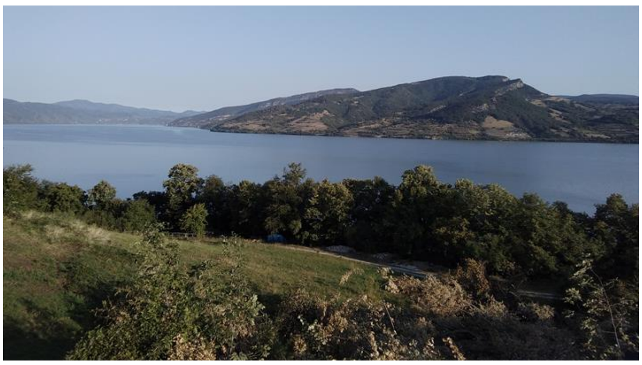
Interreg
Danube Transnational Programme
SIMONA

WP 6: Sediment sampling in Large Lakes and Reservoirs

D.T4.2.2.

GUIDANCE ON SEDIMENT MONITORING IN LARGE LAKES AND RESERVOIRS



November 2021

PROJECT TITLE Sediment-quality Information, Monitoring and Assessment System to support transnational cooperation for joint Danube Basin water management

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For further information on the project, partnership and the Danube Transnational Programme: www.interreg-danube.eu/simona

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BACKGROUND INFORMATION

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 such systems, 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 manmade, 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.

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 and 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 waterbodies 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 and reservoirs or of the total river basin.

SIMONA project responds to the current demand for the effective and comparable measurements and assessments of sediment quality in surface waters in the DRB by delivering a ready-to-deploy Sediment-quality Information, Monitoring and Assessment System to support transnational cooperation for joint DRB water management.

The system is a functional composition of sediment (1) sampling, (2) laboratory analysis, (3) evaluation protocols and (4)

The immediate and middle term benefit of the project is a transparent method supported by the SIMONA-tool for sediment quality monitoring that will encourage the cooperation in transnational water management.

One of the main tasks of the project is to deliver recommendations for policy-makers in the field of sediment monitoring in large lakes and reservoirs.

INTRODUCTION

WATER FRAMEWORK DIRECTIVE AND SEDIMENTS

The Water Framework Directive introduced a system of water management through river basin management which allows us to use natural, geographic and hydrological boundaries to view systems as a whole rather than focusing on political or administrative borders. This allows us to observe processes at a level above national level and adress problems at an all-encompassing and coordinated manner.

Chemical and physical analysis of sediments can be used as a tool for the monitoring of pollutant discharges to a river or lake system. In order to be able to make valid comparisons among stations or reference sites, consistent sampling techniques should be maintained. Sediments can be used to help locate non-point, historical, or intermittent discharges that may not be readily apparent using samples collected from the water column.

Despite regular sediment quality assessment by member states, a reliable estimation of the overall amount of contaminated sediment in Europe is hard to give. the main reason for this is the absence of uniformity in sampling methods, analytical techniques and applied sediment quality standards or guideline values. This causes a lack of inter-comparability. typically, countries along the same river basin use different methods.

The WFD does not focus specifically on sediment but seeing that sediments are a natural constituent of aquatic environments, the management of sediments, their quality and quantity has to play an important role in water legislation.

According to the data collected through means of questionnaires and review of relevant literature, it was noted that Germany, Slovakia, Serbia, Hungary and Slovenia had national laws and/or regulations dealing with sediment quality and/or quantity in inland waters whilst Bulgaria, Croatia, Bosnia and Herzegovina, Republika Srpska, Montenegro, Austria, Ukraine, Romania and Moldova do not.

None of the basin countries has specific gudlines and legislation for sediments in large lakes and reservoirs despite the significant contribution that sediments can make to the overall status of these aquatic systems.

A review of the specific situations in the project partner countries shows that most of the project partner countries have adopted some form of the ISO 5667-12 international standard which serves as Guidance on sampling of bottom sediments from rivers, lakes and estuarine areas. Whilst some countries have further devoleped or modified the guidelines given within this standard it is safe to say that this standard should serve as a baseline or starting point for further development of advanced guidelines on the methods used for bottom sediment sampling.

For the purpose of suspended sediment sampling, those countries where suspended sediment sampling is being conducted seem to have adopted the guidance and requirements of ISO 5667-17:2008 Water quality -Sampling -Part 17: Guidance on sampling of bulk suspended solids which in turn suggests that this document could serve as a baseline/starting point for further development of guidelines for the sampling of suspended sediments.

Whilst the sampling methodology between countries may vary the depth of primary sediment sampling is generally no more than 5cm.

Bearing in mind the objectives of the demonstration at the Iron Gate Reservoir and the current situation in the partner countries the topic covered durring the demonstration are broader than the sampling itself and the material that folows and which is the part of the demonstration activities is reflecting this broader perspective.

The problem of the lake and reservoirs sediment quality assessment is of particular interest since in large lakes and reservoirs sediments potentially could have a controlling role on the status of water body in question through INTERNAL LOADING processes.

Understanding and quantification of INTERNAL LOADING is only possible through an adequate monitoring focused on sediment water interaction and especially so on quality parameters that are of importance for the dynamics of water column chemistry in large lakes and reservoirs such as are micro and macro nutrients.

This knowledge is necessary in order to develop appropriate programs of measures within RBMP within WFD aimed in achieving good water body status/potential.

The broad perspective given above is summarised conceptually in Figure 1.

Figures 2 and 3. show the evolution of the WFD Common Implementation Strategy and the time frame of interest. It should be noted that it took more than a decade for sediment to be recognized as one of the important issues in the implementation and that special role of sediments in lakes and reservoirs and their contribution to the status of water bodies is yet to be fully recognized.

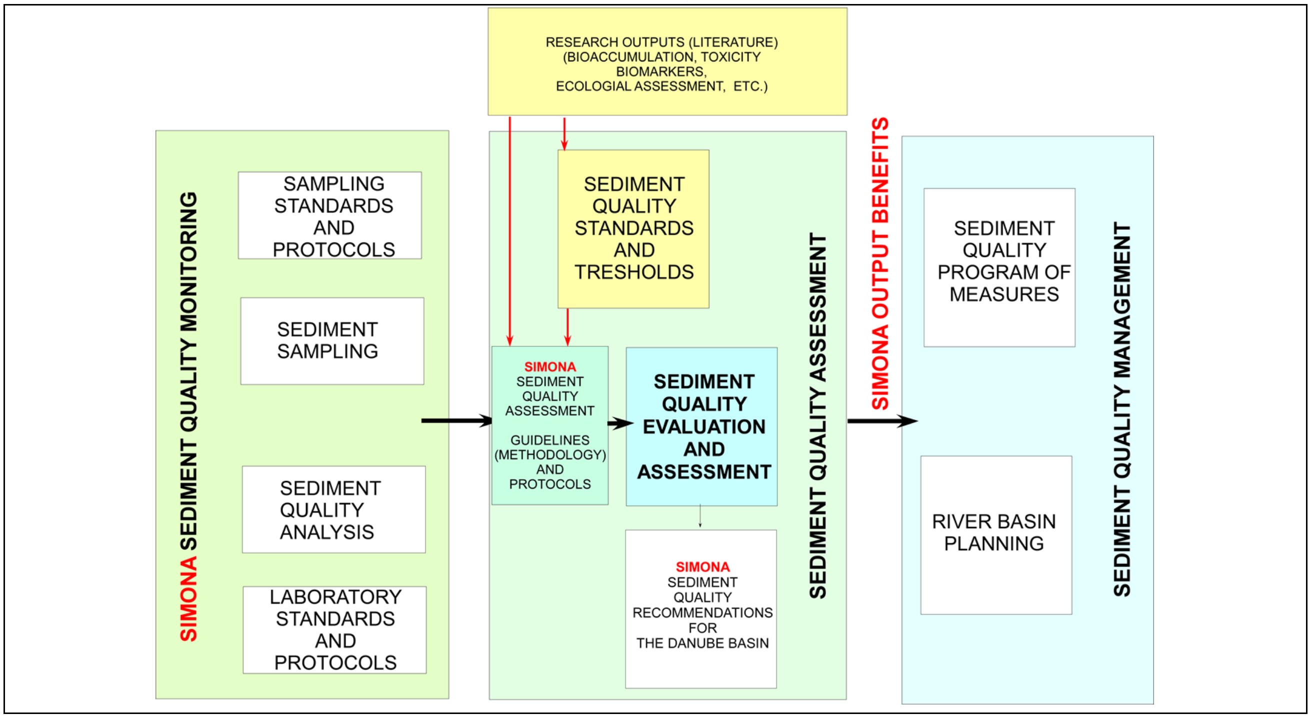

Figure 1. Broad perspective of the role of sediment quality in river basin planning as per WFD

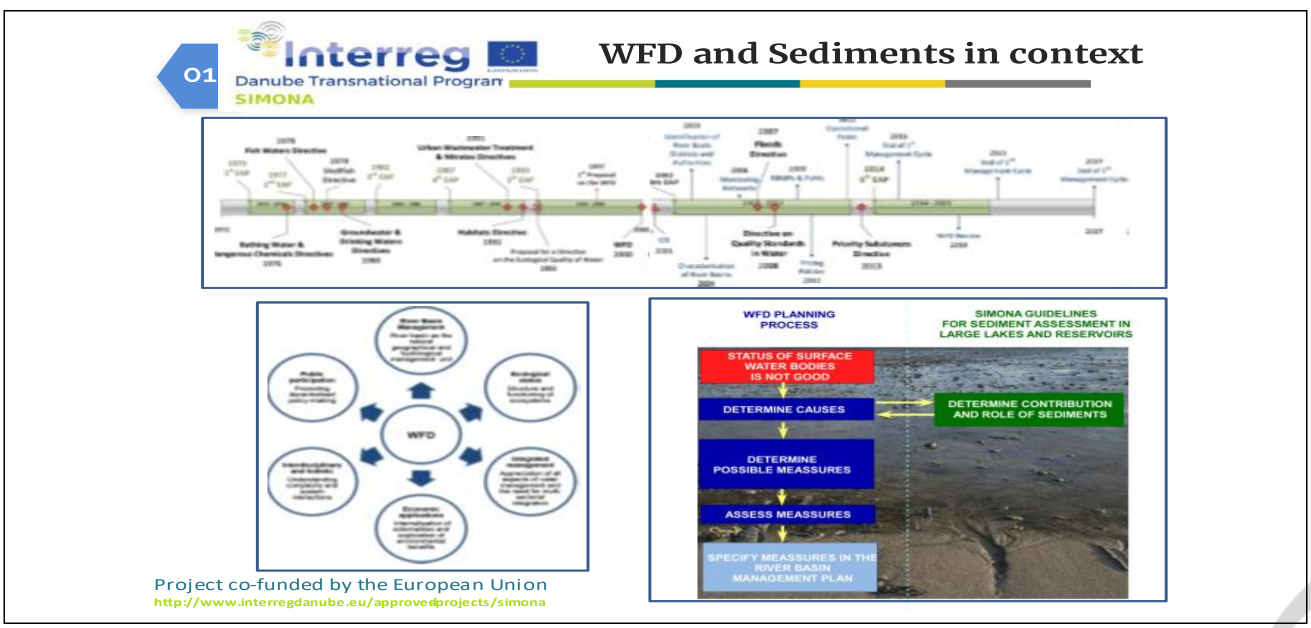

Figure 2. The role of sediment quality in the implementation of WFD

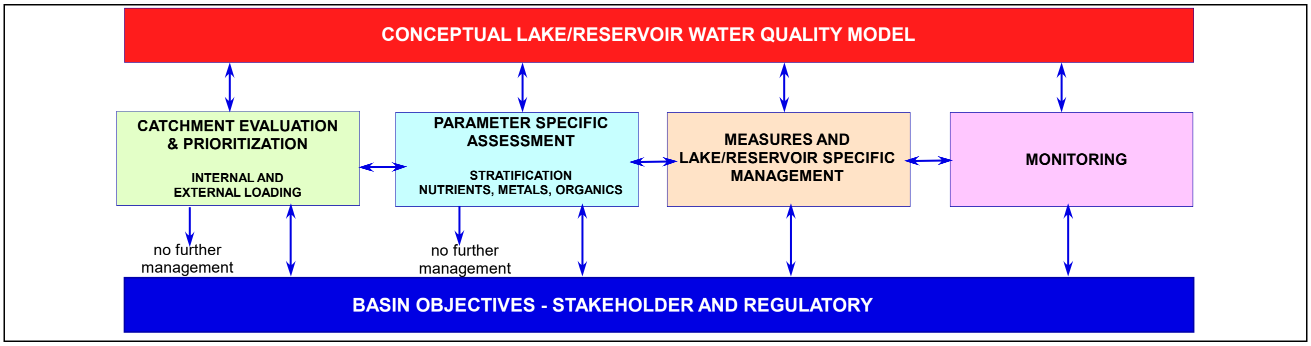

Figure 3. Sediment quality and WFD water body status objectives in context

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

In the Guidance on Monitoring for the Water Framework Directive some systematically gathered and processed information of the different quality elements have been presented.

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.

The hydrological cycle is the driving force that regulates the water resources of lakes/reservoirs.. The hydrological cycle feeds the lakes and reservoirs, removes water from the them and combined with climate and geology provides basic features for the variability of water resources. Extreme hydrometeorological events lead into floods and droughts.

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.

In most of the natural European lakes and reservoirs, 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 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 and reservoirs. 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.

SELECTION OF QUALITY ELEMENTS FOR MONITORING OF LAKESAND RESEREVOIRS 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.

The summary of the requirements of the WFD and the interpretation of the experts is expressed in the Fig. 2 (Figure 3.2 in final CIS Guidance on Monitoring (2003), page 47).

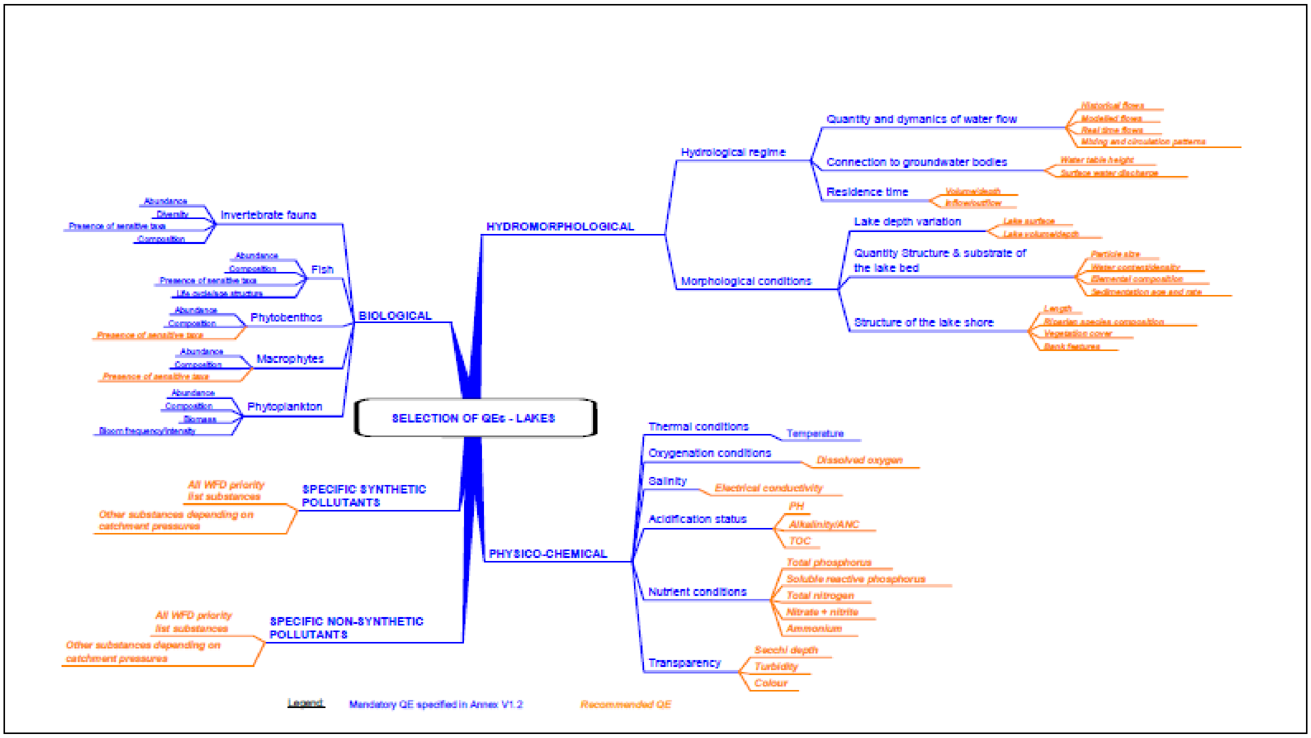

Figure 4. The mandatory Quality Elements specified in Annex V (1.2) of the EU Water Framework Directive (CIS Guidance on Monitoring 2003).

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DIFFERENCES BETWEEN LAKES AND RESERVOIRS AND RIVERS AND STREAMS

Lakes and reservoirs have significantly different characteristics (both in form and function) than rivers and streams. The differences are caused by fundamentally different structure and dynamics of dominant ecosystems which are driven and controlled by physical parameters such as water flow and velocity, light regime and thermal structure. These differences are the main cause behind the fact that the role of sediment quality in determining the status of lake and reservoir water bodies is much more pronounced than is the case with rivers and streams. The remaining part of this section is devoted to the discussion of the main differences.

A LAKE/RESERVOIR AS AN ECOSYSTEM

Lakes and reservoirs 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 and reservoirs 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.(Figure 1)

The temperature in the deeper layer of the lake is, on the contrary, usually very cold (5---10 °C) 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 alloctonic 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 reservoirs, 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/reservoir 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.

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/reservoir 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.

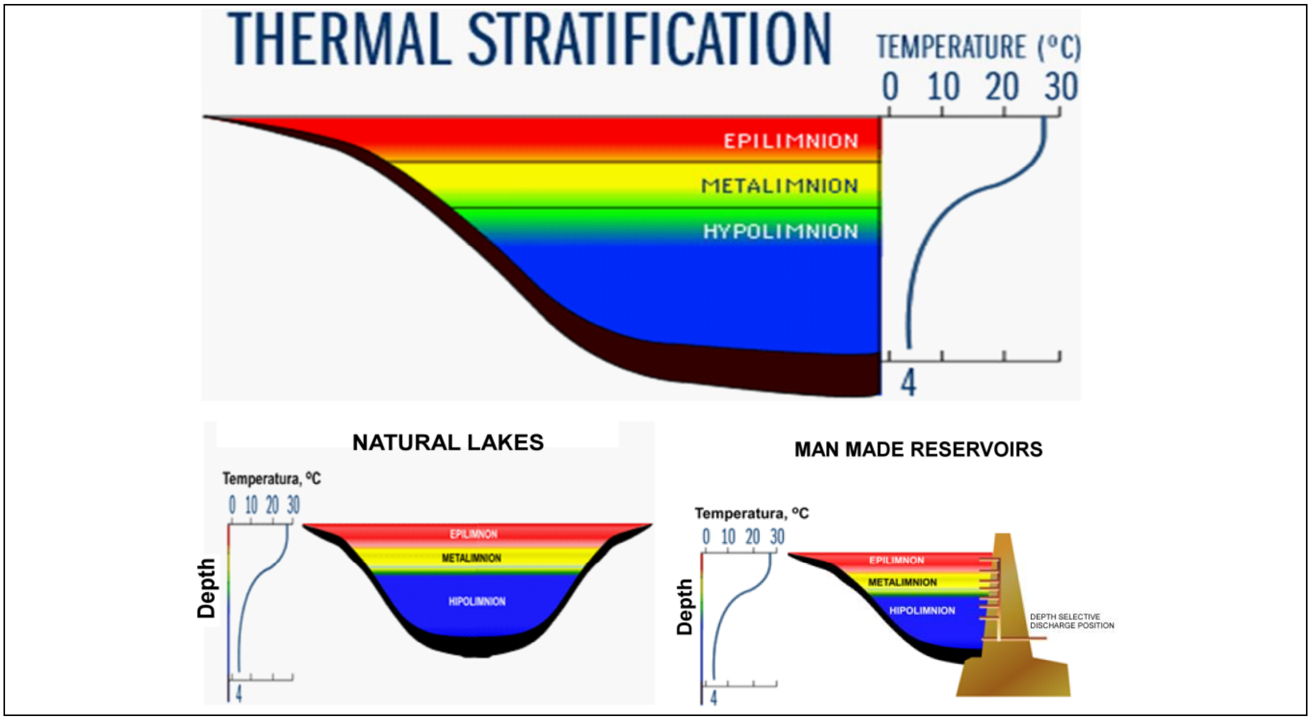

Figure 2. Thermal stratification and seasonal patterns in large lakes and reservoirs

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/reservoir 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.

