UN/ECE Working Group on Monitoring and Assessment

Guidelines on Monitoring and Assessment of Transboundary and International Lakes

Part B: Technical guidelines

UN/ECE Working Group on Monitoring and Assessment
under the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Helsinki, 1992)

Guidelines on Monitoring and Assessment of Transboundary and International Lakes

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Finnish Environment Institute • Helsinki 2003

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FOREWORD

Guidelines on Monitoring and Assessment of Transboundary and International Lakes, prepared by the Finnish Core group and assisted by experts from a number of European countries for the UN/ECE Working Group on Monitoring and Assessment, consisting of two separate volumes as follows:

Part A, the Strategy document, is primarily based on existing monitoring obligations under the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (signed in Helsinki, 17 March 1992; enforced by the UN in 1994), and the Protocol on Water and Health in the 1992 Convention on the Protection and Use of Transboundary Watercourses and International Lakes (London, 17 June 1999; UN enforcement 1999). The scope of the strategy document is limited to strategic issues. It is intended that this document could also be suitably modified to form the basis for future common UN/ECE strategy documents covering the monitoring and assessment of transboundary watercourses, international lakes and transboundary groundwaters. However, there is a strict requirement for such documents to be carefully drafted to ensure they fully incorporate the mandates and programmes of other institutions. It is intended that this strategy will remain valid for a longer period than previous strategies, e.g. for ten years.
Part B, Technical guidelines, contains the necessary practical guidelines for the monitoring and assessment of lakes and reservoirs. These guidelines are based on widely-accepted hydrological and limnological lake monitoring practices. There is clearly a requirement to harmonise monitoring programmes in Europe, for both economical and practical reasons. The economic reality is that individual countries lack sufficient resources to maintain simultaneous monitoring programmes with differing contents. Moreover, data handling and reporting practices must be as near identical as possible for various user-organisations (EU, EEA, UN/ECE, EUROSTAT, etc.). The recommendations of the EEA's Eurowaternet and the requirements of various EU water directives, especially the Water Framework Directive (December 2000), have therefore been adhered to as closely as possible. Specific technical guidelines should be tested in special pilot projects. At the same time, it is quite convenient to compare them in the praxis with the Cis Guidance on Monitoring, which was published in January 2003.

Simultaneously with the guidelines a special background paper was prepared, in which the data of monitoring activities of altogether 20 transboundary or international lakes are presented and summarised. This inventory information has been used also in the preparation of the Guidelines on Monitoring and Assessment of Lakes.

The technical guidelines on lakes consist of key topics of the usual monitoring programme in a recognised order: All start with the description of the most important hydrological phenomenon and methods (Chapter 2). Before we go to the quality questions, a short description of the estimation methods of the relevant pressure factors is presented in Chapter 3. The following Chapter discusses the question, how to build up a useful sampling network, and suitable sampling frequencies. Chapter 5 deals with thermal properties and temperature measurement.

Quality and status questions are presented in the following chapters, starting with the measuring and assessment of traditional physico-chemical variables in Chapter 6. The hydrobiological methods, which can be used to characterize the ecological status of lakes, as determined in the Water Framework Directive, will be discussed in Chapter 7. Harmful substances, especially priority substances according to the WFD are presented in Chapter 8. In Chapter 9 the microbiological quality of lakes is discussed. The highly important item of lake monitoring and sediment is discussed in Chapter 10.

Finally, the most important part of the whole monitoring activity, the assessment and presentation of monitoring results is discussed in Chapter 11. At the end of all the main Chapters there is a list of some relevant publications relating to monitoring methods and practices concerned. The main message of the chapter is presented in a special box at the end of every chapter.

Guidelines on Monitoring and Assessment of Transboundary and International Lakes as well as the background paper were accepted in the meeting of the UN/ECE Working Group on Monitoring and Assessment organised in Vääksy, Finland on 5 – 8 September 2001. The Technical Guidelines have been finalized by the following experts:

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Several other Finnish Environment Institute experts have participated in the work by introducing special texts and checking the final text. They all, without naming separately, are deeply acknowledged, as well as Tim Whale (tim.whale@eurokieli.inet.fi), who revised the English language.

Contents of Part B

1 INTRODUCTION

1.1 Lakes and lake monitoring as a part of entire river basin monitoring

There is no universal definition for a lake. The International Glossary of Hydrology (UNESCO and WMO 1992) briefly states, that a lake is an "inland body of water of considerable size". Kuusisto (1985) has given the following list of criteria, that define a lake:

A depression or a group of depressions partly or fully filled by water, all parts of the water body have the same surface, excluding temporary variability, caused by wind or ice, the ratio between inflow and volume is small enough to let most of the suspended, inflowing material to form bottom sediments, and the surface area exceeds a given minimum value (e.g. 1 ha).

Smaller lakes under 1 ha can be defined as ponds. The minimum value for a pond has not been determined.

The EU Water Framework Directive, WFD (2000/60/EC) has defined a lake as a body of standing inland surface water. The Annex II of the WFD has in a way determined also the minimum size of a lake, which should be taken into account to be 0.5 km^2 (50 ha).

According to UNESCO and WMO (1992), a reservoir is a "body of water, either natural or man-made, used for storage, regulation and control of water resources". In several connections, the term reservoir is used as a synonym for a man-made lake, and the resulting basic classification is either: "lakes and reservoirs" or "natural lakes, regulated lakes and reservoirs". The term reservoir always includes the utilisation aspect.

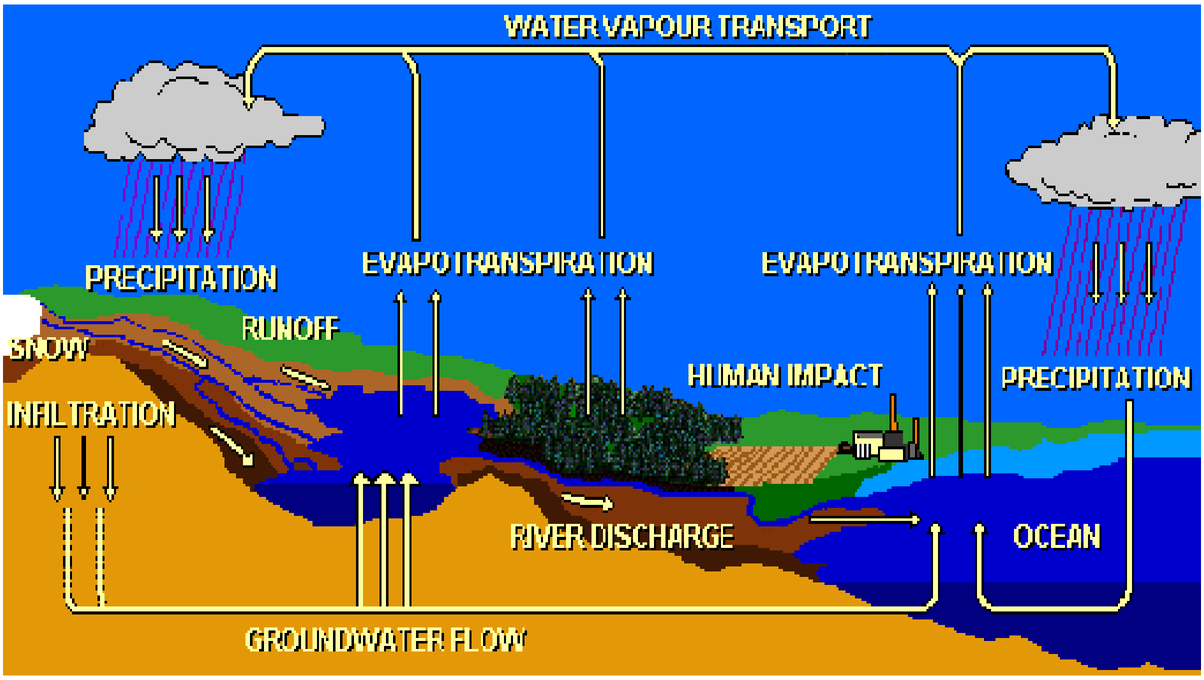

Figure 1. The hydrological cycle.

In addition to the degree of use or regulation, lakes have often been classified according to their origin. From the point of view of large lakes, the most important categories are tectonic and glacial lakes. Reservoirs can also be classified in many ways, e.g. according to their principal use, size or structure.

A lake is only one element, involved in the hydrological cycle of the river basin (Fig. 1) and lake monitoring is only a part of river basin monitoring. Different water bodies in the watershed are closely connected to the entire environment.

In water resources monitoring, one needs simultaneously adequate information on the one hand of natural conditions in the watershed area, and on the other hand all the pressure factors of the water-bodies for reliably handling monitoring (quantity and quality) data. The most important background information of the watershed area is as follows:

- Climate (seasons, temperature, precipitation, prevailing wind directions).
- Land use (for agricultural and forestry use, built environment).
- Population density in the river basin area (inhabitants/km^2, also calculated for sub-basins).
- Waste water load (urban and industrial waste water, fish farming etc.).
- Non-point loading (agriculture, forestry, storm water etc.).

Each of these items are such large issues, that they cannot be discussed in detail in the context of the preparation and implementation of the monitoring programmes, but some type of rough estimation is, however required. More specific and accurate information is required later in the assessment of monitoring data of lakes or of the total river basin.

1.2 A lake as an ecosystem

Lakes differ from rivers as ecosystems in many respects; hydrological circumstances, thermal properties, production/decomposition relations, sedimentation rate and sediments, and in stability of certain phenomena. Lakes are almost closed systems. Substances once introduced to the lake are permanently incorporated in the circulation. Only a part of them are removed (depending on water exchange rate). Rivers are open systems, in which constant downstream transport of substances takes place (more about lakes Hutchinson 1957, 1963 and 1967, Wetzell 1983, Heinonen et al. 2000).

In lakes the vertical distribution of temperature depending on the season is a very important phenomenon. During summer time a clear thermal stratification can be detected in all deeper lakes. In the upper water layer the temperature is highest, and can be at the same level than the temperature in rivers at the same time. This warm layer is called epilimnion. The epilimnion can also be called the trophogenic layer in the ecological sense.

The temperature in the deeper layer of the lake is, on the contrary, usually very cold (5---10 ^oC) during the whole summer stratification period. This cold layer near to the bottom is called hypolimnion, or tropholytic layer. The hypolimnion is a very important part of the lake from the monitoring point of view. Many slight pollution indications can particularly be detected for the first time just in the hypolimnion, usually in the very thin water layer nearest to the bottom sediments.

The dominant biological phenomenon in rivers is as a rule the decomposition of organic allochtonic matter, and primary production is of less importance. In lakes with clear thermal stratification the dominant biological phenomenon in epilimnion during summer time is primary production. In hypolimnion usually no trophogenic primary production can be detected, and the dominant phenomenon is the decomposition of organic matter mainly by bacteria.

Sedimentation is a very important process in lakes, and has a dominant role in nutrient cycles, and thus also in the eutrophication process. Sedimentation areas must be identified before the implementation of the monitoring programmes.

A lake is a very clearly bordered part of a river basin, and it forms a separate aquatic ecosystem. The lake ecosystem consists theoretically of two different parts; the biotope and the biocoenosis (Fig. 2).

The biotope is the abiotic part of the ecosystem. The primary quality characteristics of the biotope are determined primarily by the properties of the drainage basin and the hydrological conditions. It can justified notice, that a lake is a "prisoner of the watershead". If you have a lake on a fertile soil, the lake cannot be clearly oligotrophic. Because of the natural leaching of more nutrients from the soil, the lake will have more of a eutrophic character.

The biotope in a natural state can be satisfactorily described by a relatively small number of ordinary physical and chemical variables, such as measurement of concentrations of oxygen and carbon dioxide in different vertical layers, the content of the main nutrients, phosphorus and nitrogen, and organic materials, alkalinity, pH, conductivity, heavy metals etc.

All the living organisms of the lake form the biocoenosis. These organisms are used to live just in the conditions, which are characterised by the different variables of the biotope. The biocoenosis can be characterized by observations of the different groups of plants, animals and microbes. Primary production is a very dominating phenomenon in the upper water levels (epilimnion) of the lake. The algae and macrophytes have the most important responsibility of the primary production of the lake ecosystem. The information of optical properties is significantly linked to primary production.

The biotope of the lake:

- ***Hydrological characteristics***
- ***Oxygen and carbon dioxide***
- ***Nutrients***
- ***Organic matter***
- ***Acidity status (pH)***
- ***Heavy metals***
- ***Harmful organic compounds***
- ***Etc.***

The biocoenosis of the lake

- ***Phytoplankton***
- ***Macrophytes***
- ***Periphytic growth***
- ***Zooplankton***
- ***Bottom fauna***
- ***Fishes***
- ***Bacteria***

Figure 2. Simplified scheme of lake biotope and lake biocoenosis.

Theoretically, the biotope is first to change (e.g. the phosphorus concentration increases because of poorly treated sewages), and then the biocoenosis reacts to this change (e.g. the biomass of algae increases, if phosphorus is the limiting factor for algal production). In practise this order can not be seen, due to the fact that these main processes of the ecosystem affect each other continuously.

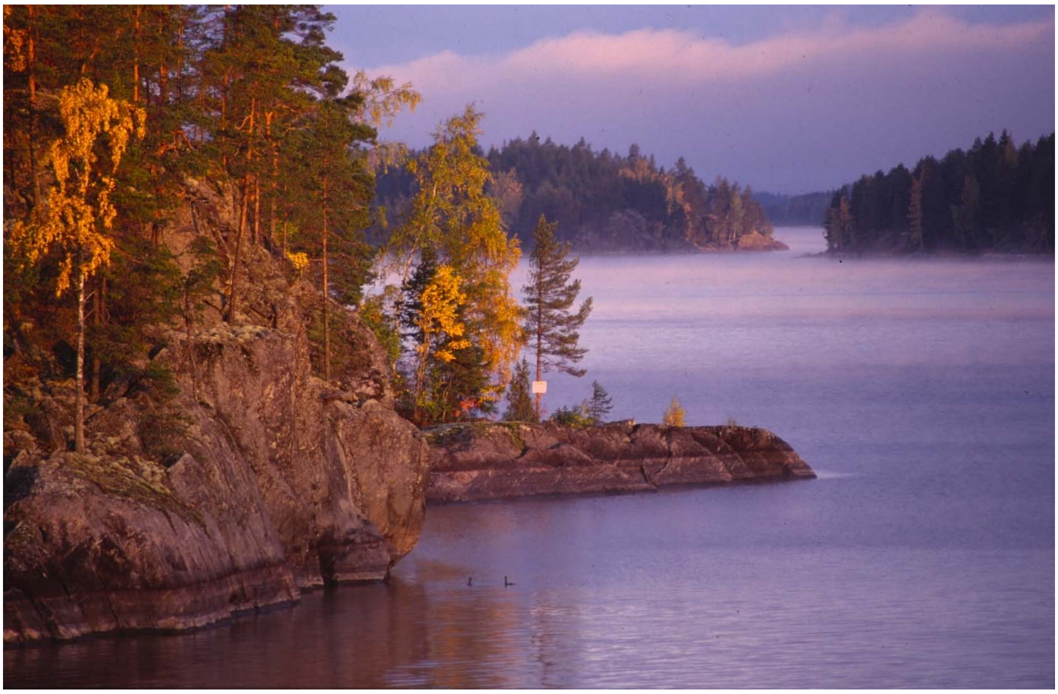

Figure 3. Lake Pihlajavesi, a typical oligotrophic Finnish lake in late autumn
(Photo Olli-Pekka Pietiläinen).

In Europe, the following types of transboundary lakes can be found:

- *Arctic lakes* (such as L.Inari, L.Torneträsk, L.Virihaure, L.Vastenjaure,etc.). These lakes are usually oligotrophic, and have long ice-cover period and low water temperature. Aquatic plant communities are not very rich in species, but the abundance of individual species of plants, phytoplankton and zooplankton may be high. The arctic ecosystems are sensitive and tender to any pollution load outside of the lake.
- *Prealpine lakes with great anthropogenic impact* (L.Constance/Bodensee, L.Léman/L.Geneve). These lakes have a relative small catchment area, are thermally stratified and have a relative large

groundwater inflow. Aquatic plant communities in the littoral zone are very much influenced by human activities, as changes in water level, shipping and sailing, discharging of nutrient loads etc. Bacterioplankton (blue-green algae) as well as phytoplakton-, zooplankton-, and zoobenthos communities are influenced by waste waters, and other human activities. Toxicants can damage fish communities.

- *Prealpine lakes with relict and endemic ecosystems* (L.Ohrid). The aquatic plant communities are rich in endemic species. Phytoplankton-, zooplankton- and zoobenthos communities are rich in relic and endemic species and fish communities are rich in species. Lakes are deep, and the residence time may be high, in L.Ohrid 83 years.
- *Lakes on the plains with a large catchment area* (L.Ladoga, L.Peipsi, L.Saimaa). Typical for these lakes is a large catchment area and remarkable fluctuations in water level. In deep lakes the thermal stratification is regular, but is lacking in shallow lakes. The groundwater inflow is insignificant compared to surface water inflow. Aquatic plant communities in the shallow littoral zone have rapid growth due to nutrient loading from the catchment area, algal blooms can occur during warm summer days, high bioproduction of phyto- and zooplankton is usually in good correlation with high fish production.

1.3 Selection of quality elements for lakes according to EU Water Framework Directive (WFD)

EU Member States, Norway and the European Commission have jointly developed a common strategy for supporting the implementation of Directive 2000/60/EC establishing a framework for Community action in the field of water policy (the Water Framework Directive). The main aim of this strategy is to allow a coherent and harmonious implementation of this Directive. The focus is on methodological questions related to a common understanding of the technical and scientific implications of the Water Framework Directive.

One of the main short-term objectives of the strategy is the development of non-legally binding and practical guidance documents on various technical issues of the Directive. These guidance documents are targeted to those experts who are directly or indirectly implementing the Water Framework Directive in river basins. The structure, presentation and terminology therefore is adapted to the needs of these experts and formal, legalistic language is avoided wherever possible.

In the context of the above-mentioned strategy, project 2.7 "Development of guidance on monitoring" was launched in December 2000. An informal working group (Working Group 2.7) was established to facilitate the production of this guidance. Project 2.7 was initiated to provide Member States with guidance on monitoring of inland surface water, transitional waters, coastal waters and groundwater, based on the criteria provided in Annex V of the Water Framework Directive. Italy and the European Environment Agency have the joint responsibility, as co-leaders of Working Group 2.7, for the co-ordination of the working group that is composed of scientists and technical experts from governmental and non-governmental organisations.

More information of the Guidance on Monitoring for the Water Framework Directive can be found on the internet: http://forum.europa.eu.int/Public/irc/env/wfd/library

A more exact address is:
http://forum.europa.eu.int/Public/irc/env/wfd/library?l=/framework_directive/guidance_documents/monitoring&vm=detailed&sb=Title

In the above mentioned Guidelines the aspect of selection of quality elements for different water bodies has been discussed in detail. The summary of the requirements of the WFD and the interpretation of the experts in the Working Group 2.7 is expressed in the Fig. 4 (Figure 3.2 in final CIS Guidance on Monitoring (2003), page 47).

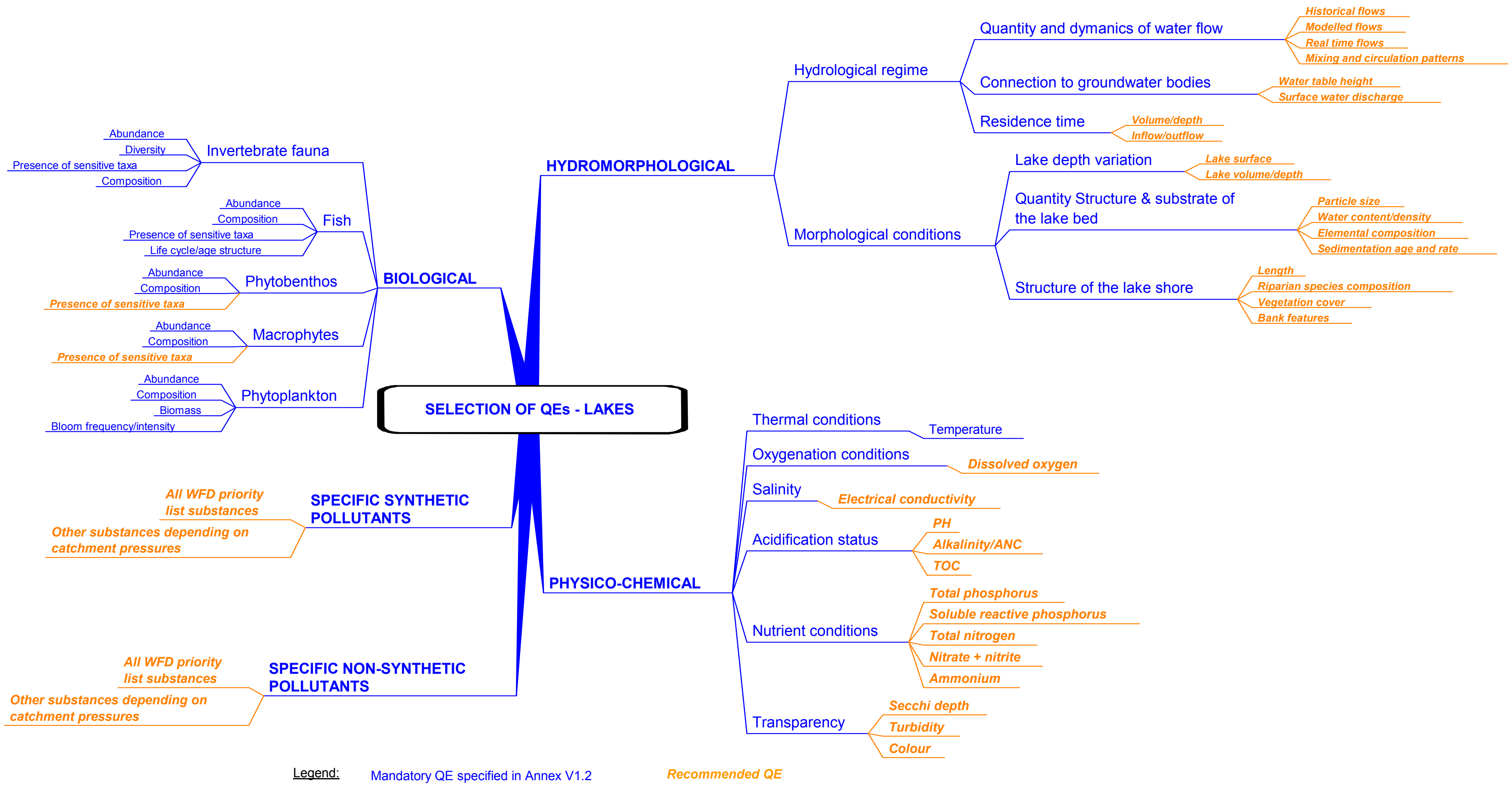

Figure 4. The mandatory Quality Elements specified in Annex V (1.2) of the EU Water Framework Directive (CIS Guidance on Monitoring 2003).

Supporting literature:

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SUMMARY of Chapter 1:

- Establish the hydrological cycle of the whole watershed before you start the planning and implementation of the monitoring programme of the lake concerned.
- Make rough estimations of climate, land use, population density, waste water load and non-point loading of the water shed of the lake concerned.
- Establish the concepts of the lake biotope and the lake biocoenosis.
- Acquaint yourself with some limnological literature.
- Have a look also at Annex V of the EC Water Framework Directive, WFD (2000/60/EC).

2 HYDROLOGICAL AND MORPHOLOGICAL FEATURES

2.1 Morphological features

Several morphological characteristics have been developed to describe the shape of a lake surface and bottom. Many of these parameters are important indicators for the ecological characteristics of lakes, and they are very central in lake management as well. The basic morphological parameters include area, volume, length, breadth, depth, length of shoreline, hypsographic curve (depth-area relation) and volume curve (depth-volume relation). Most of the above parameters can be further divided into groups of more detailed defined parameters.

It should be noted, that most of the morphological parameters depend on the variability of the surface water level. Thus the values of these parameters should include information on the reference water level.

The Water Framework Directive gives a number of so called quality elements for the definition of the ecological status of surface waters. The following hydromorphological elements should be used for the assessment and classification of lakes:

Hydrological regime:
- Quantity and dynamics of water flow,
- residence time and
- connection to the groundwater body.

Morphological conditions:
- Lake depth variation,
- quantity, structure, substrate of the lake bed and
- structure of the lake shore.

The hydrological regime elements are primarily related to the water balance of lakes discussed in more detail in 2.3.

2.2 Key features of hydromorphological quality elements for lakes according to the WFD Guidance on Monitoring

In the Guidance on Monitoring for the Water Framework Directive by the CIS Working Group 2.7 (Monitoring) some systematically gathered and processed information of the different quality elements have been presented. In the Guidance the information on the key features of each hydromorphological quality element for lakes is presented in Table 1 (Table 3.5 in the final CIS Guidance on Monitoring (2003), pages 52-54).

The structure of this table (as of all the following corresponding tables) follows Annex V of the WFD by presenting in the same order all the quality elements, and by then discussing the following topics of all the elements:

- Measured parameters indicative of QE
- Pressure to which QE responds
- Sampling and methodology
- Standards
- Applicability of the QE to lakes
- Main advantages
- Main disadvantages
- Conclusions/recommendations.

This table is presented over the following pages.

Table 1. Key features of each hydromorphological quality element for lakes.

Aspect/feature	Quantity and dynamics of water flow	Residence time	Connection to the groundwater body	Lake depth variation (water level variation)	Quantity, structure and substrate of lake bed	Structure of lake shore
Measured parameters indicative of QE	Inflow and outflow rates. Water level, spillway and bottom outlets discharges (reservoirs), mixing and circulation patterns	Volume, depth, inflow and outflow	Lake surface, lake volume	Lake surface, lake volume, lake depth	Grain size, water content, density, LOI, elemental composition, sedimentation rate, sediment age (Cs 137), microfossils in paleolimnological studies	Length, riparian vegetation cover, species present, bank features and composition
Pressures to which QE responds	Climate variability, flood control, man made activities	Climate variability, man made activities	Climate variability, man made activities	Climate variability, siltation, water use, flow discharges	Siltation	Man-made modifications, erosion, run-off Water level fluctuations in reservoirs
Level and sources of variability of QE	Med. variability	Low but may vary under extreme climatic conditions	High variability	Generally low variability, high variability in reservoirs (epilimnetic/ hypolimnetic discharges)	Highly variable, dependent on spread patterns and pollution by historical development	Variable
Sampling methodology	Water level gauge, flow meters, and current meters. In situ using scales or submersible probes associated or not to teletransmission	Echo sounding necessary for depth-volume curves, hypsographic curves	Depth-volume curves, hypsographic curves. Water level gauge.	Sonar device (echo-sounder), phathometer, Transect methodology with metered sounding poles	Core and grab samplers depending on study objectives 3 main sampling types may be distinguished: deterministic, stochastic and regular grid systems	Transects, aerial photography, planimetry
Typical sampling frequency	Weekly/monthly. Hourly/daily (reservoirs)	Every 5/ 10 years, or less frequently if no changes are suspected. Once per year for reservoirs.	Variable	Natural lakes: every 15 yrs. Reservoirs: variable	Mostly once a year, or less frequently if no changes expected (reference conditions), in polluted lakes every 3rd to 5th year	Every 6 years
Time of year of sampling	All seasons	All seasons, not during ice cover	All seasons	Reservoirs: generally during operational functioning, spring/ begin fall	Usually winter (from ice in Nordic countries)/ summer	Varied. Spring/summer during growing period
Typical "sample" size or survey area	Inflowing/outflowing waters; gauging stations	Entire lake	Entire lake	Entire lake	Varied depending on study objective	Entire lake shore habitat
Ease of sampling /measurements	Simple following minimal practical training	Easy for theoretical residence time estimation Difficult for the evaluation of effective residence time	Difficult	Relatively easy following minimal training	Relatively easy following minimal practical training	
Basis of any comparison of results/quality/stations e.g. reference conditions/best quality	Historical data	Historical data	Historical data	Historical data	Paleolimnology/ sediment core studies	Historical data
Methodology consistent across EU?	Yes, according to other countries practices	No	No	No	No	No

Aspect/feature	Quantity and dynamics of water flow	Residence time	Connection to the groundwater body	Lake depth variation (water level variation)	Quantity, structure and substrate of lake bed	Structure of lake shore
Current use in monitoring programmes or for classification in EU	No/yes (reservoirs)	No	No	No, France, UK, Spain	No	No
Existing monitoring systems meet requirements of WFD?	No	No	No	No	No	No
Existing classification systems meet requirements of WFD?	No	No	No	No	No	No
ISO/CEN standards	Yes, refer to ISO/TC 113, CEN/TC 318	No	No	No	No	No
Applicability to lakes	High	High	High	High	High	High
Main Advantages	• Hydrological measurements are essential for the interpretation of water quality data and for water resource management	• Lake hydrology forms the basis for water quality assessment; • Water residence time influences nutrient retention and development of anoxia in deep, stratified water bodies	• Lake hydrology forms the basis for water quality assessment.	• Water level fluctuation has a direct impact on littoral aquatic life • Lake basin morphology influences lake hydrodynamics and sensitivity to nutrient loading	• Can be regarded as environmental tachometers**.** The paleolimnological study is often the only tool to gather knowledge of past reference conditions. • The contaminants accumulate often in sediments, the contents are high and the sampling frequency may be quite low.	• Indicators in protection of biological integrity
Main disadvantages	Time consuming and costly	Time consuming and costly	Time consuming and costly	Accurate Hydrographic maps of lakes are rarely available in sufficient detail for ecological analysis even if bathymetric maps are available their accuracy should be checked carefully *	Paleolimnological examinations are often relatively expensive and the result depends on the undisturbed state of the sedimental archive. The preservation of microfossils may vary.	Methodology needs to be developed to incorporate requirements of the WFD

Aspect/feature	Quantity and dynamics of water flow	Residence time	Connection to the groundwater body	Lake depth variation (water level variation)	Quantity, structure and substrate of lake bed	Structure of lake shore
Conclusions/ recommendations	Important for calculating mass balances etc. A basic element for use with other relevant parameters	Important for characterising and assessing lake quality data.	Only relevant where groundwater constitutes a major part of the lake water balance. Methodology needs further development	Only relevant where it is of ecological significance. Important consideration in the design of monitoring programmes. Very important in reservoirs. As supporting elements the measurement of depth over time and space are both important. Thus recommended that both are used.	Not generally used in monitoring programmes. Exchange processes between sediment and water are important in determining the quality of many lakes.	Necessary for interpretation of biological parameters (e.g. macrophytes, some fish species) especially for shallow lakes or lakes with an extensive shallow littoral zone.

Only limited monitoring of hydrological features is currently included in existing classification systems in Europe
With the exception of lake depth variation, monitoring for morphological features is not included in any existing classification system in the EU

2.3 Hydrological features

The hydrological cycle is the driving force that regulates the water resources of lakes. In fact, geological and hydrometeorological conditions have created current lakes, and the future development of lakes depends on the same factors. The hydrological cycle feeds the lakes, removes water from the lakes and - combined with climate and geology - provides basic features for the variability of water resources. Extreme hydrometeorological events lead into floods and droughts in the lake environment as well as in other parts of the river system.

