Riverine

Appendix B (Continued).

Lake	Lat	Long	ASL (m)	S (km²)	z_m (m)	$\bar{z}$ (m)	V (× 10⁶m³)	Origin
Central America								
Dominica								
Enriquillo	18°28′ N	71°35′ W	−48	221	30	6	1330	
Dominica-Haiti								
Saumâtre	18°34′ N	72°27′ W	14	70.8	26	13.7	969	
South America								
Argentina								
Pozuelos	22°20′ S	66°00′ W	3500	90	>1			
Bolivia								
Colorada	21°10′ S	67°47′ W	4278	30	<1	0.2	6	
de Pas Pastos Grandes	21°38′ S	67°48′ W	4430	125	–	0.2	25	
Kalina	22°32′ S	67°11′ W	4530	16	–	0.2	3.2	
Chile								
de Agua Calientes III	25°00′ S	68°38′ W	3670	14	–	0.2	2.8	
de Pujsa	23°12′ S	67°34′ W	4525	15	–	0.1	1.5	
Peru								
Parinacochas	15°17′ S	73°42′ W	3272	67	>1			
Poopo	18°30′ S	67°30′ W	3694	2530	5	0.69	1742	Tectonic, volcanic
Salinas	14°59′ S	70°07′ W	3840	9.7	<1	–	–	Volcanic

Barnes, Boitano, Goodenough (Topping & Scudder 1977); Fleeinghorse (Daborn 1975); Big Quill, Humboldt, Little Manitou, Manito, Redberry, Wakaw, (Hammer & Haynes 1978), Goose (Royer 1966), Patience (Hammer & Parker 1984); 721 (Sunde & Barica 1975); Borax (Wetzel 1965), Mono (Mason 1967), Owens (Greer 1977), Salton (Arnal 1961, Carpelan 1958), South Panamint (Kubly 1982); Pyramid (Galat *et al.* 1981), Walker (Koch *et al.* 1977); Zuni Salt Lake (Bradbury 1971); Abert, Harney, Summer (Phillips & van Denburgh 1971, Langbein 1961); Devils (Young 1924, Anderson 1966), Stump (Swenson & Colby 1955); Lenore (Anderson 1958b); Enriquillo, Saumâtre (Bond 1935); Pozuelos (Hurlbert 1978); Laguna Colorada, Salar de Pas Pastos Grandes, Laguna Kalina, Salar de Aguas Calientes III (Hurlbert & Chang 1983); Salar de Pujsa (Hurlbert & Chang 1984); Parinacochas, Salinas (Hurlbert *et al.* MS); Poopo (Löffler 1961c, Serruya & Pollinger 1983). Latitudes and longitudes and elevations if not given by original authors have been estimated. * estimate. # Data for most meromictic saline lakes is given in Table 4.2.

Appendix C Water chemistry of representative saline lakes. Ions are given in $mg\,l^{-1}$ (upper line) and in percent equivalence of sums of cations or anions (lower line). Conductivity ($mS\,cm^{-1}$). Salinity (S) ($g\,l^{-1}$). Bracketed numbers represent sum of two ions. Some authors' results were recalculated. + average values.

Location Lake*	pH	Cond.	Na	K	Mg	Ca	Cl	SO_4	HCO_3	CO_3	S
Africa											
Algeria											
Merdjadja	8.3		8630	816	1940	1520	16930	11620	184	0	41.65
(Beadle 1943a)			59.4	3.3	25.3	12.0	66.1	33.5	0.4	0	
Ouargla	8.5		19180	980	1940	1080	34600	10040	268	0	68.09
			77.8	2.3	14.9	5.0	82.1	17.6	0.4	0	
Chad											
Bodou	–	40.5	13340	2502	22	12	2334	1441	8174	14160	42.0
(Iltis 1971)			89.7	9.9	0.3	0.1	9.0	4.3	19.1	67.5	
Rombou	10.2	20.0	5198	2170	1.2	10	957	1018	3965	4680	20.4
			80.1	19.7	<.0	0.2	10.0	7.9	24.1	57.9	
Yoan			24656	–	–	–	9645	15129	(484 meq l^{-1})		
			100				25.2	29.1	44.8		
Egypt											
Natron			1368	–	160	157	1145	–	(1450)		4.28
(Grabau 1920)			73.9	–	16.4	9.8	40.1	–	59.9		
Zugm	11.0		142000	2270	–	–	154560	22570	(67210)		393.9
(Im. 1979)			99.1	0.9	–	–	61.7	6.6	31.7		
Ethiopia											
Shala		29.5	6250	252	<7.5	<3	3300	650	(200 meq l^{-1})		
(T. & T. 1965)			97.7	2.3	0.2	0.0	30.4	4.4	65.4		
Aranguadi	10.3		1541	317	7	13	780	14	3135		5.81
(P. 1968)			87.7	10.6	<0.8	0.9	29.7	0.9	69.4		
Kilotes	9.6		1622	176	7	14	482	19	3867		6.49
			92.4	5.9	<0.7	0.9	17.6	0.5	81.9		
Kenya											
Bogoria	>10.5	35.7	14360	304	tr	26	3450	204	(17650)		35.99
(Beadle 1932)			98.6	1.2	0	0.2	14.1	0.6	85.3		
Elmenteita	10.9	43.75	9450	381	<30	<10	5200	2300	(289 meq l^{-1})		
(T. & T. 1965)			97.0	2.3	0.6	0.1	30.5	9.5	60.0		
Magadi	10.4		75000	1390	–	–	49400	1240	7650	54300	140.1
(J. 1977)			98.9	1.1	–	–	41.5	7.7	3.7	54.0	
Malawi											
Chilwa	8–11	12.0	2690	38	4	10	1920	65	(61.6 meq l^{-1})		
(M. & M. 1969)											
South Africa											
Blaauwater 1	8.9			(1350)	9	29	1100	100	1031	11.4	3.63
(H. 1932)				96.4?	1.1	2.3	61.5	4.1	33.5	0.8	
Banagher 3	9.1			(7784)	6	15	8236	200	4866	2.3	21.11
				99.6?	0.1	0.2	74.4	1.3	25.6	0.2	
Ronde	6.9–7.8			(4800)	3000	–	14184	2360	141	0	24.69
				45.9	54.1	–	87.8	11.7	0.5	0	
Rocher	7.6–9.0	19	3775	58	402	230	6375	1362	(90)		12.29
(Coetzer 1981)			78.1	0.7	15.7	5.4	85.6	13.5	0.8		