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.

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

- *Arctic lakes* . 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*. 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.
- *Lakes on the plains with a large catchment*. 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 phytoand zooplankton is usually in good correlation with high fish production.

Manmade lakes or reservoirs are more numerous than natural lakes in Europe. Most of them have multipurpose functions (flood protection, water supply, energy production etc) and are often the basic infrastructure for a particular catchment or a nation. Reservoirs are typically found in upper catchments but there are numerous large systems in the plains such as are the reservoirs on the Danube River in Hungary, Serbia and Romania. (Gapchikovo, Iron Gate I and Iron Gate II)

ECOSYSTEM SERVICES

When assessing the condition of Lakes/Reservoirs , ponds, and reservoirs, these water bodies are often viewed as existing along a continuum from impacted to pristine. This approach is useful for evaluating the overall health of the nation's waters, but is insufficient to adequately evaluate their suitability for alternative, and often conflicting uses. An ecosystem services perspective adds another dimension to lake management and sediment management within it in particular..

Ecosystem services as defined by the Millennium Ecosystem Assessment (2003) are: the benefits people obtain from ecosystems (for a review of the concept and additional definitions please see Fisher et al 2009). These services are often critical for life and enhance human well-being. As such they are part of the global commons and are often considered to be free. An ecosystem services perspective is an explicit acknowledgement that nature has value and that the value can be measured and used to support environmental management decisions.

To understand ecosystem services it is useful to evaluate the types of benefits provided by Lakes/Reservoirs , ponds, and reservoirs. A non-exhaustive list of benefits is presented and more information is available in reviews by Bergstrom et al (1996), Postel & Carpenter (1997), and EPA (2000). These benefits can be separated into:

1) goods and products extracted from Lakes/Reservoirs and,

2) services that depend on local ecosystem processes or lake infrastructure. In most cases, the ecosystem service benefits closely resemble the designated use categories.

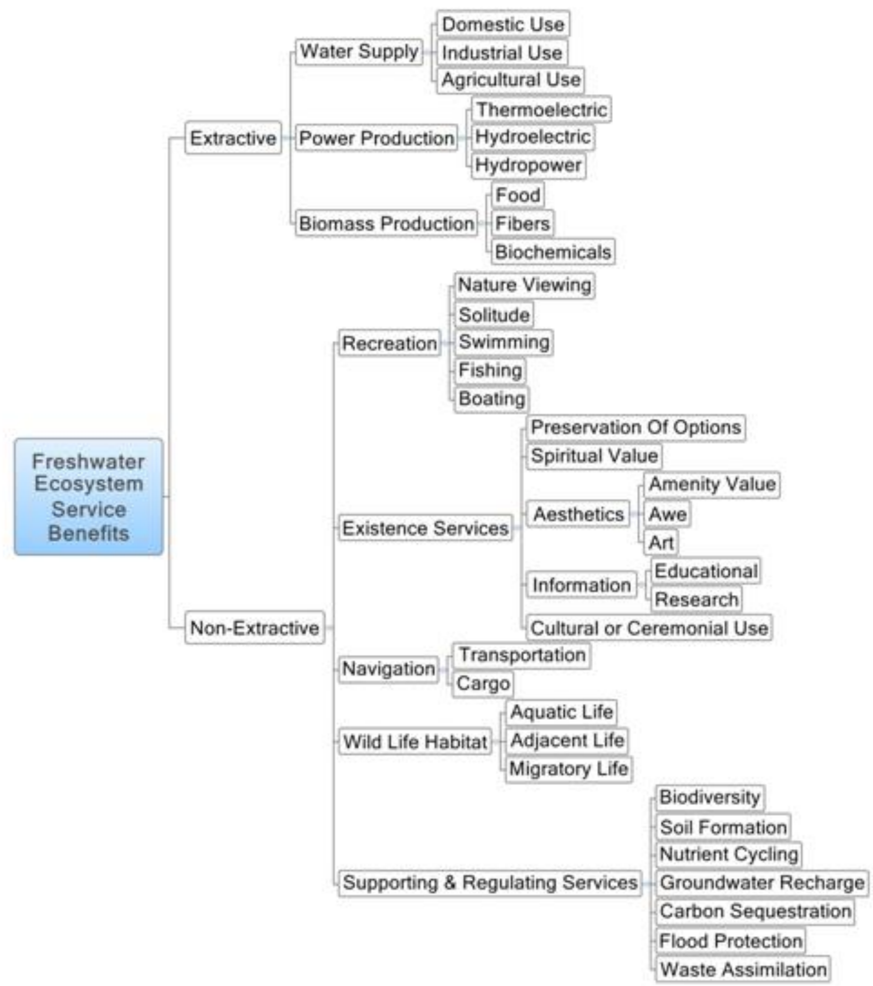

Figure 3. Benefits from ecosystem services in lakes and reservoirs (Modified on the basis of the Primer on Lake Ecology, https://www.waterontheweb.org/under/lakeecology/)

Every lake/reservoir can provide a multitude of ecosystem service benefits simultaneously but the actual output of each will depend on the physical characteristics of the basin and the quantity, quality, and timing of water and sediment regime. As anthropogenic influences increase ecosystem services and benefits will be affected. This can present significant challenges to managers interested in maintaining multiple ecosystem service benefits while ensuring overall lake health.

Within this context however, there are many options open to managers. It should be recognized that not all ecosystem system service benefits can be maximized simultaneously. Decisions will need to be made about which ecosystem services and benefits to emphasize in lake management plans. In doing so, managers need to estimate both the costs of ecosystem services losses as well as the expected gains for ecosystem service increases.

Watershed, lake habitat and sediment management strategies need to consider diverse objectives, designated uses, and implications of management decisions on various ecosystem services and benefits tradeoffs.

LAKE AND RESERVOIR VARIABILITY

People often visualize a lake/reservoir as a uniform mass of water, almost like a full bathtub that is evenly mixed from top to bottom, side to side and front to back. In fact, Lakes/Reservoirs are extremely **heterogeneous**, or patchy.

- The physical, chemical, and biological characteristics of Lakes/Reservoirs are extremely variable:
- Lakes/Reservoirs vary physically in terms of light levels, temperature, and water currents.
- Lakes/Reservoirs vary chemically in terms of nutrients, major ions, and contaminants.
- Lakes/Reservoirs vary biologically in terms of structure and function as well as static versus dynamic variables, such as biomass, population numbers, growth rates, sediment production rates, sediment trapping efficiency etc.

There is a great deal of spatial heterogeneity in all these variables, as well as temporal variability on the scales of minutes, hours, diel (day/night), seasons, decades, and geological time. Though Lakes/Reservoirs vary in many dimensions they are actually highly structured, similar to a forest ecosystem where, for example, a variety of physical variables (light, temperature, moisture) vary from the soil up through the canopy.

THE WATERSHED

The watershed, also called the drainage basin, is all of the land and water areas that drain toward a particular river or lake. Thus, a watershed is defined in terms of the selected lake (or river). There can be sub watersheds within watersheds. For example, a tributary to a lake has its own watershed, which is part of the larger total drainage area to the lake.

A lake is a reflection of its watershed. More specifically, a lake reflects the watershed's size, topography, geology, land use, soil fertility and erodibility, and vegetation. The impact of the watershed is evident in the relation of nutrient loading to the watershed:lake surface area ratio (Figure 4)..

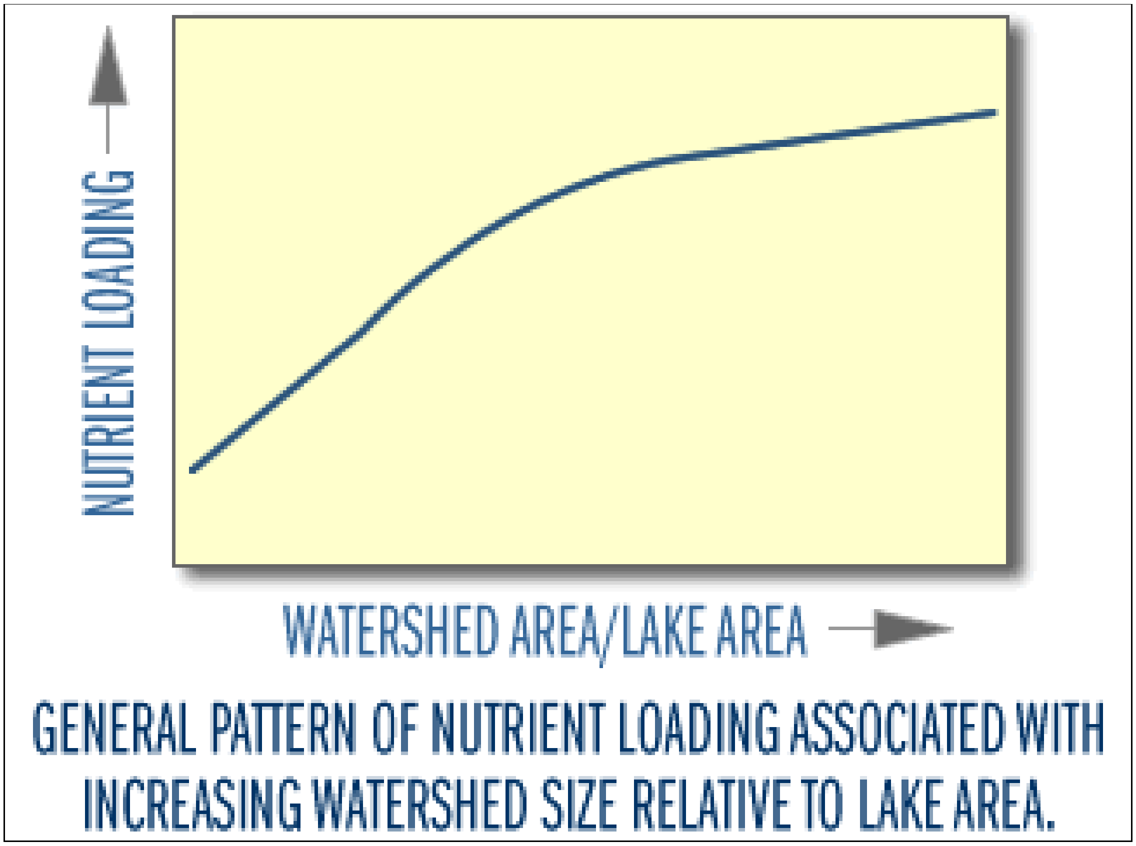

Figure 4. Nutrient loading and lake/watershed area of typical lakes and reservoirs (Modified on the basis of the Primer on Lake Ecology, https://www.waterontheweb.org/under/lakeecology/)

Typically, water quality decreases with an increasing ratio of watershed area to lake area. This is obvious when one considers that as the watershed to lake area increases there are additional sources (and volumes) of runoff to the lake. In larger watersheds, there is also a greater opportunity for water from precipitation to contact the soil and leach minerals before discharging into the lake. Lakes/Reservoirs with very small watersheds that are maintained primarily by groundwater flow are known as seepage Lakes/Reservoirs . In contrast, Lakes/Reservoirs fed primarily by inflowing streams or rivers are known as drainage Lakes/Reservoirs. In keeping with the watershed/lake area relationship, seepage Lakes/Reservoirs tend to have good water quality compared with drainage Lakes/Reservoirs . However, Lakes/Reservoirs are often more susceptible to acidification from acid rain because of their low buffering capacity.

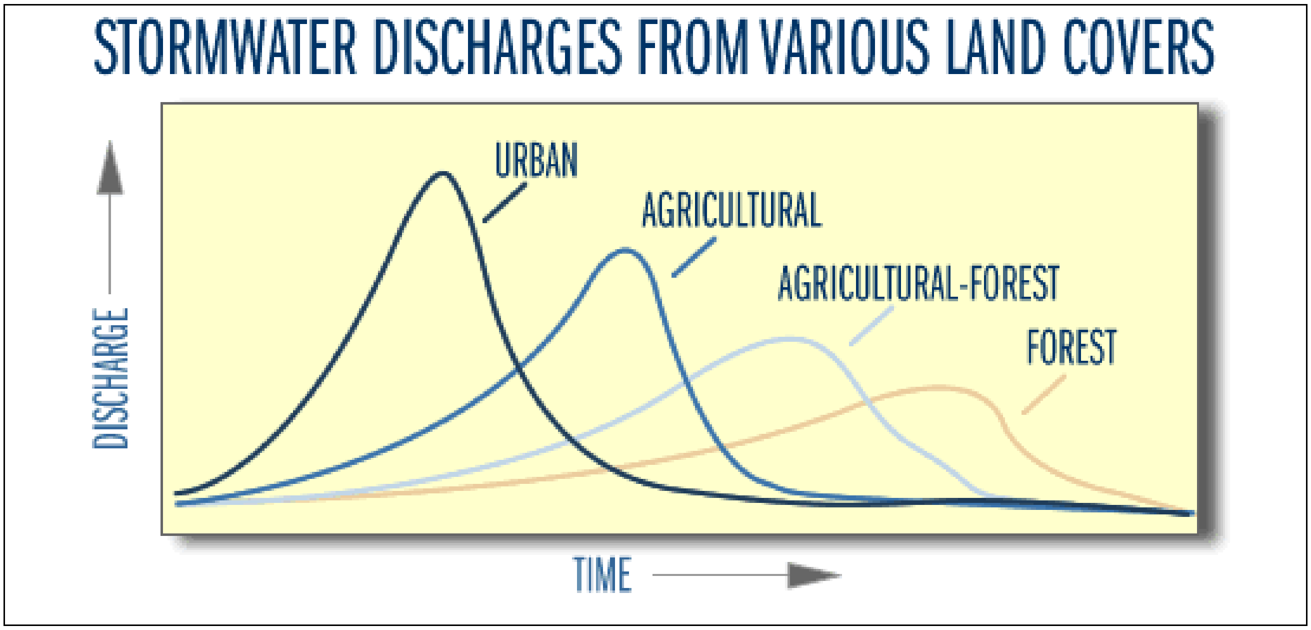

Figure 5. Lake/reservoir water inflow as a function of catchment land use (Modified on the basis of the Primer on Lake Ecology, https://www.waterontheweb.org/under/lakeecology/***)***

Landuse has an important impact on the quality and quantity of water entering a lake. As Figure 5 shows, the stormwater discharge to a lake differs greatly among landuses. In urban areas, the high proportion of impervious surfaces prevents absorbance of rainwater into the soil and increases the rate of surface water flow to the lake. The high flushing rates from urban areas can increase erosion of stream banks and provide sufficient force to carry large particles (i.e., soil) to the lake. Thus, water quantity affects water quality.

Additionally, as water flows over roads, parking lots and rooftops, it accumulates nutrients and contaminants in both dissolved and particulate form.

Table 1. Phosphorus export coefficients (from Reckhow and Simpson, 1980).

	Phosphorus (kg/km²yr)		
Characteristic of the catchment	HIGH	MID	LOW
Urban	500	80-300	50
Rural/Agriculture	300	40-170	10
Forest	45	14-30	2
Precipitation	60	20-50	15

Table 1. gives representative values of export rates of phosphorus from various landuses and other sources. Phosphorus is particularly important because its availability often controls the amount of algae and the overall productivity of a lake. These values are in units of kg/km2/yr (mass of phosphorus per unit area per year). Not included here, but also important, is the influence of soil type and slope. Finer particles and steeper slopes mean higher export rates.

To clarify the relative landuse impacts, we can compare annual loads from 10 hectare plots of the selected landuses using the high export coefficients.

Forest	4.5 kg phosphorus
Rural/Agriculture	30.0 kg phosphorus
Urban	50.0 kg phosphorus

One can see that, all other things being equal, converting a forest into a city can increase the phosphorus export to a lake more than ten times. Another way to look at these numbers is that almost seven years of phosphorus loading from a forested area can be deposited within one year by mixed agriculture areas and almost eleven years of phosphorus loading from a forested area can be deposited within a year from urbanized areas. A greater loading rate puts a greater strain on the system to assimilate the nutrients.

PHYSICAL STRUCTURE AND GEOLOGICAL CHARACTERISTICS

Knowledge of the formation and history of a lake is important to understanding its structure and its sediment dynamics. The current chemical and biological condition of a lake/reservoir depends on many factors, including:

- how it was formed
- size and shape of the lake basin
- size, topography, and chemistry of its watershed
- regional climate
- local biological communities
- activities of humans during the past century

Glaciers formed lake basins by gouging holes in loose soil or soft bedrock, depositing material across stream beds, or leaving buried chunks of ice that later melted to leave lake basins (Figure 5). When these natural depressions or impoundments filled with water, they became Lakes.

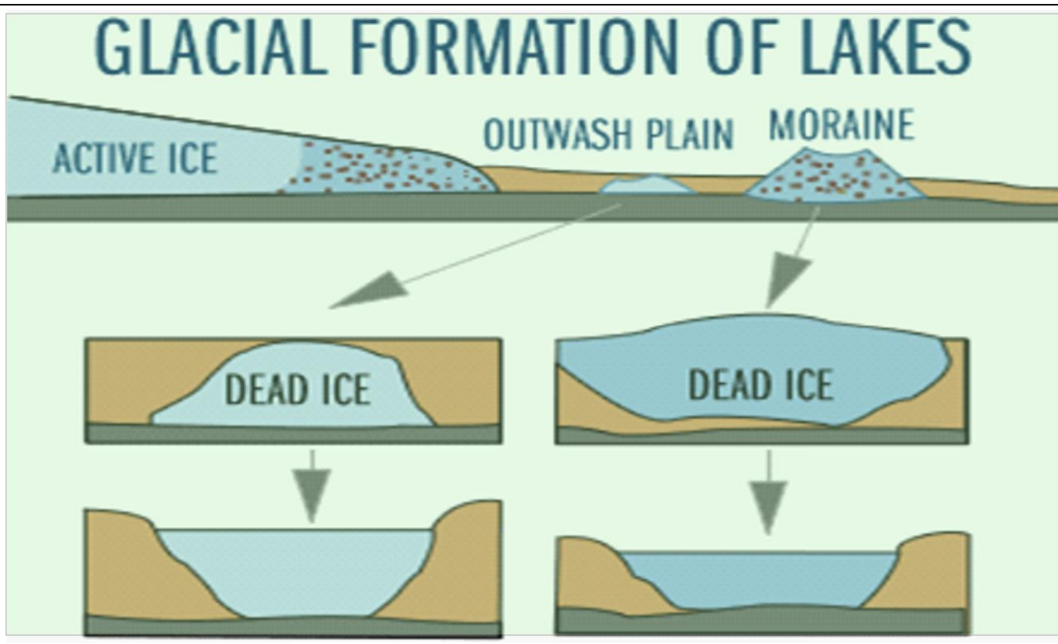

Figure 6. Formation of glacial lakes (Modified on the basis of the Primer on Lake Ecology, https://www.waterontheweb.org/under/lakeecology/)

After the glaciers retreated, sediments accumulated in the deeper parts of the lake. These sediments entered the Lakes/Reservoirs from tributaries and from decomposed organic material derived from both the watershed and aquatic from plants and algae.