Man has a great impact on water resources throughout the world. Changes in land use affect the hydrological cycle, and water is being used on a very large scale for irrigation and the needs of industry and communities. Reservoirs have been built, and the regulation of lakes and reservoirs plays a remarkable role in the water balance and behaviour of river systems.

The water balance equation of a lake is often given in the form (1):

$$\Delta L = I_s + I_u + P_l - (Q_s + Q_u + E_l) \quad (1)$$

ΔL = the change of water storage
I_s = surface inflow
I_u = subsurface inflow
P_l = lake precipitation
Q_s = surface outflow
Q_u = subsurface outflow
E_l = lake evaporation.

The sum of terms I_s, I_u and P_l is called the net inflow, and correspondingly, the sum of Q_s, Q_u and E_l is the net outflow. The unit can be either the thickness of water layer (mm), or some volumetric unit, depending on the actual volumes and the time scale.

In most of the natural European lakes, the surface flow components are the largest. If a lake has a large surface area, compared to its catchment, the precipitation and evaporation components are very important. In the dry, southern areas, the role of evaporation is remarkable. In some of the reservoirs, the change of water storage may be the largest component. The share of the subsurface flow components is often small.

The residence time of a lake is the combined consequence of its morphology and water balance. This parameter is very often used to describe the physical, chemical and biological characteristics of lakes. The theoretical residence time is the ratio of lake's volume and annual net inflow. The actual residence time can be considerably smaller, as only a limited part of the water mass may transmit the flow through the lake.

2.4 Water balance components

Some of the water balance components of lakes can be measured easily, whereas some of the elements can only be estimated or calculated. The following overall statement can be given:

- The change of water storage and surface outflow can be measured with good or satisfactory accuracy.
- Lake precipitation and surface inflow can be determined relatively well, assuming that hydrometeorological and hydrometric observations of the lake catchment are available.
- Subsurface inflow, subsurface outflow and lake evaporation cannot be measured directly – at least with satisfactory accuracy; in practice, the subsurface components can often be neglected and evaporation is calculated as the remaining term of the lake water balance equation.

Within the actual monitoring practices, the basic unit of the (surface) flow variables is m^3s^{-1}. The other variables are measured by using mm (or cm) as the primary unit. When the water balance equation is being used, the variables are given either as volumes or the change of water storage during a time step. The change in water storage is determined by surface water level monitoring. In addition to water level measurements, the depth-volume dependence of the lake should be known. The following guidelines and recommendations should be applied to water level monitoring.

- Water level measurements should be made at fixed, continuously operating observation stations. In practice, the minimum requirement is the measurement of daily momentary or mean value. In large lakes, continuous recording is recommended.
- An international lake (excluding very small lakes) should have a minimum of two water level stations.
- The stations should be located so, that they give a good picture of the main oscillations and the mean water level of the lake. In a long and narrow lake this leads to the minimum requirement of two stations located close to both ends of the lake.
- When the actual lake (shore line of the lake) is shared by two or more countries, each of the countries should participate in water level monitoring. This should be the basic principle, even if it would lead into an increasing number of monitoring stations.
- The basic (principal) water level stations of international lakes should have real time data transmission.
- Other general factors that should be taken into account in the location of stations are costs of investment, simple operation, maintenance and telecommunication facilities.

The measurement of surface outflow depends on the structure of the lake outlet(s). Two basic approaches can be given:

- If the lake has a natural outlet area (with no major civil engineering works), a stage-discharge relation can often be constructed. In this case, the water level observations of the lake can be used for the calculation of the outflow. The reference water level station should be located close to the outlet area.
- If civil engineering works are being used for the regulation of outflow, the discharge can often be monitored by using the hydraulic characteristics of hydro turbines, dam gates, channel locks or other water passages. This method should be based on well organised observations and field (calibration) measurements.

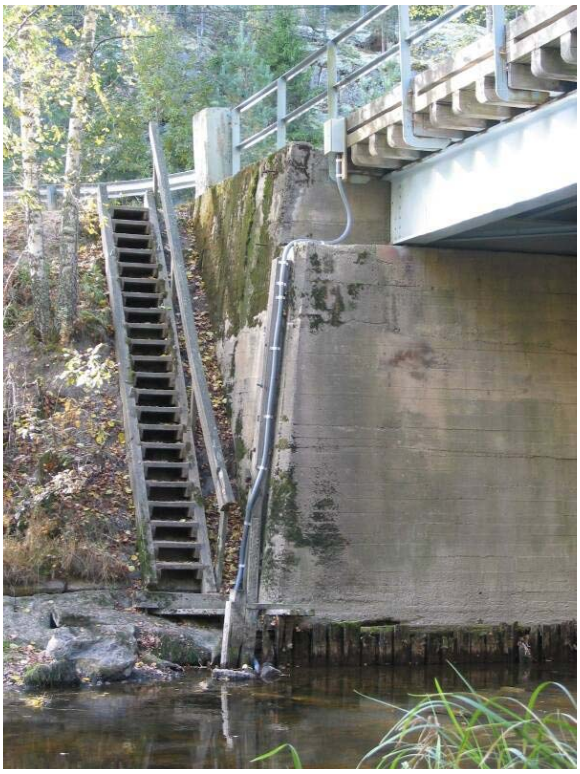

Figure 5. The hydrological measurement station.

If neither of the above methods can be used, and if the outflow cannot be calculated by using a close river station, a continuously operating flow measurement system (e.g. ultrasonic) should be installed at the outflow area. Regardless of the measurement method, the monitoring of surface outflow should be continuous. In practice, a minimum of 24 momentary values per day is recommended.

The determination of surface inflow uses the same principles as the measurement of surface outflow. However, contrary to outflow, there may be several significant sources of inflow, and this makes the task more difficult. In addition, there are a number of small catchments around most lakes. Hydraulic factors also often favour the measurement of outflow, compared to inflow. For these reasons, the determination of surface inflow may include a regional assessment routine (the individual discharges of major inflowing rivers are actually measured, and the total discharge of small inflowing rivers is estimated). The maximum time step for the determination of inflow should be one day.

The International Organization for Standardization (ISO) has produced a series of standards that provide guidelines for the measurement of inland surface water level and river discharge. This work is carried out under the ISO Technical Committee 113, called Hydrometry. At present, the total number of standards is some 50. A percentage of them are general, while others only cover a very detailed description of one specific method. So far, only a few European (CEN) standards are available for hydrology. Thus the ISO standards form a common ground that can be recommended for a number of hydrological measurements – or at least they can serve as a very good basis for several technical applications.

In most cases, the determination of lake precipitation (mean precipitation of the lake surface) is based on the data of land stations. This causes a source of error, as lakes have various effects on the spatial distribution of precipitation. When the ratio between lake surface area and catchment area increases, the role of direct lake precipitation becomes more and more important. In addition to the basic hydrometeorological observation principles, the following factors should be taken into consideration:

- In large lakes, the measurement of precipitation should be based on several point observations (rain gauges or precipitation gauges).
- Most of these stations should be located close to the shoreline. If the role of lake precipitation is very important, stations on islands and open water are recommended.
- If the role of lake precipitation is important, the spatial variability of precipitation should be estimated by using meteorological expertise. At the operational level, the use of weather radars or corresponding practices may be very useful.
- If the value of lake precipitation is calculated, the maximum time step for such calculation should be one day.

The areal precipitation of the whole lake catchment is of course very important from the point of view of hydrological modelling and forecasting. In most countries the rain gauges as well as the weather radars are operated by the meteorological institutes. However, hydrological and water sector actors may operate stations of their own in order to define some specific features of precipitation (e.g. areal estimates).

The roles of subsurface inflow and subsurface outflow depend on geological factors. They should always be considered, because even if they do not have a significant effect on the water balance of the lake, they may be important from the point of view of water quality. In most water balance calculations, the subsurface water balance components can be neglected. However, this is not always the case, and the rejection of subsurface flow must be based on relevant geological knowledge.

Lake evaporation can be calculated as the remaining term of the water balance equation. Its direct measurement at the lake scale is not possible. However, the role of evaporation should always be noted, due to the fact that large lakes and in warm climate conditions, it may be very significant. Even if the measurement of total lake evaporation cannot be carried out, several methods can be used for its estimation. Firstly, evaporation can be measured at various points by using floats with evaporation pans and other hydrometeorological equipment. Secondly, different types of mathematical models can be used. These are mostly based on meteorological factors, and they may vary from very simple to very complicated. If the value of lake evaporation is calculated, the maximum time step for the calculation should be one day.

2.5 Hydrodynamics, water temperature and ice conditions

The hydrodynamic studies of lakes are often based on flow (current) measurements. These measurements are typically made by using automatic flow meters that store values of different flow velocity components. Most meters also have sensors for various physical and chemical observations. The installation can be either fixed (that often includes a series of flow meters), or a moving boat application.

In principle, fixed flow meters can be used for continuous monitoring. However, in most cases hydrodynamic field studies are made periodically, and they aim at flow modelling within a lake or a coastal area. In general, hydrodynamic studies have a strong research component, and they cannot be considered as operational monitoring. Therefore, this guideline does not include any routine instructions on hydrodynamic measurements in lakes.

The temperature of water is very often observed in connection with hydrodynamic flow measurements. Water quality sampling often also includes measurements of surface or subsurface water temperatures. The thermal properties of the lake and the guidelines on temperature measurements are discussed in Chapter 5.

If a lake has an ice cover - either permanent or seasonal - the ice conditions should be monitored at some level. The potential parameters are freezing and break-up dates and processes, and the time series of area coverage, thickness and structure. The ice cover may have various impacts, e.g. on water transport, management, fishery, primary production and water quality.

This guideline does not provide any detailed guidelines on lake ice monitoring.

2.6 Water balance modelling and forecasting

In modern water resources management, hydrological modelling and forecasting play a very central role. In the lake environment, these tools are being utilised for several purposes, of which inflow forecasting is often the most important. Also, water levels of lakes are forecasted by modelling - in regulated lakes by assuming different regulation possibilities. In principle, a watershed model (a run-off model) covers all of the basic elements of the hydrological cycle, including subsurface waters. In addition to forecasting, models are important tools in comparing different management strategies and scenarios.

If hydrological modelling and monitoring can be used integrated, they support each other. In practice, it means that monitoring results are utilised in model input and updating updating models, and model simulations can lead to ain improved understanding of the water balance, and further into more cost-effective monitoring programmes.

In the case of international lakes, the model input procedures may be very demanding, due to the fact that data and forecasts on precipitation and air temperature are required in near real-time from the entire lake catchment. The same applies to hydrometric observations (especially discharge) in the upper parts of the river basin. In a large international lake, a great number of actors (organisations) in several countries are expected to be involved in these processes.

From the point of view of management, it is very important to aim at large-scale, operational models. When several countries have a common interest, a clear division of responsibilities and labour is clearly required. In this respect, different levels can be defined, e.g. technical operation, research and development, decision making, reporting and data service.

Supporting literature:

ISO TC 113 – Hydrometry. Series of standards available through the national standardisation bodies.

World Meteorological Organization. 1994. Guide to hydrological practices. WMO no. 168, 5th edition, World Meteorological Organization, 735 p.

SUMMARY of Chapter 2:

- Map the basic morphological characteristics of the lake concerned.
- Study the role (magnitude and variation) of the water balance components, and make sure that you have good knowledge base on all of the important components.
- Estimate the need of hydrological measurement stations of different types. Make also sure that you have enough data and information on the hydrological variables in the whole catchment are.
- Develop a quality management system for the hydrological monitoring, reporting and services. This system has to cover the whole lake and its basin.
- Develop an operational hydrological modelling and forecasting tool for the lake management, if such a system is not available.

3 ESTIMATION OF PRESSURES

3.1 General

In planning monitoring programmes for a lake and especially in the assessment of monitoring data of the lake, information on the total pressures to the lake is absolutely necessary. The most important data are usually the reliable statistics of waste water discharges. Also the WFD (Article 5) requires that the review of the environmental impact of human activity and economic analysis of water use will be carried out in the river basin district. Each Member State shall ensure that for each river basin district or for the portion of an international river basin district falling within its territory, the following estimations are performed:

- An analysis of its characteristics and
- a review of the impact of human activity on the status of surface waters and on groundwater.

Member States shall collect and maintain information on the type and magnitude of the significant anthropogenic pressures, to which the surface water bodies in each river basin district are liable to be subjected to. In many cases the waste water load discharged direct to the lake forms the most significant part of total loading. However, in increasing cases also other anthropogenic activities have a negative effect on watercourses and their biota.

Especially non-point loading from several different sources, such as agriculture and forestry has increased, and even caused bad pollution situations, especially seen in a serious increase of eutrophication. Also, land-use has altered the natural status of many water bodies, and made e.g. the usability of water courses significantly worse.

A relatively new phenomenon is so called internal loading in dimictic lakes. There are two main reasons, which are causing internal loading;

- Bottom sediments which have earlier badly deteriorated due to discharges of insufficiently purified waste waters, and which now in the purification processes transfer for a suprising long duration extra nutrient reserves from the sediment to water.
- Excessively dense fish stocks, developed during the increasing eutrophication of lakes, which usually comprise of small roach, bream etc. These fish are commonly bottom feeding and return sedimentated nutrients, especially phosphorus, back to the epilimnetic water mass in mineral form ready to be used by primary production.

3.2 Checking the pressures according to the WFD Guidance on Pressures and Impacts

Before the start of planning of a monitoring programme for a lake, you require amongst other things information on all the pressures. In performing this, it is advisable to use separate checking lists to ensure that e.g. all relevant polluters have been detected. As a highly useful example, the corresponding list from the CIS Guidance for the analysis of the Pressures and Impacts (2002) is presented in the Table 2 (Table 4.2 in the final CIS Guidance for the analysis of Pressures and Impacts (2002), pages 55-57).

Table 2. Uncompleted list of pressures to be considered.

n°		Source within the source type
10	**DIFFUSE SOURCE**	
12	Urban drainage (including runoff)	industrial/commercial estates
11		urban areas (including sewer networks)
16		airports
19		trunk roads
19		railway tracks and facilities
19		harbours

13	Agriculture diffuse	arable, improved grassland, mixed farming
13		crops with intensive nutrient or pesticide usage or long bare soil periods (e.g. corn, potato, sugar beets, vine, hops, fruits, vegetables)
13		over grazing – leading to erosion
13		horticulture, including greenhouses
13		application of agricultural waste to land
15	Forestry	peat mining
15		planting/ground preparation
15		felling
15		pesticide applications
15		fertilizer applications
22		drainage
19		oil pollution
11	Other diffuse	sewage sludge recycling to land
		atmospheric deposition
19		dredge spoil disposal into surface waters
19		shipping/navigation
	POINT SOURCE	
11	Waste water	municipal waste water, primarily domestic
11		municipal waste water with a major industrial component
11		storm water and emergency overflows
11		private waste water primarily domestic
11		private waste water with a major industrial component
19		harbours
12	Industry	gas/petrol
12		chemicals (organic and inorganic)
12		pulp, paper & board
12		woollens/textiles
12		iron and steel
12		food processing
12		brewing/distilling
12		electronics and other chlorinated solvent users
12		wood yards/timber treatment
12		construction
25		power generation
12		leather tanning
19		shipyards
12		other manufacturing processes
17	Mining	active deep mine
17		active open cast coal site/quarry
17		gas and oil exploration and production
15		peat extraction
17		abandoned coal (and other) mines
17		abandoned coal (and other) mine spoil heaps (bings)
17		tailings dams
18	Contaminated land	old landfill sites
18		urban industrial site (organic and inorganic)
18		rural sites
18		military sites
13	Agriculture point	slurry
13		silage and other feeds
13		sheep dip use and disposal
13		manure depots
12		farm chemicals
19		agricultural fuel oils
19		agricultural industries
18	Waste management	operating landfill site
18		operating waste transfer stations, scrap yards etc.
18		application of non agricultural waste to land
14	Aquaculture	land based fish farming / watercress / aquaculture
14		marine cage fish farming
12	Manufacture, use and emissions from all industrial/agricultural sectors	priority substances
12		priority hazardous substances
12		other relevant substances

	ABSTRACTION	
21	Reduction in flow	abstractions for agriculture
21		abstractions for potable supply
21		abstractions by industry
24		abstractions by fish farms
23		abstractions by hydro-energy
21		abstractions by quarries/open cast coal sites
22		abstractions for navigation (e.g. supplying canals)
20	**ARTIFICIAL RECHARGE**	
26		groundwater recharge
30	**MORPHOLOGICAL**	
22	Flow regulation	hydroelectric dams
21		water supply reservoirs
22		flood defence dams
22		diversions
22		weirs
36	River management	physical alteration of channel
35		engineering activities
31		agricultural enhancement
31		fisheries enhancement
32		land infrastructure (road/bridge construction)
36		dredging
36	Transitional and coastal management	estuarine/coastal dredging
36		marine constructions, shipyards and harbours
31		land reclamation and polders
30		coastal sand suppletion (safety)
30	Other morphological	barriers
	OTHER ANTHROPO-GENIC	
12		litter/fly tipping
11		sludge disposal to sea (historic)
33		mine adits/tunnels affecting groundwater flows
40		exploitation/removal of other animals/plants
10		recreation
41		fishing/angling
40		introduced species
40		introduced diseases
10		climate change
31		land drainage

In the same Guidance also certain criteria for different types of pressures have been presented.

3.3 Waste water discharges

The monitoring of urban waste water has a long history in most European countries, because water protection measures usually have started with the treatment of urban waste waters and soon after industrial waste water treatment. The legislation concerning waste water treatment is also well developed. Usually there is no real problem in obtaining continuously relatively reliable information on the general loading characteristics, e.g. BOD, phosphorus and nitrogen.

In addition, EU legislation has, nowadays, quite clear directives concerning treatment and monitoring of waste water discharges. The most important directives are the urban waste water treatment directive (UWWT) and the so called IPPC directive especially covering industrial effluents.

Urban Waste Water Treatment Directive (UWWT Directive)

In EU legislation the Council Directive of 21 May (91/271/EEC) covers the collection, treatment and discharge of urban waste water and the treatment and discharge of waste water from certain industrial sectors. The objective of the Directive is to protect the environment from the adverse effects of waste water discharges.

In Article 9 of the UWWT Directive it is also an obligation concerning transboundary water-bodies:

- Where waters within the area of jurisdiction of a Member State are adversely affected by discharges of urban waste water from another Member State, the Member State whose waters are affected may notify the other Member State and the Commission of the relevant facts.

Article 15 of the UWWT Directive provides general guidelines for monitoring activities as follows:

- Competent authorities or appropriate bodies shall monitor:
  - Discharges from urban waste water treatment plants.
  - Amounts and composition of sludge disposed of into surface waters.
- Competent authorities or appropriate bodies shall monitor water subject to discharges from urban waste water treatment plants and direct discharges in cases where, it can be expected that, the receiving environment will be significantly affected.

The Urban Waste Water Treatment Directive contains the following obligation concerning the methods for monitoring and evaluation of results:

- Member States shall ensure that such a monitoring method is applied which corresponds at least with the level of requirements described in the Directive.
- Flow-proportional or time-based 24-hour samples shall be collected at the same well-defined point in the outlet and if necessary in the inlet of the treatment plant in order to monitor compliance with the requirements for discharged waste water laid down in this Directive.
- Good international laboratory practices aiming at minimizing the degradation of samples between collection and analysis shall be applied.
- The minimum annual number of samples shall be determined according to the size of the treatment plant and be collected at regular intervals during the year. For instance, if the person equivalent of the treatment plant is from 2 000 to 9 999, 12 samples during the first year of the monitoring should be taken.

The most frequently analysed characteristics in the urban waste water monitoring programmes are: Biochemical Oxygen Demand (BOD_5 at 20 °C without nitrification), Chemical Oxygen Demand (COD_{Cr}, homogenized, unfiltered, undecanted sample using in oxidation Potassium dichromate), Total suspended solids, Total phosphorus (Molecular absorption spectrophotometry) and Total nitrogen (the sum of total Kjeldahl-nitrogen (organic N + NH_3), nitrate (NO_3)-nitrogen and nitrite (NO_2)-nitrogen).

Integrated Pollution Prevention and Control directive (IPPC Directive)

Council Directive 96/61/EC 24 September 1996 concerning integrated pollution prevention and control, the so called IPPC Directive, includes also obligations on monitoring activity. The purpose of this Directive is to achieve integrated prevention and control of pollution arising from the activities listed in Annex I. The main categories of industrial activities in Annex 1 are as follows:

- Energy.
- Production and processing of metals.
- Mineral.
- Chemical.
- Waste management.
- Other activities (industrial plants for the production of pulp from timber or other fibrous material and production of paper and board).

In Article 6 (Applications for permits) of the IPPC Directive the obligatory items for permit applications are listed. An application to the competent authority should include, among other things, a description of:

- The sources of emissions from the installation.
- The conditions of the site of the installation.
- The nature and quantities of foreseeable emissions from the installation into each medium as well as identification of significant effects of the emissions on the environment.
- Measures planned to monitor emissions into the environment.

The permit shall include emission limit values for pollutants, in particular those listed in Annex III, likely to be emitted from the installation concerned in significant quantities, having regard to their nature and their potential to transfer pollution from one medium to another (water, air and land). This indicative list of the main polluting substances, which should be taken into account (if they are relevant), is as follows:

- Organohalogen compounds and substances which may form such compounds in the aquatic environment.
- Organophosphorus compounds.
- Organotin compounds.
- Substances and preparations which have been proven to possess carcinogenic or mutagenic properties or properties which may affect reproduction in or via the aquatic environment.
- Persistent hydrocarbons and persistent and bioaccumulable organic toxic substances.
- Cyanides.
- Metals and their compounds.
- Arsenic and its compounds.
- Biocides and plant health products.
- Materials in suspension.
- Substances which contribute to eutrophication (in particular, nitrates and phosphates).
- Substances which have an unfavorable influence on the oxygen balance (and can be measured using variables such as BOD, COD, etc.).

In all circumstances, the conditions of the permit according to the IPPC Directive shall contain provisions on the minimization of long-distance or transboundary pollution and ensure a high level of protection for the environment as a whole.

The permit shall contain suitable release monitoring requirements, specifying measurement methodology and frequency, evaluation procedure and an obligation to supply the competent authority with data required for checking compliance with the permit.

The results of monitoring of releases, as required under permit conditions, must be made available to the public. An inventory of the principal emissions and sources responsible shall be published every three years by the Commission on the basis of the data supplied by the Member States.

In Article 17 (Transboundary effects) of the IPPC Directive there are important sections concerning transboundary water bodies. They are as follows:

- Where a Member State is aware that the operation of an installation is likely to have significant negative effects on the environment of another Member State, or where a Member State likely to be significantly affected so requests, the Member State in whose territory the application for a permit pursuant to Article 4 or Article 12 (2) was submitted shall forward the information provided pursuant to Article 6 to the other Member State at the same time as it makes it available to its own nationals. Such information shall serve as a basis for any consultations necessary in the framework of the bilateral relations between the two Member States on a reciprocal and equivalent basis.
- Within the framework of their bilateral relations, Member States shall see to it that in the cases referred to in paragraph 1 the applications are also made available for an appropriate period of time to the public of the Member State likely to be affected, so that it will have the right to comment on them before the competent authority reaches its decision.

3.4 Non-point loading

The estimation of non-point loading to a water body is not that easy, because so many different factors affect quantity and temporal variations. Generally, we can assume that the most important factors are of hydrological character. However, the following sub-areas of different activities, which may cause significant increase in non-point loading should be clarified:

1. An estimation and identification of significant diffuse source pollution from urban, industrial, agricultural and other installations and activities.
2. An estimation and identification of significant water abstraction for urban, industrial, agricultural and other uses, including seasonal variations and total annual demand and loss of water in distribution systems.
3. An estimation and identification of the impact of significant water flow regulation, including water transfer and diversion, on overall flow characteristics and water balances.
4. Identification of significant morphological alterations to water bodies.
5. An estimation and identification of other significant anthropogenic impacts on the status of surface waters.
6. An estimation of land use patterns, including identification of the main urban, industrial and agricultural areas and, where relevant, fisheries and forests.

In the WFD especially in Article 10 (The combined approach for point and diffuse sources) points out the importance of non-point loading. The significance of non-point loading from various sources as very important eutrophication factor has been accepted also in other international agreements.

Nitrate Directive

Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources has the objective of reducing water pollution caused or induced by nitrates from agricultural sources and preventing further such pollution.

Article 5 of the nitrate directive contains an obligation for monitoring: Member States shall draw up and implement suitable monitoring programmes to assess the effectiveness of action programmes, and in Article 10 the obligation for reporting: Member States shall, in respect of the four-year period following the notification of this Directive and in respect of each subsequent four-year period, submit a report to the Commission containing e.g. a summary of the monitoring results, including a statement of the considerations which led to the designation of each vulnerable zone and to any revision of or addition to designations of vulnerable zones.

3.5 Land use

Non-point loading especially from agricultural areas has been studied over a long period in several countries, and quite reliable estimations of e.g. the amount and seasonal variations of total phosphorus and nitrogen loading from cultivated areas can nowadays be established. Very similar is the situation with forestry.

Although the relation between the intensity of agricultural use of land and nutrients run off is unquestionable, so far a universal model of the phenomenon that could be used in practice remains illusive. Nutrient run off from a catchment is determined by several different factors such as hydrological and meteorological conditions, use of fertilizers, type of soils, vegetation cover, crops, sculpture of the landscape and the share of barrier habitats such as wetlands and others.

This involves an individual approach to particular bodies of water. The assessment of the export of biogenic substances from agricultural areas becomes extremely important when the point sources of pollution are significantly eliminated, and non-point sources are more likely to decide on the eutrophication process of surface water bodies.

The loading caused by urban or suburban runoff waters is, on the contrary, not so well known. There are many difficulties in monitoring this type of loading, and the variations are clearly great. However, the annual loading of e.g. total phosphorus has been found to range from 20 to 200 kg/km^2 (Melanen 1981). In some cases this loading can have significant effects on the eutrophication processes of the lake.

3.6 Internal loading

In many cases it has happened that despite totally stopping waste water discharge to a lake the improvement of the ecological status of the lake has been extremely slow. There are two main reasons, which cause internal loading;

- The re-mobilization of phosphorus and other elements from badly deteriorated bottom sediments under anaerobic conditions into the near bottom layer of the lake.
- Excessive fish stocks, which have developed during the increasing eutrophication of lakes, usually comprised up of small roach, bream etc.

The estimation of internal loading requires special investigations in the lake concerned. The differences in loadings are so great between different lakes that no general guidelines for estimation can be given. Usually the most important variables to be investigated are phosphorus and nitrogen.

Supporting literature:

CIS Guidance for the analysis of the Pressures and Impacts. 2002. In accordance with the Water Framework Directive. 104 p.

Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment. Official Journal L 135, 30/05/1991. p. 40 – 52.

Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources. Official Journal L 375, 31/12/1991. p. 1 – 8.

Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control. Official Journal L 257, 10/10/1996. p. 26 – 40.

Keto J. and Sammalkorpi I. 1988. A Fading recovery: a conceptual model for lake Vesijärvi management and research. Aqua Fennica 18: 193-204. ISSN 0356-7133.

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Soranno, P.A., S.R. Carpenter and R.C. Lathrop. 1997. Internal phosphorus loading in Lake Mendota: response to external loads and weather. Can. J. Fish. Aquat. Sci. 54:1883-1893.

SUMMARY of Chapter 3:

- Identify urban waste water load directly discharged to the lake or via rivers.
- Identify discharges from industry.
- Identify all the possible causes of non-point loading, especially agricultural areas.
- Make an estimation of land use in the water shed of the lake.
- Especially in highly eutrophied or polluted lakes try to perform some estimations of the internal loading.
- Try to determine the loading from different sources as BOD, Phosphorus and Nitrogen loading (kg/a).
- Identify all relevant polluting substances discharged to the lake.

4 MONITORING PROGRAMMES, SAMPLING SITES AND FREQUENCY OF SAMPLING

4.1 Monitoring programmes

The very first phase in implementing monitoring is the planning of the monitoring programme itself. There are numerous possibilities in outlining the object of the programme. Sometimes the objective is only one separate part, e.g. one lake in some water course. Besides this, in local monitoring there are also different types of regional monitoring programmes. Also many countries have their own national monitoring programmes.

The Water Framework Directive, WFD (2000/60/EC) divides the monitoring activity in the following three principally different parts:

- Surveillance monitoring.
- Operational monitoring.
- Investigative monitoring.

Surveillance monitoring programmes are designed to provide information on the water body concerned for:

- Supplementing and validating the impact assessment.
- The efficient and effective design of future monitoring programmes.
- The assessment of long-term changes in natural conditions.
- The assessment of long-term changes resulting from widespread anthropogenic activity.

The results of such monitoring shall be reviewed and used in combination with the impact assessment procedure, to determine requirements for monitoring programmes in current and subsequent river basin management plans. The implementation of this phase of monitoring belongs to the responsibilities of the water authority.

Operational monitoring shall be undertaken in order to:

- Establish the status of relevant bodies identified as being at risk of failing to meet their environmental objectives.
- Assess any changes in the status of such bodies resulting from the programmes of measures.

The programme may be amended during the period of a river basin management plan in light of information obtained as part of the requirements of Annex II (of WFD) or as part of this Annex. In particular, to allow a reduction in frequency where an impact is found as insignificant or the relevant pressure is removed. The implementation of this part of monitoring belongs to the responsibilities of the polluters.

Investigative monitoring shall be carried out:

- Where the reason for any exceedances is unknown.
- Where surveillance monitoring indicates that the objectives set out in Article 4 for a body of water are not likely to be achieved and operational monitoring has not already been established, in order to ascertain the causes of a water body or water bodies failing to achieve the environmental objectives.
- Or to ascertain the magnitude and impacts of accidental pollution, and to inform the establishment of a programme of measures for the achievement of the environmental objectives and specific measures necessary to remedy the effects of accidental pollution.

4.2 Sampling sites

The main hydrological and hydrometeorological characteristics, such as precipitation, snow cover, water level, river flow, sediment discharges (suspended sediment and bed load), evaporation and evapotranspiration, soil moisture, temperature and data on ice conditions, should be measured and estimated as an important part of any monitoring programme of a lake.

The selection of hydrological monitoring sites for the management of a transboundary river basin should be governed by the purpose for which the data or records are collected and by the accessibility of the site. In general, a sufficient number of gauging stations should be located along the main river to permit interpolation of water level and discharge between the stations. In addition, water balances require sufficient observation stations at small streams and tributaries. Gauges on lakes and reservoirs are normally located near their outlets, but sufficiently upstream to avoid the influence of drawdown.

Hydraulic conditions are an important factor in site selection on streams, particularly where water levels are used to compute discharge records via water level relationships (rating curves). Unambiguous relationships are found at stations that are located at streams with natural regimes, not affected by variable backwater at the gauge, caused by downstream tributaries or reservoir operations or by tidal effects.

Systematic water level recordings, supplemented by more frequent readings during floods, are required for most streams. The installation of water level recorders is essential for streams where the level is subject to abrupt fluctuations. Continuous river flow records are necessary in the design of water-supply systems, and in estimating the sediment or chemical loads of streams, including pollutants.

Factors to be considered in scheduling the number and distribution of discharge measurements within the year include:

- The stability of the stage-discharge relationship; seasonal discharge characteristics and variability.
- Accessibility of the gauge in various seasons.

Many discharge measurements at different flow levels are necessary at a new station to define the stage-discharge relationship, while at existing stations it is necessary to perform as many measurements as required to maintain an up to date stage-discharge relationship. Adequate determination of discharge during flood and under ice conditions is of prime importance.