Appendix C (Continued).

Location Lake*	pH	Cond.	Na	K	Mg	Ca	Cl	SO_4	HCO_3	CO_3	S
Tanzania											
Big Momela	10.4	15	4807	704	5	4	496	768	(168 meq l^{-1})		
(M. & K. 1974)			91.8	7.9	0.2	0.1	7.0	8.1	84.9		
Manyara		54	21500	94	<30	<10	8670	2280	(806 meq l^{-1})		
(T. & T. 1965)			99.8	0.3	–	–	22.3	4.3	73.5		
Uganda											
Katwe			180500	38200	–	–	147000	22500	(2123)		452.4
(Groves 1931)			88.9	11.1	–	–	61.6	7.0	31.5		
Mahiga			84000	16400	120	–	72300	71000	3100	8900	255.8
(A. & M. 1969)			89.5	10.3	0.2	–	52.9	38.1	1.3	7.7	
Antarctica											
Don Juan	5.4	790	11500	160	1200	114000	212000	11	49	0	338.9
(M. 1962)			7.9	0.7	1.6	90.4	100	0	0	0	
Asia											
China											
Koko Nor (Qinghai)			3397	120	322	196	4446	1980	(616)		11.08
(Clarke 1924a)			79.0	1.7	14.2	5.2	67.0	22.0	11.0		
Afghanistan											
Maimana			123920	tr.	3500	420	188300	18600	120	–	334.9
(L. 1963)			83.0	0	13.8	3.2	93.2	6.8	0.0	–	
India											
Kar	8.9		16346	5478	2716	406	11662	35075		(2141)	73.82
(H. 1937a)			64.9	12.8	20.4	1.9	30.1	66.7	3.2	–	
Khyagar	9.5		1093	724	134	24	251	2069	1701	54	6.05
			60.7	23.7	14.1	1.5	8.9	54.0	34.9	2.3	
Panggong	9.35		3527	186	232	303	3587	2750	2067	1050	13.7
			79.7	2.5	9.9	7.9	44.5	25.2	8.4	15.4	
Iran											
Maharlu			109400	951	4383	580	180200	8320	(114)		304.95
(Löffler 1956)			92.0	0.5	7.0	0.6	96.7	8.3	0.1		
Niriz	9.65	18.3	4777	63	380	178	7550	772	27		13.747
(Schamsabad)			83.0	0.6	12.5	3.6	92.6	7.0	0.4		
(Löffler 1959)											
Niriz	7.7	105.9	35280	522	3150	1360	61000	6160	(134)		101.61
(Qualeh Kirmiz)			81.9	0.7	13.8	3.6	92.9	6.9	0.2		
Urmia	7.5	563.7	103620	2603	8175	609	180500	15070	(210)		310.79
(Löffler 1956)			85.4	1.3	12.7	0.6	93.3	5.8	0.1		
U.S.S.R.											
Balkhash				(694)	164	25	574	893	493	0	2.84
(L. 1963)				67.2	30.0	2.8	37.7	43.4	18.9	0	
Issyk-Kul				(1475)	294	114	1585	2115	240	0	5.82
				68.2	25.7	6.1	48.0	47.9	4.2	0	
Biljo			2889	46	79	4	1265	4412		(99)	8.79
(Clarke 1924a)			94.1	0.9	4.9	0.1	27.3	70.2	2.5		
Altai			36642	571	100	57	15618	54492	24	898	108.4
(Ludwig 1903)			98.4	0.9	0.5	0.2	21.8	76.1	0.0	2.0	

Appendix C (Continued).