Lake/reservoir sediment deposits provide a record of a lake's history. Paleolimnology is the study of lake sediments. Paleolimnologists collect lake sediments using special coring devices to study a lake's physical, chemical and biological history. Lake sediments are often dated using the radioisotopes lead-210 and carbon-14. The age of a given sediment sample is based on the radioactive decay of the isotope. Other dating methods are based on identifying sharp increases

Main factors determining structure of lakes and reservoirs are:

- Light
- Water density
- Mixing and
- Catchment characteristics

LIGHT

Perhaps the most fundamental set of properties of Lakes/Reservoirs relates to the interactions of light, temperature and wind mixing.

The absorption and attenuation of light by the water column are major factors controlling temperature and potential photosynthesis.

Photosynthesis provides the food that supports much of the food web. It also provides much of the dissolved oxygen in the water.

Solar radiation is the major source of heat to the water column and is a major factor determining wind patterns in the lake basin and water movements.

Light intensity at the lake/reservoir surface varies seasonally and with cloud cover and decreases with depth down the water column. The deeper into the water column that light can penetrate, the deeper photosynthesis can occur. Photosynthetic organisms include algae suspended in the water (phytoplankton), algae attached to surfaces (periphyton), and vascular aquatic plants (macrophytes).

The rate at which light decreases with depth depends upon the amount of light-absorbing dissolved substances (mostly organic carbon compounds washed in from decomposing vegetation in the watershed) and the amount of absorption and scattering caused by suspended materials (soil particles from the watershed, algae and detritus).

The percentage of the surface light absorbed or scattered in a 1 meter long vertical column of water, is called the vertical extinction coefficient. This parameter is symbolized by "k".

In Lakes/Reservoirs with low k-values, light penetrates deeper than in those with high k-values. Figure 7 shows the light attenuation profiles from two Lakes/Reservoirs with attenuation coefficients of 0.2/m and 0.9/m.

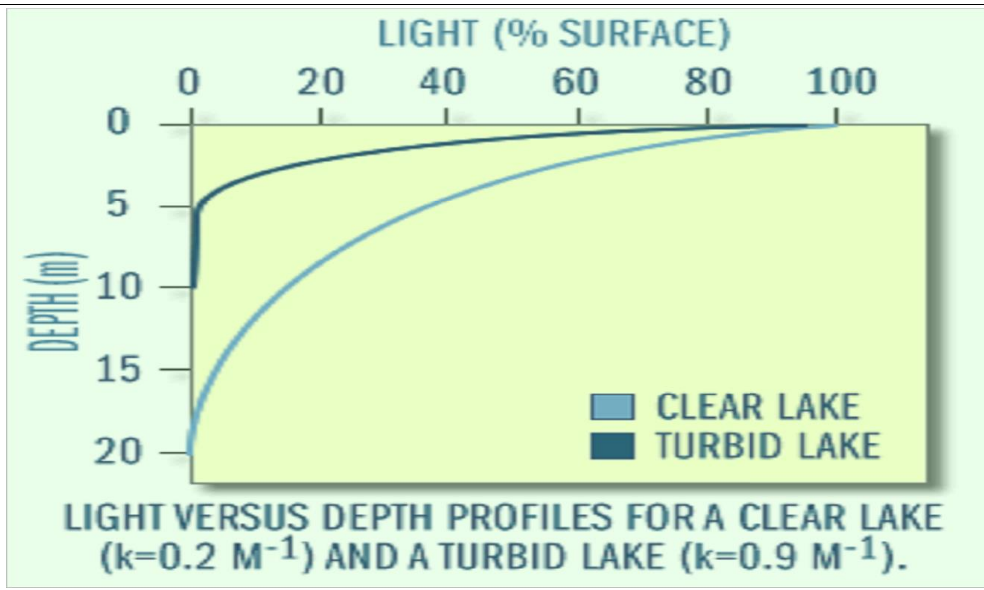

Figure 7. Light – depth profile in lakes and reservoirs (Modified on the basis of the Primer on Lake Ecology,** https://www.waterontheweb.org/under/lakeecology/**)

The maximum depth at which algae and macrophytes can grow is determined by light levels.

Limnologists estimate this depth to be the point at which the amount of light available is reduced to 0.5%–1% of the amount of light available at the lake surface.

This is called the euphotic zone. A general rule of thumb is that this depth is about 2 to 3 times the limit of visibility as estimated using a Secchi disk.

Light may be measured in a variety of ways for a number of different characteristics.

Since photosynthesis depends fundamentally on light, significant changes in light penetration in a lake will produce a variety of direct and indirect biological and chemical effects.

Significant changes in lake transparency are most often the result of human activities, usually in association with landuse activities in the watershed.

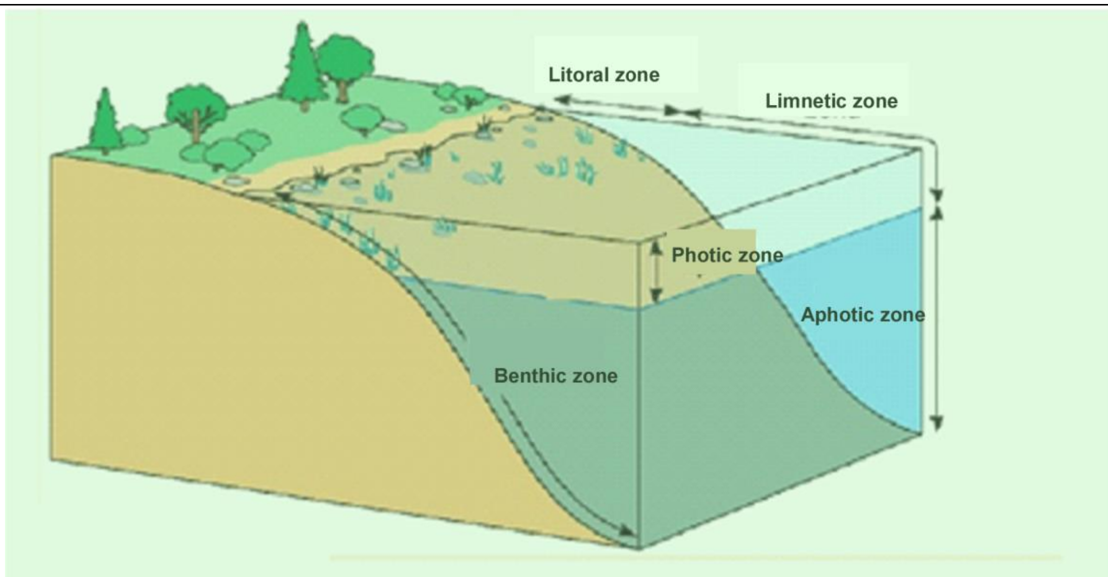

Figure 8. Zonal lake/reservoir structure (Modified on the basis of the Primer on Lake Ecology, https://www.waterontheweb.org/under/lakeecology/)

DENSITY STRATIFICATION

In the spring, immediately after ice-out in temperate climates, the water column is cold and nearly isothermal with depth. The intense sunlight of spring is absorbed in the water column, which also heats up as the average daily temperature of the air increases. In the absence of wind, a temperature profile with depth might be expected to resemble Figure 9, decreasing exponentially with depth. However, density, another physical characteristic of water, plays an important role in modifying this pattern.

Water differs from most other compounds because it is less dense as a solid than as a liquid. Consequently, ice floats, while water at temperatures just above freezing sinks. As most compounds change from a liquid to a solid, the molecules become more tightly packed and consequently the compound is denser as a solid than as a liquid. Water, in contrast, is most dense at 4°C and becomes less dense at both higher and lower temperatures.

Because of this density-temperature relationship, many Lakes/Reservoirs in temperate climates tend to stratify, that is, they separate into distinct layers.

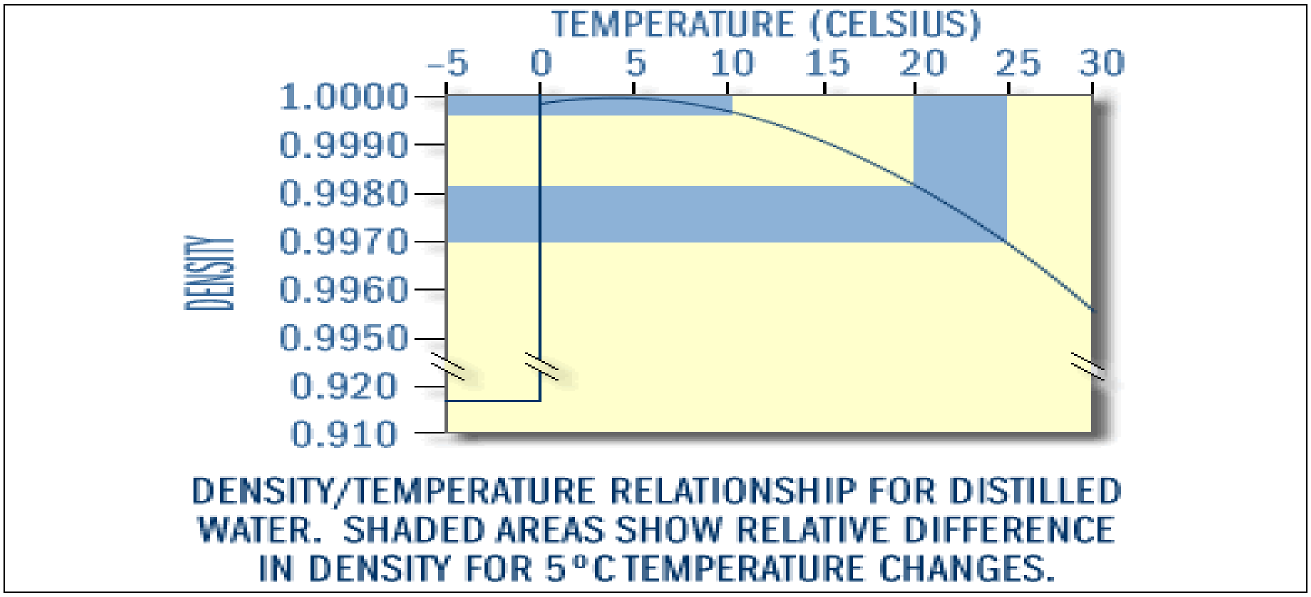

Figure 9. Water temperture-Density relationship (Modified on the basis of the Primer on Lake Ecology, https://www.waterontheweb.org/under/lakeecology/

SPRING

In Lakes/Reservoirs of the upper Midwest and at higher elevations, the water near a lake's bottom will usually be at 4°C just before the lake´s ice cover melts in the spring. Water above that layer will be cooler, approaching 0°C just under the ice. As the weather warms, the ice melts. When the temperature (density) of the surface water equals the bottom water, very little wind energy is needed to mix the lake completely. This is called turnover. After this spring turnover, the surface water continues to absorb heat and warms. As the temperature rises, the water becomes lighter than the water below. For a while winds may still mix the lake from bottom to top, but eventually the upper water becomes too warm and too buoyant to mix completely with the denser deeper water. As suggested, the relatively large differences in density at higher temperatures are very effective at preventing mixing. It simply takes too much energy to mix the water any deeper.

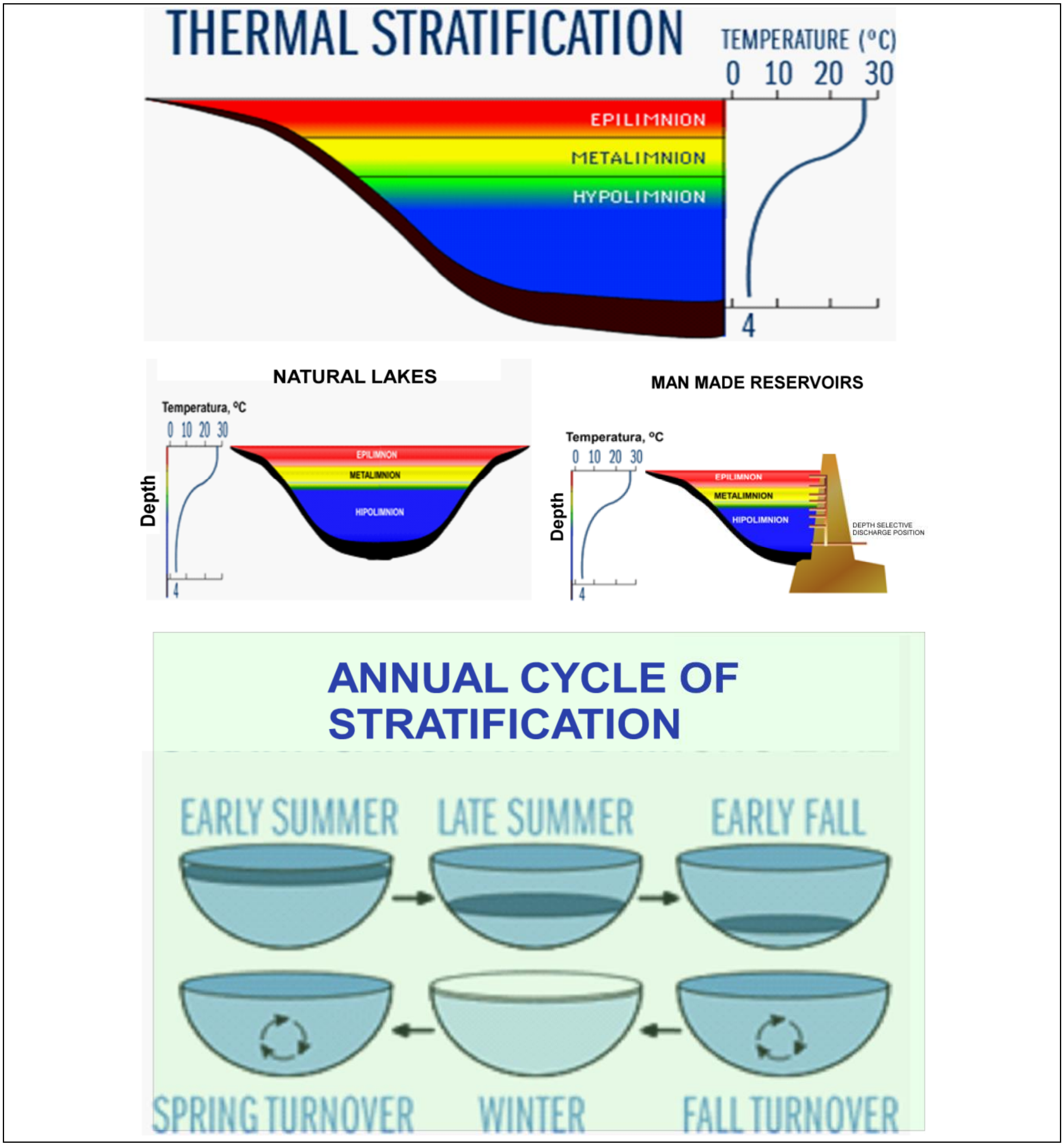

Figure 10. Annual cycle of stratification of lakes and reservoirs *(Modified on the basis of the Primer on Lake Ecology,* https://www.waterontheweb.org/under/lakeecology/)

SUMMER

As summer progresses, the temperature (and density) differences between upper and lower water layers become more distinct. Deep Lakes/Reservoirs generally become physically stratified into three identifiable layers, known as the epilimnion, metalimnion, and hypolimnion. The epilimnion is the upper, warm layer, and is typically well mixed. Below the epilimnion is the metalimnion or thermocline region, a layer of water in which the temperature declines rapidly with depth. The hypolimnion is the bottom layer of colder water, isolated from the epilimnion by the metalimnion. The density change at the metalimnion acts as a physical barrier that prevents mixing of the upper and lower layers for several months during the summer.

The depth of mixing depends in part on the exposure of the lake to wind (its fetch), but is most closely related to the lake's size.

Note that although "thermocline" is a term often used synonymously with metalimnion, it is actually the plane or surface of maximum rate of decrease of temperature with respect to depth. Thus, the thermocline is the point of maximum temperature change within the metalimnion.

AUTUMN

As the weather cools during autumn, the epilimnion cools too, reducing the density difference between it and the hypolimnion. As time passes, winds mix the lake to greater depths, and the thermocline gradually deepens. When surface and bottom waters approach the same temperature and density, autumn winds can mix the entire lake; the lake is said to "turn over." As the atmosphere cools, the surface water continues to cool until it freezes.

WINTER

A less distinct density stratification than that seen in summer develops under the ice during winter. Most of the water column is isothermal at a temperature of 4°C, which is denser than the colder, lighter water just below the ice. In this case the stratification is much less stable, because the density difference between 0°C and 4°C water is quite small. However, the water column is isolated from wind-induced turbulence by its cap of ice. Therefore, the layering persists throughout the winter.

This pattern (spring turnover — summer stratification — fall turnover — winter stratification) is typical for temperate Lakes/Reservoirs . Lakes/Reservoirs with this pattern of two mixing periods are referred to as dimictic. Many shallow Lakes/Reservoirs , however, do not stratify in the summer, or stratify for short periods only, throughout the summer. Lakes/Reservoirs that stratify and destratify numerous times within a summer are known as polymictic Lakes/Reservoirs . Both polymictic and dimictic

CHEMICAL STRUCTURE

In the absence of any living organisms, a lake contains a wide array of molecules and ions from the weathering of soils in the watershed, the atmosphere, and the lake bottom. Therefore, the chemical composition of a lake is fundamentally a function of its climate (which affects its hydrology) and its basingeology. Each lake has an ion balance of the three major anions and four major cations (see Table 2).

Table 2. ion balance for typical fresh water

Anions	Percent	Cations	Percent
HCO_3^-	73%	Ca^{+2}	63%
SO_4^{-2}	16%	Mg^{+2}	17%
Cl^-	10%	Na^+	15%
		K^+	4%
other	< 1%	other	< 1%

Ion balance means the sum of the negative ions equals the sum of the positive cations when expressed as equivalents. These ions are usually present at concentrations expressed as mg/L (parts per million, or ppm) whereas other ions such as the nutrients phosphate, nitrate, and ammonium are present at μg/L (parts per billion, or ppb) levels.