Instructions relating to the monitoring of inland waters are included in Article 8 of the WFD (Monitoring of surface water status, groundwater status and protected areas) and they are as follows:

- Member States shall ensure the establishment of programmes for the monitoring of water status in order to establish a coherent and comprehensive overview of the water status within each river basin district.
- For surface waters such programmes shall cover:
  (i) The volume, level or rate of flow to the extent relevant for ecological and chemical status and ecological potential, and
  (ii) the ecological and chemical status, as well as ecological potential.
- These programmes shall be operational, at the latest, six years after the date of entry into force of this Directive (December 2006).

Detailed requirements of the monitoring programmes are presented in Annex V.

The surface water monitoring network of ecological status and chemical status shall be established in accordance with the requirements of Article 8 (as above). The monitoring network shall be designed so as to provide a coherent and comprehensive overview of ecological and chemical status within each river basin and shall permit classification of water bodies into five classes. Member States shall provide a map or maps showing the surface water monitoring network in the river basin management plan.

The sampling procedure used in lake monitoring differs from that of rivers. As a rule, the state of lakes is more stable than that of rivers. The selection of sampling sites is the very first step in fulfilling the monitoring programmes.

Surveillance monitoring shall be carried out of sufficient surface water bodies to provide an assessment of the overall surface water status within each catchment or subcatchments within the river basin district. In selecting these bodies Member States shall ensure that where appropriate, monitoring is carried out at points where:

- The rate of water flow is significant within the river basin district as a whole; including points on large rivers where the catchment area is greater than 2500 km^2.
- The volume of water present is significant within the river basin district, including large lakes and reservoirs.
- Significant bodies of water cross a Member State boundary.
- Sites are identified under the Information Exchange Decision 77/795/EEC.
- At other sites as is required to estimate the pollutant load which is transferred across Member State boundaries, which is transferred into the marine environment.

Operational monitoring shall be carried out for all those bodies of water which on the basis of either the impact assessment carried out in accordance with Annex II or surveillance monitoring is identified as being at risk of failing to meet their environmental objectives under Article 4, and for those bodies of water into which priority list substances are discharged. Monitoring points shall be selected for priority list substances as specified in the legislation laying down the relevant environmental quality standard.

In all other cases, including for priority list substances, where no specific guidance is provided in such legislation, monitoring points shall be selected as follows:

- For bodies at risk from significant point source pressures, a sufficient amount of monitoring points within each body in order to assess the magnitude and impact of the point source. Where a body is subject to a number of point source pressures monitoring points may be selected to assess the magnitude and impact of these pressures as a whole.
- For bodies at risk from significant diffuse source pressures, a sufficient amount of monitoring points within a selection of the bodies in order to assess the magnitude and impact of the diffuse source pressures. The selection of bodies shall be created so that they accurately represent the relative risks of the occurrence of the diffuse source pressures, and of the relative risks of failure to achieve a good surface water status.
- For bodies at risk from significant hydromorphological pressure, a sufficient amount of monitoring points within a selection of the bodies in order to assess the magnitude and impact of the hydromorphological pressures. The selection of bodies shall be indicative of the overall impact of the hydromorphological pressure to which all the bodies are subject to.

An example of sampling site placement in different lake types is presented in Fig. 6.

Investigative monitoring shall be carried out:

- Where the reason for any exceedances is unknown.
- Where surveillance monitoring indicates that the objectives set out in Article 4, for a body of water, are un likely to be achieved, and operational monitoring has not already been established, in order to ascertain the causes of a water body or water bodies failing to achieve the environmental objectives.
- To ascertain the magnitude and impacts of accidental pollution, and to inform the establishment of a programme of measures for the achievement of the environmental objectives and specific measures required to remedy the effects of accidental pollution.

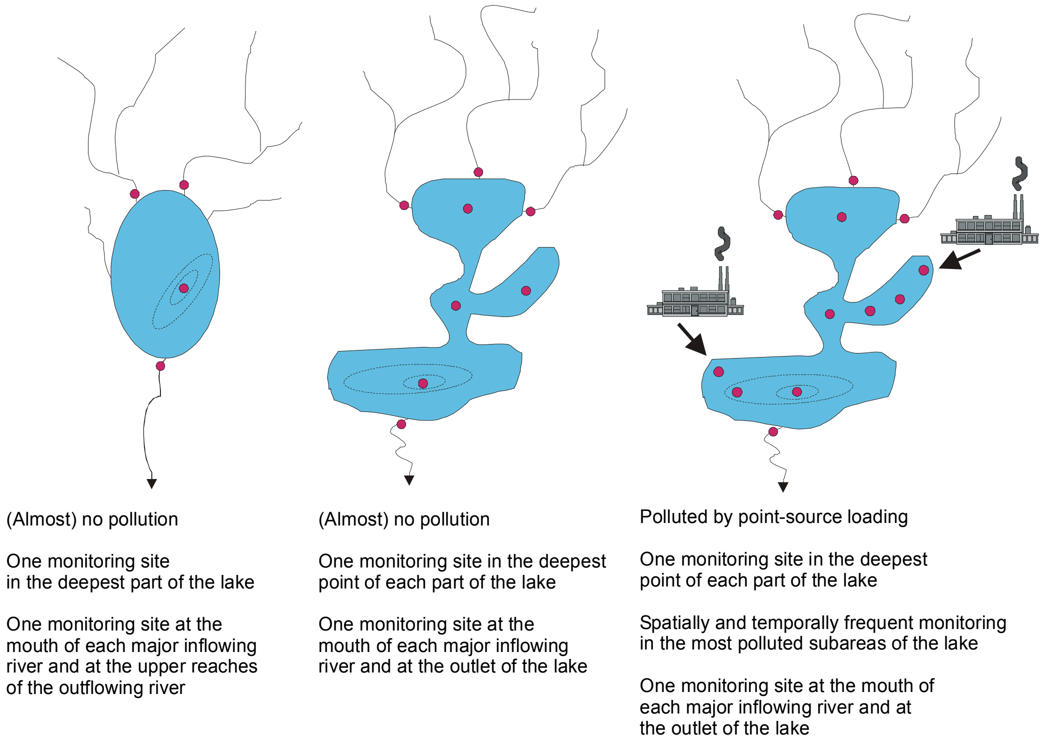

Figure 6. Examples of monitoring site placement in different types of lakes.

In stratified lakes samples should be taken always vertically from varying depths. Even in natural lakes there can be significant differences in water quality between the epilimnion and hypolimnion during the stratification period. Especially the oxygen content of hypolimnion can indicate the first signs of pollution at the end of the stratification period, especially in Northern counties, where the lakes have ice coverage for a longer period.

Biological phenomena is also different in epimnion and hypolimnion during stratification. Primary production with higher density of algae and significant diurnal variations in e.g. oxygen concentrations and pH, is the dominating phenomenon in epilimnion. In hypolimnion the bacterial decomposing processes are a dominating role, resulting in lower oxygen concentrations and in a very polluted situation even total anoxic conditions.

An example of vertical sampling is presented in Fig. 7. This lake has quite a strong summer stratification, which is demonstrated by the temperature curve. The epilimnetic and hypolimnetic layers can be identified very distinctly. The reason for vertical sampling is evident.

The normal placing of sampling depth is as presented in Fig.7. In all cases it is required to take samples from certain levels, which can be used in all lakes to improve the possibility of comparisons with different lakes. These depths are one meter and one meter above the bottom in the deepest part of the lake (z-1 meters in Fig.7). Also, the depth of five meters is quite often used in deeper lakes as a permanent sampling layer due to a more stable quality compared to just below the surface at a depth of one meter.

Other sampling depths should be determined according to thermal stratification so that information on the deeper part of epilimnion, as well as the upper part of hypolimnion, can be obtained. In deeper lakes the vertical set of samples in many cases consists of more than 10 sampling depths. In monitoring programmes with data collected over a longer period, the monitoring depths can be limited to the most informative (and stable) layers.

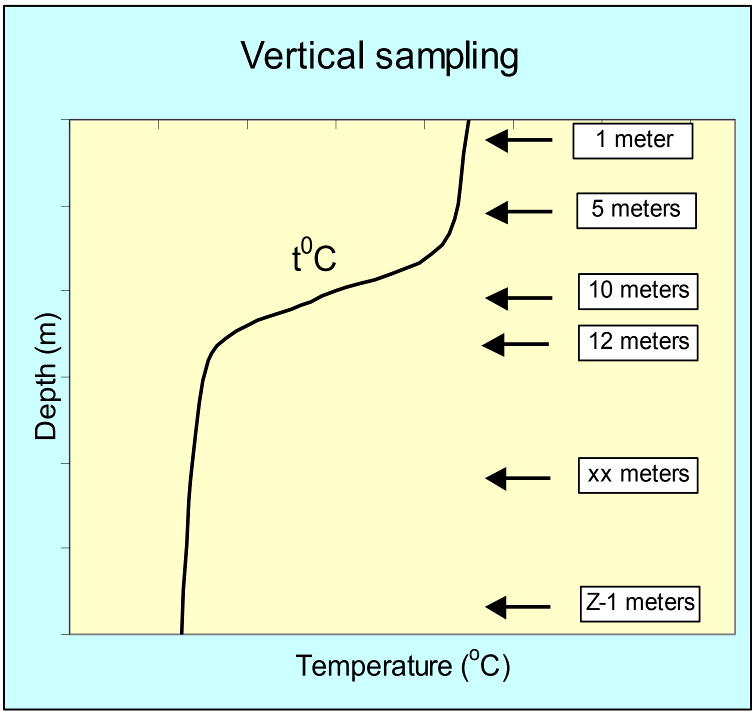

Figure 7. Example of vertical sampling site placement in a stratified lake (summer situation).

4.3 Frequency of sampling

The frequency of sampling shall be solved as a compromise between ecological needs and economic possibilities. In routine monitoring of a lake, the samples will usually be taken several times during one year. The most important seasons are when the water is stratified. The most important monitoring period is the summer stratification time. The primary production processes are at then at their highest, and also the decomposition of organic matter is most active. Especially in eutrophied or polluted lakes several samplings should be organized during the summer period.

In the northern part of Europe lakes may have a shorter or longer period of winter ice coverage. In hose cases samples from winter stratification is also required.

The WFD has also provided some general guidances on surveillance monitoring. Frequencies for monitoring variables indicative of physico-chemical quality elements would be justified on the basis of technical knowledge and expert judgement. For biological or hydromorphological quality elements, monitoring shall be performed out at least once during the surveillance monitoring period, i.e. six years.

For operational monitoring, the frequency of monitoring required for any parameter shall be determined by Member States so as to provide sufficient data for a reliable assessment of the status of the relevant quality element. As a guideline, monitoring should take place at intervals not exceeding those shown in the table below, unless greater intervals would be justified on the basis of technical knowledge and expert judgement.

Frequencies shall be chosen so as to achieve an acceptable level of confidence and precision. Estimates of confidence and precision attained by the monitoring system used shall be stated in the river basin management plan.

Monitoring frequencies are to be selected which take account of the variability in parameters resulting from both natural and anthropogenic conditions. The times at which monitoring is undertaken shall be selected so as to minimize the impact of seasonal variation on the results, and thus ensure that the results reflect changes in the water body as a result of changes due to anthropogenic pressure. Additional monitoring during different seasons of the same year shall be performed, where necessary, to achieve this objective.

Lakes exhibit a wide range of hydrologic characteristics, from very fast-flushing drainage lakes, to seepage lakes with a long residence time. Sampling frequency should be designed to characterize well the annual variability of the lakes. Monthly samples are recommended for most fast-flushing lakes; more frequent sampling may be required occasionally in lakes that undergo short-lived acidic episodes or nitrate peaks. Also, where flow data are available for calculations of yearly transport values of elements from catchments, increased sampling frequency in flood periods is recommended (Mannio 2000).

Quarterly or seasonal sampling is likely to be adequate in lakes with long residence times. In remote areas where frequent sampling is impossible for practical and economical reasons, even one sample per year may be useful for long-term monitoring. Such samples must be taken at the same time of the year each year, usually at the end of summer stratification, but in case of monitoring the acidification trend, preferably shortly after fall overturns (Mannio 2000).

Surveillance monitoring of the WFD shall be performed for each monitoring site for a period of one year during the period covered by a river basin management plan for:

- Variables indicative of all biological quality elements.
- Variables indicative of all hydromorphological quality elements.
- Variables indicative of all general physico-chemical quality elements.
- Priority list pollutants which are discharged into the river basin or sub-basin.
- Other pollutants discharged in significant quantities in the river basin or sub-basin, unless the previous surveillance monitoring exercise showed that the body concerned reached a good status, and there is no evidence from the review of impact of human activity in Annex II that the impacts on the body have changed. In these cases, surveillance monitoring shall be carried out once every three river basin management plans.

The instruction of monitoring of inland waters is included in the Water Framework Directive in Article 8 (Monitoring of surface water status, groundwater status and protected areas) as described in Chapter 1.3. Surveillance monitoring shall be carried out of sufficient surface water bodies to provide an assessment of the overall surface water status within each catchment or subcatchments within the river basin district. In selecting these bodies Member States shall ensure that, where appropriate, monitoring is carried out at points where:

- The rate of water flow is significant within the river basin district as a whole; including points on large rivers where the catchment area is greater than 2500 km^2.
- The volume of water present is significant within the river basin district, including large lakes and reservoirs.
- Significant bodies of water cross a Member State boundary.
- Sites are identified under the Information Exchange Decision 77/795/EEC.
- At such other sites as is required to estimate the pollutant load which is transferred across Member State boundaries, and which is transferred into the marine environment.

Operational monitoring shall be carried out for all those bodies of water which on the basis of either the impact assessment carried out in accordance with Annex II (of the WFD) or surveillance monitoring is identified as being at risk of failing to meet their environmental objectives under Article 4 and for those bodies of water into which priority list substances are discharged. Monitoring points shall be selected for priority list substances as specified in the legislation laying down the relevant environmental quality standard.

In all other cases, including for priority list substances where no specific guidance is given in such legislation, monitoring points shall be selected as follows:

- For bodies at risk from significant point source pressures, a sufficient amount of monitoring points within each body in order to assess the magnitude and impact of the point source. Where a body is subject to a number of point source pressures monitoring points may be selected to assess the magnitude and impact of these pressures as a whole.
- For bodies at risk from significant diffuse source pressures, a sufficient amount of monitoring points within a selection of the bodies in order to assess the magnitude and impact of the diffuse source pressures. The selection of bodies shall be made such that they are representative of the relative risks of the occurrence of the diffuse source pressures, and of the relative risks of the failure to achieve a good surface water status.
- For bodies at risk from significant hydromorphological pressure, a sufficient amount of monitoring points within a selection of the bodies in order to assess the magnitude and impact of the hydromorphological pressures. The selection of bodies shall be indicative of the overall impact of the hydromorphological pressure to which all the bodies are subject to.

Surveillance monitoring shall be performed for each monitoring site for a period of one year during the period covered by a river basin management plan for:

- Parameters indicative of all biological quality elements.
- Parameters indicative of all hydromorphological quality elements.
- Parameters indicative of all general physico-chemical quality elements.
- Priority list pollutants which are discharged into the river basin or sub-basin.
- Other pollutants discharged in significant quantities in the river basin or sub-basin.
- Unless the previous surveillance monitoring exercise showed that the body concerned reached a good status, and there is no evidence from the review of impact of human activity in Annex II that the impacts on the body have changed. In these cases, surveillance monitoring shall be carried out once every three river basin management plans.

Investigative monitoring shall be carried out:

- Where the reason for any exceeding is unknown,
- where surveillance monitoring indicates that the objectives set out in Article 4 for a body of water are not likely to be achieved and operational monitoring has not already been established, in order to ascertain the causes of a water body or water bodies failing to achieve the environmental objectives, or
- to ascertain the magnitude and impacts of accidental pollution, and to inform the establishment of a programme of measures for the achievement of the environmental objectives and specific measures necessary to remedy the effects of accidental pollution.

Supporting literature:

Bartram, J. & Ballance. R. (2001). Water Quality Monitoring. A practical guide to the design and implementation of freshwater quality studies and monitoring programmes. Spoon Press, London. ISBN 0419223207. 383 p.

CIS Guidance on Monitoring 2003. Water Framework Directive. Common Implementation Strat-egy, Working Group 2.7, Monitoring. Final Version. 23 January 2003, 164 p.

Heinonen, P., Ziglio. G. & Van der Beken, A. (Eds.) (2000). Hydrological and Limnological As-pects of Lake Monitoring. John Wiley & Sons, Ltd. Chichester. ISBN 0-471-89988-7. 372 p.

Mannio, J. 2000. Principles of Monitoring the Acidification of Lakes. In Hydrological and Limnological Aspects of Lake Monitoring (Eds. Heinonen, P., Ziglio, G. & Van der Be-ken, A.), 247-255.

Wetzel. R.G. (2001). Limnology: Lake and River Ecosystems, 3rd edition. Academic Press. ISBN 012744601. 850 p.

SUMMARY of Chapter 4:

- Define the monitoring area according to information needs.
- Define sampling sites according to hydrological and morphological information, information of discharges and other pressure factors.
- Define the characteristics you require.
- Define the frequency of sampling.
- Define the sampling depths in stratified lakes.
- Make realistic calculations of the costs of the monitoring programme and the possibilities of continuous funding.

5 THERMAL CONDITIONS

5.1 The thermal seasons of a lake

The very first information you should have from the physical properties of the lake is data on thermal conditions. Naturally it means observations of the thermal seasons and especially stratification situations. Regular/irregular stratification and circulation of water has a great effect on the physical, chemical and especially the biological characteristics of the ecosystem of the lake.

In northern countries thermal situations fluctuate the greatest. In northern lakes it is possible to regularly find four separate thermal situations during one year. They are as follows:

- Summer stratification.
- Autumn circulation.
- Winter stratification (= inverse stratification).
- Spring circulation.

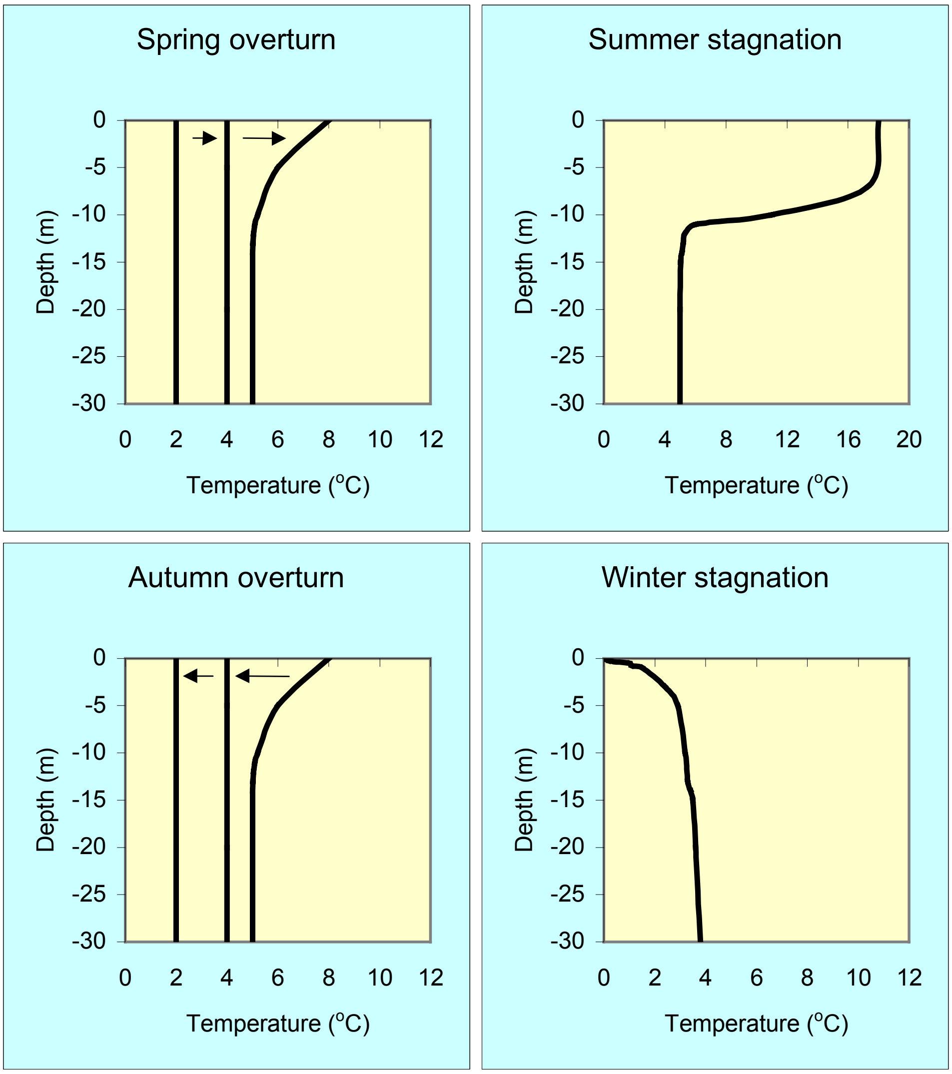

Figure 8. The four thermal seasons of a typical dimictic lake, and thermal stratification during these seasons.

The theoretical reason behind different cycles in the thermal properties of a lake, is basically the anomalous property of water; the maximum density can be detected at the temperature of +4.0 ^{0}C. When water cools, its density starts slowly to decrease so that it is 0.9998 at 0.0 ^{0}C. At the moment when this cold water freezes, the density of ice will suddenly drop to be only 0.9168 (Hutchinson 1957). In the same way, when water is warming from +4.0 ^{0}C, the density of water decreases, e.g. at +25.0 ^{0}C it is 0.9970.

We can begin to examine the thermal seasons from the situation of a lake in early spring when water is warming. Solar energy is the major factor causing the density-induced thermal cycle of lake. Solar heat is absorbed into the water and distributed and altered by several in-lake factors such as wind energy, water currents and basin morphometry. If the lake concerned is deeper, the warming of the water mass is not reaching the bottom layers. Usually the lake is stratified during this summer stratification into three layers (Figure 8): epilimnion (upper layer), metalimnion (intermediate layer) and hypolimnion (deepest layer).

Epilimnion is less dense, more or less uniformly warm, and a fairly turbulent water stratum while hypolimnion is more dense, cooler and a relatively undisturbed stratum. The transitional stratum between epilimnion and hypolimnion is metalimnion where a rapid decrease of temperature is detected in a narrow zone known as thermocline.

During summer stratification, different thermal layers can usually be detected in every deep lake. These layers are called:

- Epilimnion; the upper region of the lake, which is more or less uniformly warm and circulating.
- Hypolimnion; a deep, cold and relatively undisturbed region.
- Thermocline (or metalimnion); the region of rapid decrease in temperature separating the epilimnion from the hypolimnion.

The total depth of the lake has a notable influence on what type of summer stratification can be detected in a lake. In connection with this, the shape of the lake concerned and the prevailing wind directions are important factors. During a windy and relatively cold summer, the stratification type is totally different from a summer when calm and warm weather dominates.

In deep lakes, epilimnion and hypolimnion can usually be outlined very easily. On the contrary, in shallow (less than 10 meters deep) lakes, hypolimnion is often non evident, and the whole water volume is a totally circulating productive epilimnion. This is usually also evident in reservoirs.

During autumn the water of the lake is cooling and at a later phase, the whole water mass has reached the same temperature as the temperature of hypolimnion of the previous summer stratification period. The autumn circulation can then start. If autumn is long and relatively windy, the whole water mass cools during the autumn circulation clearly below + 4 ^{o} C and down to + 2 ^{o} C, and especially in biggest and deepest lakes, even down to +1-1,5 ^{o} C.

The winter begins when in autumn the whole water mass is colder than + 4 ^{o} C, and the air temperature falls especially during calm weather clearly below zero. In winter stratification is inverse compared to summer, i.e. the coolest water is just under the ice cover and warmer water in the deeper layers. When the lake has ice coverage, the temperature just below the ice is + 0.1 ^{o} C. If the previous autumn has been long, the difference between the temperatures of epilimnion and hypolimnion is very small. This has a great effect on e.g. the oxygen budget of the lake.

On the contrary, if winter moves in early, lake freezing can happen already after a very short circulation time. The temperature below the ice is, because of freezing, + 0.1 ^{o} C, but in the deepest part it may even be + 4 ^{o} C. At this temperature, the oxygen use of decomposing organic matter is much faster and may lead to a total deficit of oxygen near the bottom.

In spring, the ice cover breaks up and the spring circulation of water can be rapid, and if air temperatures are high, also incomplete.

A great number of various types of stratification can be found in lakes around the world. The following types are the most common:

- Cold monomictic lakes; Circulation only once a year. During the short summer period the temperature remains below + 4 ^{o} C.
- Warm monomictic lakes; Circulation only once a year which do not freeze. Temperate lakes.
- Dimictic lakes; Circulation occurs twice a year and freeze every year. Temperate lakes.
- Polymictic lakes; Circulation occurs several times a year. Lakes are shallow. Temperate or tropical lakes.

The existence of thermal stratification can be easily detected by measuring the temperature at different depths of a lake. The knowledge of the thermal condition of a lake is of great importance when determining sampling strategy (e.g. timing of sampling and depth of water samples).

5.2 Measurements of thermal properties

The actual monitoring programme on the sampling site starts with observations of the vertical stratification of the temperature. In some cases information also from horizontal distribution is required.

Temperature can be measured using a glass thermometer, which is placed inside the water sampler. More easily temperature can be measured using an electronic thermometer, which (the probe) can be lowered with long leads to different depths from the surface to the bottom.

The temperature must be measured *in situ* in vertical series starting from the water level nearest to the surface. The first measurement will usually be taken from the depth of one meter, then two, three, four and five meters. After five meters you can proceed to measure the temperature at five meter intervals, and at the depth of 20 metres then at ten meter intervals. However, if the difference between two vertically successive measurements is greater than 1 ^{o}C (an example is presented in Fig. 9), you will need more measurements.

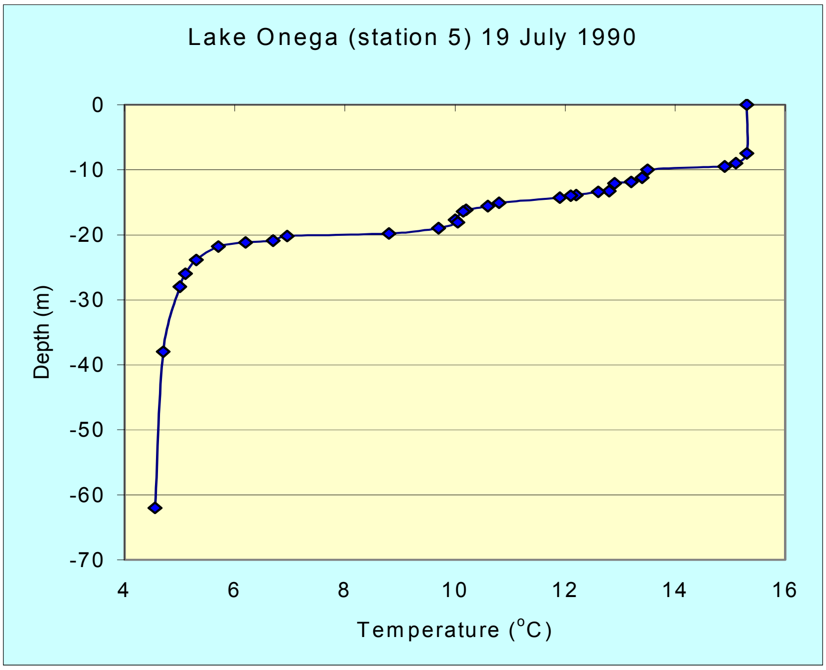

Figure 9. Measurement of the thermal properties in a dimictic lake during summer stratification (Lake Onega, summer 1990, Filatov and Heinonen 1997).

In Lake Onega, which is a very open lake, the summer stratification is very sharp. The first ten meters of the epilimnion are homogenous, the temperature is a slightly greater than 15 ^{o}C. At the depth of 10 to 20 meters the change in water temperature is significant, more than eight degrees. The hypolimnion starts from circa 20 meters. Below 30 meters and to the bottom (some 62 meters) the decrease in water temperature is only some 0.5 ^{o}C.

The significance of the epilimnion is extremely important. You are able with temperature measurements to establish reliable estimations of the thickness, and with a bathymetric map, also the volume of productive epilimnion.

In addition, you require the thickness or volume of the hypolimnion, in which decomposition partly occurs. Without accurate temperature measurements it is not possible for you to make reliable conclusions from analyses results concerning e.g. primary production or oxygenation conditions.

5.3 Some special notices

Sometimes during often repeated vertical measurements of water temperature you may face situations which can be very easily estimated as errors in the practical implementation of measurements. Most common are the situations caused by the so-called seiches phenomenon (Fig. 10) and groundwater inflow to lakes. More seldom are such cases due to the meromixis of lakes.

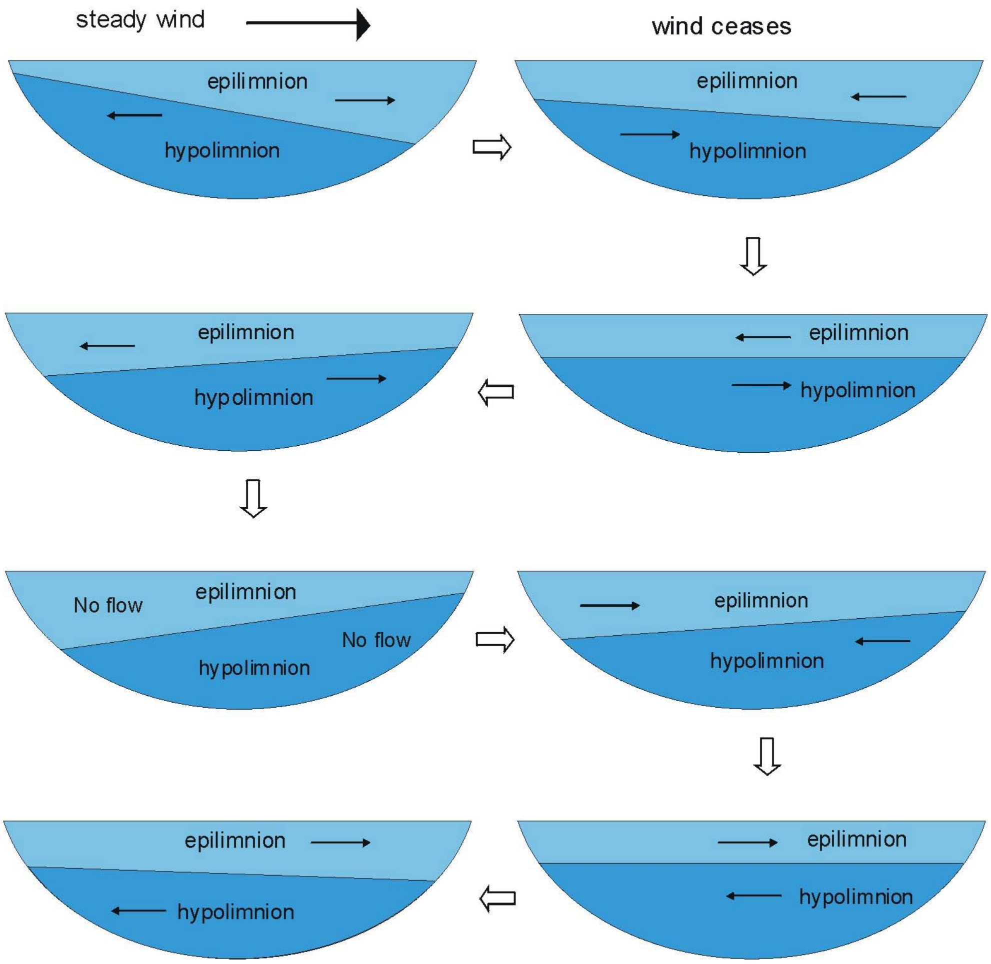

Figure 10. A schematic progress of the seiches in a lake.