Location Lake*	pH	Cond.	Na	K	Mg	Ca	Cl	SO_4	HCO_3	CO_3	S
Tagar			5947	212	870	56	6181	7324	199	238	21.03
			76.4	1.6	21.1	0.8	52.8	46.2	1.0	2.4	
Schunett			24486	501	17727	668	59074	48897	(471)		151.8
(Grabau 1920)			41.4	0.5	56.8	1.3	61.8	37.7	0.6		
Turkey											
Burdur	9.1		4720	42	710	11	3430	6940	839	320	17.01
(Irion 1973)			77.4	0.4	22.0	0.2	36.4	54.4	5.2	4.0	
Krater Aci	7.6		21270	400	2330	155	34630	6940	854	0	66.6
			81.5	0.9	16.9	0.7	86.0	12.7	1.2	0	
Tuz	7.9		117000	900	2640	413	185000	6120	122	0	312.2
			95.1	0.4	4.0	0.4	97.6	2.4	0.0	0	
Van	9.31	22.9	8100	400	107	9	5900	2447	2428	3492	23.1
(Gessner 1957)			94.8	2.8	2.4	0.1	44.6	13.6	10.7	31.1	
Australasia											
Australia, N.S.W.											
Kudgee Bore	6.0		15910	–	1830	830	24500	9320	–	–	52.39
(E. 1966)			78.3		17.0	4.7	78.1	21.9			
Jillamatong	9.6		7600	336	14	68	9803	2554	(865)		21.24
(W. 1970)			96.2	2.5	0.3	1.0	80.5	15.5	4.1		
Nichebulka			4370	29	486	325	8226	500	30	–	13.97
(Johnson 1980)			76.9	0.3	16.2	6.6	95.7	4.3	0.2	–	
Utah			75900	242	8633	4248	147159	2304	103	–	238.6
			78.0	0.1	16.8	5.0	98.8	1.1	0.0	–	
Australia, Qld.											
Qld Buchanan	8.6		31000	820	630	1400	53600	0	(75)		86.79
(B. & W. 1970)			90	1	4	5	101	0	0.1		
Australia, S.A.											
Eyre North (21.V.51)			43780	10	300	910	67960	2940	(40)		115.9
(Bonython 1955)			96.4	0.0	1.3	2.3	95.9	4.1	0.0		
Eyre South (March 1978)			10810	4	33	296	16311	806	30	0	28.29
(Johnson 1980)			96.4	0.0	0.6	3.0	96.4	3.5	0.1	0	
Kingston	–		11700	400	900	100	19800	700	700	0	33.80
(W. & B. 1976)			84.3	1.9	12.6	1.2	96.6	2.7	0.6	0	
Robe	7.4		33400	1470	5240	880	64700	6200	630	0	112.5
(B. & W. 1966)			73.9	1.6	18.2	3.7	87.1	12.3	0.6	0	
Sunday	7.0		62100	2600	21000	200	185000	20500	300	0	291.7
			59.6	1.5	38.7	0.2	92.3	7.6	0.1	0	
Bumbunga			85100	600	500	12100	172500	7600	200	0	278.6
			77.9	0.3	0.5	21.3	96.8	3.1	0.1	0	
Gillies	3.0	275.4	64100	720	6140	1240	117500	2660	0	0	216.3
(W. 1984)			82.7	0.5	14.9	1.8	98.2	1.6	0	0	
Round	8.2	6.867	1275	32	184	226	2410	398	370	0	8.23
			67.1	1.0	18.5	13.7	82.1	10.0	7.3	0	
Australia, Tasmania											
Brent's	9.61	20.8	3657	4	1033	270	8154	1008	(120)		13.24
(B. & T. 1972)			61.7	<0.0	33.0	5.2	90.9	8.3	0.8		

Appendix C (Continued).

Location Lake*	pH	Cond.	Na	K	Mg	Ca	Cl	SO_4	HCO_3	CO_3	S
Forest	9.0	7.38	1387	18	247	56	1021	749	(527)		4.005
			71.9	0.6	24.2	3.3	54.3	29.4	16.3		
Mona Vale	8.22	165	96025	997	4070	1278	150663	8256	253	0	261.5
			90.8	0.6	7.3	1.4	97.0	3.9	0.1		
Township	8.84	63.0	13984	170	1813	317	32127	528	(536)		49.48
			78.2	0.6	19.2	2.0	97.8	1.2	1.0		
Australia, Victoria											
Bullenmerri			2976	102	87	22	4352	0	(1190)		8.73
(Hussainy 1969)			92.4	1.9	5.2	0.8	86.3	0	13.7		
Gnotuk	8.1–8.8		17400	610	2230	111	33100	60	(440)		53.95
(Maddocks 1967)			77.6	2.0	19.4	1.0	98.9	<0.0	1.1		
Modewarre	8.7		1100	12	151	38	1940	33	(258)		3.53
			76.6	0.5	19.9	3.0	85.4	1.1	13.4		
Werowrap	9.8		13076	6868	81	4	13864	–	8385	2142	38.42
(Walker 1973)			95.2	3.7	1.1	0.0	65.2	–	22.9	11.9	
Australia, W.A.											
Coolungup	8.6		2710	111	528	11	5680	456	736	80	10.31
(W. & B. 1976)			71.3	1.7	26.6	0.3	87.5	5.2	6.6	0.7	
Stubbs	8.7		66470	507	3280	1150	117900	2314	(105)		191.7
(W. & B. 1976)			89.4	0.4	8.4	1.8	98.5	1.4	0.1		
Eganu			16500	300	1700	1300	28263	6899	112	–	54.69
(Halse 1981)			77.1	0.8	15.0	7.0	84.7	15.1	0.2	–	
New Zealand											
Sutton	7.7		5300	230	160	40	8980	–	430	0	15.14
(Bayly 1967)			91	2	5	1	100	–	3	0	
Europe											
Austria											
Birnbaumlacke		7.95	2592	9	10.5	tr.	500	1210	(77.4 mval)		
(Löffler 1959b)			99.0	0.2	0.8	0	12.1	21.6	66.3		
Herrensee		6.90	1458	31	320	20	513	2840	(17.8 mval)		
			69.3	0.9	28.8	1.1	19.5	64.7	(15.8)		
Hungary											
Kiskunhalasi			1802	–	87	14	358	172	2007	595	4.563
(Megyeri 1959)			90.2	–	8.3	0.8	11.7	4.2	61.2	23.0	
Oszeszékito			2139	–	30	5	732	14	3856	347	7.124
			97.2	–	2.5	0.3	21.6	0.3	66.1	12.1	
Nagyszéktó	10.5		(1553)		157	15	342	103	2357	921	5.484
(D. & P. 1957)			78.2?		15.9	0.9	12.0	2.7	47.6	38.1	
Illyés (Medve)			91208	–	70	584	140669	1028	(93)		233.7
(Grabau 1920)			99.1	–	0.1	0.7	99.4	0.5	0.1		
Szelider	8.96		(1157)		75	22	911	269	1205	145	3.783
(Donászy 1959)			86.3		10.4	3.2	46.0	10.0	35.4	8.6	
Rumania											
Sarat			18427	–	1254	226	16396	21544	(157).		58.00
(Clarke 1924a)			87.5	–	11.3	1.2	50.6	49.1	0.3		