Humans can have profound influences on lake chemistry. Excessive landscape disturbance causes higher rates of leaching and erosion by removing vegetative cover, exposing soil, and increasing water runoff velocity. Lawn fertilizers, wastewater and urban stormwater inputs all add micronutrients such as nitrogen and phosphorus, major ions such as chloride and potassium, and, in the case of highway and parking lot runoff, oils and heavy metals. Emissions from motorized vehicles, fossil fuel-burning electric utilities and industry, and other sources produce a variety of compounds that affect lake chemistry.

Perhaps the best understood ions are H+ (hydrogen ion, which indicates acidity), SO_4^{-2} (sulfate) and NO_3(nitrate) which are associated with acid rains. Mercury (Hg) is another significant air pollutant affecting aquatic ecosystems and can bioaccumulate in aquatic food webs, contaminating fish and causing a threat to human and wildlife health.

Lakes/Reservoirs with high concentrations of the ions calcium (Ca^{+2}) and magnesium (Mg^{+2}) are called hardwater Lakes/Reservoirs , while those with low concentrations of these ions are called softwater Lakes/Reservoirs . Concentrations of other ions, especially bicarbonate, are highly correlated with the concentrations of the hardness ions, especially Ca^{+2}. The ionic concentrations influence the lake´s ability to assimilate pollutants and maintain nutrients in solution. For example, calcium carbonate ($CaCO_3$) in the form known as marl can precipitate phosphate from the water and thereby remove this important nutrient from the water.

The total amount of ions in the water is called the TDS (total dissolved salt, or total dissolved solids concentration). Both the concentration of TDS and the relative amounts or ratios of different ions influence the species of organisms that can best survive in the lake, in addition to affecting many important chemical reactions that occur in the water.

DISSOLVED OXYGEN

Biological activity peaks during the spring and summer when photosynthetic activity is driven by high solar radiation. Furthermore, during the summer most Lakes/Reservoirs in temperate climates are stratified. The combination of thermal stratification and biological activity causes characteristic patterns in water chemistry. Figure 11 shows the typical seasonal changes in dissolved oxygen (DO) and temperature. The top scale in each graph is oxygen levels in mg O_2/L. The bottom scale is temperature in °C. In the spring and fall, both oligotrophic and eutrophic Lakes/Reservoirs tend to have uniform, well-mixed conditions throughout the water column. During summer stratification, the conditions in each layer diverge.

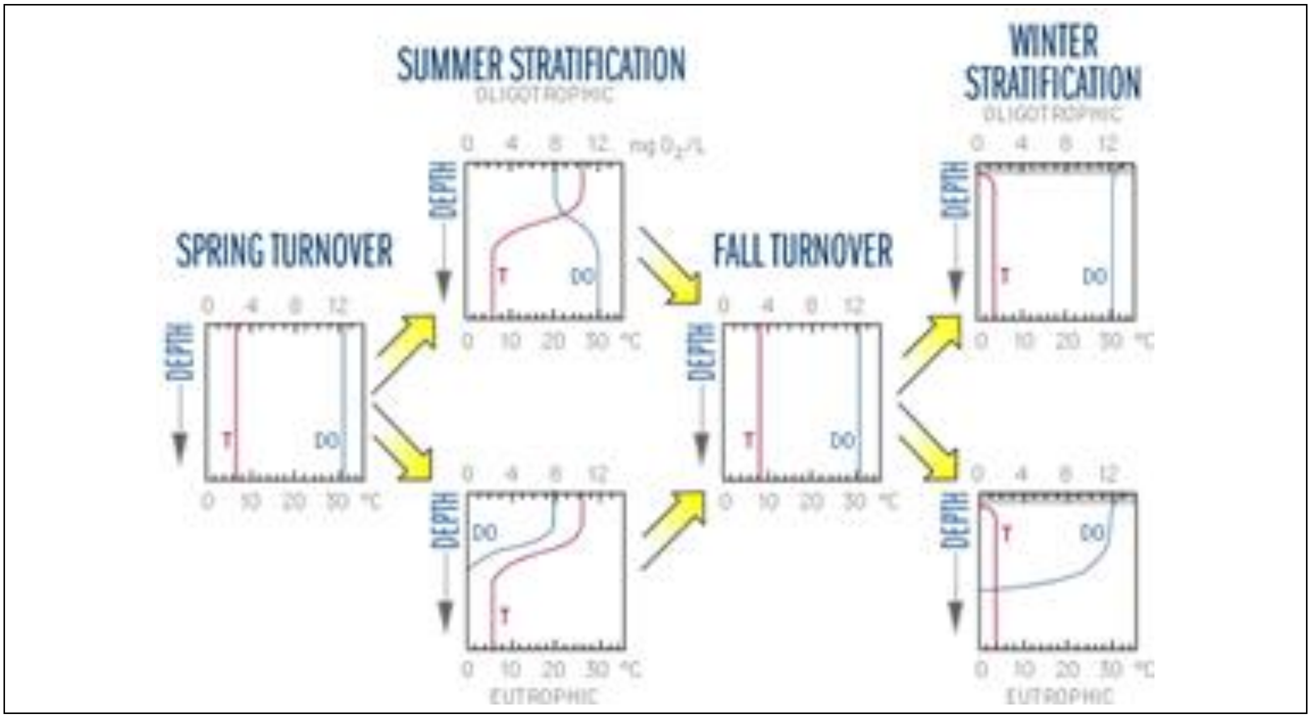

Figure 11. Oxygen regime in lakes and reservoirs at different stages of stratification (adapted from Figure 8-1 in Wetzel, R.G. 1975. Limnology. W.B.Saunders Company)

The DO concentration in the epilimnion remains high throughout the summer because of photosynthesis and diffusion from the atmosphere. However, conditions in the hypolimnion vary with trophic status. In eutrophic (more productive) Lakes/Reservoirs , hypolimnetic DO declines during the summer because it is cut-off from all sources of oxygen, while organisms continue to respire and consume oxygen. The bottom layer of the lake and even the entire hypolimnion may eventually become anoxic, that is, totally devoid of oxygen. In oligotrophic Lakes/Reservoirs , low algal biomass allows deeper light penetration and less decomposition. Algae are able to grow relatively deeper in the water column and less oxygen is consumed by decomposition. The DO concentrations may therefore increase with depth below the thermocline where colder water is "carrying" higher DO leftover from spring mixing (recall that oxygen is more soluble in colder water). In extremely deep, unproductive Lakes/Reservoirs , DO may persist at high concentrations, near 100% saturation, throughout the water column all year. These differences between eutrophic and oligotrophic Lakes/Reservoirs tend to disappear with fall turnover (Figure 11).

In the winter, oligotrophic Lakes/Reservoirs generally have uniform conditions. Ice-covered eutrophic Lakes/Reservoirs , however, may develop a winter stratification of dissolved oxygen. If there is little or no snow cover to block sunlight, phytoplankton and some macrophytes may continue to photosynthesize, resulting in a small increase in DO just below the ice. But as microorganisms continue to decompose material in the lower water column and in the sediments, they consume oxygen, and the DO is depleted. No oxygen input from the air occurs because of the ice cover, and, if snow covers the ice, it becomes too dark for photosynthesis. This condition can cause high fish mortality during the winter, known as "winter kill." Low DO in the water overlying the sediments can exacerbate water quality deterioration, because when the DO level drops below 1 mg O_2/L chemical processes at the sediment-water interface frequently cause release ofphosphorus from the sediments into the water. When a lake mixes in the spring, this new phosphorus and ammonium that has built up in the bottom water fuels increased algal growth.

NUTRIENTS

Aquatic organisms influence (and are influenced by) the chemistry of the surrounding environment. For example, phytoplankton extract nutrients from the water and zooplankton feed on phytoplankton. Nutrients are redistributed from the upper water to the lake bottom as the dead plankton gradually sink to lower depths and decompose. The redistribution is partially offset by the active vertical migration of the plankton.

In contrast to DO, essential nutrients such as the bioavailable forms of phosphorus and nitrogen (dissolved phosphate, nitrate, and ammonium) typically increase in the spring from snowmelt runoff and from the mixing of accumulated nutrients from the bottom during spring turnover. Concentrations typically decrease in the epilimnion during summer stratification as nutrients are taken up by algae and eventually transported to the hypolimnion when the algae die and settle out. During this period, any "new" input of nutrients into the upper water may trigger a "bloom" of algae. Such inputs may be from upstream tributaries after rainstorms, from die-offs of aquatic plants, from pulses of urban stormwater, direct runoff of lawn fertilizer, or from leaky Lakes/Reservoirs shore septic systems. In the absence of rain or snowmelt, an injection of nutrients may occur simply from high winds that mix a portion of the nutrient-enriched upper waters of the hypolimnion into the epilimnion. In less productive systems, such as those in Northeastern Minnesota, significant amounts of available nitrogen may be deposited during rainfall or snowfall events (wet deposition) and during the less obvious deposition of aerosols and dust particles (dry deposition). Nitrogen and phosphorus in dry fallout and wet precipitation may also come from dust, fine soil particles, and fertilizer from agricultural fields.

THE FOOD WEB

The biological communities within Lakes/Reservoirs may be organized conceptually into food chains and food webs to help us understand how the ecosystem functions (Figures 12 and 13). The simplest illustration of the organization of the organisms within an ecosystem is the ecological pyramid (Figure 12). The broad base of primary producers supports overlying levels of herbivores (zooplankton), planktivores and much smaller numbers of carnivores (predators). These individual trophic levels may be idealized as a food chain, but in fact many organisms are omnivorous and not necessarily characterized by a particular level. Further, consumers in particular often shift levels throughout their life cycle. For example, a larval fish may initially eat fine particulate material that includes algae, bacteria and detritus. Then it may switch and graze on larger zooplankton and ultimately end up feeding on so called "forage fish" or even young game fish (i.e., top predators) when it reaches maturity (Figure 13).

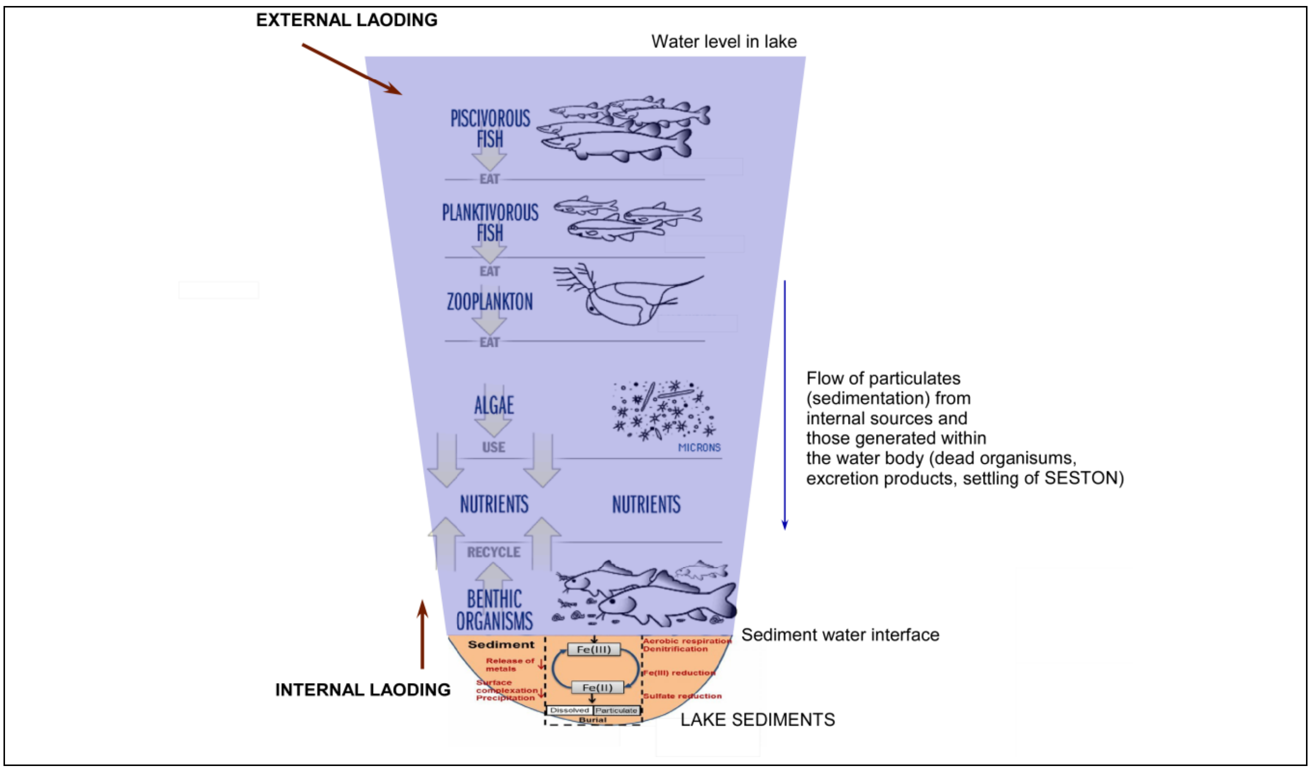

Figure 12. Typical lake/reservoir food web supported by external and internal loading showing the importance of sediments as the source of internal loading for lakes and reservoir ecosystems. (Modified on the basis of the Primer on Lake Ecology, https://www.waterontheweb.org/under/lakeecology/)

Food webs may be described in terms of both energy and nutrient (carbon, nitrogen or phosphorus) flows and flows of micronutrients (molybdenum, copper, etc.). Although the process typically begins with sunlight-driven photosynthesis by algae and plants, balanced nutrition is also required to sustain life. For example, we cannot live strictly on sugar, despite its high caloric content, irrespective of what our kids may argue.

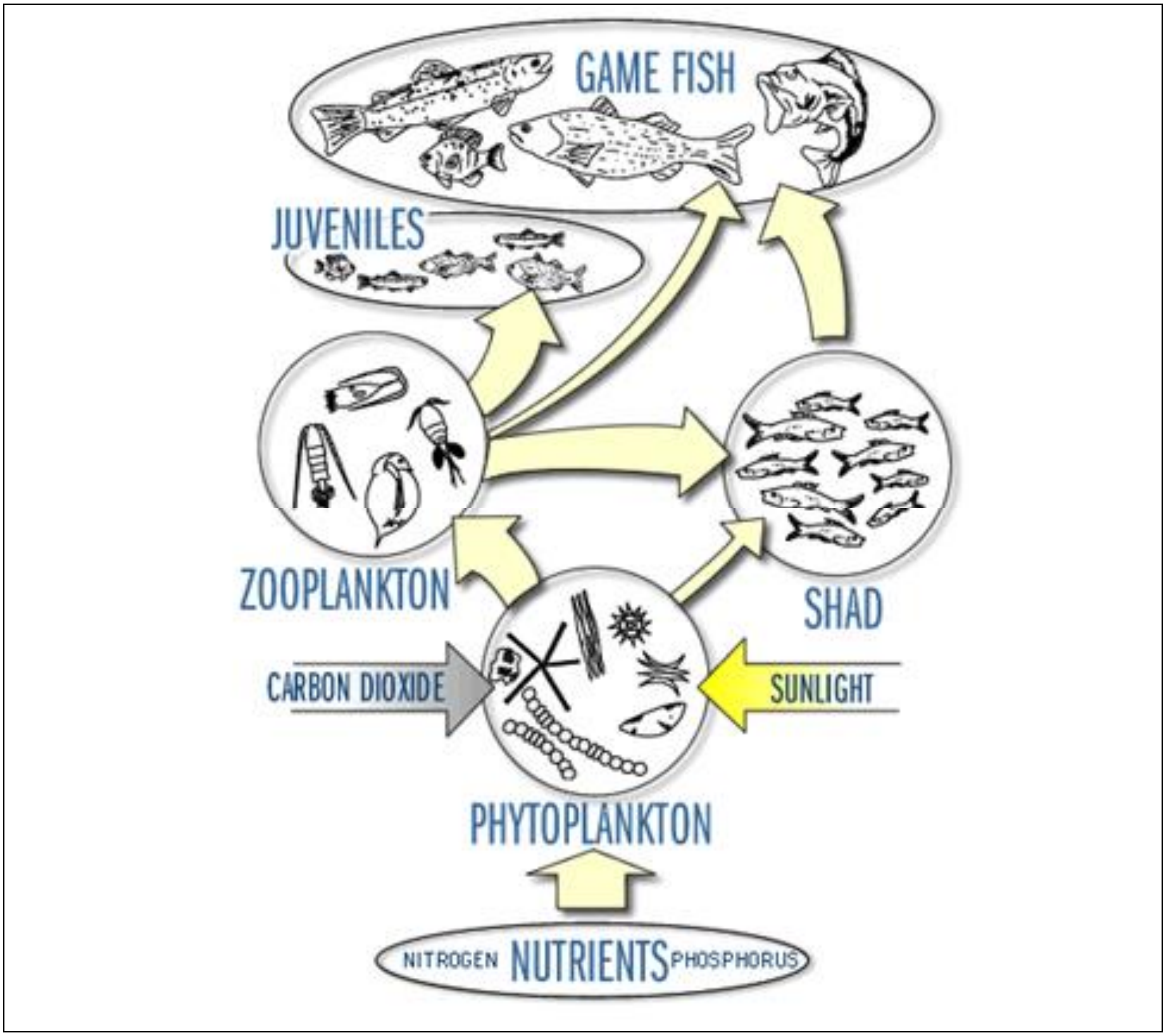

Figure 13. Nutrients as the main driver supporting living organisms within a lake/reservoir ecosystem (Modified on the basis of the Primer on Lake Ecology, https://www.waterontheweb.org/under/lakeecology/)

There are two basic life-sustaining processes in Lakes/Reservoirs , just as on land; photosynthesis and respiration. Green plants capture energy from sunlight to convert nonliving, inorganic chemicals (carbon dioxide, water, and mineral compounds) into living, organic plant tissue. Lake photosynthesizers include algae and macrophytes. Together, they are the primary producers, because they create the organic material required by most other organisms for nutrients and energy. Oxygen, the waste product of photosynthesis, adds to the oxygen supplied to the lake by the atmosphere. In water layers where photosynthetic rates are very high, such as during an algal bloom, the water may become supersaturated. That is, the oxygen content may exceed 100% of saturation with respect to the amount the water could hold if it was allowed to equilibrate with the atmosphere. This saturation value, in turn, depends on the temperature of the water. Colder water can hold more O2 than warmer water. During periods of stratification, the only potential source of O2 to the deeper zones of the lake is photosynthesis. This occurs only if light penetrates below the thermocline. In Lakes/Reservoirs where light does not penetrate below the thermocline, there is no internal source of oxygen to the deeper waters.

Besides light, algae and higher plants need oxygen, carbon dioxide (CO_2), and mineral nutrients to survive and grow. Except for a very few species of blue green algae, most are unable to survive in anoxic(no O_2) water. CO_2 is virtually always available and comes from the weathering of carbonate rocks, such as limestone, in the watershed, diffusion from the atmosphere (very important in softwater, acid rainsensitive Lakes/Reservoirs), and from the respiration of organic matter by all of the organisms in the lake (see below). Dissolved mineral nutrients are absorbed from the water by algae and from the water and the sediments by higher plants. Typically, the most important nutrients are phosphorus and nitrogen, because they are present in very low concentrations unless there are sources of pollution and are typically low enough to limit the growth of algae. Other minerals essential to life, such as the major ions (calcium, magnesium, sodium, and potassium) and certain trace metals (iron, cobalt, molybdenum, manganese, copper, boron, and zinc), are usually present at sufficient concentrations. Silicon is required by diatoms and a few other groups of algae and is usually, though not always, present at sufficient levels. Another mineral required by all living things, sulfur (in the form of sulfate), is typically not deficient in Lakes/Reservoirs .