Hutchinson (1957) describes the word seiches to express a stationary oscillation of a lake or a large independent part of a lake. Seiche is a French word and translates as something resembling "to sway back and forth". Seiches are sometimes also known as standing waves. The reason for seiches is in most cases any force, e.g. a rapid change in the prevailing wind, atmospheric pressure and heavy rain that pushes water to one end of a basin and then ceases.

There are two different types of seiches, surface and internal seiches. Surface seiches are characteristic of unstratified large and usually long lakes, where a strong wind pushes water to one end of the lake. When the wind then stops the water returns back upwind, and the water oscillates back and forth. The amplitude of oscillation is usually very small compared to internal seiches and the impacts are not important on the chemistry or biology of lake. Surface seiches can be detected on lakes only as small up and down motions.

Internal seiches are characteristic in large, long and stratified lakes. They usually occur when the lake is stratified and involve epilimnetic, hypolimnetic layers and thermocline oscillation in a standing wave. Most frequently internal seiches can be found at the thermocline and they are usually detected by the rise and fall of the thermocline. Internal seiches can are undetectable from the surface. Internal seiches are usually much greater than surface seiches and may be 10 m or even higher. Internal seiches form the major movement of water in the hypolimnion.

During internal seiches temperatures may vary significantly especially at the depth of the thermocline. Internal seiches are important because they transport heat and dissolved substances large distances both vertically and horizontally and may thus significantly alter the distribution, as well as the productivity of phytoplankton and zooplankton through the changes in thermal and chemical stratification.

The other reason for unexpected results in temperature measurements is the relatively warm groundwaters, which inflow to stratified lakes, usually in the cool or cold hypolimnion. Usually they can be detected in the limnologically important and relatively thin water layers very close to the bottom sediments. The water is clearly warmer than the surface water, e.g. during winter stratification you can find temperatures, which are significantly above the theoretical maximum value, + 4 ^{o}C. There are also quite many differences in the chemical status of these layers of groundwater.

One reason for anomalous temperature curves is the phenomenon known as meromixis. Hutchinson (1957) determines the term meromixis as follows: A lake, in which some water remains partly or wholly unmixed with the main water mass at the circulation periods is said to be meromictic. The ordinary lake type is called holomictic.

The reasons for meromixis can be grouped according to Hutchinson in ectogenic, crenogenic and biogenic reasons. Especially in temperate zones, the possibility of finding meromictic conditions in a lake lies with relatively great depths and sheltered location from winds. The continental climate assists the development of meromixis. Most common is the situation of a relatively deep lake sheltered by high mountains during a prolonged winter.

Supporting literature:

Filatov, N. & Heinonen, P. (Eds.). 1997. Results of the Finnish-Russian Joint Study of the Lakes Onega, Ladoga and Saimaa Conducted in the Summer of 1990. The Finnish Environment. International Cooperation 105, 97p. ISBN 952-11-0131-8, ISSN 1238-7312.

Herve, S., 2000. Chemical Variables in Lake Monitoring. In: Hydrological and Limnological Aspects of Lake Monitoring (Eds. Heinonen, P., Ziglio, G. & Van der Beken, A.). John Wiley & Sons, Ltd. Chichester. ISBN 0-471-89988-7. 41-54.

Hutchinson, G.E., 1957. A Treatise on Limnology, Volume I: Geography, Physics, and Chemistry, John Wiley & Sons, New York.

Wetzel. R.G. (2001). Limnology: Lake and River Ecosystems, 3rd edition. Academic Press. ISBN 012744601. 850 p.

SUMMARY of Chapter 5:

- Always start the monitoring of the lake with temperature measurements from the deepest part of the lake.
- Try to determine as accurately as possible the thermocline.
- Plan the final vertical sampling procedure according to thermal information.
- Use temperature data in the assessment of data.

6 CHEMICAL STATUS

6.1 Definitions

This chapter discusses the physical and chemical variables which describe the abiotic part of the water biotope. These are mentioned in the Water Framework Directive (WFD) as supporting physico-chemical quality elements in assessing the ecological status of a water body by biological quality elements (as described in Chapter 7 of these guidelines).

The following chemical and physico-chemical elements, which support the biological elements, are listed in the Water Framework Directive (Annex V):

- General.
- Transparency.
- Thermal conditions.
- Oxygenation conditions.
- Salinity.
- Acidification status.
- Nutrient conditions.
- Specific pollutants.
- Pollution by all priority substances identified as being discharged into the body of water.
- Pollution by other substances identified as being discharged in significant quantities into the body of water.

The WFD provides general definitions for the general conditions in different ecological status of the lakes. If a lake is determined as in high status, the characteristics are as follows:

- The values of physico-chemical elements correspond totally or nearly totally to undisturbed conditions.
- Nutrient concentrations remain within the range normally associated with undisturbed conditions.
- Levels of salinity, pH, oxygen balance, acid neutralising capacity, transparency and temperature do not show signs of anthropogenic disturbance and remain within the range normally associated with undis turbed conditions.

If the lake is already slightly altered due to anthropogenic impact, the lake can be determined to be in good ecological status, if:

- Temperature, oxygen balance, pH, acid neutralizing capacity, transparency and salinity do not reach levels outside the range established so as to ensure the functioning of the ecosystem and the achievemment of values specified for the biological quality elements (as described in Chapter 6).
- Nutrient concentrations do not exceed established levels so as to ensure the functioning of the eco-system and the achievement of values specified for the biological quality elements (as described in Chapter 7).

If the lake is badly altered and polluted, then it must be classified only as of “moderate status”, the definition is, that the conditions should be consistent with the achievement of values specified for the biological quality elements.

6.2 Key features of chemical and physico-chemical quality elements for lakes according to the WFD Guidance on Monitoring

In the Guidance on Monitoring for the Water Framework Directive by the CIS Working Group 2.7 (Monitoring) some systematically gathered and processed information of the different quality elements have been presented. Information on key features of each chemical and physico-chemical quality element for lakes is presented in Table 3 (Table 3.6 in the final CIS Guidance on Monitoring (2003), pages 55-57).

The structure of this table follows Annex V of the WFD by presenting, in the same order, all the quality elements and by then discussing the following topics of all the elements:

- Measured parameters indicative of QE.
- Relevance of QE.
- Pressure to which QE responds.
- Sampling and methodology.
- Standards.
- Applicability of the QE to lakes.
- Main advantages.
- Main disadvantages.
- Conclusions/recommendations.

This table is presented over the following pages (43-45).

Figure 11. Lake Haapajärvi, a eutrophied lake in south-eastern Finland with high phosphorus and nitrogen concentrations.

Table 3. Key features of each chemical and physico-chemical quality element for lakes.

Aspect/feature	Transparency	Thermal Conditions	Oxygenation Conditions	Salinity	Acidification	Nutrients
Measured parameters indicative of QE	Secchi depth, turbidity, colour, TSS	Temperature	DO,TOC, BOD, COD DOC	Conductivity	Alkalinity, pH, ANC	Total P, SRP, Total N, N-NO3, N-NO2, N-NH4
Relevance of quality element	Eutrophication, acidification	Hydrological cycle, biological activity	Production, respiration, mineralisation		Buffering capacity, sensitivity to acidification	Eutrophication
Pressures to which QE responds	Agricultural, domestic and industrial discharges	Thermal discharges. Water management in reservoirs.	Eutrophication, organic pollution, industrial discharges	Industrial discharges, run-off	Acid rain, industrial discharges	Agricultural, domestic and industrial discharges
Level and sources of variability of QE	High, influenced by allocthonous and autocthonous material	High, influenced by climate conditions, topography, morphology and waterbody dimensions	Variable, diel changes due to respiration/ photosynthesis	Low-medium, influenced by climatic events	Low-medium, influenced by climatic events	Low-medium, influenced by climatic events
Monitoring considerations	Seasonal variation	Seasonal variation (mixing and stratification)	Diel variation High gradient in stratified lakes	Seasonal variation	Seasonal variation	Sufficient speciation to enable discrimination (point and diffuse)
Sampling methodology	*In situ* using Secchi disc TSS: field sample collection followed by laboratory analysis Turbidity: *in situ* turbidimeters, nephelometers Colour: *in situ* comparison to Forel-Ule scale or in lab.	*In situ* using thermistor probes or reversing type Hg thermometer	On-line data acquisition; *in situ* submersible probes; field sample collection followed by laboratory Winkler titration	*In situ* using submersible probes	*In situ* measurement of pH with probe. Sample collection followed by laboratory analysis	Sample collection in the field followed by laboratory analysis
Typical sampling frequency	Monthly / quarterly related to the biological elements sampling periodicity. Fortnightly or monthly during growth season in Nordic countries.	Monthly / quarterly	Depends on morphological characteristics of lake: daily/monthly, or at the end of stratification periods (late winter if ice cover or late summer.	Monthly/ quarterly. Should be measured during snow melt or heavy rainfall events	Monthly/ quarterly. Should be measured during snow melt or heavy rainfall events	Monthly/ quarterly Fortnightly of monthly during growth season in Nordic countries.
Time of year of sampling	All seasons.	All seasons	All seasons	All seasons	All seasons	All seasons, or mainly during growth season, SRP also measured during late winter in bottom waters
Typical "sample" size	In-situ observations. Sample collections for chemical analyses (turb, TSS)	Water column profile	Single measurements, water column profiles. 100mL for Winkler titration	In-situ water column profile, integrated epilimnion or single sample from outlet (depending on monitoring purpose)	Single sample from outlet of lake or water column profile	integrated epilimnion, single samples or water column profile (100-500mL)
Ease of sampling /measurements	Simple , using *in situ* probes or surface water sample	Simple, using *in situ* probes or water samplers	Simple, using *in situ* submersible probes or sample collection followed by titration	Simple, using *in situ* probe	Simple	Relatively easy, depth sampler need for deep lakes

Aspect/feature	Transparency	Thermal Conditions	Oxygenation Conditions	Salinity	Acidification	Nutrients
Basis of any comparison of results/quality/stations e.g. reference conditions/best quality	Historical data or data from comparable pristine lakes	Historical data or data from comparable pristine lakes	Historical data or data from comparable pristine lakes	Historical data or data from comparable pristine lakes	Historical data or data from comparable pristine lakes	Statistical methods: MEI index for total phosphorus Historical data or data from comparable pristine lakes
Methodology consistent across EU?	No	No	No	No	No	No
Current use in monitoring programmes or for classification in EU	Yes	Finland, France, Italy, Norway	Finland, France, Italy, Norway Sweden	Finland, Belgium, France, Italy	Belgium, Finland, France, Italy, Norway, Sweden, UK	Germany, Spain, Finland, France, Italy, Ireland, Netherlands, Norway, Sweden, UK
Existing monitoring systems meet requirements of WFD?	No	No	No	No	No	No
Existing classification system meets requirements of WFD?	No	No	No	No	No	No
ISO/CEN standards	No	No	ISO 5813:1983 DO ISO 5815:1989 BOD_5	Yes	Yes, no standard for ANC	Yes, several ISO standards exist
Applicability to lakes	high	High	High	Moderate	High	High
Main advantages	• Simple to sample • It is possible the most universally used parameter in limnology: it is a simple and powerful tool for tracking long-term trends	• Simple to measure • Fundamental to understand the hydrological cycle and lake ecology	• Simple to sample and to measure • Extremely useful because it can act as an integrator of the lake health	• Simple to measure • Conductivity is little influenced by anthropogenic inputs. A good correlation was found with the MEI cond and P concentration allowing the determination of natural background (reference) concentrations for P	• Simple to measure • Provides long term trends in acidification • Alkalinity is little influenced by anthropogenic inputs(except in acidified and limed lakes). A good correlation was found with the MEI alk and P concentration allowing the determination of natural background (reference) concentrations for P	• Provide information and long-term information on the trophic state
Main disadvantages	• No disadvantages	• May require intensive monitoring for appropriate description of thermal conditions	• May require intensive monitoring following depletion events in stratified lakes	• Does not provide long term information on trends	• None	• Need for standardisation of analytical techniques

Aspect/feature	Transparency	Thermal Conditions	Oxygenation Conditions	Salinity	Acidification	Nutrients
Conclusions/ recommendations	Easy to monitor. The Secchi disc is widely used in limnology for assessing the biological condition of lakes. However, in humic lakes Secchi disc is not useful for assessment of eutrophication..	Important supporting parameter for interpreting ecological conditions. Seasonal variation, variation with depth and in large lakes horizontal variation should be monitored.	Recommended, and particularly important in deep/stratified lakes and lakes with ice cover.	Important for at characterisation of a lake. For example, it gives an indication of lake mixing processes and of metabolic activity of the lake.	Important for lake characterisation. Acidity is important because it governs the chemical form which metals occur in water body. Alkalinity and Its related variables, pH and conductivity are important classification parameters	Very important indicator for human activity/eutrophication. Total N and P, nitrate and orthophosphate should be monitored as a minimum. Ammonia monitored where concentrations are expected to be problematic e.g. exceedences of limit values over a specific limit. Phosphorus is most often considered to be the nutrient that determines algal production in lakes Thus the focus is mainly on P with regards to lake eutrophication. Nutrients should be monitored not only in water but also in sediments where sediment water interchange processes are expected to be important

6.3 The physical variables

From physical measurements one of the oldest, and remaining useful, is the Secchi disc transparency method (Hutchinson 1957). The procedure of this method is rather simple in that you have to estimate how deep you can see. A white disk, usually only 10x20 cm large is let from the surface down, and the depth at which the desk just disappears from view, is referred to as the Secchi depth. Usually it is determined at the depth at which it can be seen again when it is lifted upwards. The mean value of these two depths is the final value for Secchi disc transparency.

However, this method provides a fairly good estimate of the transmission of light to water. Values obtained from the Secchi disc transparency method can be used e.g. in the estimation of the trophogenic layer of the lake, and in naturally very clear lakes also in monitoring the eutrophication trend, due to the fact that algal population decreases the Secchi depth.

In the clearest oligotrophic lakes Secchi disc transparency values can be as deep as 20 meters, although values of 10-20 meters are more common. However, the situation is quite different in Nordic lakes where natural humic substances decrease Secchi disc transparency quite significantly. In polyhumic lakes of natural status Secchi disc values as low as 0.5-1.0 meters have been measured. The water colour because of humic compounds is so dark, that the primary production by algae is limited already at the depth of one meter.

Water colour is the other current physical characteristic, which has been used for a long time in lake monitoring. It is a very useful and cheap method especially in humic waters to evaluate the content of humic substances. Water colour is expressed in a water colour number, which provides values compared to a certain standard (usually prepared of platinum (Pt) and cobalt (Co) chlorides and expressed as Pt units).

In heavily polluted waters it is advisable to measure also the so called true colour after filtration and apparent colour before filtration.

Very clear waters have a colour number very close to zero. The maximum values of colour number have been measured in dark polyhumic small lakes surrounded by peat bogs. Colour numbers over 300 Pt units are not rare in such waters.

6.4 Oxygenation conditions

Oxygen is without doubt the most important gas that dissolves in water from the atmosphere, owing to the fact that it is the dominant biotope factor regulating life in waters. The solubility of oxygen in water is directly proportional to the partial pressure in the gas phase, and decreasing in a nonlinear manner with increasing temperature. In a very flat country such as Finland, we are taking into consideration only the temperature of water in calculating oxygen saturation.

The samples for oxygen determinations are always taken as vertical series starting from the uppermost layer in the epilimnion (usually one meter) and finishing in the hypolimnion at a depth that is one meter above the bottom sediment. The number of samples required for the estimation of the oxygen budget of the lake depends totally on the thermal stratification of the lake. During circulation periods the oxygen status can be measured by less samples than in the case, where the difference between epilimnetic and hypolimnetic temperatures is great.

Oxygen concentration is determined by the titrimetric method starting from analysis already in the field after the vertical measurements of temperature. The results are expressed as mg/L or as percentages of the saturation values (Fig. 12).

In oligotrophic lakes the difference between epilimnion and hypolimnion in oxygen concentrations is relatively small. This also applies to deep lakes. The oxygen curve is called the orthogradic. In eutrophied lakes the situation is quite different. In epilimnion primary production is dominant, and therefore also the oxygen content may increase significantly. Saturation values over 150% are not rare in hypereutrophic lakes. On the contrary, in hypolimnion the decomposition of organic matter produced in primary production is dominant. The oxygen concentrations are decreasing.

The oxygen situation in a polluted or eutrophied lake is changing during a long wintertime. In the beginning of the winter, after autumn circulation, the oxygen concentrations may be quite normal throughout the whole water mass. During winter the intensity of oxygen consumption is highest near the bottom layer, where the temperature is highest. During a long winter consumption may lead to a total oxygen deficit. Oxygen concentration is a very good variable in monitoring the long term trend of water quality in polluted or eutrophied lakes.

The other gas measured in lake monitoring is carbon dioxide (CO_2). There is a certain balance between oxygen concentration and carbon dioxide concentration, because the changes of these gases in lakes are significantly connected to biological reactions.

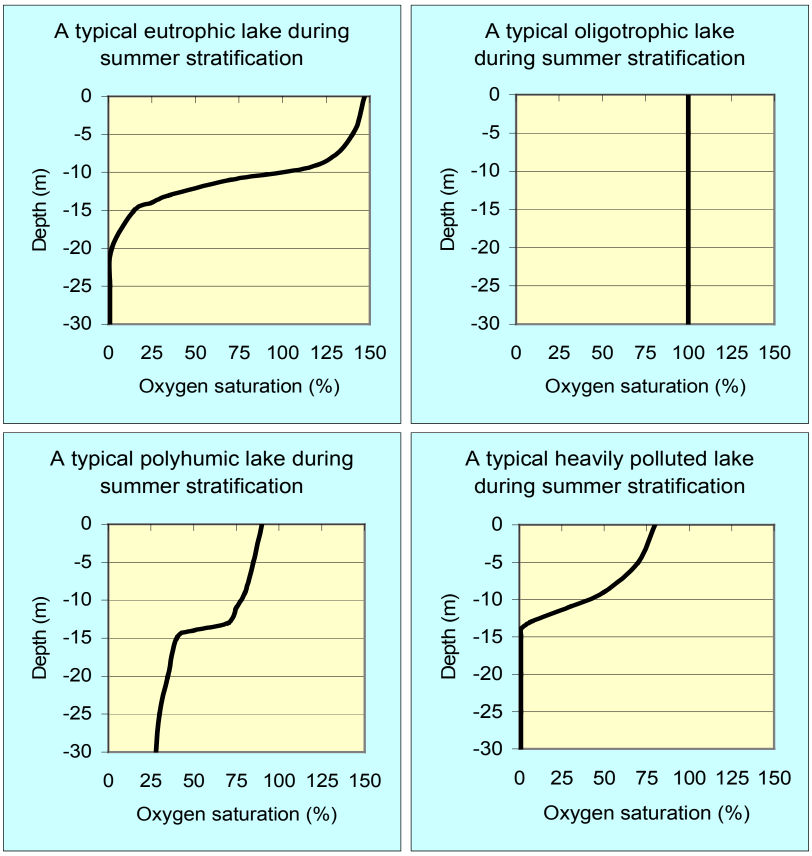

Figure 12. The oxygen status in different types of lakes.

The organic matter of lake waters is determined directly by analyzing TOC (total organic carbon) or, more frequently, indirectly by analyzing the biochemical oxygen demand ($BOD_{5 \text{ or } 7 \text{ days}}$) especially from rivers, or the chemical oxygen demand (usually COD_{Mn} measured with potassium permanganate, or COD_{Cr} measured with dichromate).

The natural humic substances may in most Finnish lakes increase COD_{Mn} and COD_{Cr} values. In addition, the variations between different seasons may be of great amplitude. Some estimations of the concentrations of organic matter can also be drawn from the water color and Secchi depth transparency measurements.

6.5 Salinity

The salinity of lake waters depends primarily on the quality of the bedrock, the soil of the water shed, where the lake is situated and from where its water source. There are great differences in salinity between different geological areas. Fresh waters contain alkali and alkaline earth bicarbonate and carbonate, sulfate, chloride in dilutions and largely undissociated silicic acids. In smaller quantities there are a great number of different elements (such as important nutrients phosphorus and nitrogen, as well as aluminium, iron, manganese, copper, zinc, etc.), which can be measured everywhere in the globe.

The considerable fluctuation in the salt concentration of lake water is resulting from its changeable water level. Long term alterations are also detectable in the proportion of individual ions. A drop in the water level can bring about the drainage of large marginal areas and salt concentration may rise rapidly. The evaporation and evapotranspiration of lake water can also increase the salt content. On the other hand, heavy rain can lead to a decrease in salinity.

The number of algae species is mainly due to the chemistry of the lake and to its strong fluctuation. The strong concentration processes of ions in the desiccation periods also exert as a selective effect of algal species (*Moina rectirostis* can tolerate high salinities, *Rotatoria laticeps*, and *Lecane nana* are also saltwater forms).

Estimation of salt concentration can easily be performed by measuring the electrical conductivity, because there is a firm relationship between salt concentration and electrical conductivity. The conductivity of water is seen in its ability to carry an electric current. It depends on the ion concentrations of water. The greater the number of ions results in higher mobility and a higher level of conductivity. Pure water dissociation is very low making a bad conductor resulting in low conductivity. Conductivity is expressed in units of microSiemens/cm (µS/cm) or milliSiemens/m (mS/m). Conductivity is an easy, but in some cases very informative indicator for e.g. the increase of eutrophication. The first signs can be found usually in the hypolimnion during the stratification periods.

The most common elements which have been monitored from inland surface waters are sodium, potassium, calcium, magnesium, chlorine and sulphur.

Sodium (Na) in water exists principally as the cat ion Na^+. The range of in inland waters is from some mg/L to several hundreds of mg/L.

Potassium (K) does not exist in nature as a free element, it forms salts as chloride, bromide, sulphate, nitrate and aluminium silicates. Potassium is an essential element for plant growth.

Calcium (Ca) is the fifth most abundant element in rocks and soils on the earth. In surface waters calcium is one of the most abundant cat ions because of the weathering of rocks and soils. It is largely as the Ca^{2+} ion but complexes can also occur. The cc. of calcium in surface waters is usually no greater than 1000 mg/L.

Magnesium (Mg) is the eighth most abundant element on the earth. In water it exists largely as Mg^{2+} ion. It also forms complexes.

Chlorine (Cl) does not occur free in nature. The chloride ion is the principal ion in sea water. The chloride ion is widely distributed in the environment as salts with sodium, potassium and calcium.

Sulphur (S) is the ninth most abundant element on the earth. Sulphur compounds are widely distributed in minerals and rocks. In water, sulphates occur mainly as free anion SO_4^{2-}, and form ion pairs with Ca^{2+}, Mg^{2+}, Na^+, Fe^{2+}, Fe^{3+} and Mn^{2+}.

In connection with drinking water supply many times the variable water hardness is used. Water hardness expresses the sum of all the metallic cat ions, except for alkali metals. The principal ions responsible for water hardness are calcium and magnesium. The following types of water hardness are commonly used:

- Total hardness is equivalent to the total concentration of Ca^{2+} and Mg^{2+}, as well as the other bivalent ions such as Fe^{2+}, Mn^{2+}, Ba^{2+} and Sr^{2+}.
- Carbonate hardness.
- Non-carbonate hardness.

In the monitoring of lakes it is important to define the natural status of the salinity and the natural concentrations of the relevant elements. In the preparation of the monitoring programmes all possible sources of loading factors in this sense should be clarified.

6.6 Acidification status

The acidification of lakes is a real risk especially in countries where the natural salt concentration is low as is the case in Finland, Sweden and Norway. Original alkalinity values are very small, and the buffering capacity therefore is extremely low. Because of relatively high concentrations of natural humic substances, the original pH is usually distinctly below 7.0. Airborne loading of different acidifying compounds such as sulphates and nitrates can lower pH values significantly so that harmful biological consequences occur. Especially some fish species are very sensitive to acidification.

The important variables in monitoring of acidification are pH and alkalinity. Acid Neutralizing Capacity (ANC) measurements analysed by Gran alkalinity have been a very useful tool in estimating the possible trends in the acidification phenomena of lakes with a low buffering capacity. The base cat ion level (Ca+Mg+Na+K) is also a suitable variable in estimating lake water sensitivity to acidification (Mannio 2000).

Non-filtered samples are generally preferred for lake waters. The essential determinands are those that define the degree of and causes behind the acidification of surface waters. In the group of suitable characteristics are HCO_3^- or alkalinity, SO_4^{2-}, NO_3^-, Cl^- and TOC/DOC.

Correspondingly, in the group of cat ions the following variables are very useful for monitoring: Ca^{2+}, Mg^{2+}, K^+, Na^+, H^+ and Al^{n+} (labile Al [2]).

6.7 Nutrient conditions

Nitrogen and phosphorus are the major nutrients causing eutrophication of surface waters. These nutrients originate partially from natural sources but mainly from the anthropogenic sources in areas affected by various human activities. Nitrogen loading is mainly due to diffuse sources such as agriculture while phosphorus loading is dominated by point sources such as municipal sewage waters or industrial effluents.

Excessive loading of nitrogen and phosphorus may drastically change the biological structure of a water body leading up to undesirable phenomena such as blue-green algal blooms, pronounced overgrowth of macrophytes, or even fish kills caused by intensive decomposition of organic material and subsequent oxygen deficiency in the water column. In most cases, phosphorus is the limiting nutrient for algal growth in lakes, especially in oligotrophic-mesotrophic conditions. The regulating role of nitrogen becomes more important in eutrophic or hypertrophic lakes and marine waters.

An example of a long lasting monitoring case is presented in Fig. 13. Lake Pyhäjärvi in southern Finland was loaded especially by intensive agriculture. The trend was clear eutrophication up to the last years of 1980s. After limitation of phosphorus in agriculture, together with so called "Good agricultural practice", the trend is now significantly decreasing.

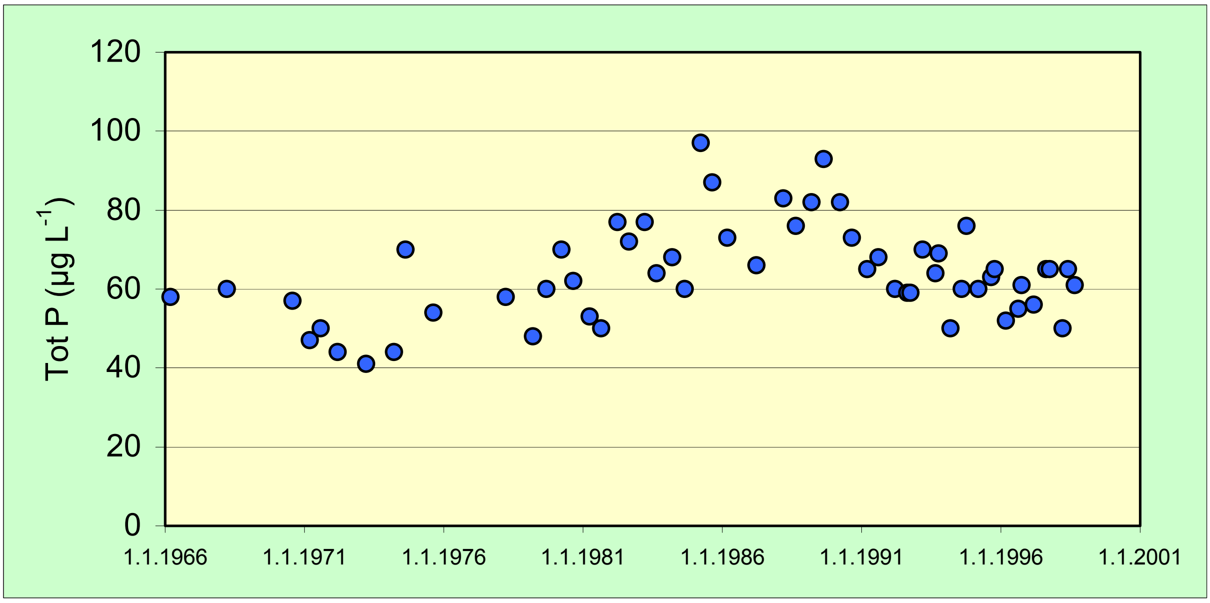

Figure 13. Total phosphorus concentrations at the depth of 35 metres (total depth 68 metres) of Lake Pyhäjärvi (Artjärvi municipality, southern Finland) in spring (March) and autumn (August) .

The same situation can be observed with total nitrogen (Fig 14). The earlier threatening trend towards bad eutrophication status has positively reversed.

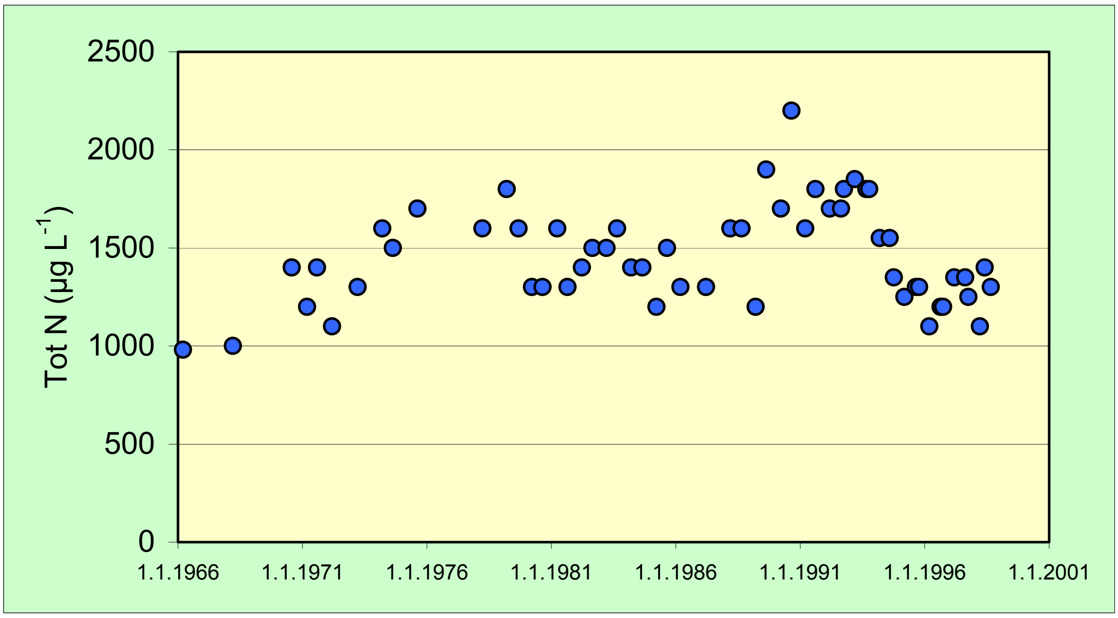

Figure 14. Total nitrogen concentrations at the depth of 35 metres (total depth 68 metres) of Lake Pyhäjärvi (Artjärvi municipality, southern Finland) in spring (March) and autumn (August).