Appendix C (Continued).

Location Lake*	pH	Cond.	Na	K	Mg	Ca	Cl	SO_4	HCO_3	CO_3	S
Spain											
Gallocanta			7924	244	3411	342	18109	9730	41	65	39.87
(Comin.											
pers. comm.)			53.1	1.0	43.3	2.6	71.3	28.3	0.0	0.3	
U.S.S.R.											
Elton			29866	–	46508	265	170183	18073	(106)		265.0
(Clarke 1924a)			25.3	–	74.5	0.3	92.7	7.3	0.0		
Marfovka			20670	550	3880	720	29200	21130	180	–	76.43
			71.7	1.1	25.5	2.9	65.0	34.7	0.2	–	
Iletsk			60322	tr.	124	512	93542	21130	–	–	155.2
(Grabau 1920)			98.7	0	0.4	1.0	99.4	0.6	–	–	
United Kingdom											
Watch Lane		6.83	1541	16	37	107	2447	256	159	0	4.563
(Savage 1971)			88.4	0.5	4.0	7.0	89.7	6.9	3.4	0	
North America											
Canada, Alberta											
Fleeinghorse	9.1	6.5	1228	24	46	49	360	1800	976	420	4.90
(Hammer unpubl.)			88.6	1.0	6.3	4.0	15.9	57.7	24.6	2.2	
Gooseberry	9.2	30.0	11040	310	168	44	550	15900	2440	1600	37.0
			95.2	1.6	2.7	0.4	3.5	75.2	9.1	12.1	
Handhills	9.6	11.5	3588	121	42	35	320	3750	3782	1200	15.72
			94.9	1.9	2.1	1.0	4.8	41.3	32.8	21.2	
Leane	9.5	7.5	1800	89	69	12	450	1250	2204	896	6.77
			90.2	2.6	6.6	0.7	12.1	24.8	34.5	28.6	
Miquelon	9.5	8.4	2178	159	233	128	446	4200	1480	336	9.16
			73.1	3.2	14.8	9.0	9.3	64.5	17.9	8.3	
Canada, B.C.											
Barnes	9.4	11.5	2760	500	31	15	1291	968	3330	768	9.664
(T. & S. 1977)			88.2	9.4	1.9	0.6	26.6	14.7	39.9	18.7	
Boitano	9.0	3.85	782	116	135	15	145	1401	1061	153	3.808
			69.7	6.1	22.7	1.6	7.3	52.3	31.2	9.1	
Clinton	8.1	55.93	7533	735	19821	23	1108	98125	3215	0	130.6
			16.6	1.0	82.4	0.1	1.5	96.1	2.5	0	
Goodenough	10.2	40.5	16675	538	47	3	5850	0	4148	17208	44.5
			97.6	1.9	0.5	0.0	20.4	0.0	8.4	71.1	
Wallender			4991	199	2225	246	560	18972	207	240	27.64
(Blinn 1971)			52.0	1.2	43.9	2.9	3.7	93.6	0.8	1.9	
Canada, Manitoba											
*721	8.69	3.44	228	60	475	101	34	2079	491	48	3.52
(Barica 1975)			17.8	2.8	70.2	9.1	1.8	86.4	14.9	3.0	
Canada, Sask.											
Big Quill			2537	163	1169	502	1937	8368	(236)		14.68
(Huntsman 1922)			46.8	1.8	40.8	10.6	23.1	73.6	3.3		
Big Quill	8.7	37.5	8050	575	4482	382	3510	30200	793	133	48.13
(Hammer 1978b)			46.5	2.0	49.0	2.5	13.3	84.4	1.7	0.6	

Appendix C (Continued).