The whole interaction of photosynthesis and respiration by plants, animals, and microorganisms represents the food web. Food webs are usually very complex and, in any one lake ecosystem, hundreds of different species can be involved. Because the available energy decreases at each trophic level, a large food base of primary producers (mostly plants) is necessary to support relatively few large fish.

These plants may die and decompose or be eaten by primary consumers – the second trophic level. This link in the food chain typically involves zooplankton grazing on algae but also includes larval fish eating zooplankton and a variety of invertebrates that eat attached algae (periphyton) and higher plants. Other animals, such as small fish, secondary consumers (third trophic level) eat the primary consumers and thus are considered secondary consumers. Still larger consumers such as large fish, ospreys, and people are tertiary consumers (fourth trophic level). Thus, energy and nutrients originating from the photosynthetic production of biomass and energy cascade through the food web.

There is recycling of nutrients back up to the top of the cascade. Respiration, the oxidation of organic material, releases the energy that was originally captured from sunlight by photosynthesis. Both plants and animals respire to sustain their lives, and in doing so, consume oxygen. Microorganisms (bacteria and fungi) consume a large fraction of available oxygen in the decomposition of excreted and dead organic material.

Decomposers are sinks for plant and animal wastes, but they also recycle nutrients for photosynthesis. The amount of dead material in a lake far exceeds the living material. Detritus is the organic fraction of the dead material, and can be in the form of small fragments of plants and animals or as dissolved organic material. This in essence is the reason behind the importance of sediments and sediment quality in lakes and reservoirs and their fundamental role in supporting good status of water bodies.

HYDROLOGICAL AND MORPHOLOGICAL FEATURES

Morphological features

Several morphological characteristics have been developed to describe the shape of a lake/reservoir surface and bottom. Many of these parameters are important indicators for the ecological characteristics of lakes and reservoirs, and they are very central in lake/reservoir 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 and reservoirs:

- Hydrological regime:
  - Quantity and dynamics of water flow,
  - residence time and
  - connection to the groundwater body.
- Morphological conditions:
  - depth variation,
  - quantity, structure, substrate of the bed and
  - structure of the shore.

The hydrological regime elements are primarily related to the water balance.

FINAL REMARKS

This section has been is intentionally extensive despite the fact that it only presents the differences between lakes and reservoirs and rivers and streams only in general terms. Our intention is to reiterate and stress the unique importance of sediments in these aquatic systems and understand what the important factors associated with sediment quality monitoring in lakes and reservoirs are. We hope that this has been achieved and that it is clear that it is of critical importance that sediment quality studies in lakes and reservoirs do not omit monitoring of all the important parameters needed for the quantification of the sediment quality and its dynamics, all of this in support of the development of sediment quality management strategies to support the implementation of the WFD and achievement of the good status of lake and reservoir water bodies.

From what has been presented in this section it is clear that sediment quality assessment for large lakes and reservoirs needs to include the following monitoring activities:

1. Monitoring of external loading of lake and reservoir systems. Monitoring of suspended sediment load and quality from the tributaries of the system (parameters of interest are organic matter, macro and micronutrients and specific parameters of interest (e.g. priority substances for example)

2. Monitoring of in lake/reservoir sediment production rates (monitoring of in situ sediment production) via monitoring of in lake suspended sediments and their sedimentation rates (of particular interest are quality and deposition rates of sediments to the bottom of the lake). Since in situ sediment production rates are highly spatially variable it is necessary to monitor these at sufficient number of locations to be able to differentiate and quantify deposition rates and quality in the littoral and limnetic zones of lakes and reservoirs.
3. Monitoring of sediment accumulation rates and sediment quality at the bottom of the lake in a manner that can support quantification of internal loading of the lake especially by organics, nutrients and metals. As the internal loading processes depend on the water quality at the sediment water interface (especially its oxygen content) adequate spatial resolution is need to characterize the system. Spatial and temporal heterogeneity is of particular concern and needs to be considered.

SIMONA Project in general and WP 6 in particular, address items 1 and 3 above while item 2 is considered to be outside the project scope.

Sampling approaches and tools for item 1 are already covered by other WP of the SIMONA Project and apply for large lakes and reservoirs and will not be discussed further. Item 3 is of specific interest to WP 6 and demonstration activities subject of this report

As a final note we need to stress that it is assumed that any sediment sampling and analysis is always carried out with appropriate and adequate water quality sampling and analysis since without appropriate water quality data the results of sediment quality analysis can not be interpreted adequately.

Interreg
Danube Transnational Programme
SIMONA

MONITORING OF SEDIMENTS IN LARGE LAKES AND RESERVOIRS AS A PART OF ENTIRE RIVER BASIN MONITORING

INTRODUCTION

Key feature of any sediment and surface water quality monitoring system is its supporting role to water resources management. This being the case monitoring objectives (Why?) are required to support water resources management functions and the monitoring system design (What, where and how?) has to meet these objectives (Figure 14). The system design specifies how is monitoring to be carried out and also in many ways determines how data is to be analysed and interpreted. On the other hand water resources management functions impose reporting and analyses and interpretation needs as is shown in Figure 14.

Development of monitoring system therefore starts with analyses of the water resources management functions and quality data and information needs needed to support these functions. This is summarised in Figure 15.

Each of the 5 steps shown in Figure 14 requires systematic and thorough process of implementation and different, largely similar, methodologies for this purpose are available in literature. Common to these is an optimization process in relation to management which reuiers revision of the objectives but also partnerships with the professional fraternity and data and information exchange between stakeholders (which also includes neighbouring states). These relations are shown in Figure 16.

Methodology typically used for the determination of the objectives of the surface water quality monitoring system is shown in Figure 17.

Once the objectives of the monitoring system have been defined and specified it is possible to design the whole monitoring system. The system design needs to consider the following:

- Decisions to be made during the design stage (Figure 18)
- Field and lab analyses and measurements (Figures 19, 20)
- List of parameters to be monitored (Figure 21)

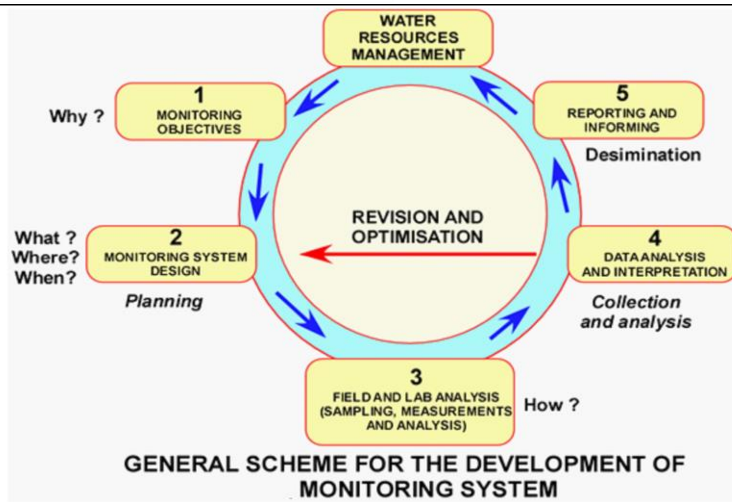

Figure 14 Systems view of the surface water quality monitoring

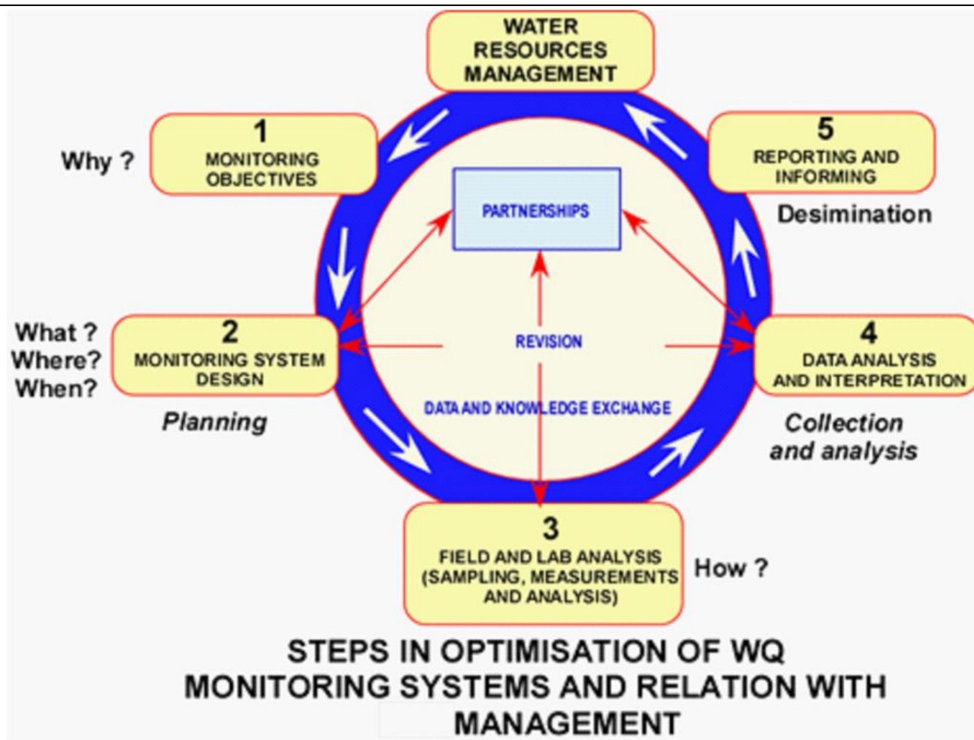

Figure 16. System level optimization methodology

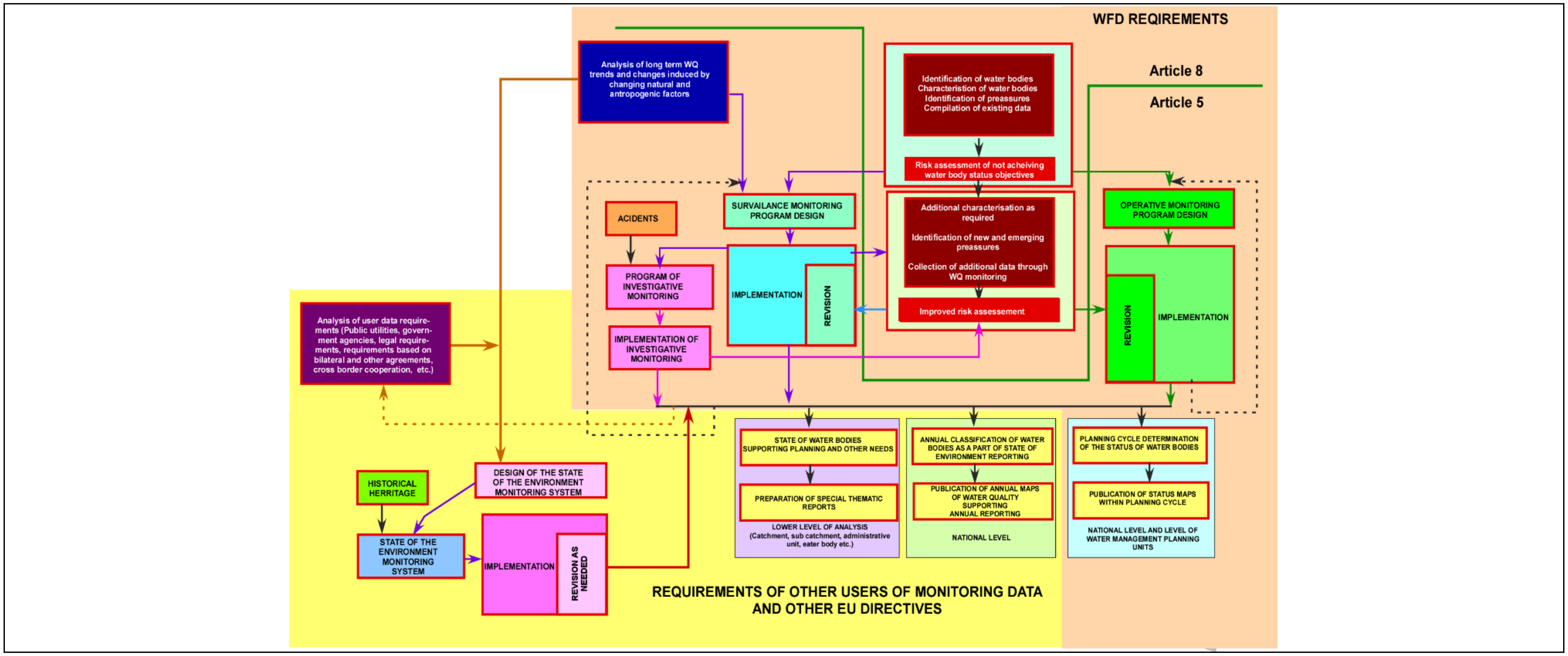

Figure 15 Monitoring requirements as specified in the EU WFD

Each of the above points has to be structured and should contain a set of basic requirements and tasks as is shown on the mentioned figures. The system is indeed very complex and interwoven, Some aspects of the system design are often written in Law and Regulations (For example regulations often contain lists of parameters to be monitored), some are mostly a part of the standard procedures and requirements (Such as are the requirements for the certification of analytical laboratories or standards for standard methods for water quality analyses) an in the design stage of the monitoring system these standards, procedures and legal requirements have to be taken into consideration. Other aspects (e.g. frequency of sampling and criteria for selection of the location of monitoring stations) are often left undefined or are subject to guidance documents in the form of minimum requirements issued by responsible institutions (for example guidance for the frequency of surface water quality monitoring as apart of the common implementation strategy for the EU Water Framework Directive and variants there off.

It is interesting to note that it is often the case that laws and regulations as well as specific required guidelines often preclude system level optimization since system level analyses are typically not apart of the process of development of laws and regulations and standards and guidelines often represent a compromise solution rather than an optimal design. Having said this it is never the less important to consider in the system design stage as this could often indicate weak points in the whole system and could lead to an initiative to change laws and regulations and thus improve the whole system. This is especially relevant for defining a list of parameters to be monitored and to procedures needed for an efficient system for data analyses and interpretation and for reporting.

We specifically draw readers attention to the methodology for selection of parameters given in figure 21 which leaves a lot to be desired in many of the existing WQ monitoring systems throughout the world. We believe that this is a part of the system design where optimization can lead to biggest economic savings in the implementation of the surface water quality monitoring system. Unfortunately implementation of this methodology is not possible within current legal framework in Serbia and most EU countries.

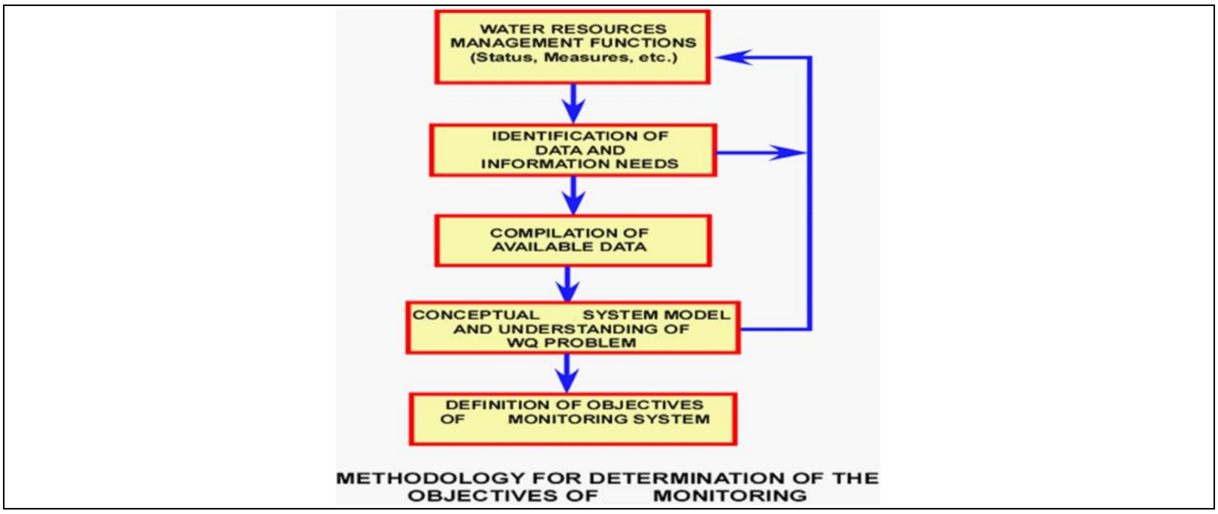

Figure 17. Methodology for establishing the objectives of surface water quality monitoring system