Most primary producers (e.g. phytoplankton, periphyton and macrophytes) can only utilize dissolved forms of nutrients such as ammonium, nitrite, nitrate, urea and phosphate. Therefore, the total concentrations of nitrogen and phosphorus do not necessarily reveal the limiting nutrient of the lake ecosystem. In many temperate lakes, for example in Scandinavia, a great proportion of nitrogen is bound to humus which can not be directly utilized by most primary producers. The actual bioavailability of nutrients is also affected by varying levels of alkalinity, ionic balances and particulate matter content in the water column (EEA 1998).

The most pristine and nutrient-poor lakes in Europe are found in sparsely populated regions such as northern Scandinavia or mountainous regions such as the Alps. The severest polluted lakes are situated in densely populated and/or intensively cultivated agricultural areas in western and central Europe. Average phosphorus concentrations in a typical Scandinavian lake is below 25 µg L^{-1} while the levels in central European lakes often exceed 100 or even 500 µg L^{-1} (EEA 1998). The variation of nitrogen concentrations in lakes across different geographical regions is not as clear as in the case of phosphorus.

The state of European lakes seems to be gradually improving (EEA 1998). Despite clear improvements in waste water treatment and recent adaptations of environmentally-friendly agricultural practices, the levels of phosphorus and nitrogen are usually clearly higher than would be accepted from the point of sustainable development of water resources.

More information of the eutrophication situation is arrived at by using an easy chemical variable demonstrating phytoplankton biomass, i.e. chlorophyll *a*, together with nutrients. The correlation between different nutrients and chlorophyll *a* can provide a good basis for discussions of the relevant minimum factors of primary production (Fig. 15).

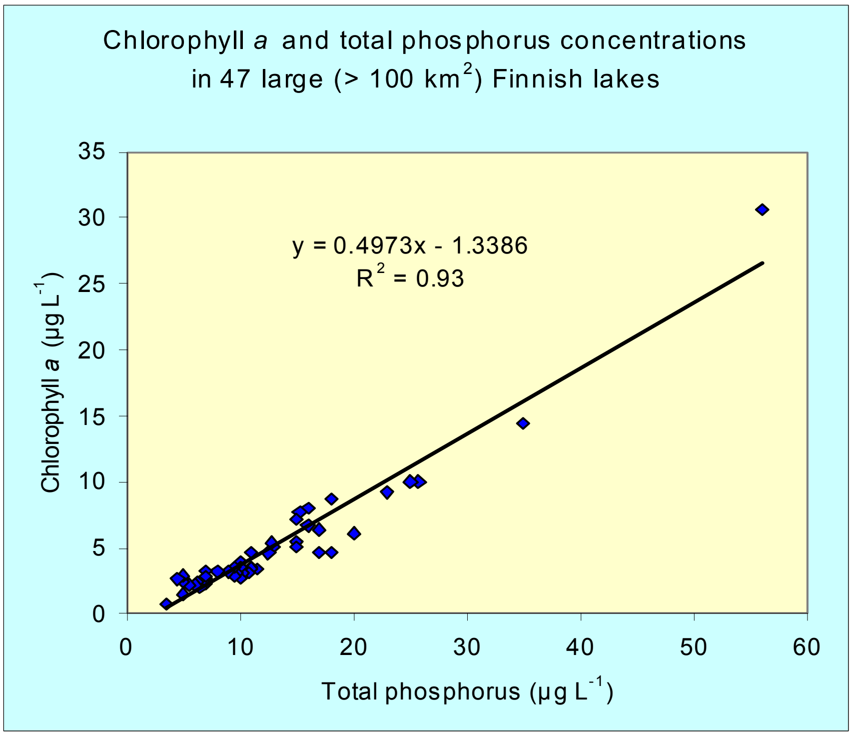

Figure 15: The relationship between total phosphorus and chlorophyll *a* concentrations in large Finnish lakes. The data refers to the surface water samples (0 – 2 m) taken during the summer periods (June – August) in 1990 – 1997. (The figure is based on subdata from Pietiläinen and Räike 2001).

In monitoring, total phosphorus and phosphate-phosphorus are determined by photometric means. In cases where nitrogen may also play a meaningful role in the eutrophication processes, especially in lakes with a higher eutrophic level, the most important nitrogen compounds in monitoring are NH_4-N and NO_3-N. Analyses of these compounds are carried out with spectrophotometry. Total N is also determined.

Supporting literature:

CIS Guidance on Monitoring 2003. Water Framework Directive. Common Implementation Strategy, Working Group 2.7, Monitoring. Final Version. 23 January 2003, 164 p.

Bartram, J. & Ballance. R. (2001). Water Quality Monitoring. A practical guide to the design and implementation of freshwater quality studies and monitoring programmes. Spoon Press, London. ISBN 0419223207. 383 p.

Heinonen, P., Ziglio. G. & Van der Beken, A. (Eds.) (2000). Hydrological and Limnological Aspects of Lake Monitoring. John Wiley & Sons, Ltd. Chichester. ISBN 0-471-89988-7. 372 p.

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Hutchinson, G.E. (1975). A treatise on limnology, Volume 2. Introduction to lake biology and the limnoplankton. John Wiley & Sons, New York.

Mannio, J. (2000). Principles of Monitoring the Acidification of Lakes. In: Heinonen, P., Ziglio. G. & Van der Beken, A. (Eds.) (2000). Hydrological and Limnological Aspects of Lake Monitoring. John Wiley & Sons, Ltd. Chichester. ISBN 0-471-89988-7. pp. 247–255.

Pietiläinen, O.-P. & Räike, A. (2001). Water quality trends of large Finnish lakes during 1970–1999. In: Timmermann, G. et al. (Eds.) Proceedings of Monitoring Tailor-made III, International workshop on information for sustainable water management, September 2000, Nunspeet, the Netherlands, pp. 267–276.

Wetzel, R.G. (2001). Limnology: Lake and River Ecosystems, 3rd edition. Academic Press. ISBN 012744601. 850 p.

SUMMARY of Chapter 6

- Acquaint yourself with the chemical and physico-chemical determinants, which are necessary in implementation of the WFD.
- Secchi disc transparency and water colour measurements are required to define the illumination situation of the lake.
- Remember the role of natural humic substances.
- The vertical measurements of oxygen concentrations (with corresponding temperature observations) are of great importance in assessing the status of the lake.
- TOC or COD measurements are needed to clarify the possible organic loading (natural and anthropogenic) of the lake.
- Phosphorus and nitrogen measurements are needed to estimate the eutrophication situation of lakes.

7 ECOLOGICAL STATUS

7.1 Definitions

The Water Framework Directive has taken into use the term “Ecological status”. According to the definitions, "Surface water status" means the general expression of the status of a body of surface water, determined by the poorer of its ecological status and its chemical status. “Ecological status" is an expression of the quality of the structure and functioning of aquatic ecosystems associated with surface waters, classified in accordance with Annex V (this Annex is an important part of the WFD concerning monitoring obligations).

The biological elements for classification of the ecological status in lakes are in accordance with the WFD and they are as follows:

- Composition, abundance and biomass of phytoplankton.
- Composition and abundance of other aquatic flora.
- Composition and abundance of benthic invertebrate fauna.
- Composition, abundance and age structure of fish fauna.

These biological elements are discussed in the following sub chapters.

7.2 Key features of biological elements for lakes in accordance with the WFD Guidance on Monitoring

The use of non-biological indicators for estimating the condition of a biological quality element may complement the use of biological indicators but it may not replace it. Without comprehensive knowledge of all the pressures on a water body and their combined biological effects, direct measures of the condition of the biological quality elements using biological indicators will always be necessary to validate any biological impacts suggested by non-biological indicators.

In the Guidance on Monitoring for the Water Framework Directive drawn up by the CIS Working Group 2.7 (Monitoring), some systematically gathered and processed information of the different quality elements have been presented. The same information on the key features of each biological quality element for lakes is presented in Table 4 (Table 3.4 in the final CIS Guidance on Monitoring (2003), pages 48-51).

The structure of this table follows the Annex V of the WFD by presenting, in the same order, all the quality elements (QE) and by then discussing the following topics of all the elements:

- Measured parameters indicative of QE.
- Supportive/interpretative parameters often/typically measured or sampled at the same time.
- Pressure to which QE responds.
- Sampling and methodology.
- Standards.
- Applicability of QE to lakes.
- Main advantages.
- Main disadvantages.
- Conclusions/recommendations.

This table 4 is presented on the following pages 54-57.

Table 4. Key features of each biological quality element (QE) for lakes.

Aspect/feature	Phytoplankton	Macrophytes	Phytobenthos	Benthic invertebrates	Fish
Measured parameters indicative of QE	Composition, abundance biomass (Chla), blooms	Composition and abundance	Composition and abundance	Composition, abundance, diversity and sensitive taxa	Composition, abundance, sensitive species and age structure
Supportive/interpretative parameters often/typically measured or sampled at the same time	Nutrient concentrations (total/soluble), chlorophyll, DO, POC, TOC, pH, alkalinity, temperature, transparency, Fluorometric in-situ monitoring	Nutrient concentrations (total/soluble) in lake water, sediment and pore water, substrate type, pH, alkalinity, conductivity, transparency, Secchi disc, ca concentration	Nutrient concentrations (total/soluble) in lake water, sediment and pore water, substrate type, pH, alkalinity, conductivity, transparency, Secchi disc, ca concentration	Nutrient concentrations (total/soluble), DO, pH, alkalinity, sediment analysis, toxicity bioassays	Nutrient concentrations (total/soluble), DO, pH, alkalinity, temperature, toxicity bioassays, trophic condition, Zooplankton dynamics, ANC, TOC
Pressures to which QE responds	Eutrophication, organic pollution, acidification, toxic contamination	Eutrophication, acidification, toxic contamination, siltation, river regulation, lake water level, introduction of exotic species	Eutrophication, acidification, toxic contamination, siltation, river regulation, lake water level, introduction of exotic species	Eutrophication, organic pollution, acidification, toxic contamination, siltation, river regulation, hydro-morphological alteration (littoral)	Eutrophication, acidification, toxic contamination, fisheries, hydromorphological alteration, Introduction of exotic species
Mobility of QE	Medium	Non-mobile	Non-mobile	Low to Medium, high when hatching	High
Level and sources of variability of QE	High inter and intra seasonal variation in community structure and biomass. Medium to high spatial variability	Medium-high seasonal variability in community structure and biomass. High spatial variability	Medium-high seasonal variability in community structure and biomass, low interannual variability. High spatial variability	Medium-high seasonal variability in community structure and biomass. High spatial variability	High spatial and seasonal variability. Populations clumped in respect to habitat variables
Presence in lakes	Abundant	Abundant, rare in reservoirs	Abundant, rare in reservoirs	Abundant	Abundant
Sampling methodology	Integrated or discrete samples in the water column. 1-5 sites per lake. A number of sampling gear are commonly used such as hand-held bottles or flexible hose	Aerial photography or/and transect sampling perpendicular to the shore line	In-situ observations of occurrence of natural substrate in littoral zone and/or among macrophyte beds as well as scraping of sub-strata	Qualitative or semi-quantitative hand net or kick-sampling; Ekman grab or core sampling. Gear type depends on type of substrate, e.g. submerged aquatic vegetation – dip net; sand and clay - Peterson, Van Veen grabs; mud – Ponar, Ekman grabs	Electrofishing Net captures, several types (e.g. gill nets, trammel net) Trawls Acoustic
Habitats sampled	Water column (i.e. epilimnion, euphotic zone, metalimnion)	Macrophytes: littoral zone	Benthic substrata/ artificial substrata	Littoral, sub-littoral and profundal	Littoral, open waters
Typical sampling frequency	Monthly/ quarterly In Nordic countries 6 times/summer	Yearly (late summer in Nordic countries), in natural lakes every 3-6 years	Varied from several times during the growing season to once a year	Yearly, in natural lakes every 3-6 years Twice yearly in littoral	Depend upon water body physical characteristics and objective, yearly
Time of year of sampling	All seasons, at least twice a year during spring overturn and summer stratification In Nordic countries, no sampling during ice coverage. More stations required if high spatial variation.	Late summer, decided through expert judgement	Quarterly/ 6 monthly/ several times during the growing season. In Nordic countries no sampling during ice coverage	Early spring and late summer	Late spring through to early autumn

Aspect/feature	Phytoplankton	Macrophytes	Phytobenthos	Benthic invertebrates	Fish
Typical sample effort	Often 1 station located in the centre of the lake	3-10 transects per lake with 2-3 quadrants on each transect should be sufficient for the majority of the lakes	Lake wide, 3-10 transects, littoral to sub-littoral	Lakewide composite samples of 2/ 3 grabs at each of 3-5 sub-littoral sites (7-15 grabs total	Dependent on type of sampling gear: For electrofishing multiple habitats are selected in littoral areas based on the substrate and cover. CEN-standard in preparation. In shallow lakes fish can be sampled with multimesh gillnets and random sampling. Sampling time 10-12 h overnight. Time less in small lakes and those where fish densities are high. In deeper lakes stratification related to depth zones is recommended. CEN standard under development
Ease of sampling	Relatively simple	Variable, requires specialised sampling equipment and relatively specialised personal with diving qualifications. Alternative methods can be used such as drop cameras/ROV/Rakes.	Relatively simple, some difficulty in deep lakes, boat required and expert knowledge of potential hazards in specific lakes	Relatively simple, some difficulty in deep lakes, boat required and expert knowledge of potential hazards in specific lakes	Difficult, requires specialised sampling equipment
Laboratory or field measurement	Laboratory sample preparation followed by identification, counting and biomass determination under microscopy. Algal toxin determinations in laboratory, chlorophyll a.	Field measurements through aerial photography; samples from transects, laboratory identification to species; analysis of chl-a content, fresh, dry and ash free dry biomass (AFDM), organic content		Sample processing in the laboratory, at least 100 organisms per subsample (if possible) are identified to the appropriated taxonomic level frequently to species	Sampling duration and area or distance sampled are recorded in order to determine the level of effort. In the laboratory the specimens are identified to species, enumerated, measured, weighted and examined for the incidence of external abnormalities
Ease and level of Identification	Relatively simple for measures based on high taxonomic levels (e.g. family), difficult for identification to lower taxonomic levels (i.e. genus and species). Biomass evaluation is difficult	Identification to species relatively easy with exception of vegetative stages of certain genera (e.g. Potamogeton)	Identification to species relatively easy for high taxonomic groups (e.g. family), difficult for genus or species. Biomass evaluation difficult.	Relatively simple for measures based on high taxonomic levels, difficult for identification to lower taxonomic levels (i.e. species)	Relatively easy, some difficulties may appear with rare specimens and early fry
Nature of reference for comparison of quality/samples/stations	Estimates of phytoplankton indicators/ indices (e.g. cell density, biovolume) to be expected in the absence of significant anthropogenic pressures	Reference values refer to typical indicator values (TRS) and species diversity of flora in lakes not significantly affected by human activities	Little knowledge of reference conditions for phytobenthos in lakes. No established methodology	Reference values for the diversity, abundance and distribution indices indicate expected conditions if the lakes are not significantly affected by human activities. References set using the 25 percentile of sites considered unimpaired-Sweden.	Difficult to determine because only impacts of the physico-chemical and hydromorphological pressures are to be addressed not fisheries/ stocking/ species introductions

Aspect/feature	Phytoplankton	Macrophytes	Phytobenthos	Benthic invertebrates	Fish
Methodology consistent across EU?	No	No	No	No	No
Current use in biological monitoring or classification in EU	Denmark, Finland, Ireland, Netherlands, Sweden, UK and Norway	Denmark, Netherlands, Sweden, UK for conservation and Norway	No	Finland, Netherlands, Sweden and Norway	Finland, Netherlands, Sweden and Norway
Current use of biotic indicators and indices/scores	Taxonomic analyses (e.g. diversity indices, taxa richness, indicators species) Phytoplankton total volume, presence of spring diatom blooms, occurrence of harmful algae, number and proportion of toxin- producing cyanobacteria (blue-greens)	Trophic Ranking Score (TRS), species with low TRS values occur primarily in waters poor in nutrients, while high values are associated with eutrophic waters); level of diversity. Relative occurrence of functional groups. Macrophyte Trophic Index (TIM)	No	Shannon's diversity index (measure of variation and dominance within animal communities); ASPT index (Average Score Per Taxa, related to the occurrence of sensitive (high index value) and tolerant (low value) species); Danish fauna index (evaluation of the effects of eutrophication and organic pollution in the exposed littoral zone of lakes); Benthic Quality Index (BQI, to evaluate eutrophication and organic pollution in the deep bottom areas); O/C Index (complementary or alternative to BQI); acidity index (reflects the presence of species with varying pH tolerances)	Index of Biotic Integrity (IBI) incorporates measurements of fish assemblage composition and relative abundance; % of piscivore/ zooplanktivore (a surrogate for age structure of fish community); % of invertevore/ omnivore
Existing monitoring system meets requirements of WFD?	No	No	No	No	No
ISO/CEN standards	Under development	Under development	Under development	Under development	Under development
Applicability to lakes	High	High (very low in reservoirs)	High (moderate in reservoirs, depending on water management)	Moderate	High (moderate to low in reservoirs).
Main advantages	• Easy to sample. • Relevant for water quality and trophic state. • Used in many countries to evaluate eutrophication. • Easy to standardise.	• Easy to sample and identify (especially in shallow water). • Good indicator of a broad range of impacts, especially eutrophication and siltation.	• Easy to identify at family level • Good indicator of eutroph cation	• Easy to sample (particularly in shallow waters). • Relatively simple to anal yse. • Some existing methods developed. • Combines chemical and biological features	• Possibility of adapting classification systems to incorporate the requirements of the WFD

Aspect/feature	Phytoplankton	Macrophytes	Phytobenthos	Benthic invertebrates	Fish
Main disadvantages	• Requires taxonomic expertise for species identification. • High temporal variability requires frequent sampling. • Vertical and horizontal sample profiles required due to spatial heterogeneity.	• Difficult to sample in deep waters. • Not commonly used in EU. • Lack of information for comparison to reference. • Methodology needs to be developed to incorporate the requirements of the WFD.	• No standard methods. • Lack of information for comparison to reference conditions. • Not commonly used in EU. • Methodology needs to be developed to incorporate the requirements of the WFD	• Not commonly used in EU. • Lack of information for comparison to reference. • Methodology needs to be developed to incorporate the requirements of the WFD. • Time consuming and expensive to analyse.	• Requires specialised sampling equipment. • Methodology needs to be developed to incorporate the requirements of the WFD.
Conclusions/ recommendations	Responds rapidly to changes in phosphorus concentration levels. Identification to order or genus are suitable/ recommended levels for monitoring phytoplankton taxonomic composition. While at present it is not clear that identification to species represents a substantial improvement of the information value of the data. More work required in this area.	Key parameter for evaluating other biological components in lakes. Macrophytes hold an important role in the metabolism of lakes. However, their monitoring is not frequently used in the assessment of ecological quality.	The phytobenthos holds an important role in the metabolism of lakes. However, there is very little experience and information on the use of phytobenthos. Further work is required in this area.	Important parameter for evaluating other biological components. Their use is at an early stage of development. It is required to develop meaningful methodologies. The drafting of a suitable guideline is the part of method development of CEN. The CEN group recommends that the identification of benthic invertebrate fauna should be carried out to the species level.	Key biological quality element. Can be difficult to interpret (fishery, biomanipulation etc.) Integrate all anthropogenic and natural impacts. The composition, abundance and structure of fish communities can be very useful indicators of ecological quality. Fish are only included in monitoring systems of very few EU member states.

7.3 Phytoplankton

Plankton algae are the most important group of primary producers in a lake. As planktic algae have very short generation times they also react rapidly to shifts in the environment. Changes in the physical and/or chemical status of the water are traced after some weeks through alterations of the species and their abundances (Willén 2000).

The amount and the species composition of algal biomass is significantly dependent on growth factors such as temperature and the concentrations of different nutrients. The minimum nutrient in freshwaters is in most natural lakes usually phosphorus. The highest density of algae can be found in the uppermost level of lake known as epilimnion.

The reaction of planktic algae to environmental changes

The following changes in the planktic algal community is expected in a trophic gradient of increased nutrient availability (according to Willén 2000):

- Increasing biomasses.
- A prolonged waterblooming season.
- Increasing biomass variations within the growth season of a year.
- A change in size structure of the community, the proportion of large species increases and many are considered as stresstolerants.
- A decreasing evenness and a few species become dominant.
- Species richness decreases especially in hypertrophic environments.
- A changed structure among the algal classes.
- A changed structure in the species composition.

In the suggested classifications of ecological water quality in Europe, based on the biota, mass-developing cyanobacteria are almost always considered. When these water-blooms occur during longer periods they are used as an indicator of poor or bad water quality (Nixon et al. 1996).

A massive water-bloom is not only an ecologically inferior phenomenon it also has a negative impact on the use of water by restraining open-air activities and by decreasing the production of fish used for consumption. It also affects the use of water in drinking water supplies (Willén 2000).

The WFD provides general definitions for phytoplankton in different ecological status. If the lake will be determined to be in high status, the characteristics of phytoplankton are as follows:

- The taxonomic composition and abundance of phytoplankton correspond totally or nearly totally to undisturbed conditions.
- The average phytoplankton biomass is consistent with the type-specific physical-chemical conditions and is not such as to significantly alter the type-specific transparency conditions.
- Planctonic blooms occur at a frequency and intensity which is consistent with the type specific physical-chemical conditions.

If a lake is already slightly altered due to anthropogenic impact, then the lake can be determined to be in good ecological status, if:

- There are slight changes in the composition and abundance of planctonic taxa compared to the type-specific communities. Such changes do not indicate any accelerated growth of algae resulting in undesirable disturbance to the balance of organisms present in the water body or to the physical-chemical quality of the water or sediment.
- A slight increase in the frequency and intensity of the type specific planktonic blooms may occur.

If the lake is so badly eutrophied, in that it must be classified only at the class of “moderate status”, the phytoplankton can be described as follows:

- The composition and abundance of planctonic taxa differ moderately from the type-specific communities.
- Biomass is moderately disturbed and may be such as to produce a significant undesirable disturbance in the condition of other biological quality elements, and the physico-chemical quality of the water or sediment.
- A moderate increase in the frequency and intensity of planktonic blooms may occur. Persistent blooms may occur during summer months.

In classification of lakes the phytoplankton is the most important factor, especially in deeper lakes with clear stratification. Therefore, also in the guidelines measuring of phytoplankton is discussed in a more detailed manner than the others.

One of the oldest biological research methods of water quality is the examination of the biomass and composition of phytoplankton by microscopy. Preservation is necessary as samples seldom are studied immediately they have to be preserved properly. The considerable advantage to this method is that simultaneously important information on specie composition and dominant species is achieved.

Phytoplankton can also be used in local pollution control monitoring of recipient waters as an indicator of the toxic effects of sewage. In this case samples are not preserved. The aim is to investigate if phytoplankton is alive or damaged by toxic substances.

Sampling

Phytoplankton should be sampled from sufficient distance from the shore (e.g. the two metre depth curve) to avoid the sampling species originating from the littoral zone. Monitoring samples are generally taken from the deepest part of the lake, from the main basin. If the lake is divided in several basins, and if there is reason to believe that there is a substantial difference between the basins, the basins should be sampled separately.

Sampling frequency at minimum level should cover as many as possible "limnological seasons" i.e. different stratification and mixing periods. In south temperate areas at least three sampling occasions are recommended (later part of spring circulation, the later part of summer stagnation period and in the middle of fall circulation). In north temperate areas, where an ice-cover is formed regularly, an additional sampling during the later part of the winter stratification period is recommended (Olrik et al.1998).

In order to achieve a general picture of the distribution of phytoplankton, an integrated vertical sample from the upper circulating layer (determined by vertical temperature measurements) is taken. The sampling depth of 0-4 metres is recommended, but can be restricted to 0-2 metres (Olrik et al. 1998). If light penetration allows primary production in deeper strata, separate samples can additionally be taken. However, the sampling must not be performed closer to the sediment than 1 metre. Samples should be taken around the boat with a tube sampler. In the Finnish lake monitoring programme the sampling depth is 0-2 metres.

Integrated samples are collected in a large plastic bucket. The container must have a greater volume than the volume of the final mixed sample. Usually, a 20 - 30 litre plastic bucket is large enough. The lid is essential, both in order to keep the water inside the bucket while on the boat, and to prevent the sampled organisms from being exposed to too high irradiancy. A large plastic ladle is needed to mix the water in the bucket before subsampling. Water is poured to glass bottles with a small mouth.

The acid Lugol's solution is added in advance (0.5-1.0 ml/ 200 ml sample, i.e 5-8 drops with a Pasteur pipette). The sample should gain a colour like brandy. Glass bottles are preferable as the Lugol preservatives absorbs in the plastic bottles. As the preserved samples must be kept in the darkness, brown bottles have been used traditionally, but it is easier to trace samples that need re-preservation, if clear bottles are used. Lugol-preserved samples should be kept in cool (< 10 ^{o}C) and in darkness.

Preferably, samples should be worked up within one year after the sampling. When stored, samples should be checked and if necessary, re-preserved with Lugol's solution. For long-term storage (>1 year), an addition of formalin to the Lugol-preserved sample should be done (35-37 % formaldehyde, 2 ml/200 ml sample).

In addition, a subsample for estimation of chlorophyll *a* concentration is taken from the integrated sample. For supplement of species list the rest of integrated sample should be poured through a plankton net (mesh diameter 10-20 µm). Net samples are bottled e.g. to a scintillation vial (20 ml) and the sample with high densities of plankton should be preserved with a higher concentration of Lugol's solution (1-2 drops / 20 ml sample).

Acid Lugol's solution (Willén 1962):

100 g potassium iodide (IK)
1000 ml distilled water
50 g resublimated iodine (I_2)
100 g glacial acetic acid (96-100 % CH_3COOH)

One litre of Lugol's solution can be made at one occasion but have to be bottled in small flasks, preferable brown-coloured glass bottles. In larger, half-empty bottles, the iodine is oxidized and the Lugol's solution loos its preservative effect (Olrik et al. 1998).

Sampling during mass occurrences of harmful or noxious species

During mass occurrences of harmful or noxious algae, the sampling should be both horizontal and vertical, to study the distribution of the species in question. Horizontal samples could be collected from different parts of the lake system. Special instructions are needed for sampling algal mass for toxicity analyses.

Microscopical examination of samples

Quantitative analyses are done under an inverting phase-contrast microscope with magnitudes of e.g. 100x or 200x, and 600-800x (1000x). Both taxonomical knowledge and an access to identification literature is needed in order to perform phytoplankton analysis. However, cyanophyte literature is under revision and also other groups will be revised with time. Thus the list of literature used should be included to the results.

Sedimentation

In order to reduce the number of air bubbles in the counting chambers, the samples must be adapted to room temperature before they are set up for sedimentation. The sample is mixed by turning the bottle upside-down approximately 100 times (not shaken) and the subsample is poured into the sedimentation chambre of a known volume. The sedimentation time (in dark) is depending on the volume of sample (sample of 5 ml sedimentation of 6 hours, sample of 50 ml/24 hours). As the composition and concentration of phytoplankton is unknown before the counting, the samples should be set up in different chambers simultaneously. Oligotrophic and mesotrophic water is usually set up in 10 - 50 ml chambers. Eutrophic waters in 2.5-10 ml and hypereutrophic waters in 0.1-5 ml chambers.

Counting procedure

The sample is scanned at different magnitudes. The preliminary species identification is carried out and listed. The chamber size is estimated in which it is possible to achieve approximately 100 individuals of the most common species when counting the organisms in 1-6 diagonals or in 50-100 random fields at high magnification. If possible the individual cell of colonies should always be counted separately as well as number of colonies. Large colonies in order Chroococcales should be counted after ultrasonic treatment (alternatively the cell number is estimated from the colony size) and filamentous forms (e.g. Oscillatoriales with no clearly differentiated cells) counted as number of filaments and each of the filament should be measured.

Each taxa should be counted separately. The different taxa of the same genus should be named by using running numbers (e.g. Anabaena sp1), although identification should be omitted. Suitable size groups of taxa should be used. The species larger than 50 µm are counted at a low magnification (100x or 200x) from the whole chamber bottom (e.g. *Ceratium*) or over diagonals or fields. The species less than 50 µm are counted at a magnification of 400-1000x until a reasonable number of cells or units is reached (e.g. 400-500 cells).

Species identification

Processing of the quantitative samples can be made in three levels depending on the resolution in the species identification as presented in the nordic standard method for quantitative and qualitative analyses by the phytoplankton section of the Nordic Phytoplankton and Periphyton Group (Olrik et al. 1998). Levels 1 and 2 are suitable for monitoring purposes. Level 3 is used in taxonomical investigations. There are some details in levels 2 which are more demanding than in level 1 and also in level 3 compared to the previous levels.

Level 1 Reduced programme:

All organisms are identified under an inverting light microscope from a Lugol-preserved quantitative sample to a higher taxonomic level (class, order). Number of individuals and number of other plankton units (colonies, filaments) are counted. Calculation of biovolume is performed after measurement of one selectively chosen "type organism". Evaluation is based on the indicator value of groups, genera and species.

Level 2 Standard ecological programme:

All common and dominating species are identified under the light microscope and / or after preparation to species-level. Calculation of biovolume is performed after measurement of several casually chosen organisms of dominating and common taxa.

Level 3 Complete programme:

A full species identification after preparation, analysis of live samples, cultivation of doubtful species, SEM and TEM. In many cases the use of cf- confer, gives much information for the further treatment of the results.

Conversion of counting number to number per volume

To calculate the number of phytoplankton units (cells, filaments,colonies) per volume of water following parameters are needed:

- volume of the chamber,
- area of the chamber bottom,
- area of the part of the bottom counted, and number of individuals counted of each species.

The specific volume of different species is calculated by using the measurements of cell dimensions and subsequently the geometrical formulas. At different levels the number of measured cell varies from one (level 1), to five at minimum (level 2) and finally to 10 at minimum (level 3). Small cells have to be measured at 400-1000x magnification.

Some data based counting programmes have been developed (in Helcom the PHYTO-programme). Biological data base with mean volumes of taxa is used in Finland for phytoplankton monitoring data. Photodokumentation by video tapes and photos are the reference material in the identification and is used in the intercalibration meetings.

The use of results

Phytoplankton results can be used especially for assessment of the eutrophication status of lakes. A good characteristics is the total volume (or total wet weight) of phytoplankton estimated by microscopy. Many classifications based on total amount have been presented. The following classification (Table 5) is based on the large material (over 800 sampling sites during the mid-summers of 1963 and 1965) from Finnish inland waters (Heinonen 1980).

Table 5. Classification of Finnish lakes according to the total amount of phytoplankton biomass (Heinonen 1980).

The eutrophication status of the lake	**Phytoplankton biomass mg/L, wet weight**
Ultra-oligotrophic	< 0.20
Oligotrophic	0.21 – 0.50
Incipient eutrophy	**0.51 – 1.00**
Mesotrophic	1.01 – 2.50
Eutrophic	**2.51 – 10.0**
Hypereutrophic	**> 10.0**

An indirect, but very practical method to get relatively reliable estimation of the phytoplankton quantity, is the chemical chlorophyll analysis. These two characteristics are significantly correlated with each others. Therefore different classifications have been established based on chlorophyll *a* concentrations. In the following table (Table 6) the classification prepared by Lepistö (1999) from Finnish inland waters have been presented.