Location Lake*	pH	Cond.	Na	K	Mg	Ca	Cl	SO_4	HCO_3	CO_3	S
Humboldt	8.7	3.9	250	94	517	145	88	2620	268	31	4.01
			17.3	3.8	67.5	11.4	4.0	87.3	7.1	1.6	
Little Manitou	8.8	72.5	12300	890	9518	497	18000	39600	776	209	81.79
			39.2	1.7	57.3	1.8	37.5	61.0	0.9	0.5	
Manito	9.3	25.0	8025	248	400	42	1825	12400	2220	1176	26.34
			89.5	1.6	8.4	0.5	13.4	67.1	9.5	10.2	
Redberry	9.2	15.6	1860	178	2271	99	220	12500	551	125	17.80
			29.2	1.7	67.4	1.8	2.2	93.1	3.2	1.5	
Wakaw	8.3	3.5	313	32	350	228	154	2310	142	17	3.55
			24.9	1.5	52.7	20.9	7.8	87.0	1.5	1.1	
Goose	8.6	40.0	9500	165	438	662	16500	385	106	13	27.77
(Royer 1966)			84.9	0.9	7.4	6.8	97.8	1.7	0.4	0.1	
Little Quill			1802	120	826	181	1198	5676	(219)		10.02
(Huntsman 1922)			49.5	2.0	42.9	5.7	21.2	74.2	4.6		
Patience	7.2	280.0	103000	48100	4120	740	252500	35000	210	0	443.7
(H. & P. 1984)			73.6	20.2	5.6	0.6	90.7	9.3	0.0	0	
Mexico											
Coahuila Grande			350	20	225	624	291	2700	121		4.33
(M. & C. 1968)			23.3	7.7	28.3	47.6	12.0	82.2	5.8		
Salada			6000	1250	14414	1232	10200	66500	252		99.8
			16.9	2.1	77.0	4.0	13.3	86.4	0.3		
Chichen-Kanab			533	19	325	600	362	2607	–	–	4.45
(Clarke 1924a)			28.8	0.6	33.3	37.3	15.8	84.2	–	–	
U.S.A., California											
Borax	9.61	47.2	16319	1140	218	24	16071	31	2543	7892	44.24
(Wetzel 1964)			93.6	3.8	2.4	0.2	59.8	0.1	5.5	34.7	
Mono			19685	961	55	20	12104	6672	3172	10518	53.24
(Chatard 1890)			96.7	2.8	0.5	0.1	38.7	15.7	5.9	39.7	
Mono			29500	1500	33	4	17600	10300	11200	18900	89.04
(Winkler 1977)			96.9	2.9	0.2	0.0	32.6	14.1	12.0	41.3	
Owens			81398	3462	21	43	53040	21220	(52463)		213.7
(Clarke 1924a)			97.5	2.4	0.0	0.1	40.6	12.0	47.4		
Salton	8.3–8.8		9939	224	951	764	14422	6806	159	21	33.29
(Carpelan 1958)			78.0	1.0	14.1	6.9	73.7	25.7	0.5	0.1	
South Panamint	8.2	7.975	1072	81	18	248	1720	600	73	0	3.81
(Kubly 1982)			74.5	3.3	2.4	19.8	78.0	20.1	1.9	0	
South Panamint	8.3	>100	63394	4311	1426	4233	112971	3535	442	0	190.31
(Kubly 1982)			86.3	3.5	3.7	6.6	97.5	2.3	0.2	0	
U.S.A., Nebraska											
Jesse			9312	10506	tr.	0	1665	6663	4800	11907	44.85
(Clarke 1924a)			65.5	34.5	0	0	7.1	21.0	11.9	60.0	
Richardson	10.6	31.82	(7500)		–	–	1550	1300	15215	23358	48.92
(McCarraher 1970)							4.0	2.5	22.7	70.9	
Toms	9.9	5.13	(1800)		–	–	5	55	4292	1675	7.83
(McCarraher 1970)							0.1	0.9	55.2	43.8	

Appendix C (Continued).