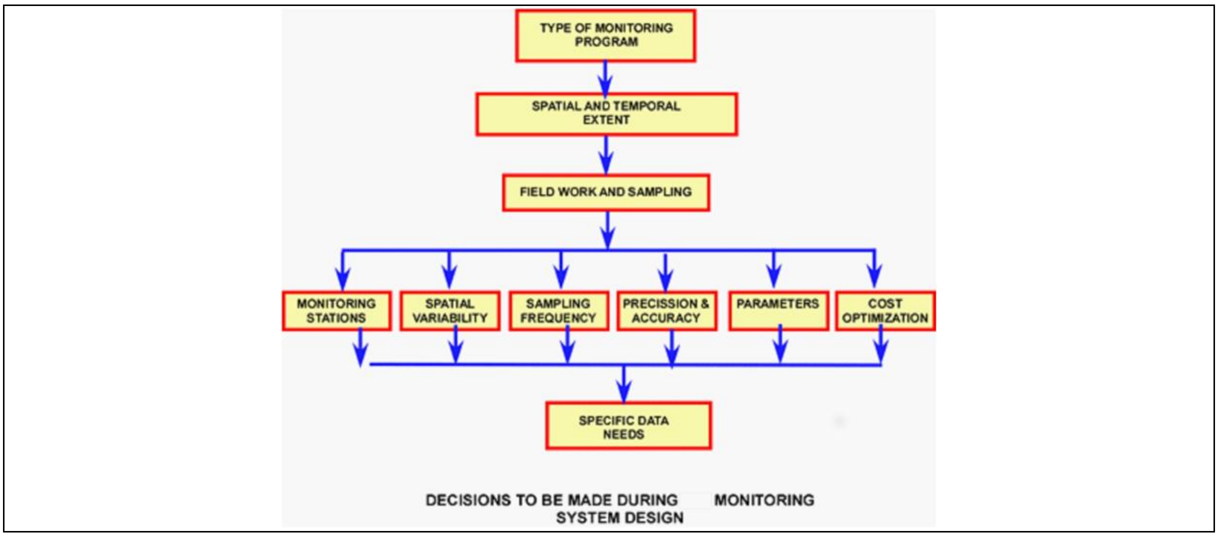

Figure 18. Decisions to be made during monitoring system design

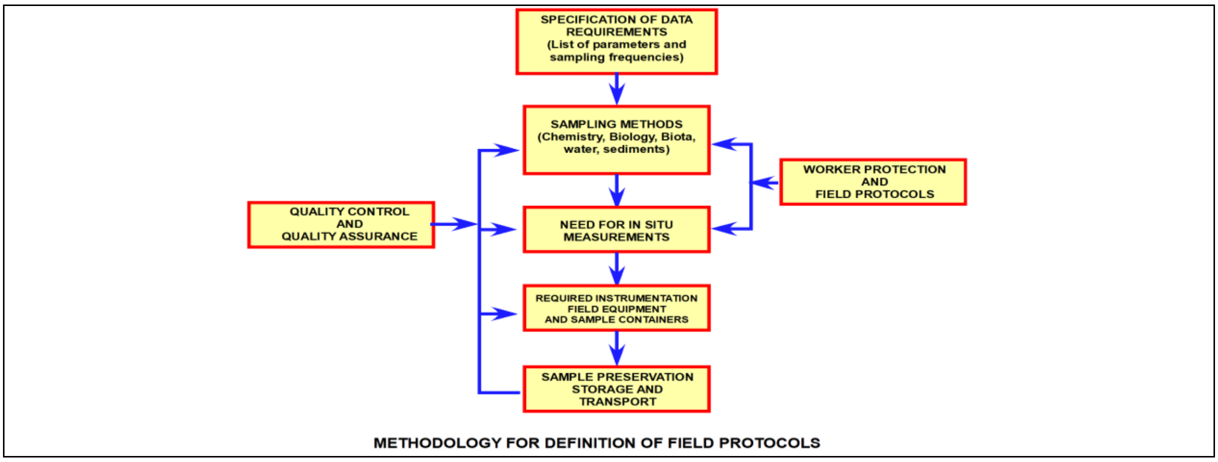

Figure 19 Factors to consider for field sampling and measurement

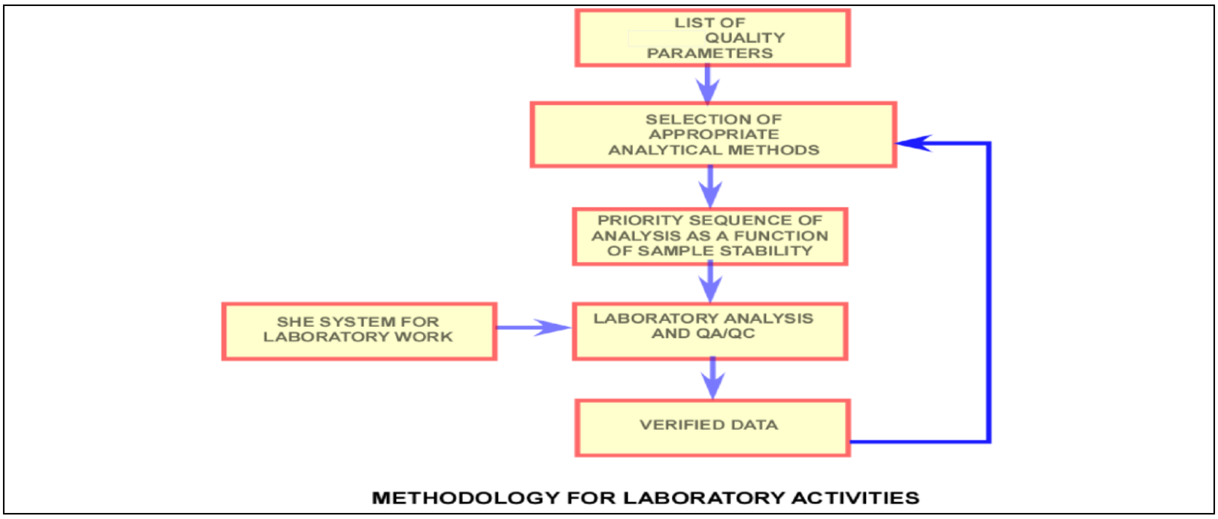

Figure 20. Factors to consider for laboratory measurements

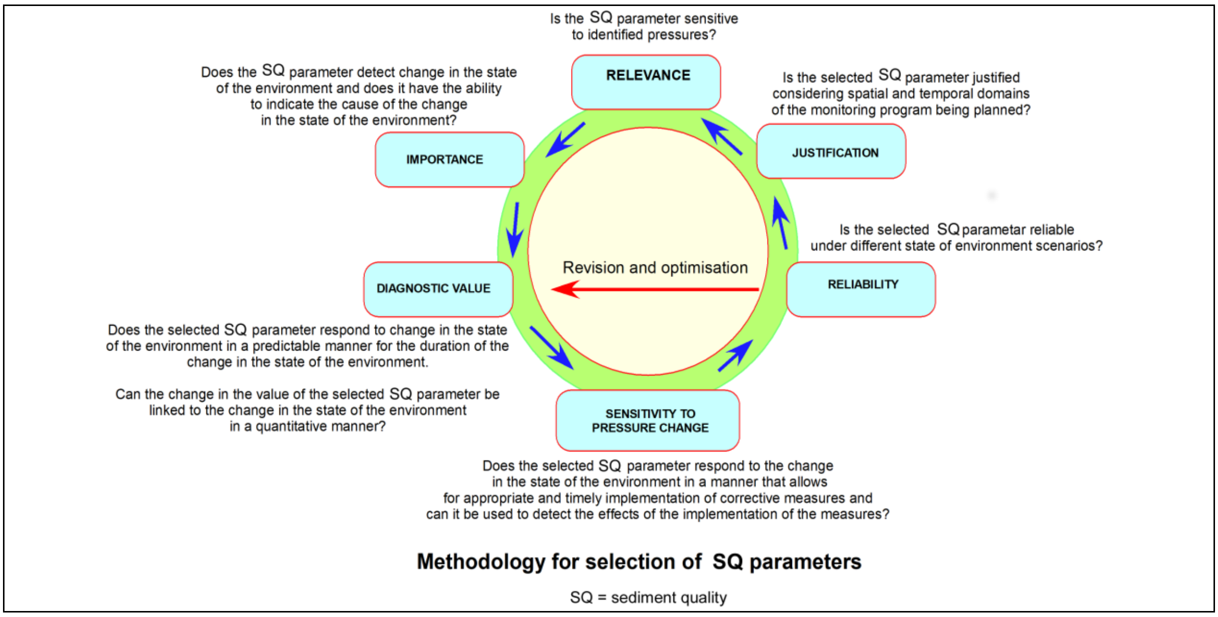

Figure 21. Suggested methodology for the selection of quality parameters.

ROLE OF SEDIMENT SAMPLING

The main role of sediment sampling is to collect sediment samples which are representative of the field conditions and the location at which they are taken so that their quality analysis can support the quantification of flux of substances of interest (organics, nutrients, priority substances) along different sediment pathways. Furthermore, aside from the quantification of relevant fluxes, sediment samples shall be representative enough to enable the evaluation of sediment quality against the threshold values for sediments with respect to current legislation and standards for a particular aquatic system.

The quantification of sediment fluxes are of particular importance for the assessment of trends in order to be able to forecast future conditions and evaluate the need for a particular set of management measures to be included in River Basin Management Plans for a given water system.

Therefore, sediment sampling must enable, as a minimum the following (Figure 22):

- Evaluation of seasonal dynamics of sediment quality with respect to relevant parameters (incluing a minimum of quarterly sampling program)
- Must enable evaluation of spatial variability of sediment quality (sampling most cover littoral and limnetic zones of the lake and reservoir at sufficient number of points to evaluate variability).
- Must cover different sediment quality parameters and pollutant forms (suspended and bottom sediments, organics, nutrients, metals, priority substances), and
- Quantification of different source pathways (tributary inflows (suspended sediments), in situ sediment generation rates (SESTON suspended sediments in lake), and bottom sediments.

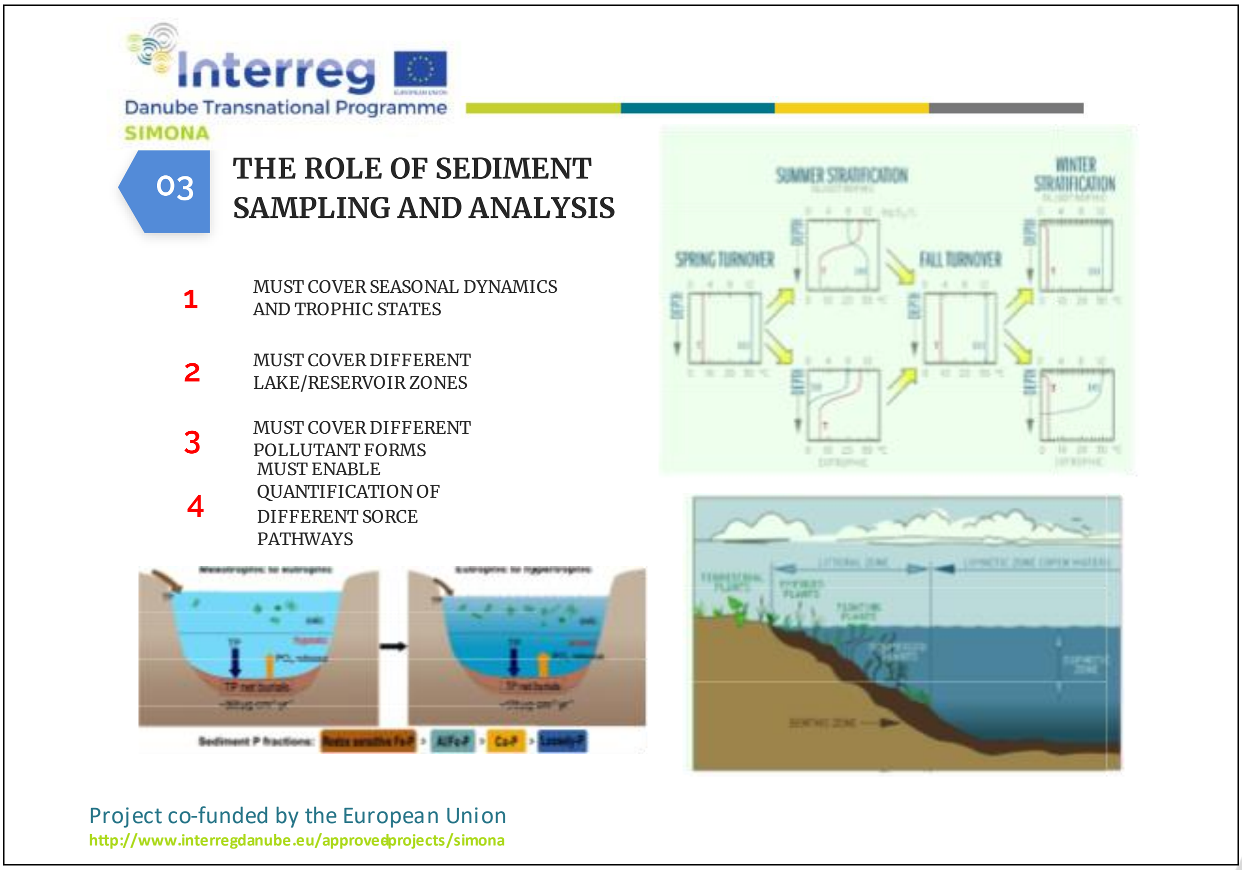

Figure 22. The role of sediment sampling

SAMPLING PLAN AND MOBILIZATION

Sampling sediments in large lakes and reservoirs is not something that can be done from the shore or a bridge and requires specialized equipment for accessing the sampling site (appropriate boat or small ship) and equipment (samplers that can access the sediments at depths that are often beyond few meters and can be more than 100 m at times. It is time consuming and costly and if not appropriately planned it can lead to failure and unrepresentative samples and unreliable results.

It is necessary to do proper planning of sampling before the activity is started. This, in practice, calls for the preparation of an appropriate mobilization plan.

The mobilization plan should contain the following as a minimum (Figure 23)

Figure 23. Minimum contents of a sampling activity mobilization plan

Example mobilization plan is given in ANNEX 1. Of this document

ACTUAL SAMPLING

Actual sampling demonstration was carried out on two tributaries in the catchment of the Danube near the Iron gate reservoir and in the Iron gate reservoir near the town of Donji Milanovac (Figure 24)

Figure 24. Sediment sampling at tributaries of the lake/reservoir and the Iron Gate I reservoir

The sampling demonstration was recorded and videos and photographs documenting the process are part of this report. Two PowerPoint files with embedded videos is attached to this report and are its integral part

ADDITIONAL COMMENTS ON SAMPLING TO EVALUATE NON-POINT AND INTERNAL LOADINGS

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:

- An estimation and identification of significant diffuse source pollution from urban, industrial, agricultural and other installations and activities.
- 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.
- An estimation and identification of the impact of significant water flow regulation, including water transfer and diversion, on overall flow characteristics and water balances.
- Identification of significant morphological alterations to water bodies.
- An estimation and identification of other significant anthropogenic impacts on the status of surface waters.
- 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.

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/reservoir 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/reservoir concerned. The differences in loadings are so great between different lakes/reservoirs that no general guidelines for estimation can be given. Usually the most important variables to be investigated are phosphorus and nitrogen.

POST SAMPLING ACTIVITIES

Post sampling activities include but are not limited to:

- Labeling and storing samples for transport to the lab.
- Completing Field Observation data sheets with all the necessary data and information
- Post processing and analysis of the data once the results from the lab are available

Relevant procedures and standards need to be followed throughout the process

Sample data sheet is shown on figures below.

For further information on the SIMONA Sampling, Laboratory and Evaluation protocols; on the project, partnership and the Danube Transnational Programme: www.interreg-danube.eu/simona

FIELD OBSERVATION SHEET FOR SEDIMENT SAMPLING

APPENDIX 3 OF THE SIMONA SEDIMENT QUALITY SAMPLING PROTOCOL

MONITORING PROGRAMME/ SAMPLING PROJECT INFORMATION:			
Project name:		**Sample identifier (ID):**	
Collection date (DD/MM/YYYY):		**Collection time** (HH:MM):	
Sampling matrix: □ stream/bottom sediment; □ suspended sediment; □ other (floodplain sediment, …):			
Sampling: □ accredited; □ not accredited		**Sampling standard:**	
MONITORING SITE IDENTIFICATION:			
Monitoring Site ID (WISE-SoE):		**Monitoring Site ID (national):**	
Name of the Monitoring Site (e.g. name of the surface water and the city):			
Sample location description with specific information (bridge, high power electric lines, railway line, major road, natural park, …) (provide map on opposite side):			
Type of the monitoring site (can be different from representing waterbody): □ river; □ lake; □ wetland; □ other (floodplain, …):			
Aim of sampling: □ general status; □ reference site (without/small anthropogenic sources); □ investigation site – find contamination source; □ investigation site for other:			
WGS84	Latitude:	**National Coordinate system**	Latitude:
	Longitude:		Longitude:
MONITORING SITE REPRESENTING THE FOLLOWING WATERBODY AND ITS BASIN:			
Is it the same waterbody as the Monitoring Site has? □ YES or □ NO **If no, describe the connection** between waterbody and monitoring site (tributary, recipient, …):			
Waterbody ID (WISE-SoE):		**Waterbody ID (national):**	
Name of the Waterbody:			
Type of the Waterbody: □ river; □ lake; □ wetland; □ coastal; □ transitional			

MONITORING SITE CONDITIONS (PART I):		
River width [m]: □ estimated; □ measured value	**Depth of water** estimated average depth [m]:	**Flow rate** [m/s]: □ estimated; □ measured value
Water temperature [°C]:	**Water electrical conductivity** [μs/cm]:	
Water pH:	**Water transparency** (Secchi disk method) [cm]:	
Geology and background value of parent material/lithology in the area:		

SIMONA

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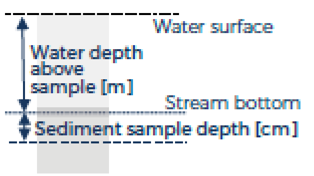
For further information on the SIMONA Sampling, Laboratory and Evaluation protocols; on the project partnership and the Danube Transnational Programme: www.interreg-danube.eu/simona

MONITORING SITE CONDITIONS (PART II):	
Extreme conditions: □ none; □ flooding status; □ ice; □ pollution plume; □ contaminated coast/bank; □ other:	
Weather conditions: □ hot; □ sunny; □ cloudy; □ changeable; □ rainy; □ frosty	
SEDIMENT COLLECTION INFORMATION:	
Water depth above sample [m]:	
Sediment sample depth [cm]:	
Collection device: □ stainless steel scoop; □ corer; □ sampler for suspended sediment; □ other:	
Sample type: □ composite – number of subsamples: ______	
Distance between the first and last sampling site? [m]:	
Sample replicate collected? □ YES or □ NO	**Replicate ID/name:**
Sample is duplicated? □ YES or □ NO	
SAMPLE INFORMATION:	
Sampling volume estimated, wet weight [liter]:	
Temperature of sample (field observation, right after sampling) [°C]:	
Sediment pH (undisturbed):	**Sediment pH** (post-homogenization):
Colour (Munsell soil colour chart number):	
Texture (particle size description):	
Odour: □ none; □ light; □ strong; □ earthy; □ mildewed; □ putrid; □ farm slurry; □ fishy; □aromatic; □ sewage; □ fuel/oil	
Information on sediment components (seashells, animals, peat, wood, tar, stones, waste, plastics, etc.):	
Sample photograph identification:	
Additional comments (e.g. map of the sampling site):	
Sampler name (readable):	**Signature:**

SIMONA

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Project co-funded by the European Union (ERDF, IPA and ENI)
A stream of cooperation

MONITORING PROGRAMMES, SAMPLING SITES AND FREQUENCY OF SAMPLING

The material presented in this section has been prepared on the basis of the UNIECE Working Group on Monitoring and Assessment report entitled "Guidelines on Monitoring and Assessment of Transboundary and International Lakes published by UNIECE Working Group on Monitoring and Assessment in 2003 with appropriate modifications by the authors of this report.

We particularly note that monitoring of sediment quality contributes to overall monitoring within the river basin and is a tool used to develop appropriate management strategies and program of measures for a particular river basin. In view of this it can not be viewed as an activity which is outside of the other monitoring activities.

In principle, sediment monitoring should be aligned with the other monitoring activities in the river basin. This applies to the monitoring program, sampling site selection, monitoring frequencies and similar as well as the objectives of the monitoring program.

In the context of transnational monitoring activities this requiers also the alligment of monitoring programs between contries.

In view of the above what follows in the rest of this section applies to both sediment and water monitoring programs, sites and frequencies.

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/reservoir 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.

SAMPLING SITES

The main hydrological and hydrometeorological characteristics, such as precipitation, snow cover, water level, river flow, sediment discharges (suspended sediment, bed load, bottom sediments), 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/reservoir.

The selection of 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 stations should be located within the system.

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.

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:

- The volume, level or rate of flow to the extent relevant for ecological and chemical status and ecological potential, and
- 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 and sediment monitoring networkto support evaluation 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 and sediment monitoring network in the river basin management plan.

The sampling procedure used in lake/reservoir monitoring differs from that of rivers. As a rule, the state of lakes/reservoirs 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/reservoir types is presented in Fig. 25.

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.