Table 6. Classification of Finnish lakes according to the total amount of phytoplankton biomass and chlorophyll *a* concentrations (Lepistö 1999).

Lake type	**Phytoplankton biomass mg/L, wet weight**		**Chlorophyll *a* µg/L**	
	mean value	**standard deviation**	**mean value**	**standard deviation**
Oligotrophic	0.3	0.2	2.7	1.2
Dystrophic	0.9	0.7	6.2	3.0
Mesotrophic	2.3	2.0	8.7	4.8
Eutrophic	**7.6**	**7.7**	**36.9**	**30.1**
Hypereutrophic	**13.2**	**12.4**	**52.4**	**44.0**

Besides the total amount of phytoplankton, a very important characteristic is the species composition. Some species are typical in eutrophic waters, some species indicate quite oligotrophic waters, etc. Therefore several quotient systems based on phytoplankton species have been developed and used in the assessment of lakes. Usually they are most suitable in smaller geographical areas, or even only in the same river basin.

However, there are some algae species, which nearly always are connected with eutrophy, the blue-green algae. The mass occurrence of cyanophytes is always a signal of severe eutrophication of a lake. The share of cyanophytes, which is in oligotrophic lakes only some percentages of the total biomass, increases in hypereutrophic lakes up to 60-80 percent. Usually these bloomings are found in late summer, when the water temperature is high.

Any general quotient system e.g. for whole Europe is not possible to develop. However, new ideas for different quotients are absolutely needed, because of the obligations of EU Water Framework Directive to calculate in the future special ecological quality ratios (EQRs) for assessing the ecological status of the water body.

Also zooplankton has an important role especially in eutrophication process and on the other hand as a remarkable part of the food chain in lakes. Zooplankton analyses have, however, not added to the lake monitoring programmes. In cases of incipient eutrophication, as well as in biological manipulation of lakes zooplankton data should be used more frequently.

7.4 Macrophytes and phytobenthos

Macrophytes

Other biological quality elements for lakes mentioned in the EU Water Framework Directive are macrophytes and phytobenthos.

The WFD gives general definitions for macrophytes and phytobenthos in different ecological status of the lakes. If a lake will be determined to be in high status, the characteristics of the macrophytes and phytobenthos are as follows:

- The taxonomic composition correspond totally or nearly totally to the undisturbed conditions.
- There are no detectable changes in the average macrophytic and the average phytobenthic abundance.

If the lake is already a little bit altered because of anthropogenic impact, lake can be determined to be in good ecological status, if

- There are slight changes in the composition and abundance of macrophytic and phytobenthic taxa compared to the type-specific communities. Such changes do not indicate any accelerated growth of phytobenthos or higher forms of plant life resulting in undesirable disturbance to the balance of organisms present in the water body or to the physico-chemical quality of the water.
- The phytobenthic community is not adversely affected by bacterial tufts and coats present due to anthropogenic activity.

If the lake is so badly altered and polluted, that it must be classified only to the class of "moderate status", the macrophytes and phytobenthos can be described as follows:

- The composition of macrophytic and phytobenthic taxa differ moderately from the type-specific communities and are significantly more distorted than those observed at good quality.
- Moderate changes in the average macrophytic and the average phytobenthic abundance are evident.
- The phytobenthic community may be interfered with, and, in some areas, displaced by bacterial tufts and coats present as aresult of anthropogenic activities.

The EU habitat directive (1992/43/EEC; Annex 1) includes also fresh-water biotopes. The list of fresh-water nature types in the Habitat Directive with amendments is as follows:

- Oligotrophic waters containing very few minerals of sandy plains
- Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or *Isoeto-Nanojuncetea*
- Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.
- Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*-type vegetation
- Natural dystrophic lakes and ponds
- Fennoscandian natural rivers
- Alpine rivers and the herbaceous vegetation along their banks
- Alpine rivers and their ligneous vegetation with *Myricaria germanica*
- Watercourses of plain to mountain levels with the *Ranunculion fluitans* and *Callitricho-Batrachion* vegetation
- Fennoscandian mineral-rich springs and springfens
- Petrifying springs with tufa formation

Each member state shall carry out appropriate conservation measures for these habitats. The favourable conservation status, as well as changes in the representativeness of these nature types will be regularly monitored in the future.

There are many characteristics of aquatic macrophytes, which can be used as indicator in environmental monitoring. However, due to local heterogenuity of habitats generalizations of indicator values are difficult, and variation in responses should be interpreted carefully. Main uses of aquatic macrophytes in the monitoring and assessment can be grouped in five following ways (Toivonen 2000):

- In plant tests carried out under controlled laboratory / field conditions,
- By using the chemical content of certain species as indicators of heavy metal and other toxic loads,
- By using species or species groups as indicators of water or habitat quality
- By studying temporal (long-term) changes in flora and vegetation, and
- By studying or assessing biodiversity in water bodies.

As the aquatic vegetation in a lake is influenced simultaneously by several factors, macrophytes only rarely has a good indicative value when evaluating some specific environmental variables. Instead, they give a good general estimation of the trophic state of the site. Their use as indicators is further motivated by their relative persistence in the site. Fluctuations in the population size of aquatic macrophytes are also usually minor in comparison to many other organisms (Toivonen 2000).

The research methods applied to aquatic plants vary greatly according to both the aim of the study and the area or species studied. In the studies of aquatic macrophytes there is, therefore, a great need of standardization of survey methods. Following issues should at least be harmonized:

- Time of survey
- Size and selection of survey sites
- Selection of survey transects
- Recording scales for macrophytes (abundance, cover, frequency)
- Biomass sampling and measurements

Figure 16. The macrophytes and algal blooming in the littoral area of a eutrophied lake.

Macrophytes are especially suitable for longer-term (5-20 years) studies of changes in the littoral and open water areas. An example of the use of macrophytes in a long-term monitoring programme is presented in Figure 17.

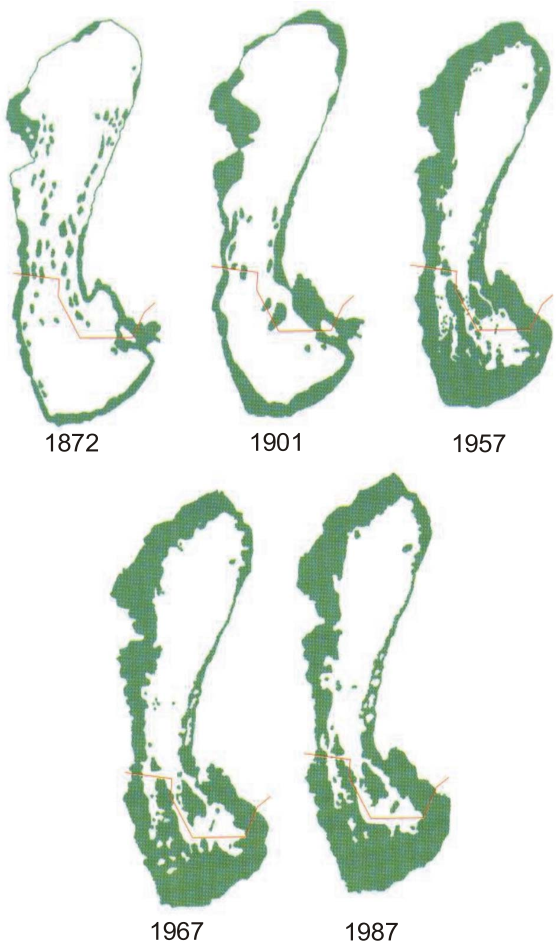

Figure 17. Changes of the reed belt during the last 100 years in Lake Neusiedler See/Fertö Tó (In Pietiläinen and Heinonen 2002).

In more than 100 years the reed belt has increased significantly in this transboundary lake between Austria and Hungary. The changes have been especially remarkable and indicative between the years 1901 and 1957. In the later phase the changes have been clearly smaller.

Periphyton

Periphyton is a complex community of microbiota (algae, bacteria, fungi, animals, inorganic and organic detritus) that is attached to substrata (Wetzel 1983, Eloranta 2000). A distinct and unpleasant sliming of underwater surfaces, e.g. stones, fishing nets and piers, is the most visible nuisance effect caused by periphyton communities. Periphyton is often a major primary producer in rivers but also in lakes with extensive littoral area. Periphyton has proved to be a good and useful indicator of water quality, responding to and reflecting conditions of immediate past (Weitzel 1979, Eloranta 2000).

Periphyton community is a long-term result (days, weeks, months) of several biological and physico-chemical factors affecting its growth simultaneously. Temperature and water currents also play an important role in controlling periphyton growth.

The measurement of periphyton growth on an artificial substata has been widely used when assessing the effect of point source loading (industrial effluents, municipal sewage waters etc.) on the primary production of the recipient surface waters (Eloranta 2000).

The analyses usually determined from the quantitative periphyton samples are chlorophyll *a* content, fresh mass, dry mass, organic content and ash free dry mass (AFDM). Chlorophyll *a* describes the algal mass of the periphyton. This determinand is most suitable for estimation of the eutrophication.

Also qualitative samples and community analyses are useful especially for the littoral monitoring purposes. Typical variables calculated from samples are the species richness, diversity and especially the contributions of different taxa belonging to different indicator groups (Eloranta 2000).

Periphytic growth on artificial substrates

Periphytic growth is determined very often also from artificial substrates, like glass slides and sticks, and different types of plastic or ceramic plates incubated for a certain time (usually for three weeks is enough) at a certain depth (usually one meter) of the lake concerned. The advantages of this method are as follows:

- the free possibility to select the incubation site e.g. based on pollution situation, not only on the quality of bottom,
- better comparability from different areas,
- possibility to standardize some important growth factors, e.g. incubation time, the depth and the illumination.

The possible disadvantages are, that you may miss some important indicator species, which are not capable to grow e.g. on plastic plates during so short incubation time as three weeks. Some plate materials, like ceramics may be also selective for some algae species.

Two types of incubation equipments for estimation of periphytic growth are described in the Figs. 18 and 19.

Figure 18. The incubation equipment for estimation of periphytic growth in lakes (Photo Sirpa Herve).

The equipment presented in Fig. 18 is widely used in Finland. The sites for incubation can be selected from different parts of the lake. The incubation time is three weeks at the depth of one meter. From the plates periphytic growth is determined by the chlorophyll *a* analyses. Usually four replicates are used. In some cases also the species composition is followed by microcopy.

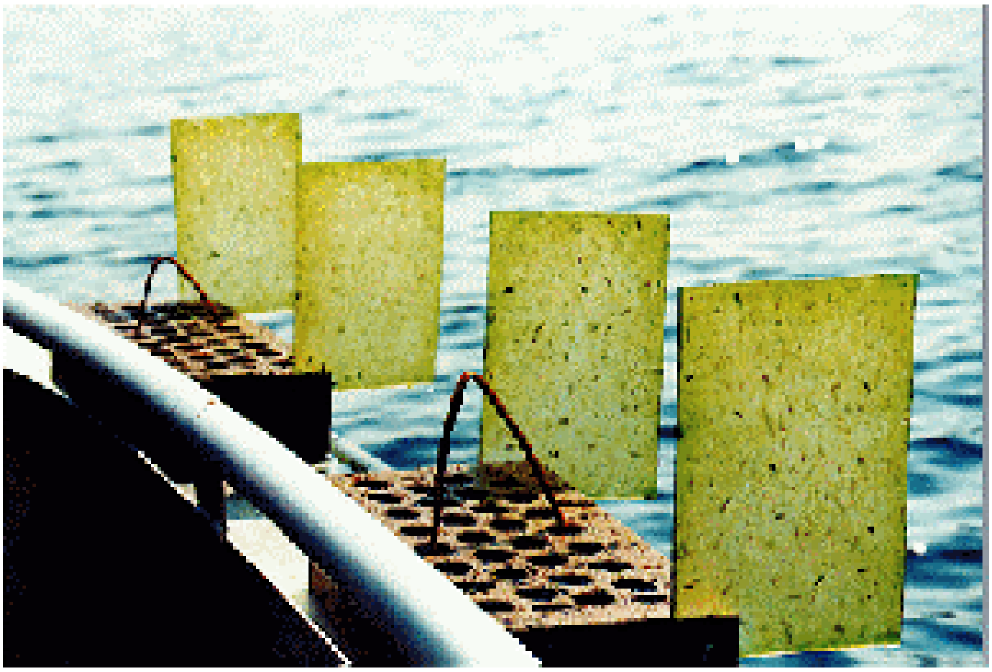

Figure 19. The incubation equipment for estimation of periphytic growth in the littoral zone of the lake (Photo Pertti Manninen).

The role of littoral zone is quite important, especially in small lakes with relative large areas of shallow waters. The other suitable monitoring method for these areas besides the macrophytes is the observations of the periphytic growth during summer, the high season of primary production.

One suitable type of incubation equipment for the littoral zone is described in Fig. 19. The equipments can be located in the monitoring area very close to the shoreline in the depth of 0.5-1.0 meters and incubated for three weeks. In many cases already the colour of plates after the incubation period shows the eutrophication degree of the lake in a very unambiguous way. This is of great importance for the people who are living onshore of the lake concerned.

The periphytic growth is a very sensitive determinand to indicate especially the early phases of the eutrophication process in lakes. In many cases the eutrophication can be detected as a sliming of different surfaces in the shallow waters near the shore line.

In Fig. 20 the results of investigation on from four sampling sites lake with first signs of eutrophication are presented. In this study samples were collected from four sites so, that the status of the site 1 was near natural oligotrophic, and the sites 2-4 were slightly eutrophic because of different non-point phosphorus loading. The water samples (total phosphorus and chlorophyll *a*) are from the depth of one meter. The periphytic growth was analysed from the artificial substrates (polycarbon plastic plates) incubated at the depth of one meter after three weeks incubation time. The results from the site 1 were kept as reference values (value 1.00), and the other results were compared to the corresponding results of the site 1.

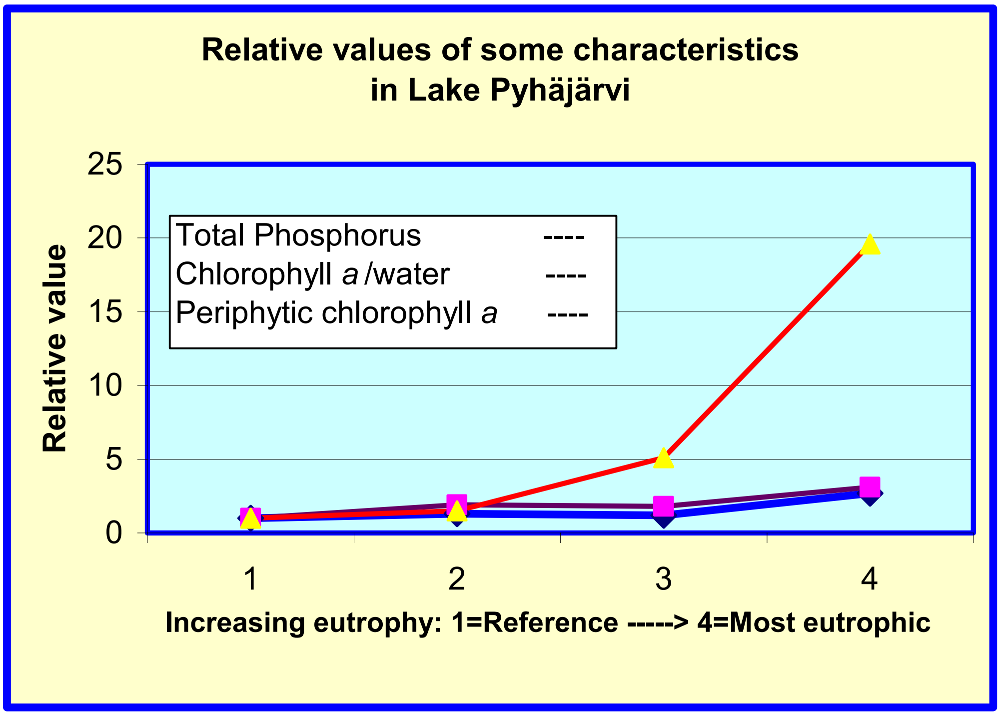

Figure 20. Relative values of three different indicators for eutrophication in Lake Pyhäjärvi.

From the results it can be seen, that the periphytic growth is some five times bigger in the site 3 than in the reference site. The phosphorus and chlorophyll values measured from the water phase were only slightly bigger in the site 3 than in the reference site. In the most eutrophic site the periphytic growth was nearly 20 times bigger than in the reference site.

7.5 Benthic invertebrate fauna

Benthic invertebrates (zoobenthos) have been increasingly used in freshwater monitoring programmes. Due to its large species richness covering all types of freshwater habitats and to increased ecological knowledge on species response to environmental conditions, zoobenthos can be used for different monitoring topics, such as eutrophication, acidification, changes in habitat structure and species diversity and toxicity.

Zoobenthos is relatively easy to sample, and as sedentary and rather long-lived organisms they can reflect site-specific, long-term changes in nature. In lake ecosystems zoobenthos is an important energy link, constituting a number of species with different ecological traits and limits (Koskenniemi 2000).

Benthic invertebrata fauna is one of the biological quality elements of the EU Water Framework Directive. The WFD (Annex V) provides general definitions for benthic invertebrate fauna for different ecological status of lakes as follows:

If a lake will be determined to be in “high status”, the characteristics of benthic invertebrate fauna are as follows:

- The taxonomic composition and abundance correspond totally or nearly totally to the undisturbed conditions.
- The ratio of disturbance sensitive taxa to insensitive taxa shows no signs of alteration from undisturbed levels.
- The level of diversity of invertebrate taxa shows no sign of alteration from undisturbed levels.

If the lake is already slightly altered due to anthropogenic impact, the lake can still be determined to be in “good ecological status”, if:

- There are slight changes in the composition and abundance of invertebrate taxa compared to the type-specific communities.

- The ratio of disturbance sensitive taxa to insensitive taxa shows slight signs of alteration from undisturbed levels.
- The level of diversity of invertebrate taxa shows slight signs of alteration from undisturbed levels.

If the lake is so badly altered and polluted, that it must be classified only to the class of "moderate status", the benthic invertebrate fauna can be described as follows:

- The composition and abundance of invertebrate taxa differ moderately from the type-specific conditions.
- Major taxonomic groups of the type-specific community are absent.
- The ratio of disturbance sensitive to insensitive taxa, and the level of diversity, are substantially lower than the type-specific level and significantly lower than for good status.

Zoobenthos communities vary largely in their assemblage both within a lake and among lakes. The within-lake aspect illustrates the bathymetric, vertical distribution of the species in the littoral-sublittoral-profundal areas and horizontal distribution of the species with a large variation in community structure especially in different littoral habitats. Zoobenthos communities are here understood as a species set occurring at a site in a lake. The sieve mesh size used for sample rinsing is usually between 200 and 500 μm (Koskenniemi 2000).

Zoobenthos samples can be taken in principle from all parts of a lake. Usually zooplankton samples have, however, been taken from the deepest parts of the lake. The zones (littoral, sublittoral or profundal) or habitat types to be included in the monitoring programmes and in the assessment of ecological quality ratios (EQRs) are not defined in the WFD.

Profundal and littoral benthic communities may respond differently to various types of anthropogenic stresses. Impacts of some stresses, such as water level regulation, acidification, recreational activities and shoreline alteration e.g. by summer cottages and other constructions may be mainly defined to the littoral zone. Furthermore, non-point load of nutrients and suspended load (agriculture, forestry) may first affect the littoral zone. Thus, littoral communities would respond more rapidly to the anthropogenic impacts compared to the profundal invertebrates.

The profundal communities may be more reflected by long-term changes in the environmental conditions of the lake. In the littoral zone, each habitat type often support fairly characteristic fauna. Thus, samples from different habitat types are not comparable to each other and stratification of the sampling by habitat type is obviously necessary (Tolonen et al. 2001).

The importance of lake littoral has been underestimated until now in environmental monitoring and assessment. Monitoring of littoral communities is primarily focused on assessing acidification effects, whereas profundal communities are used for evaluating the effects of organic loading (Koskenniemi 2000).

Suitability of profundal macroinvertebrates as indicators of the trophic status of a lake and eutrophication is well documented (e.g. Wiederholm 1980, Brodersen and Lindegaard 1999).

The methods used for sampling benthic macroinvertebrate communities are very similar among European countries. This similarity is in part due to the international (ISO), European (CEN) and national standardisation work concerning biological and ecological assessment methods that began in the late 1980´s.

At the moment there exist several standardised methods for sampling of macroinverebrates. Sampling is often qualitative or semi-quantitative using standardised methods with a handnet or kick-sampling for stream and lake littoral habitats. In lakes the profundal macroinvertebrates are usually sampled both from the deepest part of the lake and from the intermediate depth (arithmetic mean depth between surface and maximum depth) by using an Ekman grab sampler. More detailed information related to sampling can be found from the relevant standards.

7.6 Fish

Fish are a very important part of the biocoenosis in a lake. Fish has an important role in the food web of the lake, but additionally it is the most interesting part of biocoenosis for human consumption. Therefore it is quite natural, that fish fauna is also one of the biological quality elements, which is obliged by the EU Water Framework Directive, to use for ecological classification.

The WFD provides general definitions for fish fauna in different ecological status of the lakes. According to the Annex V, if a lake will be determined to be in high status, the characteristics for fish fauna are as follows:

- Species composition and abundance correspond totally or nearly totally to the undisturbed conditions.
- All the type-specific sensitive species are present.
- The age structures of the fish communities show little sign of anthropogenic disturbance and are not indicative of a failure in the preproduction or development of a particular species.

If a lake is already slightly altered because of anthropogenic impact, the lake can be determined to be in good ecological status, if:

- There are slight changes in the species composition and abundance of of fih fauna from the type-specific communities attributable to anthropogenic impacts on physico-chemical or hydromorphological quality elements.
- The age structures of the fish communities show signs of disturbance attributable to anthropogenic impacts on physico-chemical or hydromorphological quality elements, and, in a few instances, are indicative of a failure in the preproduction or development of a particular species, to the extent that some age classes may be missing.

If lake is so badly altered and polluted, that it must be classified only to the class of “moderate status”, the fish fauna can be described as follows:

- The composition and abundance of fish species differ moderately from the type-specific communities attributable to anthropogenic impacts on physico-chemical or hydromorphological quality elements.
- The age structure of the fish communities shows major signs of disturbance, attributable to anthropogenic impacts on physico-chemical or hydromorphological quality elements, to the extent that a moderate proportion of the type specific species are absent or of very low abundance.

Fish are at the top of the food webs of the lake ecosystem. Therefore, fish have a strong influence on other parts of food webs. They feed organisms belonging to other lower trophic levels, but they are simultaneously also food for other fish and invertebrates, and finally for birds and mammals, including human beings. Fish populations have found to have also significant effects on water quality, e.g. dense fish populations may inhibit the growth of phytoplankton and macrophytes through reducing the clarity of water (Lehtonen 2000).

Fish populations have been monitored up until the present mostly for economic reasons. Fish catches have been estimated with the aid of different types of questionnaires, but also by test fishing important information on e.g. the structure of fish population has been provided. The focus of the previous monitoring programmes have been commercially valuable fish species only.

At present the role of fish has changed, and fish populations are considered as a part of the ecosystem. The reason for this turn has especially been, besides the implementation of the WFD, food web manipulation for the purpose of water quality management. Manipulation of food webs has proven to be a very suitable tool in the improvement of ecosystem health in lakes.

The goal of food web manipulation is usually to diminish phytoplankton biomass which may be harmful for the use of water and, in some cases, also toxic. Manipulation management is based on two principles:

- Piscivorous fish control planktivorous fish which have a negative influence on herbivorous zooplankton.
- Benthivorous fish recycle bottom material by releasing sedimented nutrients and through excretion and digestion.

Monitoring methods for fish populations are test fishing with standardized gill nets, and questionnaires organized on a regular basis among professional fishermen. During test fishing, observations of other quality elements should be performed. Especially important is analysis of possible sliming of gill nets, as well as the blooming of algae.

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SUMMARY of Chapter 7

- Read through the key features of the biological quality elements (QE) for lakes.
- Make an inventory of the previous investigations (or monitoring programmes) containing information on the biota.
- Seek good experts on each of the different biological QE.
- Seek an expert judgement on the most important QE of the lake concerned.
- Prepare the programme of biological QE in very close co-operation with other QEs.
- Prepare a preliminary schema for handling and reporting the results of the biological QEs, as a part of the entire report.

8 HARMFUL SUBSTANCES

8.1 Definitions

The concept of "harmful substances" in environmental monitoring is a very large one, and the standpoints of different persons and organizations may vary in large ranges. In this relatively short technical paper the following harmful groups are presented and discussed:

- Persistent Organic Pollutants (POPs).
- Priority substances of the WFD.
- Mercury.
- Heavy metals.
- Radionuclear contamination.

Persistent Organic Pollutants (POPs) are chemical substances that persist in the environment, bioaccumulate through the food web, and pose a risk of causing adverse effects to human health and the environment. There is firm evidence of long-range transport of these substances to regions where they have never been used or produced and the consequent threats they pose to the environment of the whole globe.

The list of priority substances in the field of water policy and the amending Directive 2000/60/EC consists of 33 different substances, which have been accepted with Decision No 2455/2001/EC of the European Parliament and of the Council, 20 November 2001. Possible occurrence of these compounds in river basin districts should be followed up in the beginning of the implementation phase of the WFD.

Mercury (heavy metal) is still a very important pollutant in many countries. There are two kinds of mercury: Inorganic Mercury and Organic Mercury. Organic mercury is more dangerous since it can easily penetrate cell walls, it is easily absorbed in fatty tissues of animals and it is easily absorbed into nerve and brain cells. For this reason, organic mercury can be 100 times more dangerous than inorganic mercury.

Heavy metals are a group of heavy, dense, metallic elements that occur only at trace levels in water, but are very toxic and tend, as with mercury, to accumulate in biota.

Radio nuclear contamination is in some countries still a real threat for the environment. This short chapter is only to remind persons, responsible for monitoring, in all cases to take care of this type of pollution.

8.2 Persistent Organic Pollutants (POPs)

Persistent Organic Pollutants (POPs) is, from an environmental point of view, a group of 12 particularly difficult, toxic organic compounds mentioned by the United Nations Environment Program (UNEP). In many countries these compounds already belong to the history of environmental pollution, but as very persistent compounds they can be found tens of years after the use of compounds and discharges to nature through, e.g. watercourses has been stopped.
The compounds in Table 7 play a certain role in assessing the status of water bodies. If any such compound can be found from e.g. a lake, usually from biota or very often also from sediments, the status of the lake concerned must be estimated to be in so bad status, that special actions are needed to improve the situation.

The possible occurrence and distribution of these hazardous compounds (named unofficially as the "Dirty Dozen") should therefore be clarified immediately in the beginning of every new monitoring programme.

Table 7. Persistent Organic Pollutants (POPs).

COMPOUND	
Aldrin	A pesticide used to protect crops from soil insects. Widely banned.
Chlordane	A pesticide used to protect crops from termites. Widely banned.
DDT	A pesticide used on crops for vector control. Used on troops during WWII to stop malaria, typhus and other diseases. Widely banned. Still produced and used.
Dieldrin	A pesticide used for the control of insects and disease vectors. Restricted.
Dioxins	Industrial by-products. Limited regulation.
Furans	Industrial by-products. Limited regulation.
Endrin	A pesticide used on field crops and to control rodents. Widely banned.
Hexachlorobenzene (HCB)	A pesticide and industrial by-product released during plastics manufacture. Its use as a pesticide is widely banned; limited regulation of by-products.
Heptachlor	A pesticide used against soil insects and termites. Widely banned.
Mirex	A pesticide used against various ants, termites, wasps and bugs. Also used as a fire retardant in plastics, rubber, paint paper and electrical goods. Widely banned.
Polychlorinated biphenyls (PCBs)	An industrial chemical used in heat exchange fluids, paint additives, carbonless copy paper, plastics and various other industrial applications. Released as a by-product. Widely banned. Limited regulation of releases.
Toxaphene	A pesticide used on cotton, grains, fruits, nuts and vegetables and to control ticks and mites in livestock. Widely banned.

POPs effectively bioaccumulate in the food web, especially in the fatty issues of fish and mussels. The compounds are very persistent, which means they can be found with relative ease. Different methods, usually based on bioaccumulation can be practiced. Many times POPs are analysed from the natural biota, in some cases different incubation methods have been used.

In Finland a special mussel incubation method has been used in the monitoring of harmful substances for more than 15 years. In this method, transplanted mussels incubated in a free water column were used because the aim was to collect information on the present discharges. Natural field mussels take their food from bottom sediments and also collect historical residues from earlier pollutant loadings. Freshwater mussels (*Anodonta piscinalis*) were collected from a pristine mesohumic lake and kept for 2-3 weeks in pure water in a laboratory.

The four weeks of incubation of the mussels was performed using plastic traps anchored at the sampling sites at a depth of one meter (Fig. 21). Trial incubations confirmed that the four week time period is optimal (Herve, 1991). After incubation, the mussels were measured and weighed with and without shells. The shells were used for age determination. The soft parts of the mussels were freeze-dried, and later in a laboratory, three composites of five individual mussels were prepared for analysis.

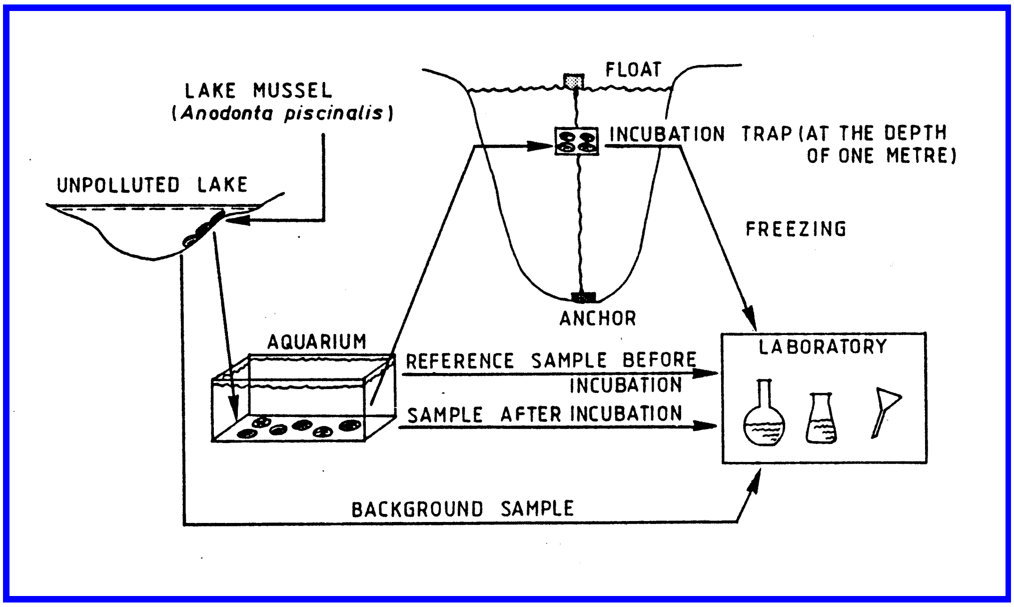

Figure 21. The principle of the mussel incubation method (Herve 1991).

An example of two long lasting PCB pollution cases is presented in Fig. 22. In the case of Kuusaankoski (blue line) PCBs have been discharged to water courses from an industrial area via groundwaters. The loading is slowly decreasing.