Location Lake*	pH	Cond.	Na	K	Mg	Ca	Cl	SO_4	HCO_3	CO_3	S
U.S.A., Nevada											
Big Soda			45840	2520	270	–	45690	12960	10919	10194	129.4
(Chatard 1890)			95.8	3.1	1.1	–	62.5	13.0	8.6	16.4	
Pyramid			1174	74	79	9	1431	183	(498)		3.45
(Clarke 1924a)			85.3	3.2	10.9	0.7	66.8	6.3	26.9		
Pyramid	9.2	8.42	1720	118	114	9.3	2080	280	860	300	5.48
(G. 1981)			85.3	3.4	10.7	0.5	66.2	6.6	15.9	11.3	
Walker	9.3		3200	170	130	10	2300	2200	(2908)		10.92
Koch *et al.* 1977)			85.4	6.6	5.0	3.0	31.7	22.4	45.9		
U.S.A., New Mexico											
Zuni			75000	498	2550	345	113100	14650	235	46	206.4
(Bradbury 1971)			93.2	0.4	6.0	0.5	91.1	8.7	0.1	0.0	
U.S.A., North Dakota											
Devils			2548	204	844	70	1310	7187	345	169	12.68
(Young 1924)			58.6	2.8	36.7	1.8	18.7	75.6	2.9	2.7	
East Stump	8.4	70.6	31570	1144	3685	328	2350	6989	340	130	45.51
(Blinn 1972)			81.1	1.7	17.9	1.0	29.9	65.6	2.5	2.0	
U.S.A., Oregon											
Abert	9.8	30.5	8370	295	1.5	1.0	7440	397	2160	3230	21.89
(W. & F. 1961)			97.9	2.1	–	–	58.1	2.3	9.8	29.8	
Summer			6567	264	tr.	tr.	3039	695	(5916)		16.48
(Clarke 1924a)			97.7	2.3	0	0	28.8	4.9	66.3		
U.S.A., Texas											
La Sal Vieja			8250		72	308	13090	995	256	–	22.79
(Deevey 1957)			94.6		1.5	3.9	93.8	5.3	1.1		
La Sal del Rey			68670		128	932	107000	1100	230	–	177.45
			98.2		0.3	1.5	99.1	0.8	0.1		
U.S.A., Utah											
Great Salt (N)	7.7		105386	6690	11124	312	181000	27000	454	270	332.2
(Post 1975)			80.6	3.0	16.0	0.3	89.8	9.9	0.2	0.2	
Great Salt (S)	8.15	113	44000	4000	1703	840	68500	8400	493	0	127.9
(S. & G. 1976)			87.1	4.7	6.4	1.9	91.4	8.3	0.4	0	
U.S.A., Washington											
Lenore			5129	438	14	10	1438	2112	3544	3000	15.69
(Anderson 1958a)			94.6	4.7	0.5	0.2	16.7	18.1	23.9	41.2	
Soap			11868	1134	8	21	5467	6240	5209	6870	36.82
			94.4	5.3	0.1	0.2	25.8	21.7	14.3	38.3	
U.S.A., Wyoming											
de Smet			1342	82	436	71	58	4129	536	67	6.72
(Clarke 1924a)			58.4	2.1	35.6	3.6	1.7	87.2	8.9	2.3	
Soda			20036	1525	3371	643	4080	50416	1508	841	82.42
			71.4	3.2	22.7	2.6	9.5	86.2	2.0	2.3	
Dominica											
Enriquillo	8.3		15973	503	378	1649	25547	3833	512	0	48.90
(Bond 1935)			84.6	1.6	3.8	10.0	89.1	9.9	1.0	0	

Appendix C (Continued).

Location Lake*	pH	Cond.	Na	K	Mg	Ca	Cl	SO_4	HCO_3	CO_3	S
Haiti											
Bois Neuf	8.1		8349	80	589	416	4582	14580	98	40	28.76
			83.6	0.5	11.2	4.8	29.6	69.6	0.4	0.5	
Saumâtre	8.5		(2159)		279	94	3660	711	161	46	7.11
			77.67		19.0	3.5	89.0	8.3	1.5	1.3	
South America											
Argentina											
Aquada de Azaguate			(10782e)		680	880	11878	10995	287	0	35.50
(Olivier 1953a)			82.4		9.8	7.7	58.9	40.3	0.8	0	
De la Isla	10.5		–	–	–	0	2692	2190	(2220)		TDS 14.69
							48.1	28.9	23.0		
El Salado	8.0		–	–	–	112	1061	930	400.0		TS 3.78
							53.6	34.7	11.7	0	
La Salada	8.1		–	–		5220	3820	40	0		TDS 19.9
							64.7	35.0	0.3	0	
Salada Granda	8.7		–	–	–	–	2960	325	(319.7)		TDS 7.37
							90.3	5.5	4.2		
Epecuen			107502	–	–	–	122436	48992	(6071)		285.0
(Grabau 1920)							75.5	22.3	2.2		
Bolivia											
Pastos Grandes	7.14		77280	8915	3478	2668	156733	1864	608	0	252.7
(R. & E. 1979)			82.4	5.6	7.0	3.5	98.7	0.9	0.2	0	
Brazil											
Lagoa Escondida			1660	193	6	14	1242	46	2004	0	5.165
(L. 1963)			92.2	6.3	0.7	0.9	50.8	1.5	47.8	0	
Chile											
Tamentica			100924	6538	1713	29	144006	26180	6110	–	285.5
(Clarke 1924a)			93.4	3.6	3.0	0.0	86.3	11.6	2.1	–	
Verde	7.5		24000	1800	1600	5400	52000	2500	530	0	87.83
(H. 1976)			70.0	3.1	8.8	18.1	98.2	3.5	1.8	0	
Peru											
Parinacochas			3936	462	99	142	5652	1277	(260)		11.83
(Clarke 1924a)			86.3	6.0	4.1	3.6	81.9	13.7	4.5		
Poopo			7470	301	94	634	10190	3788	?		22.5+
(Löffler 1961c)			87.3	2.1	2.1	8.5	78.4	21.6			
Salinas	8.2	59.2	14300	4100	1150	1036	20800	16300	11.56 mval		57.76
			71.2	12.0	10.8	5.9	62.5	36.4	3.9		