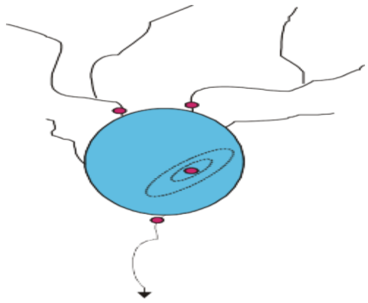	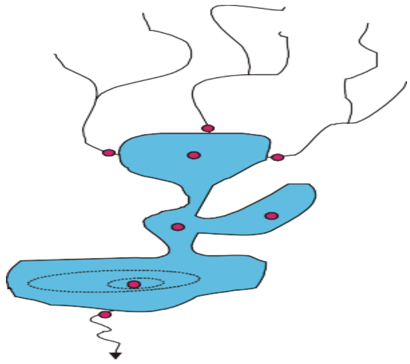	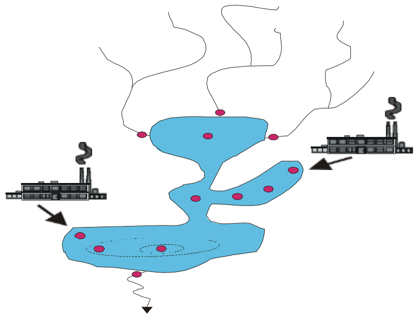
Almost no pollution One monitoring site in the deepest part of the lake One monitoring site at the mouth of each major inflowing river and at the upper reaches of the outflowing river	Almost no pollution One monitoring site in the deepest point of each part of the lake One monitoring site at the mouth of each major inflowing river and at the outlet of the lake	Polluted by point-source loading One monitoring site in the deepest point of each part of the lake Spatially and temporally frequent monitoring in the most polluted subareas of the lake One monitoring site at the mouth of each major inflowing river and at the outlet of the lake

Figure 25. Examples of monitoring site placement in different types of lakes.

In stratified lakes/reservoir water samples should be taken always vertically from varying depths and bottom and suspended sediments should be taken at the same location. Even in natural lakes there can be significant differences in water and sediment 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 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.

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. 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.

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/reservoir, 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.

The WFD has also provides 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 hydro morphological 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.

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/reservoirs 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/reservoirs. Monthly samples are recommended for most fast-flushing lakes/reservoirs; more frequent sampling may be required occasionally in lakes/reservoirs 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/reservoirs 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.

Sediment monitoring specific issues

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/reservoir 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.

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/reservoirs are continuously depositing sediments, which incorporate fossil remains of organisms that lived in the lake/reservoir. 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/reservoir.

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/reservoir, 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. (Figures 26, 27)

Figure 26. A sediment sample taken with a gravity corer. In this case different layers can be detected easily (Photo Seppo Knuuttila).

Figure 27. A sediment sample taken with a gravity corer. (Photos Marko Marjanović).

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.

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 210Pb method is a much used tool for dating layers accumulated during the last 150 years. 137Cs 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).

The assessment and presentation of the monitoring results

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. 28).

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).

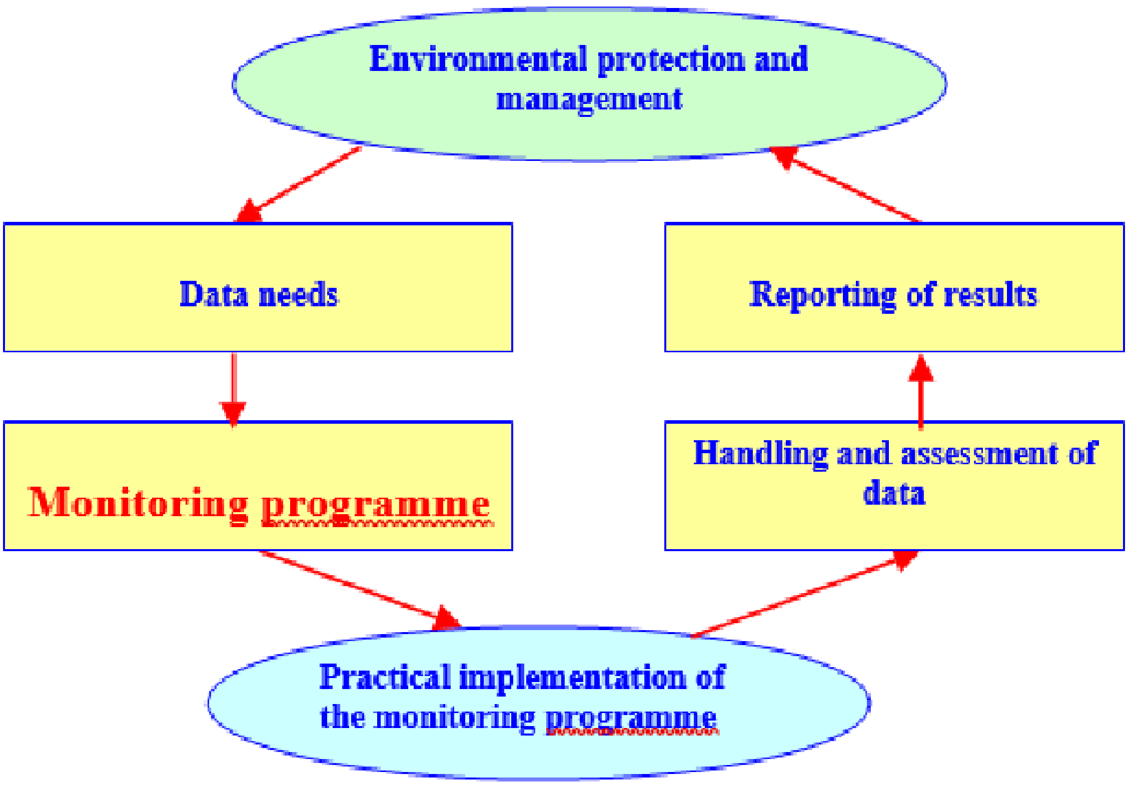

Figure 28. The monitoring cycle.

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. 29.

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.

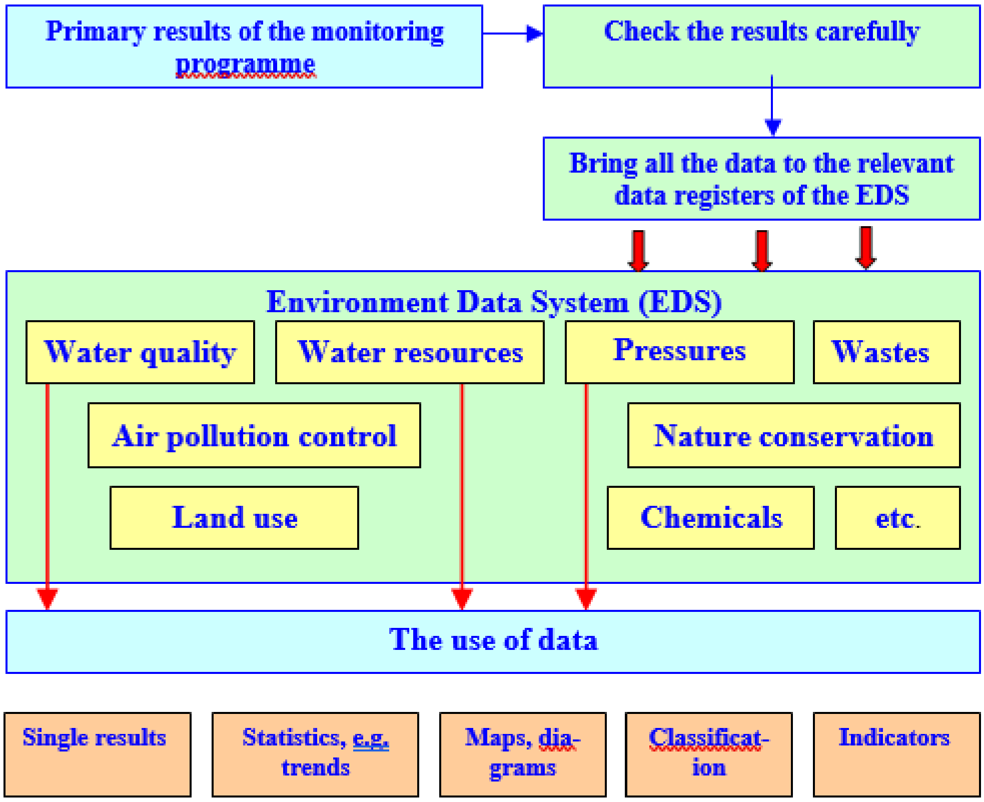

Figure 29. Flow chart of the use of the monitoring data.

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.

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 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).

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.

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 concerning transboundary water bodies. 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.

CLOSING REMARKS

This guidance document covers the minimum requirements to ensure quality and consistency of the field aspects of lake reservoir bottom sediment data collection. Sediments collected using the techniques outlined here will be analyzed for sediment chemistry and for physical characteristics such as particle size distribution. The essential tasks in sediment sampling are to collect representative, undisturbed samples that meet the requirements and objectives of the activity, and to prevent deterioration and contamination of the samples before analyses.

Summary of the main activities and important things to considered are listed below

PREPARING TO GO TO THE FIELD

PREPARATION FOR EACH SAMPLING TRIP IS CRITICAL SINCE OVERSIGHTS ARE NOT USUALLY NOTICED until staff reach the first station. The most effective way to prepare for a sampling trip is with a checklist that is designed to meet the requirements of each project. Other than considering site-specific instructions, the checklist should identify the following needs:

- Type and number of (labeled) bottles and containers, including extras
- Field equipment such as meters (with adequate trouble-shooting equipment for small repairs), sampling tools (sediment grabs, corers), etc.
- Preservatives
- Appropriate quantity of ice packs and coolers
- Log books
- Personal gear (for all possible weather conditions, e.g., survival suits, raincoats, protective footwear, etc.)
- First aid kit and other safety equipment (life jackets, survival suits)
- A section on the working status of equipment (i.e., properly loaded to avoid damage during transport, batteries charged, probes not damaged or dried, etc.)
- Camera or video equipment as required
- Laboratory requisition forms (partially filled out)

A general operating procedure is to have the key equipment in a box or plastic “tote” which is dedicated to this activity.

LOCATING THE SITE IN THE FIELD

It is the responsibility of the field staff to locate all sampling stations accurately. Only if the same location is consistently sampled can temporal changes in the sediment quality be interpreted with confidence. Therefore, accurately written station location descriptions (that identify key landmarks) must be prepared on the first visit to every sampling site. It is essential that each site be referenced by watershed code. The

Good photographic documentation is the best way of ensuring that each site is easily recognized. A map that labels the sample sites should accompany the site identification log book. This log book can be in the form of a 3-ring binder with a 1:50 000 map. The basic site location data (latitudes, longitudes, map sheet number, site identification number, etc.) should be incorporated into the database (EMS in the case of BC Environment). GPS units are becoming generally available and should be used whenever possible to locate a site.

FIELD NOTES/OBSERVATIONS

Good sampling practice always involves the use of detailed field notes. Specific information about seemingly unimportant facts such as the time of day or weather conditions are often important when interpreting data. A field log book (3-ring binder with water proof paper) for each project is mandatory. All field measurements should be entered (by date) directly into this field log book. The following list emphasizes those observations that should be recorded:

- Site name and code
- Date and time
- Station depth
- Names of all personnel on sampling crew
- Gross characteristics of sediment
    - Texture
    - Colour
    - Biological structure (e.g., shells, tubes, macrophytes)
    - Debris (e.g., wood chips, plant fibers)
    - Presence of oily sheen
    - Obvious odour
- Gross characteristics of vertical profile (distinct layers, depth of layer changes)
- Penetration depth of sediment sampler

All information recorded in the log book should be entered into the database as soon as possible upon return from the field.

QUALITY ASSURANCE/QUALITY CONTROL

Field Quality Assurance

The field quality assurance program is a systematic process which, together with the laboratory and data storage quality assurance programs, ensures a specified degree of confidence in the data collected for an environmental survey. The field quality assurance program involves a series of steps, procedures, and practices which are described below.

The quality of data generated in a laboratory depends, to a large degree, on the integrity of the samples that arrive at the laboratory. Consequently, the field investigator must take the necessary precautions to protect samples from contamination and deterioration.

There are many sources of contamination; the following are some basic precautions to consider:

- Sample containers, new or used, must be cleaned according to the recommended methods and certified by the issuing laboratory as 'contamination free' (if pre-cleaned by the laboratory).
- Only the recommended type of sample container for each analysis should be used
- The inner portion of sample container and caps must not be touched with anything (e.g., bare hands, gloves, etc.) other than the sample itself.
- Sample containers must be kept in a clean environment, away from dust, dirt, fumes and grime. Containers must be capped at all times and stored in clean shipping containers (coolers) both before and after the collection of the sample. Vehicle cleanliness is an important factor in eliminating contamination problems.
- Petroleum products (gasoline, oil, exhaust fumes) are prime sources of contamination. Spills or drippings (which are apt to occur in boats) must be removed immediately. Exhaust fumes and cigarette smoke can contaminate samples with lead and other heavy metals. Air conditioning units are also a source of trace metal contamination.
- Samples must never be permitted to get warm; they should be stored in a cool place; coolers packed with ice packs are recommended (most samples must be cooled to 4°C during transit to the laboratory). Conversely, samples must not be permitted to freeze unless freezing is part of the preservation protocol (see Appendix 2 of this chapter).
- The sample collectors should keep their hands clean and refrain from smoking or eating while working with samples.

Field Quality Control

Quality control is an essential element of a field quality assurance program. In addition to standardized field procedures, field quality control requires the submission of replicate and reference samples. Replicate samples detect heterogeneity within the environment, allow the precision of the measurement process to be estimated, and provide a check that the sample is reproducible. Reference samples are used primarily to document the bias of the analytical (laboratory) process, however, any influence or contamination introduced during sample preparation, handling, or during lab analysis will be reflected. The timing and the frequency of replicate and reference samples are established in the project design and will vary with each project.

Replicate Samples

To determine the degree of heterogeneity within the sediments, it is necessary to take replicate samples. These replicates can consist of multiple samples (grabs) from the same general area (to measure site heterogeneity), or portions of a single grab (to measure more localized heterogeneity). Grab samples that are homogenized (physically stirred) in the field and then sub-sampled into replicates serve as a tool to estimate the analytical (laboratory) precision. Refer to section 5.1 for the protocol to collect the samples.

Reference Samples

Laboratory tested and preserved reference sediment samples have been prepared and certified by a national, international or standards agency such as the National Research Council of Canada. These reference samples have been subjected to a large number of analyses performed by independent laboratories using several different analytical techniques. Consequently, the laboratory supplying the reference material provides mean values and confidence intervals for these substances.

These reference samples should be submitted to the analyzing laboratory along with the samples collected during a field trip. Reference sediment samples are distributed as a dry dust, therefore, the analyzing laboratory will be aware that they are reference samples. Nevertheless, they should be transferred to a regular, coded sample container so the lab does not know which reference sample it is dealing with.

SAMPLING EQUIPMENT

Generally, there are two types of samplers used for collecting bottom sediments: (1) grab samplers for collecting surface sediments, thereby providing material for the determination of horizontal distribution of variables; and (2) core samplers for collecting a depth profile of sediments, thereby providing material for determination of vertical distribution of variables. Grab samplers, due to their ease of use and large quantity of sample obtained, are ideal for assessing recent inputs of pollutants. The core samplers are better suited for assessing long-term (historical) inputs. The type of sampler used at particular sites will vary depending on the purpose of the study and will be dictated by the project design.

Grab Samplers

Simplified drawings of grab samplers with their essential components are shown in Figure 1. The grab samplers commonly used by BC Environment are of designs that use a set of jaws which shut when lowered to the sediment. In the case of the Ekman and Ponar grabs, vented or hinged tops allow water to flow freely through the device during descent, thereby reducing sediment disturbance that would otherwise be created by a shock wave in front of the sampler. The advantages associated with these grab samplers are that they are easy to use and obtain relatively large volumes of sediment. A disadvantage is that upon retrieval, fine surface particulates can be carried away by outflowing water. Several designs for sediment samples, are available and may be appropriate in certain conditions. (Eckman dredge, Ponar and mini Ponar, the Van Veen grab sampler etc)..

Core Samplers

Core samplers penetrate the sediment more deeply than grab samplers. Consequently, they provide a cross-sectional slice of sediment layers and thus, information about the sediment deposition. A valve at the top of the sampler closes by messenger, creating a vacuum seal that prevents the sediments from washing out..

COLLECTING SEDIMENT SAMPLES

Sediment samples are collected for either analysis of chemical and physical properties of the sediment, or to assess the benthic biotic community structure (biomass and/or taxonomy). A number of basic requirements must be met to obtain representative sediment samples:

- The sampling device must penetrate the sediment to a sufficient depth to measure the variables of concern accurately.
- The sampling device must close completely each time.
- Care should be taken not to disturb the sediments prior to deployment of the sampling device.

Note: Since sediment samplers disturb overlying waters they should be used only after the ambient water sampling has been completed at the site.

COLLECTING LAKE SEDIMENT SAMPLES

Regardless of the equipment chosen for the sample collection, it is necessary to know the water depth at each station before starting. If water depth information is unavailable, it is recommended that it first be measured. Measurement equipment can range from a weighted rope to an electronic depth sounder. The purpose is to ensure adequate cable (rope) length for operation of the equipment and to control the speed of entry of the sampler into the sediment. The speed of deployment of the sampler can be critical to good operation and sample recovery. Too rapid deployment generates and increases the shock wave advancing in front of the equipment. This shock wave can displace the soft unconsolidated surface sediments. Rapid deployment may also cause equipment malfunction, such as activating the trigger mechanism before the device reaches the sediment. In the case of core samplers, if the deployment is too slow, an insufficient quantity of sediment is obtained. Since the site-specific conditions will dictate the speed of sampler deployment, the specifics should be recorded in the field log book (i.e., the height from which the corer was allowed to free fall).

EXAMPLE PROTOCOL (SAMPLING FROM A BOAT WITH A CORE SAMPLER)

a. Open the valve and set the trigger mechanism (Figure 2). Ensure the rope is securely fastened to the corer and attach the other end of the rope to the boat.
b. Lower the corer to just above an area of undisturbed sediments and then allow it to penetrate the sediments with its own weight. Specialized corers and different types of sediment may require different techniques but what seems to be important is to avoid the disturbance caused by impact.
c. Send the messenger down to release the trigger mechanism.
d. Carefully retrieve the sampler and place a stopper into the bottom opening before removing from the water to prevent loss of the sample.
e. Remove the liner from the corer and stopper the upper end. Store erect. Repeat this procedure to obtain replicate cores, each at least 20-30 cm in length.
f. Once on shore, carefully siphon off most of the water overlying the sediments in the core tube (leave a small amount at the sediment-water interface). Do not disturb the sediment-water interface.
g. Make careful measurements of the total length of the core and precise points (nearest mm) of any layers of sediment that appear to be different. Note any changes in stratigraphy, such as colour and texture.
h. A rubber stopper of a size sufficient to fit inside the liner tube tightly to form a watertight seal and mounted in a extruder. The core is then gently and slowly forced upward to the top of the tube. Most extruders allow the increment of sediment slices to be adjusted.
i. As the sediment core is extruded, carefully cut slices (from 2mm to 1 cm or more thick) with clean spatulas and place into labeled sample bottles. An extruder greatly assists this operation, but good samples can be obtained by mounting the core tube in a vice and manually extruding the sediment if done carefully.
j. Place the samples in a cooler with ice packs as soon as they are transferred to the labeled bottles.

Note: For samples that are to be analyzed for organics, the spatula and container must not be plastic (the container must be glass bottles provided by the laboratory). For samples that are to be analyzed for metals, the spatula must not be metallic.