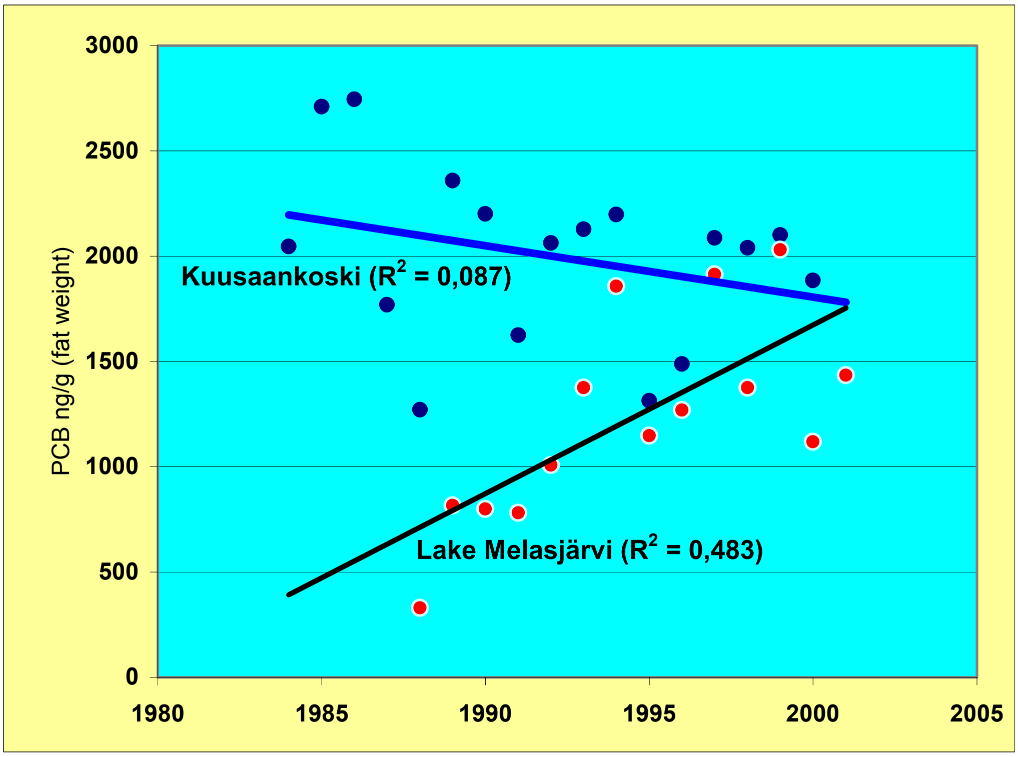

Figure 22. The trends of PCB concentrations in two industrial recipients measured by the mussel incubation method.

In the case of Lake Melasjärvi (black line and according to the red dots) the situation is different, the trend is significantly increasing. The reason for this may be the use of recycled paper in the pulp mill, but also there is a possibility of polluted ground in this old industrial area. The situation will be monitored regularly.

8.3 Priority substances of the WFD

According to the EU Water Framework Directive Article 16 (Strategies against pollution of water), The European Parliament and the Council shall adopt specific measures against pollution of water by individual pollutants or groups of pollutants presenting a significant risk to or via the aquatic environment, including such risks to waters used for the abstraction of drinking water. Such pollutant measures shall be aimed at a progressive reduction and, for priority hazardous substances at the cessation or phasing-out of discharges, emissions and losses.

The Commission shall submit a proposal setting out a list of priority substances selected amongst those which present a significant risk to or via the aquatic environment. Substances shall be prioritised for action on the basis of risk to, or via the aquatic environment. This list has been accepted by the European Parliament and the Council on 20 November, 2001 and added to the Directive as Annex X. The list is presented here in Table 8 on the following page.

The Commission's proposal shall also identify priority hazardous substances. In doing so, the Commission shall take into account the selection of substances of concern undertaken in the relevant Community legislation regarding hazardous substances or relevant international agreements. The Commission shall review the adopted list of priority substances at the latest four years after the date of entry into force of this Directive (it means in December 2004) and at least every four years thereafter, and come forward with proposals as appropriate.

For priority substances, the Commission shall submit proposals of controls for:

- The progressive reduction of discharges, emissions and losses of the substances concerned, and, in particular,
- the cessation or phasing-out of discharges, emissions and losses of priority hazardous substances, including an appropriate timetable for achieving this.

The Commission shall submit proposals for quality standards applicable to concentrations of priority substances in surface water, sediments or biota.

For substances included in the first list of priority substances, in the absence of an agreement at Community level six years after the date of entry into force of this Directive, Member States shall establish environmental quality standards for these substances for all surface waters affected by discharges of such substances, and controls on the principal sources of such discharges, based, inter alia, on consideration of all technical reduction options. For substances subsequently included in the list of priority substances, in the absence of agreement at Community level, Member States shall take such action five years after the date of inclusion in the list.

Monitoring obligations concerning priority substances are very strict. The possible occurrence of all priority substances should be first clarified before the end of 2004, and if any are found, they must be monitored at an interval of one month.

Table 8. The list of priority substances according to the EU Water Framework Directive.

	CAS number (***Chemical Abstract Services***)	**Name of the priority substance**	**Identified as priority hazardous substance**
(1)	**15972-60-8**	**Alachlor**	
(2)	**120-12-7**	**Anthracene**	**(X)*****
(3)	**1912-24-9**	**Atrazine**	**(X)*****
(4)	**71-43-2**	**Benzene**	
(5)	**n.a.**	**Brominated diphenylethers (**)**	**X******
(6)	**7440-43-9**	**Cadmium and its compounds**	**X**
(7)	**85535-84-8**	**C_{10-13}-chloroalkanes (**)**	**X**
(8)	**470-90-6**	**Chlorfenvinphos**	
(9)	**2921-88-2**	**Chlorpyrifos**	**(X)*****
(10)	**107-06-2**	**1,2-Dichloroethane**	
(11)	**75-09-2**	**Dichloromethane**	
(12)	**117-81-7**	**Di(2-ethylhexyl)phthalate (DEHP)**	**(X)*****
(13)	**330-54-1**	**Diuron**	**(X)*****
(14)	**115-29-7**	**Endosulfan**	**(X)*****
	959-98-8	**(alpha-endosulfan)**	
(15)	**206-44-0**	**Fluoroanthene(*****)**	
(16)	**118-74-1**	**Hexachlorobenzene**	**X**
(17)	**87-68-3**	**Hexachlorobutadiene**	**X**
(18)	**608-73-1**	**Hexachlorocyclohexane**	**X**
	58-89-9	**(gamma-isomer, Lindane)**	
(19)	**34123-59-6**	**Isoproturon**	**(X)*****
(20)	**7439-92-1**	**Lead and its compounds**	**(X)*****
(21)	**7439-97-6**	**Mercury and its compounds**	**X**
(22)	**91-20-3**	**Naphthalene**	**(X)*****
(23)	**7440-02-0**	**Nickel and its compounds**	
(24)	**25154-52-3**	**Nonylphenols**	**X**
	104-40-5	**(4-(para)-nonylphenol)**	
(25)	**1806-26-4**	**Octylphenols**	**(X)*****
	140-66-9	**(para-tert-octylphenol)**	
(26)	**608-93-5**	**Pentachlorobenzene**	**X**
(27)	**87-86-5**	**Pentachlorophenol**	**(X)*****
(28)	**n.a.**	**Polyaromatic hydrocarbons**	**X**
	50-32-8	**(Benzo(a)pyrene),**	
	205-99-2	**(Benzo(b)fluoroanthene),**	
	191-24-2	**(Benzo(g,h,i)perylene),**	
	207-08-9	**(Benzo(k)fluoroanthene),**	
	193-39-5	**(Indeno(1,2,3-cd)pyrene)**	
(29)	**122-34-9**	**Simazine**	**(X)*****
(30)	**688-73-3**	**Tributyltin compounds**	**X**
	36643-28-4	**(Tributyltin-cation)**	
(31)	**12002-48-1**	**Trichlorobenzenes**	**(X)*****
	120-82-1	**(1,2,4-Trichlorobenzene)**	
(32)	**67-66-3**	**Trichloromethane (Chloroform)**	
(33)	**1582-09-8**	**Trifluralin**	**(X)*****

* Where groups of substances have been selected, typical individual representatives are listed as indicative parameters (in brackets and without a number). The establishment of controls will be targeted to these individual substances, without prejudicing the inclusion of other individual representatives, where appropriate.

** These groups of substances normally include a considerable number of individual compounds. Currently, appropriate indicative parameters cannot be provided.

*** This priority substance is subject to a review for identification as possible "priority hazardous substance". The Commission will make a proposal to the European Parliament and Council for its final classification no later than 12 months after the adoption of this list. The timetable laid down in Article 16 of Directive 2000/60/EC for the Commission's proposals of controls is not affected by this review.

**** Only Pentabromobiphenylether (CAS number 32534-81-9)

***** Fluoranthene is on the list as an indicator of other, more dangerous Polyaromatic Hydrocarbons

8.4 Mercury

Mercury has for a long time been known as a very hazardous global pollutant. Mercury has gaseous, aqueous, and particulate phases as well as different chemical forms that strongly affect its transport and cycling in the environment. Because of its gas phase, mercury is widely distributed around the globe. Mercury is emitted through human activities and from natural sources such as volcanic eruptions and degassing or vaporization and it is re-emitted (Fitzgerald et al. 1998, Verta 2000).

The complete mercury cycle has yet to be unraveled. From the environmental point of view, organic mercury (a mercury atom attached to a CH_3 molecule) is the most dangerous.

Human exposure to methylmercury (MeHg) through consumption of fish is the principal public health concern in the environment. Elevated methylmercury concentrations in fish are frequently found not only in heavily contaminated areas, but also in terrestrial waters distant from point sources. Mercury pollution cases may be in some cases very severe. Therefore it is well-grounded to follow the mercury situation in all transboundary and international water courses with certain intervals.

Environmental monitoring performed on transboundary and international lakes should provide answers to questions such as:

- Hg-concentration levels of different parts of the ecosystem.
- Recent history of contamination and possible sources of mercury.
- Possible food web effects (including humans).

The most important parts of the ecosystem, from the monitoring point of view concerning mercury, are sediments (to obtain better information of history) and biota, especially different economically important fish species. If elevated concentrations are found, the possible reasons for this should be clarified as soon as possible.

8.5 Heavy metals

Heavy metals are the natural constituents of the Earth's crust. Human activities have drastically altered the biochemical and geochemical cycles and balance of some heavy metals. Heavy metals are stable and persistent environmental contaminants since they cannot be degraded or destroyed. Therefore, they tend to accumulate in soils and sediments.

The main anthropogenic sources of heavy metals are various industrial point sources, including mining activities, foundries and smelters, and diffuse sources such as piping, constituents of products, combustion by-products, traffic, etc. Relatively volatile heavy metals and those that become attached to air-borne particles can be widely dispersed on very large scales.

The most important heavy metals, which should be monitored from lakes are listed in the following table.

Table 9. The main heavy metals, their origin and their possible effects.

Metal	Sources/use	Problems
Antimony (Sb)	In the manufacture of foil, batteries, ceramics, safety matches and textiles.	Antimony irritates mucous membranes and tissues.
Arsenic (As)	In some areas natural sources and industrial effluents contribute arsenic to water. Arsenic is also used commercially e.g. in alloying agents and wood preservatives.	Severe health problems in drinking water.
Cadmium (Cd)	In plating metals and solders.	Ingestion of as little as 10 milligrams causes marked symptoms. Severe gastrointestinal inflammation with liver and kidney damage as a possible result.
Chromium (Cr)	Used in steel-making, electroplating, leather tanning and as a radiator anti-rust inhibitor.	Irritates and destroys cells. Causes dizziness, intense thirst, abdominal pain, vomiting and shock.
Lead (Pb)	In storage batteries, solder, pottery glaze, rubber, toys, brass alloys, plastic beads coated with lead, home-glazed pottery, ashes and fumes from burning old painted wood, newspapers and magazines.	Lead is a greater danger, when inhaled as opposed to when ingested.
Mercury (Hg)	Used in the manufacture of thermometers, felt, paints, explosives, lamps, electrical apparatus, batteries. Diethyl and dimethyl mercury compounds are used in treating seeds.	
Nickel (Ni)	Nickel mines, smelters and refiners, nickel alloy manufacturers and nickel platers.	
Zinc (Zn)	Mining and smelting (metal processing) operations.	The presence of zinc in drinking water does not generally present health risks and in small amounts is essential to health. Large doses of zinc by mouth even for a short time, may cause stomach cramps, nausea, and vomiting. Ingesting high levels of zinc for several months may cause anemia, panraes damage and decrease levels of high-density lipoprotein (HDL) cholesterol.

All the relevant heavy metals should be added to the monitoring programmes of the transboundary and international lakes. In the first phase only a general survey is needed, and if elevated values compared to the natural background is detected, more frequent monitoring should be carried out. The reason for elevated levels should always be clarified.

8.6 Radio nuclear contamination

When a radio ecological investigation of a lake is performed it is necessary to define the presence or absence of radio nuclear contamination of surface water, soil and bottom sediments of the lake and catchment area. Under normal circumstances, it is achieved by gamma screening all surrounding territory, water and soil samples are taken. The mean contamination level of the catchment area is obtained by Cs-137, Sr-90 and other radionuclides.

If there is a Nuclear Power Plant (NPP) in the vicinity of the lake, then in a 30-km zone around the NPP additional atmosphere fallouts should be radiologically studied. If it is possible, in the 30-km zone it would be very desirable to organize an online automatic system to measure gamma ray dosage (GRD) and meteorological parameters. Such a system (GAMMA-1) is operating near lake Drisvyaty in Belarus (Ignalina NPP). The results of a radiological investigation of the Drisvyaty lake sediments shows that there is a radiological element (Co-60), which has originated through NPP activity.

When radiological measurements are required, the main methods of radiological monitoring are:

- A scaled network of GRD measurements at the catchment area.
- A radiological investigation of atmospheric fallout using horizontal tables.
- A radiological investigation of atmospheric liquid and solid particles (aerosols) using equipment for the sampling of atmospheric aerosols.
- An investigation of radioactive contamination of surface water and sediment samples of the lake (4 times per year).

The assessment of radiological contamination of the lake catchment is performed by special expeditions, which fulfill gamma and beta measurements in the network (in field conditions) and take soil, flora, aerosol, fallout and sediment samples for further investigation under laboratory conditions.

In the process of determining the type and concentration of radio nuclei in water, soil and flora samples a preliminary sample preparation is required using a standard procedure for every separate case. Cs-137 is defined by gamma-spectrometric methods and Sr-90 by radiochemical method. Sample preparation of sediments is fulfilled by using standard procedures as well as by further gamma-spectroscopic measurement. As for the concentration of Sr-90 and isotopes of Pu in sediments, they are defined by radiochemical methods.

With aerosol and fallout samples total beta-activity, concentration and separate activity of gamma radioactive nuclei and Sr-90 contamination are all measured. For a gamma spectroscopic investigation a semiconductor gamma spectrometer is normally used.

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SUMMARY of Chapter 8

- Check all possible harmful substances, which are (or have earlier been) discharged to the lake itself and the watercourse above the lake.
- Take care of the persistent organic pollutants (POPs).
- Make an inventory of the Priority Substances of the WFD.
- Make an inventory of mercury in different compartments of the lake (water, sediments, biota).
- Check for possible discharges of heavy metals, which may have an effect on the lake.
- Define the presence or absence of radio nuclear contamination of surface water, soil and bottom sediments of the lake and the whole catchment area.
- Include all the relevant harmful substances in the monitoring programme, with an adequate sampling frequency.

9 MICROBIOLOGICAL QUALITY

9.1 Microbiological water quality and water hygiene

Microorganisms are responsible for the major processes in the circle of elements both in soil and in the aquatic environment. Information available on quantitative aspects of biodegradation processes today is so limited that these functions cannot be used for routine monitoring of the state of lake ecosystems. Even the behaviour of potentially harmful chemicals is deducted from the biotest data from laboratory experiments even in cases where uncertainty is considerable. Quantitative chemical analyses are extensively applied to observe the state of the lake, but in the future, assessment of microbial processes can supplement their use. On the other hand, microorganisms are the only feasible means to monitor for the health hazards due to infectious agents.

Microorganisms capable of causing disease in humans and animals are introduced into lake water in treated wastewater, in runoff, in contaminated brook and river water entering the lake and, occasionally, directly in animal droppings. Infectious agents are various bacteria, viruses and protozoa together with other parasites. Today, it is not possible to monitor the occurrence of every pathogen possibly present in lake water. The main concern are those pathogens transmitted through faeces and capable of causing epidemics *via* contaminated water. Direct routine monitoring for the detection these pathogens is still impracticable but the rapid developments in molecular methods (*e.g.* microarrays or DNA chips) may in the future offer powerful methods for the direct monitoring of different pathogens simultaneously.

However, enumeration of bacteria normally occurring in high numbers in faeces of humans and homoiothermic animals has been very successfully used for more than a century for the detection of faecal contamination. This strategy has been of immense importance in protecting humans against infectious diseases transmitted *via* water and causing easily extensive epidemics if drinking water is contaminated but also due to contaminated water supplies, in water used for irrigation and in recreational waters.

World Health Organization (www.who.int), EU and national authorities provide information on water hygiene and requirements for the hygienic quality. Organisation for Co-operation and Development (www.OECD.org) has elaborated a guidance document for microbiological testing of drinking water including water supplies, illuminating novel methodological possibilities. The International Organization for Standardization (www.ISO.org) publishes standard methods for global use, Comité Européen de Normalisation, CEN (http://www.cenorm.be/) for European countries and national standards bodies for national use (Niemi and Lahti 2000).

An overview of present policies to secure water quality and recommendations to improve management and to increase efficiency of actions in providing healthy water have recently been published on behalf of WHO (Fewtrell and Bartram 2001). In this book, the importance of considering the different sources of faecal microorganisms and all the barriers to prevent their circulation as a whole, is emphasised. Detailed information on monitoring of bathing water quality is given by Bartram and Rees (2000). Niemi and Niemi (2000) discuss ecological and methodological aspects of monitoring of faecal pollution in surface water in the temperate climate.

9.2 Temporal and spatial variation of lake water hygiene

Occurrence of faecal bacteria in lake water depends on the transmission of faecal material into lake, dilution, sedimentation and survival of bacteria.

When planning sampling programmes, it is important to assess the possible contamination sources and their temporal and spatial impacts. Pipelines conducting treated wastewater should be located and, ideally, the volume and quality of wastewater noticed. Pipes bringing non-treated domestic wastewater and waters from animal husbandry should be identified. Pastures adjacent to lake shore are probable sources of faecal contamination, especially during run-off episodes. Flocks of birds are known sources of direct contamination of lake water. Naturally, hygienic quality of river and brook water entering the lake affects its hygienic state. Usually, surface water is most vulnerable to contamination, but introduction of wastewater to deeper water layers or resuspension of sediment may cause heavy contamination of subsurface as well.

Temporal variation of lake water hygiene is great. Dry periods during summer may result to high quality surface water because of lack of run-off and efficient die-off of faecal microorganisms due to sunlight. On the other hand, wet periods cause drastic increase in contamination, orders of magnitude higher particle densities, due to run-off, sediment resuspension and less efficient radiation impact.

Seasonal variation is important as well. In temperate climate, during winter low water temperature increases survival of both bacteria and viruses. When ice and snow cover the lake excluding radiation damage from sunlight and biological activity is low, microbial survival is remarkably good. This can result to several magnitudes higher contamination level than during the warm and dry season.

9.3 Indicator organisms and their enumeration methods

Selection of microbiological determinands

Ashbolt et al. (2001) describe the history of different faecal indicators of water quality, their usefulness and limitations together with methodological aspects. They describe coliform and thermotolerant coliform bacteria, *Escherichia coli*, faecal streptococci and enterococci, sulphite-reducing clostridia and *Clostridium perfringens*, bifidobacteria, different bacteriophages (viruses attacking bacteria) and faecal sterol markers.

Selection of microbiological determinands for monitoring depends on the aim: If the aim is to follow the level of faecal contamination in the lake water, enumeration of indicators of faecal contamination shall be monitored. On the other hand, if the identification of actual health risks are of concern, detection of pathogens is needed.

In the selection of determinands it is necessary to consider geographical, socio-economical and technological aspects. It is reasonable to set minimum requirements for the monitoring and to allow additional determinands to be selected on the basis of local circumstances. The most important candidates for monitoring purposes are described in the following.

Coliform bacteria and E. coli

The traditional indicators of faecal contamination are the coliform bacteria, thermotolerant coliform bacteria and, in particular, *Escherichia coli*. A multitude of methods have been applied for the detection of coliform bacteria in water during a whole century of use.

Many members of the coliform and even of the thermotolerant coliform group reproduce in the natural environment and, in particularly, in the industrial systems. Even if *E. coli* has been reported to multiply in some, mainly tropical environments, it is widely accepted as the true indicator of faecal contamination in the vast majority of cases. When monitoring is based on the quantification of this species, missinterpretation of faecal contamination is much more limited than when other coliform bacteria are used.

Methods for the direct enumeration of viable *E. coli* are increasingly available. An international standard (EN ISO 9308-3 1999) has been published for the direct enumeration of *E. coli* in surface water. This method can detect 15 *E. coli* cells in 100 ml. Methods based on the same or related specific substrate principles are *e.g.* commercially available for cleaner waters. More traditional cultivation methods are available (*e.g.* EN ISO 9803-1: 2000, ISO/DC 9803-2), but in surface waters they are laborious and, therefore, costly and, due to confirmation steps, uncertainty of measurement is often significant. DNA and, especially RNA, based methods may be feasible in the future.

Faecal enterococci

The earlier term, faecal streptococci, has been substituted with the term faecal enterococci. The reason for this change is the following: When taxonomy developed, the new genus *Enterococcus* was created and the majority of faecal streptococci (and some primarily non-faecal streptococci) were transferred to this genus. Two major faecal species, *bovis* and *equinus*, however, remained in the genus *Streptococcus*. Ecological studies revealed that both *S. bovis* and *S. equinus* rapidly disappear in the aquatic environment. It is therefore probable that the majority of bacteria detected in the enumeration of faecal enterococci represent the main species of the genus *Enterococcus*. Even if the occurrence of different *Enterococcus* species in the aquatic environment is not thoroughly known and other sources than faeces of these bacteria are known, they are generally regarded as useful faecal indicators (Ashbolt et al. 2001). Because they tend to be more persistent in the aquatic environment than *E. coli*, their parallel use with *E. coli* can be recommended.

International standards are available for the enumeration of faecal enterococci. EN ISO 7899-1 (1999) describes a one-step procedure, based on specific substrates, for surface waters with the detection limit of 15 faecal enterococci in 100 ml. EN ISO 7899-2 (2000) can also be applied for the detection of contamination in even cleaner waters. In this method, confirmation is necessary and all the colonies are tested.

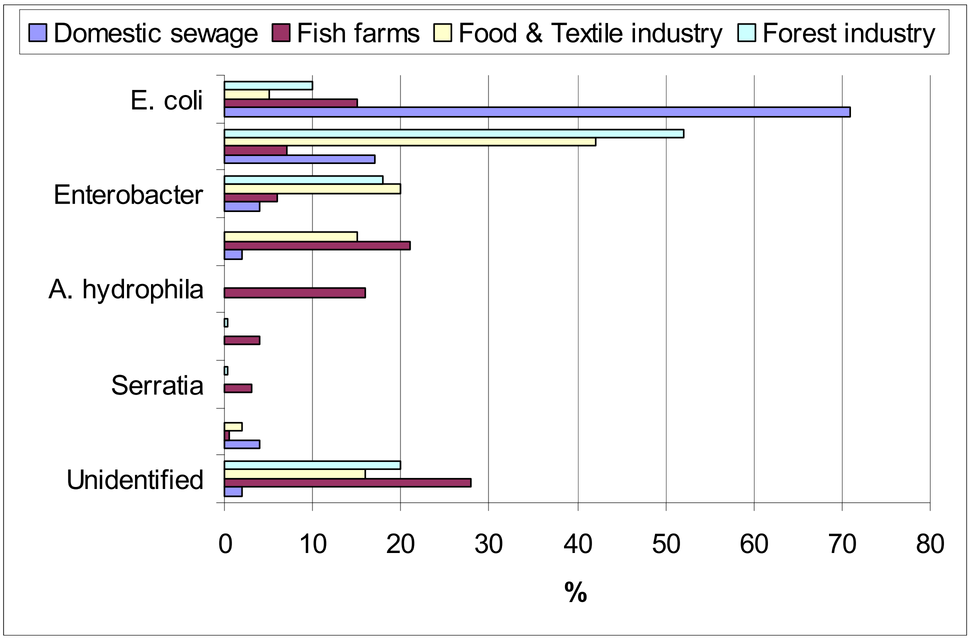

Fig. 23. Species distribution of coliform bacteria isolated from LES Endo agar indifferent wastewaters (data from Niemi et al. 1997)

Clostridium perfringens

Sulphite reducing clostridia have been used as faecal indicators for their relatively easy enumeration, but their value as faecal indicators has been questioned. The most important member of this group, *Clostridium perfringens*, is the selected target today. Two aspects restrict its use: The numbers of these bacteria entering the aquatic environment are lower than the numbers of *E. coli* and faecal enterococci restricting the sensitivity of their enumeration to detect faecal contamination. On the other hand, the spores of these bacteria are very persistent in the environment and may detect past pollution events not necessarily indicating health hazards. Their value must be assessed on considering local situation. Clostridia have been suggested as faecal indicators in freshwater in tropical climates (Deere et al. 2001). International standard methods (EN ISO 26461-1 and –2: 1993) are under revision.

Bacteriophages

Viruses infecting bacteria, bacteriophages, have been proposed as additional indicators. Their persistence in the aquatic environment should be more related to the persistence of viruses infecting humans than bacterial behaviour. The ecology and behaviour of different bacteriophages considered varies and thereby their value as faecal indicators. The EU financed evaluation study on feasibility of bacteriophages as indicators in bathing waters recommended the use of somatic coliphages (Jofre et al. 2000). A set of international standards (ISO 10705 series) are available or under elaboration for the enumeration of different bacteriophages. ISO 10705-2 (2001) describes the enumeration of somatic coliphages.

Pathogens

Monitoring for the occurrence of pathogens in environmental waters is seldom practised. The exception is the requirement to analyse for the presence of *Salmonella* species and enteroviruses in bathing beaches and in some rivers in the European legislation. ISO (ISO: prEN/CD 6340 under revision for *Salmonella*) and CEN (CEN/Draft prEN 230145: 2001 proposal for enteroviruses) provide standardised cultivation methods for the detection of these pathogens. Need for the detection of other pathogens rises mainly when epidemiological studies are carried out.

Because occurrence of a multitude of different pathogens is dependent on the local epidemiological situation, monitoring for their presence is not feasible today. However, rapid development of novel biotechnological methodology may increase the feasibility of pathogen detection in near future. However, the main emphasis in the protection of water quality and human health will be in the restriction of faecal contamination.

9.4 Assessment of microbiological monitoring data

Quantities of faecal microorganisms may vary very rapidly in surface waters, which challenges the interpretation of monitoring data. Frequent sampling improves the quality of data and grouping of data on the basis of season and weather conditions helps to understand the factors contributing to water hygiene and to predict local water quality. Percentiles and probability density functions of $\log_{10}$-transformed microbial counts (Havelaar et al. 2001) have been recommended for the evaluation of the data.

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SUMMARY of the Chapter 9

- Make an inventory of all the activities, which may affect water hygiene of the lake.
- Became acquaint with the suitable target microorganisms, their enumeration methodology and relevant standards.
- Remember, that frequent sampling improves the quality of data.
- Take care of the prevailing weather and hydrological conditions during the sampling.
- If there are inconsistences between results of the same sampling occasion, or if there are large changes of the results from the previous sampling, be ready to make repetition of sampling.

10 SEDIMENT

10.1 Sediment as a sink and source of elements

Bottom sediments consist of particles of different size, shape and chemical composition that have been transported mainly by water from the sites of their origin in a terrestrial environment, and they have been deposited on the lake floor. In addition, bottom sediments contain material precipitated from chemical and biological processes in water. Bottom sediments are a sink as well as a source of contaminants in an aquatic environment.

Particles transported in the water become sorted and deposited - and re-suspended - according to their textural properties in different areas of the lakes. The areas of erosion are characterised by coarse and consolidated deposits. The deposits within the areas of accumulation in the deeper parts of the lake are fine and loose with a high organic content and it is here that possible high nutrient and toxic element contents are to be found. In areas of higher hydrodynamic energy, coarser sediments of natural origin and low contaminant content may dilute these substances. The sedimentation rate depends on the location. In some restricted areas high sedimentation can cause problems and a requirement for dredging and monitoring.

Limnological monitoring data are required to make effective environmental decisions. But such observation series are rarely available and they are often somehow limited. However, paleolimnological techniques can provide proxy data of past environmental changes and provide a good foundation for monitoring work. Lakes are continuously depositing sediments, which incorporate fossil remains of organisms that lived in the lake. If the sediments are not disturbed, then sedimentary sequences can be dated and the information preserved in the sedimentary profiles represent "archives" of the history of the lake.

One can use the testimony of the sediments to establish factors that caused the change, to verify the change in the state of a lake, to determine the "natural" state and to weight the influence of man. A considerable archive of information is also contained in the physical and chemical sedimentary record, often providing information on the coupling of catchment and aquatic processes.

Figure 24. Figure 24. A sediment sample taken with a gravity corer. In this case different layers can be detected easily (Photo Seppo Knuuttila).

Water chemistry and water biology has been the mainstay in most long term monitoring programs of aquatic systems. Most studies are based on a "snapshot" approach, whereby the detection of changes in ecosystems is based on only a few samplings. Organisms monitor environmental conditions continually, reacting not only to subtle changes in individual physical, chemical and biological variables, but also to synergistic interactions. E.g. diatoms can be analysed from surface sediments and should be resampled every four to five years. Changes in thanatocenoses will be used to interpret the development of environmental conditions.

In monitoring programmes there are many benefits to focus on the concentrations of micro pollutants in bottom sediments instead of water. These sediments incorporate water pollution over a number of years and are therefore are better suited for monitoring than water itself. Most contaminants (metals, pesticides, hydrocarbons) show high affinity to particulate matter and, consequently, are enriched in bottom sediments.

10.2 Monitoring of sediments

Planning

Especially concerning physical and chemical parameters the correct right timing of sampling is sometimes important and the oxygen state / redox potential of the bottom near water affects the movements of phosphorus. Knowing the status of bottom near water is important; especially oxygen and phosphorus should be analysed.

When defining the positions and number of sediment sampling sites, the following factors should be considered: Required accuracy, available information, bottom dynamics at the sampling area, size of sampling area and available funds vs. estimated (real) monitoring costs.

The sedimentation rate in lake sediments is mostly low and the thickest sediment beds are concentrated in the deeper parts of lakes. The sedimentation rate fluctuates from parts of a millimetre to several millimetres per year. To correctly select the location of sediment sampling stations in studies of sediment contamination, it is necessary to obtain information on the type of sediments, particularly on the location of fine grained sediments and their extent at the study area.