Key to sources: A. & M. 1969, Arad & Morton 1969; B. & T. 1972, Buckney & Tyler 1972; B. & W. 1966, Bayly & Williams 1966; B. & W. 1970, Bayly & Williams 1970; D. & P. 1957, Dvihally & Ponyi 1957; E. 1966, Ettershank *et al.* 1966; G. 1981, Galat *et al.* 1981; H. 1932, Hutchinson *et al.* 1932; H. 1937a, Hutchinson 1937a; H. 1976, Hurlbert *et al.* 1976; H. & P. 1984, Hammer & Parker 1984; Im. 1978, Imhoff *et al.* 1978; J. 1977, Jones *et al.* 1977; L. 1963, Livingstone 1963; M. 1962, Meyer *et al.* 1962; M. & C. 1968, Minckley & Cole 1968; M. & K. 1974, Melack & Kilham 1974; M. & M. 1969, Moss & Moss 1969; P. 1968, Prosser *et al.* 1968; R. & E. 1979, Risacher & Eugster 1979; S. & G. 1973, Stephens & Gillespie 1973; T. & T. 1965, Talling & Talling 1965; T. & S. 1977, Topping & Scudder 1977; W. 1970, Williams *et al.* 1970; W. 1984, Williams 1984, pers. comm.; W. & B. 1976, Williams & Buckney 1976; W. & F. 1961, Whitehead & Feth 1961.

Appendix D Water chemistry of saline meromictic lakes. Shallow depths represent mixolimnia and deeper depths monimolimnia. Upper line is ions in $mg\,l^{-1}$ while lower line is per cent equivalent of cation or anion sums. Cond (conductivity in $mS\,cm^{-1}$). S (salinity in $g\,l^{-1}$). Bracketed values represent total alkalinity.

Location Lake*	Depth	pH	Cond.	Na	K	Mg	Ca	Cl	SO_4	HCO_3	CO_3	S
Antarctica												
Bonney	(9 m)	6.7	11.63	1670	112	383	166	3760	6246	155	0	6.25
				63.2	2.5	27.4	7.0	44.4	54.7	1.1	0	
(A. 1964)	(30 m)	7.3	213	41300	2730	25900	1540	140000	2850	153	0	214.5
				44.1	1.7	52.3	1.9	98.5	1.5	0.1	0	
Fryxell	(6 m)	7.2	4.854	1350	108	129	77	1640	144	1332	0	4.780
				77.3	3.6	14.0	5.1	65.1	4.2	30.7	0	
(A. 1962)	(12 m)	7.0	22.73	2050	187	229	33	2740	460	2136	0	7.835
				78.0	4.2	16.4	1.4	63.4	7.9	28.7	0	
Vanda	(48 m)	7.2	5.265	228	53	173	614	1910	80	84	0	3.142
				17.7	2.4	25.3	54.6	94.6	2.9	2.4	0	
(A. 1965)	(66 m)	6.1		6761	766	7684	24254	75870	770	126	0	116.2
				13.6	0.9	29.3	56.1	99.2	0.7	0.1	0	
Australia												
West Basin	(2 m)	8.4		29992	1001	1665	66	48240	–	1360	–	82.32
				88.7	1.7	9.3	0.2	98.4	–	1.6	–	
(T. 1972, T. & B. 1973)	(12 m)	7.0		39498	1584	2292	34	65824	–	5289	–	114.5
				88.2	2.1	9.7	0.1	95.5	–	4.5	–	
Canada												
Lyons	(4.5 m)			1336	305	1509	2932	111	8738	320	5.5	17.96
				17.3	2.3	35.9	43.5	1.6	95.5	2.8	0.1	
(N. & H. 1969)	(7.0 m)			6165	410	2978	14879	419	18265	2415	0	49.22
				24.7	1.0	5.7	68.6	2.7	88.1	9.2	0	
Mahoney	(5.0 m)			3949	650	1234	2226	800	11034	1285	225	21.40
				42.8	4.1	25.3	27.7	8.0	81.8	7.5	2.7	
	(9.0 m)			6369	1180	3374	7190	709	20643	5181	0	44.65
				29.4	3.2	29.4	38.0	3.7	80.4	15.9	0	
White	(3.0 m)			1211	287	209	221	121	393	3300	770	6.51
				69.9	9.7	5.8	14.6	3.7	9.0	59.2	28.1	
	(12.0 m)			1416	310	264	145	159	834	4225	875	8.23
				62.5	8.1	22.1	7.3	3.7	14.4	57.6	24.3	
Deadmoose	(0 m)	8.9	28.7	5980	280	1660	18	5760	10800	743	135	25.35
				64.2	1.8	33.9	0.2	40.2	55.7	3.0	1.1	
(H. unpubl.)	(8 m)	8.1	46.8	11000	520	2880	23	10400	22000	1017	0	47.84
				65.6	1.8	32.5	0.2	38.2	59.6	2.2	0	
Waldsea	(0 m)	8.1	16.3	2400	160	1650	280	2700	8250	279	0	15.71
				40.4	1.6	52.6	5.4	30.1	68.0	1.8	0	
	(6.9 m)	7.2	44.0	8000	560	6000	104	8500	30400	850	0	54.41
				40.4	1.7	57.3	0.6	23.7	62.5	13.8	0	
Israel-Jordan												
Dead		6.1–6.7		38510	6500	36150	16380	196940	580	230	0	295.3
(N. & E. 1967)	(0–40 m)			29.7	2.9	52.8	14.5	98.7	0.2	0.1	0	(Br 1%)

Appendix D (Continued).