EXAMPLE PROTOCOL (FROM BRIDGE WITH A GRAB SAMPLER)

a. Set the grab sampling device with the jaws cocked open (see Figure 1). Great care should be taken while dealing with the device while it is set; accidental closure could cause serious injuries.
b. Ensure that the rope is securely fastened to the sampler and that the other end of the rope is tied to the bridge.
c. Lower the sampler over the upstream side of the bridge until it is resting on the sediment (its own weight is adequate to penetrate soft sediments). At this point the slackening of the line activates the mechanism that releases the jaws of the Ponar and Petersen grabs.
d. For the Ekman grab, send the messenger down to 'trip' the release mechanism.
e. Retrieve the sampler slowly to minimize the effect of turbulence that might result in loss of surface sediments.
f. Place a container (i.e., a shallow pan) beneath the sampler as soon as it is on the bridge.
g. Note: If the jaws were not closed completely, the sample must be discarded (over the downstream side of the bridge or on shore if sensitive water uses exist immediately down stream. Dump the unwanted sample only after a sample has been successfully collected.
h. If replicates are to be collected, then refer to Section 5.1.1 steps (g) and (h). Otherwise, for a bulk sample, gently open the jaws and allow the sediments to empty into the container.
i. Immediately record, in the field log book, observations regarding the appearance of the sediment (i.e., texture, colour, odour, presence of biota, presence of detritus, and the depth of sediment sampled).
j. With a clean spatula either remove the top portion of the sediment (when this is outlined by the study design), or carefully stir the sediment to homogenize. Place an aliquot into a pre-labeled sediment sample bottle.
k. Note: For samples that are to analyzed for organics, the spatula and container must not be plastic (the container must be a glass bottle provided by the laboratory). For samples that are to analyzed for metals, the spatula must not be metallic.
l. Place the samples in a cooler with ice packs as soon as they are transferred to the bottles.

RECOMMENDATIONS FOR SEDIMENT QUALITY MONITORING IN TRANSNATIONAL LAKES AND RESERVOIRS

SIMONA project responds to the current demand for the effective and comparable measurements and assessments of sediment quality in surface waters in the DRB, Monitoring and Assessment System to support transnational cooperation for joint DRB water management has been developed for streams, rivers and lakes and reservoirs within different Simona Project work packages. The system developed system covers:

1. sampling,
2. laboratory analysis,
3. evaluation protocols and
4. SIMONA-tool (online IT application)

The tools and guidelines developed are applicable at local and also at strategic level, thus actively contributing to achieving the WFD sediment quality monitoring and chemical status assessment requirements.

The immediate and middle term benefits of the project are a transparent method supported by the SIMONA-tool for sediment quality monitoring that will encourage the cooperation in transnational water management.

The main result of SIMONA is improved, harmonized and coordinated sediment quality monitoring in the Danube River Basin. SIMONA delivered a benchmark for monitoring the future changes of the water quality via sediment quality, and this benchmark has been co-developed with stakeholders, verified by case studies.

Within WP6 of the SIMONA Project specific attention was devoted to sediment monitoring in large lakes and reservoirs focussing on transnational water bodies. The laboratory protocols and procedures developed for streams and rivers in other Project work packages also apply to lakes and reservoirs and are discussed in appropriate reports from the relevant work packages.

Within WP 6 specific guidelines for sediment sampling and analysis in large lakes and reservoirs have also been developed and are reported in "T4.2.1 Guidance on sediment monitoring in large lakes and reservoirs. These guidelines are technical in nature and apply at local, regional and transnational levels.

However, neither the laboratory nor sampling guidelines developed within the SIMONA Project address the management and organizational issues of importance in transnational context in general and especially those of relevance for transnational water bodies and transnational lakes and reservoirs in particular.

With the above in mind the remaining part of this section addresses specific organisational and management issues in the context of transnational lakes and reservoir water bodies and makes appropriate recommendations in this regard.

Main recommendations

1. Sediment sampling activities for transnational water bodies need to be jointly planned by the parties concerned (all parties within whose territories transnational water body is located) and should cover the following as a minimum:
    a. Selection of number and location of appropriate sampling locations.
    b. Determination of frequency for sampling sediments at selected location
    c. Specification of sampling equipment to be used for sediment sampling
2. Adoption of common sample storage, transport and record keeping procedures and standards by the parties concerned (all parties within whose territories transnational water body is located) which should cover the following as a minimum:
    a. Standardized sample labelling methods and procedures
    b. Standardized sample storage and transport procedures
    c. Standardized reporting forms and field observation sheets in multiple languages.
3. Adoption of common laboratory standards and procedures for sediment quality analysis by the parties concerned (all parties within whose territories transnational water body is located) which should cover the following as a minimum:
    a. Acceptable analytical methods and limits of detection
    b. Requirement that all analysis are to be conducted by nationally accredited analytical laboratories
    c. Standardized reporting formats and procedures.

In view of the possibility that different legal regimes could exist in different countries we further recommend the following:

1. Bilateral and/or multilateral agreements should be made between the parties concerned which would cover recommendations made above. These agreements can be amended to existing agreements already in place or can be subject to separate dedicated agreements between the parties concerned.
2. If at all possible sampling sediment sampling campaigns should be jointly organised and implemented and sediment samples should be split in equal aliquots for quality analysis in national labs.

3. Reports on sampling and quality analysis should be shared between the parties concerned.

Finally for transnational lakes and reservoirs where water body status as per WFD is at risk or is not good, we recommend that the parties concerned develop a joint focused sediment quality study to trace the source of pollution responsible for violation of sediment quality standards in a particular water body.

LINK TO VIDEO MATERIALS SUPPORTING THE GUIDELINE:

As a part of the work on WP6 and preparation of these guideline document field demonstration activities have been implemented.

The links to files containing photo and video documentation are given here

1. Part 1. Initial data collection, station positioning, velocity profiles and bathymetry

   PART 1 INITIAL DATA AND SAMPLE (

2. Part 2 Collecting samples for suspended sediments and grab sample of bottom sediments

   PART 2.mp4

3. Part 3 Collecting undisturbed sediment samples using sediment corer

   PART 3.mp4

4. Photo documentation from the field

   PHOTO ALBUM.mp4

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ANNEX 1. Example of Sampling Mobilization Plan

MOBILIZATION PLAN

FOR SAMPLING OF SURFACE WATERS AND SEDIMENTS IN CATCHMENT OF A RESERVOIR XXXX

(Sampling period start date/end date)

Place, Date

THE CONTENT

INTRODUCTION

As part of the annual water monitoring within the XXX project, in the period between [redacted] and [redacted]. field teams of the Jaroslav Černi Institute will perform field works on the monitoring of surface water and sediment quality in the areas of [redacted]. Within the field works, the following will be performed:

1. flow measurements (hydrometric measurements)
2. morphological measurements of surface waters
3. sampling and in situ measurements of surface waters and sediments

SURFACE WATER and sediment MONITORING

The following equipment will be used for the purpose of performing works for the campaign of hydrometric and morphological measurements, sampling and reading of divers:

B . For hydrometric measurements:

1. Macro Water velocity and current meter
2. Micro Water velocity and current meter
3. Speed counter

C. Morphological measurements:

1. GNNS receiver
2. Zodiac boat

D. The following equipment will be used for sampling and in situ measurement of surface and water quality parameters :

1. Telescopic sampling system (Figure 7)
2. YSI ProDSS multiparameter probe
3. Various packaging for samples
4. Portable sample refrigerator

E . Various small mechanically driven tools (wrenches, pliers, etc.)

As part of surface water and sediment monitoring, works will be performed on the profiles listed in Table 1.

Table 1. Monitoring profiles and works performed on them

Monitoring profile	Hydrometric measurements	Level readings manual and automatic	Morphological measurements	Sampling
[redacted]	/	/ √		
[redacted]				/
[redacted]	/	/ √		
[redacted]				/
[redacted]	/	/ √		
[redacted]	/	/ √		
[redacted]	/	/ √		/

Below are pictures of the equipment used during monitoring.


Light intensity meter   Current meter


Micro current meter   Revolution counter

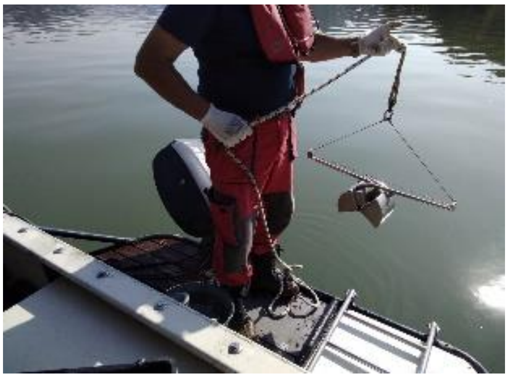
GPS Receiver „Sampling ship

Telescopic water samplling bottle

In situ multiparameter probe „YSI ProDSS“

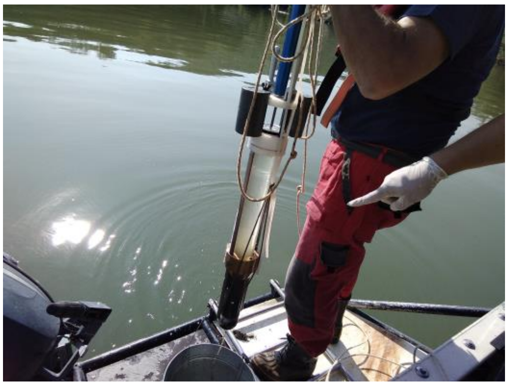
Sample containers

Sediment core samplers for shallow sediments and bank soil   Undisturbe sample correr



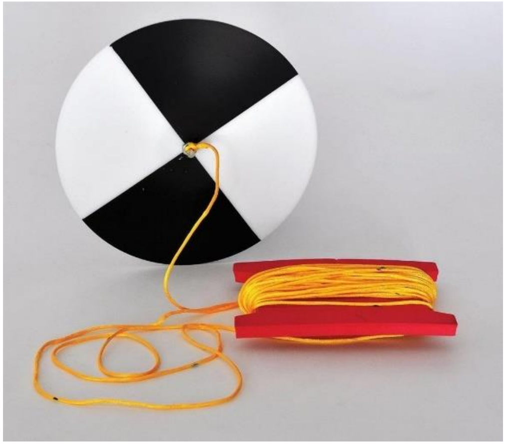
Sample field refirigirator

Eckmn Dredge sediment sampler



Undisturbed sediment core sampler

Van Dorn water sampler



Sechhi Disk

Accessories (plastic bags, bucket, gloves etc

HYDROMETRIC MEASUREMENTS

Hydrometric measurements will be performed by two separate teams. One team is composed of two members while the other is composed of 3 members.

One team carries out meassurements on streams tributaries to the lake and the second team takes meassurements in the lake.

Depending on the depth and width of the tributary, speed measurements take up to an hour per site. For the lake sites the time required is about 1 hour per measuring point (number of points need to be measured at each cross section)According to the situation on the field and the current water level in the measuring profile, the appropriate speed measurement procedure will be applied. The categorization from the water safety procedure envisages works from the boat (Figure 6)

MORPHOLOGICAL MEASUREMENTS

Morphological measurements measurement of the transverse profile of the riverbed is performed by a team of three members. The measurement is performed from a boat using a GNSS receiver.

SAMPLING

Sampling can be done by directly filling the packaging from the river flow by descending into the riverbed, or by capturing water with a telescopic sampling system (Figure 7), from which the packaging for the samples is then filled (Figure 9).

In-situ measurements of pH, temperature, dissolved oxygen content and electrical conductivity will be performed by immersing the YSI ProDSS multiparameter probe (Figure 8) directly into the watercourse and reading the measured values from the display of the measuring apparatus. Sampling will be performed in accordance with the previously agreed methodology and in accordance with the requirements of international ISO standards that define guidelines for the collection of surface water samples.

ENGAGING FIELD TEAMS

The mobilization plan for sampling of surface and groundwater envisages the engagement of the following workers:

1. [redacted], B.Sc. in Environmental Protection , team leader 060 3835592
2. [redacted], master chemist, team leader, 064 244 5835
3. [redacted], technician
4. [redacted], tech.
5. [redacted], technician
6. [redacted], technician
7. [redacted], technician

Two Dacia Duster off-road vehicles and one Toyota Hilux will be used to transport people and equipment.

ʀ. ıo.	Vehicle / Equipment	Place of loading	Place of unloading	Purpose	Note
.	Dacia Duster	White City	Loznica	4x4	Transportation of workers and equipment
:	Dacia Duster	White City	Loznica	4x4	Transportation of workers and equipment
;	Toyota Hilux	White City	Loznica	4x4	Transportation of workers and equipment

As the sampling is planned to last for several days, there is still the possibility of changes in the plan, ie. to suspend sampling due to bad weather conditions such as heavy rainfall. You will be notified in a timely manner of any changes to the sampling and mobilization plan. In case of suspension of works, the team leaders are obliged to inform the contact person who represents the investor **immediately** after determining the need for suspension of works.

In the event of a change in the composition of the teams on the ground or the rotation of the planned team members, the contact person representing the investor will be notified at least **12 hours in** advance. Due to the nature of the work and unpredictable field conditions, it is possible that there will be changes in the planned sampling locations for a given day. Seeing that this cannot be determined in advance, but depends on current field conditions, meteorological conditions, etc., any changes and deviations from the planned sampling locations for the day, the contact person representing the investor will be notified **immediately** after determining the need for deviation from the planned dynamics before the team is sent to the newly chosen location.

Estimated working hours are from 8:00 am to 5:00 pm but this time may be exceeded in case the job requires it.

ACTIVITY PLAN

DATE		
Time	Description of works	The works are realized by:

23-03-2021		
Team 1		
Time	Description of works	The works are realized by:
08^{30}-9^{00}		Marko Marjanović, D. Radovic, S. Ostojic
09-16^{00}		
16^{00} 17^{00}		
Team 2		
08^{30}-9^{00}		M.Lумовић, T. Arizanovic
10^{30}-16^{00}		
16^{00} 17^{00}		

Etc for each day in the field

RISK ASSESSMENT

During the execution of works, there is a possibility that workers are exposed to certain risks. In order to reduce the likelihood of undesirable situations or consequences, the risks to which workers will be exposed have been analyzed and recommendations of preventive measures that must be taken in order to minimize or completely eliminate the risks are given. An overview of the identified risks is given below.

Table 3. Identified risks and measures for risk reduction and safe operation

	ASSESSED RISKS	RISK	MEASURES FOR SAFE WORK
1.	Danger of falling	Low	Obligatory observance of safety measures and technical regulations when working in the field. Locations of works (field measurements) should be properly provided. Use prescribed personal protective equipment. Perform a visual inspection of the terrain and assess whether it is safe to move on it.
2.	Risks due to participation in traffic	High	Obligatory observance of safety measures when working in the field, perform daily and weekly vehicle inspections. Use the prescribed personal protective equipment in the event of a car breakdown (high visibility vests, triangle, etc.) Observance of the OSH procedure and driving procedure. Prohibition of using the phone for the driver, even with "bluetooth" devices.
3.	Danger of landslides	Low	Obligatory observance of safety measures when working in the field. Adherence to OSH and driving procedures.
4.	Danger of falling objects	Low but there is	Obligatory observance of safety measures when working in the field. Use the prescribed personal protective equipment, which includes shoes with a protective metal cap.
5.	Dangerous surfaces / possible slipping or tripping (all types of treads that the employee comes into contact with, wet, slippery uneven surfaces, etc.)	Low but there is	Adherence to safety procedures regarding safety and health at work. Marking of dangerous places for easier observation. Be sure to move carefully on wet, slippery and uneven surfaces. Use prescribed personal protective equipment.

	ASSESSED RISKS	RISK	MEASURES FOR SAFE WORK
6.	Danger of insect bites.	Very Low	Adherence to safety procedures regarding safety and health at work. Use prescribed personal protective equipment that includes work clothes and shoes that provide protection. In case of bites, act in accordance with the instructions with the document Response plans in case of accidents and emergencies.
7.	Harmfulness due to possible contact with waste materials, soil and water poisoning (pesticides, waste, etc.)	Low but there is	Observance of work procedures and general safety measures in places where contact with waste and hazardous substances is possible. Application of personal protective equipment intended for work under such conditions. Wear safety data sheets for necessary chemicals that describe first aid measures in case of an incident.
8.	Risk of cuts, stings and similar injuries due to the use of auxiliary tools or movement in the field (use of axes, mowers, plant injuries)	Middle	This risk is more pronounced when working in the area of "Rakovica". It is necessary to use the prescribed personal protective equipment, including work suits, shoes, helmets and gloves.
10.	Danger of bad weather	Low	This risk is present in both research areas. In case of weather, it is necessary to act in accordance with the Procedure in case of weather.
11.	Danger when working with the unit	Low	There is a risk of electric shock when working with the unit. In order to minimize this risk, it is necessary to perform an attestation in order to ensure their technical correctness and earthing of the unit during operation. It is necessary to turn the unit so that the exhaust gases from the unit are directed in the direction of the employees.
12.	Danger when carrying cargo	Low	Compliance with all requirements in the procedure for manual transfer of cargo and increased caution when transferring cargo. Conducting a visual assessment of the terrain, places for storing cargo, places for movement, etc.
13.	Risk of exposure and infection with COVID-19 virus	Middle	Obligatory observance of all measures prescribed in the Rulebook on work organization and protection measures for employees in the transitional period after the cessation of the state of emergency due to the pandemic caused by the COVID-19 virus , which we submit with this

ASSESSED RISKS	RISK	MEASURES FOR SAFE WORK
		Mobilization Plan. These measures include mandatory wearing of protective masks and gloves in all situations where it is not possible to keep a distance of at least 2m between employees, regular hand washing with soap and disinfectant. Every morning before starting work, employees will fill out a questionnaire related to the symptoms of Covid-19. Employees will have their temperature measured every morning before starting work.

NOTE:

Due to the current situation regarding the Corona virus, all participants in the monitoring must fill in and submit to the Investor the form submitted to the IJC by Rio Sava before starting the works. In this regard, the form will be submitted to all participants in groundwater monitoring for inspection and signature in a timely manner.

During the stay in the field and in the accommodation premises during the monitoring, it is recommended to avoid handling, it is desirable to wear protective masks, each team should have a disinfectant as part of the equipment and maintain hand hygiene whenever possible.

SAFETY AT WORK

For all planned works during the measurement, measures will be taken to protect the environment and protect workers from potential hazards of the environment in which the work is performed.

The group leader will be in charge of implementing safety measures at work, and to warn each worker of irregularities during the works. All protection measures are defined in the instructions:

1. Procedure for safe operation during water and sediment sampling
2. Procedure in case of bad weather
3. OSH Procedure and driving style
4. Jewelry wearing procedure
5. Ordinance on the organization of work and measures for the protection of employees in the transitional period after the cessation of the state of emergency due to a pandemic caused by the COVID-19 virus
6. Procedures for performing all the above works in the area of lake/reservoir xxxx by localities are described in the "Study on OSH risk assessment during surface water and sediment monitoring in the area xxxxx.

All workers must respect the protection measures from the protocol and which are determined by the manager. In case of non-compliance with the procedures, the worker will be removed from the place of work.

As the program of works envisages movement along roads of different categories, all workers are obliged to wear high visibility clothes fluorescent jackets or vests (Figure 10). If there is a need to move through the forest belt, the obligatory part of the OSH equipment is a protective helmet and goggles (Figures 11 and 12).

Compulsory safety at work protective gear

A protective water vest will be used as a mandatory part of OSH equipment when working on water (Figure 13).

In Belgrade, DATE,

Head of the team for monitoring

[redacted]

Head of surface water monitoring team

[redacted]

1

Attachmet

MAPS with relevant data: Roads, sampling points, hospitals, petrol stations etc.

SIMONA