Generally, two methods are available to obtain such information. The first is an acoustic survey of the bottom, with a low frequency (50 MHz), of the water body to be sampled and the second is limited scale sediment sampling at selected locations. Preliminary information obtained by one or a combination of both methods will provide guidance in the design of appropriate selection of sediment sampling stations in the final sampling program. Later locating the exact same sampling position is important. One should use GPS preferably DGPS as the sedimentation rate and the quality of sediment may fluctuate. Accuracy should be preferably down to only a few metres.

Sampling

The used sampler should be chosen according to the monitored sediment. Many samples are collected with bed grabbers, although this type of equipment is mostly not recommended, as they do not provide undisturbed samples and the finer topmost sediment layer may be lost. The most common tube sampler is the so called gravity corer. It is simply a tube with weights and a valve. This corer is suitable for sampling soft, fine grained sediments. It is lowered into the bottom and, after the valve is closed, it is raised. The valve part and weights are then moved and the monolith can be pushed out with a piston and parted to subsamples.

Sediment samples should generally be kept in glass, polythene, polypropylene or polycarbonate containers, transported and stored cool. Depending on analysis, deep-freezing is recommended whilst paying attention to the physico-chemical changes that can affect e.g. microfossils and colloids when freezing.

Variables

Dating. To obtain the sedimentation rate one has to date the sediment. The ^{210}Pb method is a much used tool for dating layers accumulated during the last 150 years. ^{137}Cs was first introduced into the atmosphere in the early 1950s during testing of nuclear weapons and reached then its maximum input in 1963. Then the Chernobyl accident in the year 1986 created a new peak in sediment. Fly-ash particles comprise two particle types, spheroidal carbonaceous particles and inorganic ash spheres. In sediments, these particles form an unambiguous record of atmospheric pollutants.

The best scenario is when sediments are yearly laminated as trees, as one can then study the events with a high degree of accuracy. Dating is the backbone of paleolimnological studies, but on some occasions the amount of sedimenting matter has, also, to be monitored. Often accurate dating of some sediment profiles provides good knowledge of the future sedimentation rate.

Metals and toxic compounds. The coarse components that normally have low levels of heavy metals and organic pollutants produce a downward shift of the concentration in the total sample. Normalisation is defined as a procedure to compensate the influence of natural processes on the measured variability of the concentration of contaminants in sediments. It is essential to normalise the effects of grain size in order to provide a basis of meaningful comparisons of the occurrence of the substances in sediments of various granulometry and texture within individual areas or among areas. Excess levels, above normalised background values, could then be used to establish sediment quality.

There are various approaches used for the normalisation of trace elements. The most used is purely physical characterising the sediment by measuring its content of fine material. Another approach is chemical in nature and based on the fact that a small size fraction is usually rich in clay materials, iron and manganese oxihydroxides and organic matter.

In soft lake sediments, from the depths of the lake, the texture is always very fine and one can overlook the grain size effect. When monitoring great lakes in sites with transportation bottoms with occasionally high hydrodynamic forces, at least the amount of material under 63 μm should be determined. However, sieving the sample at 63 μm is often not sufficient, especially when sediments are predominantly fine grained. In such cases, it is better to normalise with lower size thresholds, since the contaminants are mainly concentrated in the fraction lower than 20 μm.

Organic matter. Carbon is present in large quantities in lake sediments, which in fact constitute one of the rare permanent sinks in the global carbon cycle. Organic carbon stored in such sediments comprises of both allochthonous material transported into the lake from the drainage basin and autochthonous carbon derived from biomass produced in the lake itself. Decomposing organic matter affects the oxygen status and may cause anoxies which in turn lead to the escape of phosphorus and some metals in the water phase. The other effective factor is pH. These parameters can be quickly measured. The halved loss-on-ignition value gives an economic approximation of organic carbon. Sediment nitrogen is in correlation with organic matter, but the C/N ratio is used in obtaining knowledge of the parts of material of allochtonic and autochtonic origin.

Sediment phosphorus. Sediment total phosphorus values are used to provide a picture of the changes. Organic surface sediments usually have a water content of 95-99% in freshwater ecosystems. Only a minor part is bound to solid chemical substances. The major part of water content constitutes the mobile liquid medium, which surrounds the sediment particles. This mobile water fraction is named interstitial water or pore water and is a highly important transition medium for the movement of solute species across the sediment-water interface. The extraction methods are mostly based on filtration, but semipermeable membranes or centrifugation may also be used. Sediment samples readily take oxygen although nitrogen gas is preferably to be used. To obtain a get more precise knowledge of the forms of phosphorus there are fractionation methods available (Al-bound, Fe-bound, Ca-bound P).

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SUMMARY of Chapter 10

- Become acquainted with the suitable methodology and relevant standards for sediment research.
- Make an inventory of all the good sedimentation areas of the lake.
- Make in the first phase an evaluation of the lake history based on core samples.

11 THE ASSESSMENT AND PRESENTATION OF THE MONITORING RESULTS

11.1 Introduction to the use of monitoring results

The monitoring results have to be handled and assessed with a certain procedure designed simultaneously with the planning of the monitoring programme. Handling and assessment of data and finally, reporting to all parties involved, are essential parts of the monitoring cycle (Fig. 25).

The monitoring cycle starts always with the evaluation of the data needs for sustainable solutions in water protection and management. The requirements are then described with different characteristics, which are taken into the monitoring programme. The programme will be implemented during a longer period (at present often three years, or in the future six years according to the EU WFD) without any alterations in sampling procedure (same sites, same dates, same depths and same methodology).

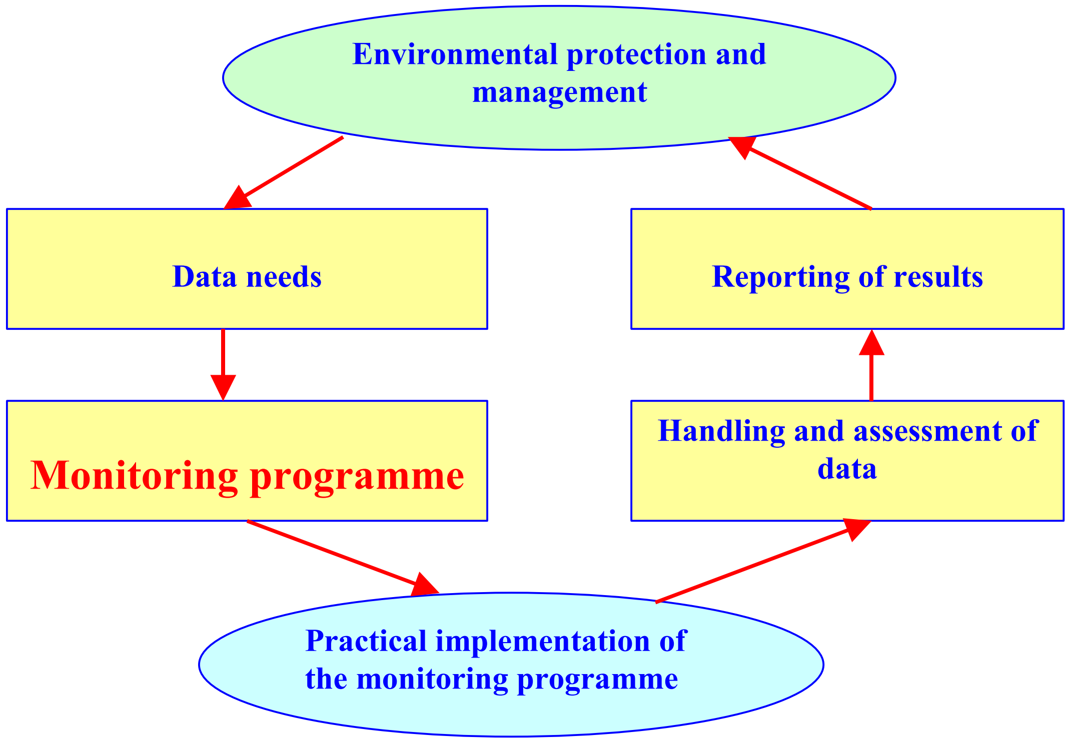

Figure 25. The monitoring cycle.

After the sampling and observations have been fulfilled, and the final results have been completed by the relevant laboratory, the handling of data can commence. The steps after the sampling and analyses are described to a general level in Fig. 26.

The very first step is to check the results, how they fit to the corresponding levels and ranges of the characteristics of the lake concerned. For instance, if you have phosphorus results from a very oligotrophic lake, you will wait for the phosphorus levels to be some 5 to 10 µg/L only. However, if the concentration is greater, e.g. 25 µg/L, you have to check for inaccuracies first from the field documents and then from the corresponding laboratory. If not, you can bring the result to the corresponding register.

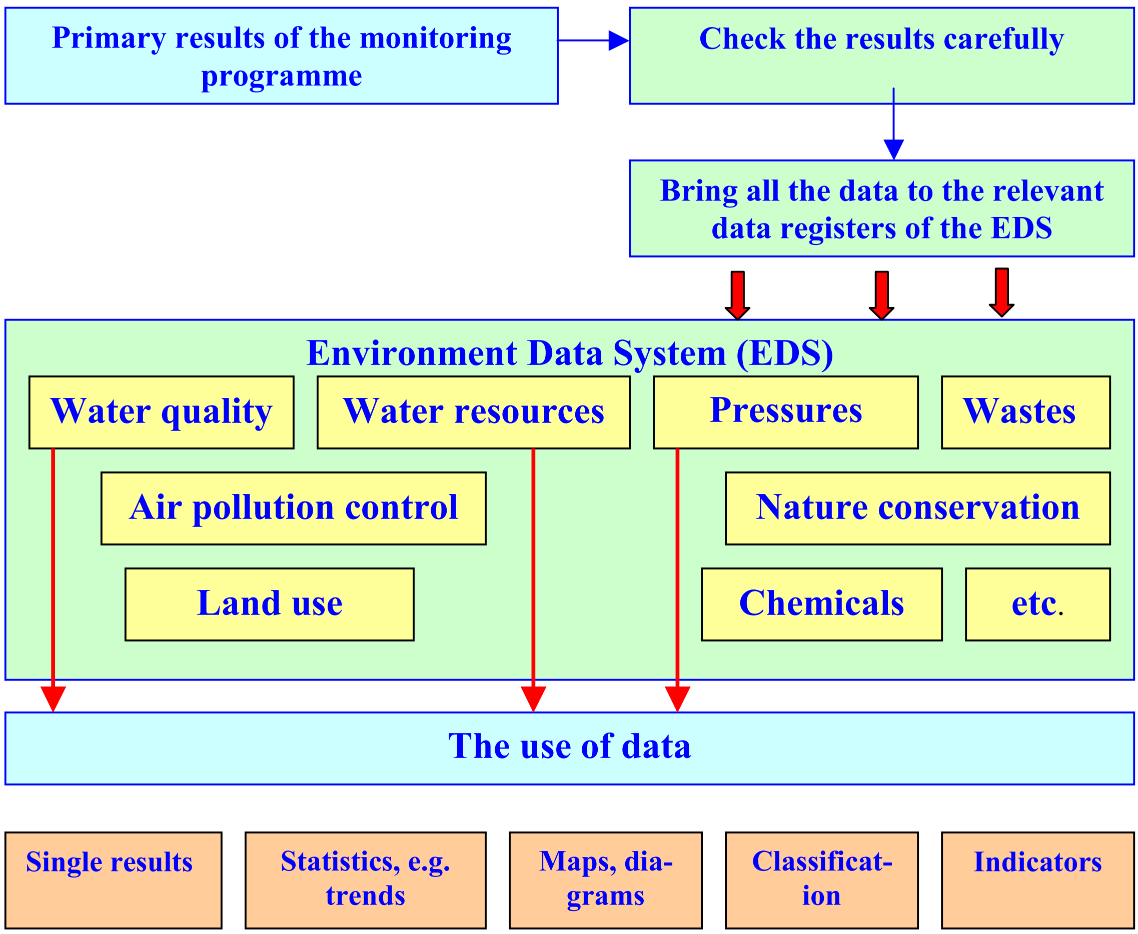

Figure 26. Flow chart of the use of the monitoring data.

You can commence data processing only when you have made all the checks. If the results seem doubtful they must be considered inaccurate, and you must organise new sampling in order to obtain more reliable data as soon as possible.

11.2 Original data, data registers, indicators and maps

The first level to utilise environmental monitoring data is simply to select, already prior to entry to the database, one single result e.g. the result of the microbiological characteristic from a bathing area of the lake. This single result can provide information on the usability of this area for recreational swimming purposes. This single value will be compared to the normative value for acceptable quality. Similar data which should be checked, immediately after analyses is completed, are the results of toxic substances. They also have acceptable limit values, to which the values should be compared. The use of a single analytical result is often connected with certain official supervising tasks.

The following step is to collect the results in a register. As an example, the Environment Data System (EDS) maintained by the Finnish Environment Institute is the basic tool for environmental control, monitoring and assessment in Finland. It contains data from several items, such as water quality, hydrological characteristics, pressure information, waste waters, etc. (Fig. 26). It is used by the environmental authorities at all levels of its organisation through the Finnish Environment Network. This EDS is also open to other users outside environmental governance.

A corresponding system is absolutely required in the case of all transboundary and international lakes, especially to assist data processing and finally the co-ordinated reporting process. For instance, the integrated use of results from different registers can easily be organised in this system. In most cases you have to use water quality data together with hydrological observations as well as e.g. data of the wastewater discharges to the same lake area.

Currently, various types of indicators are a very popular way to present environmental monitoring results. An indicator can be defined as a variable or a value derived from variables, which provides information about a phenomenon. The indicators:

- Reduce the number of measurements and variables which normally would be required to provide an "exact" presentation of a situation. As a consequence, the size of a set of indicators and the amount of detail contained in the set need to be limited.
- Simplify the communication process by which the information of results of measurement is provided to the user. Due to this simplification and adaptation to user needs, indicators may not always meet strict scientific demands to demonstrate causal chains. Indicators should therefore be regarded as an expression of "the best knowledge available".

As indicators are used for varying purposes it is necessary to define general criteria for the selection of indicators. Three basic criteria have been used in OECD work:

- Policy relevance.
- Analytical soundness.
- Measurability.

The OECD core set of environmental indicators is a commonly agreed upon set of indicators for OECD countries and for international use and it is regularly published. It covers issues that reflect major environmental concerns in OECD countries. The publication incorporates major indicators derived from sectoral sets as well as from environmental accounting (e.g. intensity of water use or of forest use).

The European Environment Agency has for a while published their own indicator-based overview, Environmental signals, which is meant to be a short and concise report on the environment for policy-makers and the public. The last edition, Environmental signals 2002, discusses the following topics:

- Households.
- Transport.
- Energy.
- Agriculture.
- Fisheries.
- Climate change.
- Air pollution.
- Inland and coastal waters.
- Waste and material flows.
- Land.
- Forests.
- Environmental taxes.

From sector inland waters the following indicators are presented and the situation in the EEA area is discussed:

- Water use versus resources.
- Organic pollution in rivers.
- Wastewater treatment.
- Nutrients in rivers.
- Bathing water quality.

The EEA has published also more comprehensive documents containing detailed information to support the development of strategic, long-term environmental policies and to provide general public information.

One very simple yet informative way for the public is to build up maps from the results of a larger lake. There are numerous possibilities to choose the most informative determinand for these maps.

For instance, the eutrophication situation of the lake can be described by phosphorus concentration and chlorophyll *a* contents (Fig. 27).

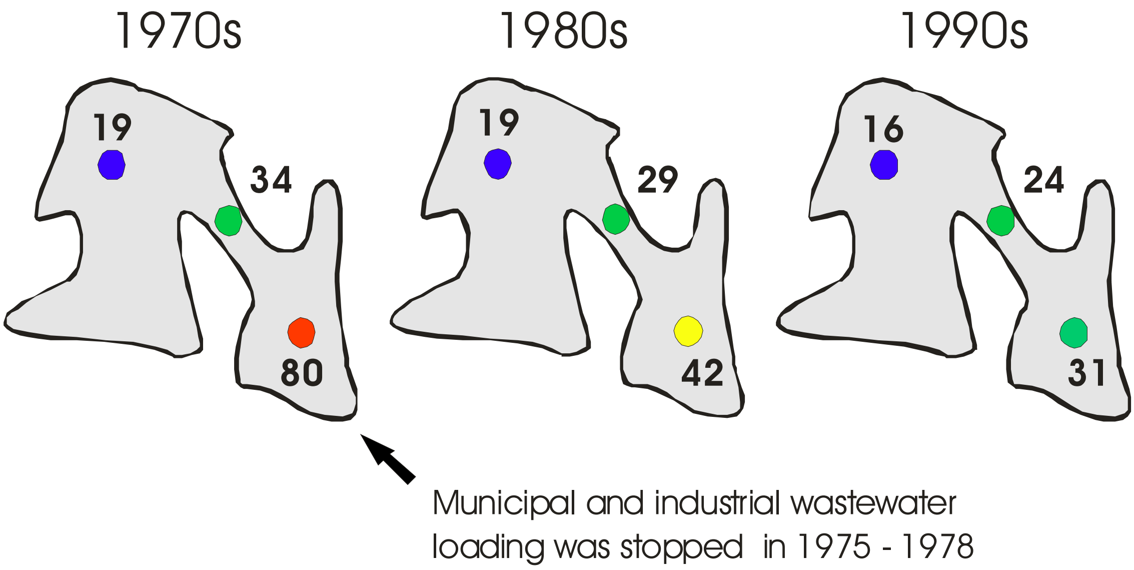

Figure 27. The mean phosphorus concentrations (µg/l) in Lake Vesijärvi, Southern Finland. The improvement of the water quality of this lake has been significant since the rejection of substantial point source loading in the late 1970s.

At a glance you can see the overall eutrophication situation of the lake and where are the most eutrophic parts in such a large lake as Lake Vesijärvi (over 100 km^2). The results of the characteristics can also be classified, thus making much easier for the public to understand the prevailing situation. The monitoring aspect of the maps can be added by taking results of several successive years in the same figure.

11.3 Statistical methods

In monitoring programmes, where usually large amounts of different data are collected continuously over several years, you also, in every case, require statistical methods to effectively summarize and manage the data. You have to calculate averages (e.g. for the maps in Fig. 27), and look at annual variations etc. In most cases you need, however, to use more sophisticated statistical methods to obtain all the possible information from monitoring data. With statistical methods you can also determine the necessary frequencies of sampling.

The attribute of monitoring data should be that the usability of single results is constantly improving, when the series are becoming longer and longer. The natural variations in many characteristics can then be understood better on the basis of corresponding results from the reference stations and the important anthropogenic effect, the real main object of the environmental monitoring, can be differentiated more reliably.

There are some important objectives in environmental monitoring, where statistical methods are without doubt required. The first objective is to analyse the appearance of trends. To analyse long term site-specific trends in water quality, the nonparametric Seasonal Kendall test, SKT has become as a standard. It can accept the non-normality of data, missing and censored data and seasonality that are very common in all environmental monitoring data. In a statistical sense, it is a powerful trend test (Minkkinen 2000). The SKT limitation is that it detects only monotonic trends. They need not be linear, but must proceed in one direction only (decreasing or increasing).

In Fig. 28 some examples of the use of SKT are presented using monitoring data from some Finnish lakes. Only quality data is used.

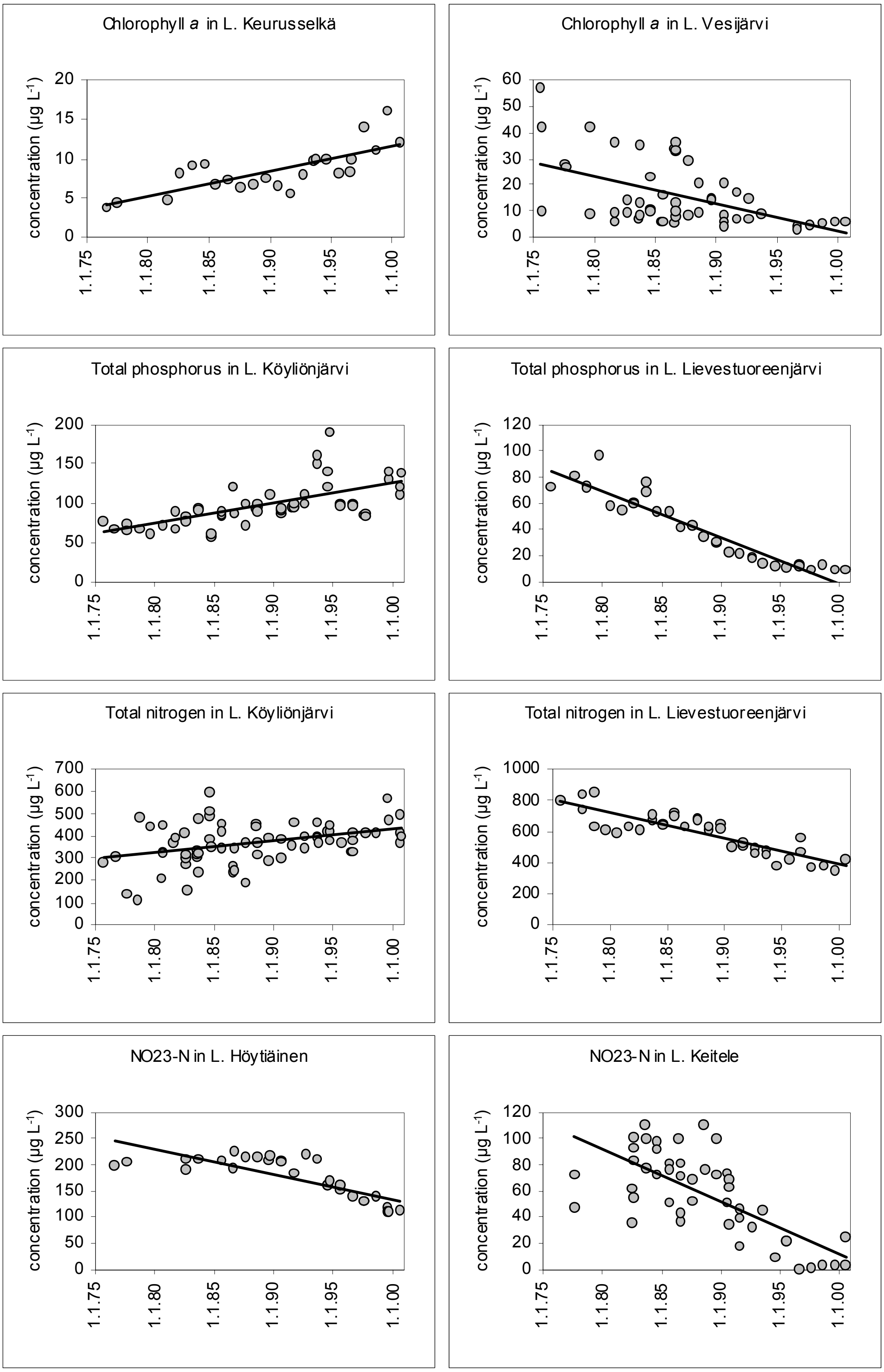

Figure 28. Examples of statistically significant long-term trends of four determinands related to eutrophication in Finnish lakes. Lakes affected by point source loading has shown a clear recovery from eutrophication while lakes affected by agriculture has shown an opposite trend in many cases.

The other objective is to compare, in a more detailed way, two different areas of a lake. Usually you are trying to solve the basic question of water protection, if one part of lake is polluted/eutrophied or not, then you have to compare the results of this suspected area (by using relevant characteristics e.g. total phosphorus, phytoplankton biomass etc) with the reference area. For this purpose, Analysis of variance (ANOVA) will be one suitable solution.

This method performs comparisons such as the t-Test, but for an arbitrary number of factors. Each factor can have an arbitrary number of levels. Furthermore, each factor combination can have any number of replicates.

The use of different statistical methods helps also to maintain all key parts (sampling sites, determinants used, frequency of sampling etc.) of the monitoring programme as relevant as possible.

11.4 Classification systems

There are numerous classification systems in use in Europe. Some are based on physical-chemical variables, and can be estimated in water-quality or water usability classifications. Some classification systems are based on biological data, which can be estimated to be the nearest to the ecological classification system as required by the WFD.

In the Water Framework Directive the general guidelines of Classification and presentation of ecological status have been defined from the following three main topics:

- Comparability of biological monitoring results.
- Presentation of monitoring results and classification of ecological status and ecological potential.
- Presentation of monitoring results and classification of chemical status.

To guarantee the comparability of biological monitoring results:

- Member States shall establish monitoring systems for the purpose of estimating the values of the biological quality elements specified for each surface water category or for heavily modified and artificial bodies of surface water. In applying the procedure set out below to heavily modified or artificial water bodies, references to ecological status should be construed as references to ecological potential. Such systems may utilise particular species or groups of species which are representative of the quality element as a whole.
- In order to ensure comparability of such monitoring systems, the results of the systems operated by each Member State shall be expressed as ecological quality ratios (EQRs) for the purposes of classification of ecological status. These ratios shall represent the relationship between the values of the biological parameters observed for a given body of surface water and the values for these parameters in the reference conditions applicable to that body. The ratio shall be expressed as a numerical value between zero and one, with high ecological status represented by values close to one and bad ecological status through values close to zero.
- Each Member State shall divide the ecological quality ratio scale for their monitoring system for each surface water category into five classes ranging from high to bad ecological status. The value for the boundary between the classes of high and good status, and the value for the boundary between good and moderate status shall be established through the inter-calibration exercise described below.
- The Commission shall facilitate this inter-calibration exercise in order to ensure that these class boundaries are established consistent with the normative definitions and are comparable between Member States.
- As part of this exercise the Commission shall facilitate an exchange of information between Members States leading to the identification of a range of sites in each ecoregion in the Community; these sites will form an inter-calibration network. The network shall consist of sites selected from a range of surface water body types present within each ecoregion. For each surface water body type selected, the network shall consist of at least two sites corresponding to the boundary between the normative definitions of high and good status, and at least two sites corresponding to the boundary between the normative definitions of good and moderate status. The sites shall be selected by expert judgement based on joint inspections and all other available information.
- Each Member State monitoring system shall be applied to those sites in the inter-calibration network which are both in the ecoregion and of a surface water body type to which the system will be applied pursuant to the requirements of this Directive. The results of this application shall be

used to set the numerical values for the relevant class boundaries in each Member State monitoring system.
- Within three years of the date of entry into force of the Directive, the Commission shall prepare a draft register of sites to form the inter-calibration network which may be adapted in accordance with the procedures laid down in Article 21 of WFD. The final register of sites shall be established within four years of the date of entry into force of the Directive and shall be published by the Commission.
- The Commission and Member States shall complete the inter-calibration exercise within 18 months of the date on which the finalised register is published.
- The Commission within six months of the completion of the inter-calibration exercise shall publish the results of the inter-calibration exercise and the values established for the Member State monitoring system classifications.

The inter-calibration phase will be completed during the next coming years so, that at the end of 2006 the harmonized classification systems are ready for all EU Member States.

Besides the WFD ecological classification there are a great number other classification schemes or systems, which have been for a long period been used and still are in use in most European countries. A very common classification basis has been to evaluate the usability of watercourses (or water in the water body) for different purposes. It is a very suitable and simple way to concentrate the results and inform the public and the administration not acquainted with special scientific terms of limnology, microbiology etc. As an example the Finnish classification of the general usability of watercourses will be presented.

Authorities responsible for monitoring and reporting of watercourses have used in Finland a type of quality classification schema for over 30 years. The original classification has been revised several times, but the system, currently in use, originates from the mid 1980s. The system comprises three utilisation-specific watercourse classifications, i.e.:

- For recreational purposes.
- Raw water (for domestic use) classification.
- Quality classification of water courses for fishing.

In addition to these utilization-specific classifications, the general water quality classification has been presented. The quality criteria of water are divided into five groups, from excellent to bad. The most important characteristics used in the classification have been chlorophyll a, total phosphorus, colour number (because of humic waters very common in Finland), oxygen concentrations during stagnation periods and faecal indicator bacteria.

This classification has provided quite useful information on the general situation of lakes. The disadvantage has been the lack of biological data. Only in some cases there have been data of phytoplankton and bottom fauna.

11.5 Monitoring reports

The most important phase in the whole monitoring cycle is reporting. The usual requirement is to report monitoring results in different phases of the monitoring period, from different areas of the entire river basin (or country) and finally for different groups of persons. Monitoring material should be used very effectively. All the analyses should be used at least in some of the reports. The reporting phase is also a very suitable moment to revise the monitoring programme according to the results and observations of the previous monitoring period.

The closest local reports are from the public living on the shores of the lake concerned. This report can focus on e.g. the situation of one small part of the lake near some polluting industrial source. Reports of this nature are usually published annually. These short reports should be written very clearly, and not using any difficult scientific terminology. The key message should be concentrated in practical questions like: Is the common situation of the lake improved, is the water in lake suitable for swimming, are the fishes still inedible because of high mercury content, etc.

The regional reports are needed for bigger areas, like river basins or even one country. In these reports all the possible monitoring data should be used as an integrated way. The lake is only one part of larger water system, and the situation should be assessed for whole river basin. The biocoenosis and water quality data should be used together with pressure information, as well as with hydrological monitoring data. Important key questions in regional reporting are e.g.: long term changes in pressure factors, phosphorus loading originating from urban waste waters, correlations between different loading characteristics and water quality characteristics, and the trends.

Finally, you need also international reporting in European scale and especially con-cerning transboundary water courses. They should be well documented and prepared in good co-operation of all relevant member states. The interval of these thoroughgoing reports may be several years.

Previous reports such as "Europe's Environment: the Second Assessment" and "Environment in the European Union at the Turn of the Century" are

Supporting literature:

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SUMMARY of Chapter 11

- In all monitoring activity you have to take into account the obligations of reporting for different purposes and for different levels.
- Data registers are absolutely needed in handling different monitoring data of lakes and relevant river basins.
- Try to establish suitable statistical means for handling and presenting the data.
- Try to find indicator characteristics for different purposes in reporting.
- The reliable classification of the ecological status according to WFD necessitates continuous monitoring of different biological quality elements.
- Reporting phase is also very suitable moment for checking the monitoring programmes.

Guidelines on Monitoring and Assessment of Transboundary and International Lakes

Part B: Technical guidelines

Between 1996 and 2000, the UN/ECE Working Group on Monitoring and Assessment (WGMA) prepared two separate publications: Guidelines for Transboundary Rivers (1996, new edition 2000), and Guidelines for Transboundary Groundwaters (2000). Both sets of guidelines were largely strategic, and technical details were not fully elaborated. These Guidelines for the Monitoring and Assessment of Transboundary and International Lakes have been structured differently, and are divided into two parts. Part A consists of a strategy document, while Part B contains more detailed technical guidelines. The strategy document is broadly designed to be used in the same contexts as the other technical guidelines prepared by the WGMA (for rivers, estuaries and groundwaters).

Part B, Technical guidelines, contains the necessary practical guidelines for the monitoring and assessment of lakes and reservoirs. These guidelines are based on widely-accepted hydrological and limnological lake monitoring practices. There is clearly a requirement to harmonise monitoring programmes in Europe, for both economical and practical reasons. The economic reality is that individual countries lack sufficient resources to maintain simultaneous monitoring programmes with differing contents. Moreover, data handling and reporting practices must be as near identical as possible for various user-organisations (EU, EEA, UN/ECE, EUROSTAT, etc.). The recommendations of the EEA's Eurowaternet and the requirements of various EU water directives, especially the Water Framework Directive (December 2000), have therefore been adhered to as closely as possible.