Location/Lake*	Depth	pH	Cond.	Na	K	Mg	Ca	Cl	SO_4	HCO_3	CO_3	S
				39700	7590	42430	17180	219250	420	220	0	326.8
	(100–400 m)			27.5	3.1	55.7	13.7	99.8	0.1	0.1	0	
Kenya												
Sonachi		9.8		2567	345	3	3	304	51	2819	1717	7.809
(M. 1982)	(0.05 m)			98.0	1.9	0.0	0.0	7.6	1.0	40.8	50.6	
		9.65		3725	452	2	3	351	58	4129	1899	10.62
	(5 m)			93.3	6.7	0.0	0.0	7.0	0.8	47.6	44.5	
South Africa												
Pretoria Salt		10.4	58.2	29000	130	<1	<1	30000	240	(400 meql)		60.54
	(0 m)			98.7	0.3	–	–	67.6	0.4	32.0		
(A. & S. 1983)	(2.5 m)	9.2	208.5	103000	500	<1	<1	85000	0.8	(2120 meql)		252
				99.7	0.3	0	0	53.1	<0.1	46.9		
Tanzania												
Gidamuniud	(0 m)	9.0	10.8	2806	189	108	14	2872	663	(42.8 meql)		
				89.4	3.5	6.5	0.5	58.9	10.0	31.1		
(K.) (bottom)		9.5	53.6	18400	641	38	41	17304	1220	(323 meql)		
				97.4	2.0	0.4	0.2	58.3	3.0	38.6		
U.S.A.												
Big Soda (mixo)		9.7		8000	310	145	5	6500	5600	(4000)		24.55
				94.5	2.1	3.2	0.05	50.2	31.9	17.9		
(C. 1983)												
(monimo)		9.7		28000	1100	6	0.8	27000	6700	(24000)		86.81
				97.7	2.3	0.0	0.0	58.8	10.8	30.4		
Hot	(0 m)	8.2	57.9	7337	891	22838	640	1668	103680	3148	0	140.2
				14.2	1.0	83.4	1.4	2.1	95.6	2.3	0	
(A. 1958b)	(3 m)	7.8	60.4	16790	1564	53619	720	1882	243552	3062	0	321.2
				14.0	0.8	84.5	0.7	1.0	98.0	1.0	0	

* *Key to sources:* A. 1958b, Anderson 1958b; A. 1962, Angino *et al.* 1962; A. 1964, Angino *et al.* 1964; A. 1965, Angino *et al.* 1965; A. & S. 1983, Ashton & Schoemann 1983; C. 1983, Cloern *et al.* 1983; H. unpubl., Hammer unpublished; K. pers. comm., Kilham pers. comm.; M. & M. 1982, MacIntyre & Melack 1982; N. & E. 1967, Neev & Emery 1967; N. & H. 1969, Northcote & Halsey 1969; T. 1972, Timms 1972; T. & B. 1973, Timms & Brand 1973.

APPENDIX VIII

Glossary

GLOSSARY

Included in this glossary are words which are not included in the WMO/Unesco glossary of hydrology (report of the fifth session of the joint WMO/Unesco panel on terminology, Geneva, 17-21 November 1986).

aestivate	pass the summer in a resting type
bathymetric map	map of a waterbody indicating depths
biocenosis, bio-community	the total of living organisms at a certain place in more or less intense relationship to each other
canopy	foliage of shrubs and trees
collector	animal in streams that collects small organic particles
consumer	animal (as opposed to producers or reducers)
decomposer	organism that reduces dead organic material to (finally) minerals
ecology	science of the mutual relationships between organisms and the relationships between organisms and their environment
ecosystem	the total of abiotic and biotic components in relationship to each other at a certain place, viz. a waterbody
epiphyton	microscopic small organisms adhering to (water)plants
filter feeder	animal that filters small organic particles from the water
grazer	animal that eats free floating or attached algae
habitat	place where a certain species lives
heleoplankton	plankton of shallow waters
helophyte	emergent aquatic plants, such as reeds
hydraulic stress	forces of running water on benthic animals
invertebrate	animal without backbone (insect, worm, snail etc.)
lentic	belonging to stagnant water
lotic	belonging to running water
nymphaeid	plant with floating leaves of more or less circular form
oviposition	laying of eggs
pentade	period of five days
plankton	(microscopic) small plants and animals, free floating in the water

predator	animal that preys on other animals
pristine	not influenced by man (viz. primary forest)
producer, primary	green plant (or micro-organism)
" secondary	animal eating plants
production	augmentation of biomass (living material) per unit of time
productivity	the process of production (generally within a short period)
respiration	the use of oxygen by plants and animals
shredder	animal that fragments large organic particles such as leaves
terrestrialization	the natural process of converting swamp into land
tychoplankton	plankton of shallow waters
zonation	division of running waters into zones, characterized by abiotic and biotic features
zonobiome	areas of the world characterized by climatological and vegetational criteria
zonoecotone	areas of transition from one zonobiome to another