Report on Output T4.1 Reports on national methods and databases

Output T4.1.1 Report on national methods and databases regarding sediment quality in large lakes and reservoirs

Output T4.1.2 Report on national methods and databases regarding sediment quantity in large lakes and reservoirs

PROPOSAL

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

ACRONYM
SIMONA

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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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PREFACE

Sediment quality in large lakes and reservoirs plays an important role in controlling water quality especially in times of stratification and reduced mixing through the mechanism of internal loading that may determine the overall status of a given water body. Sediment quality monitoring of HSs requirements in such systems are unique and require appropriate sampling and analysis methodologies, standards and protocols. The focus of the WP is thus on related methodological and technical issues in large lakes and reservoirs in DRB within the context of the WFD requirements and identification of measures for the RBMP. The main objective is to develop SIMONA Guideline for sediment quality monitoring of HSs in large lakes and reservoirs for the DRB.

The SIMONA Guideline are targeted to those who are implementing the WFD and those developing RBMPs for particular river basins. SIMONA Guideline will be adaptable to national priorities and to the EU systems. WP6 collects the necessary information, experiences, practices and technical issues in participating countries and compiles an inventory of national protocols, methods and databases related to sediment quality monitoring in large lakes and reservoirs as a first step.

On the basis of the knowledge best-practice examples will be documented and Guide on sediment quality monitoring in large lakes and reservoirs will be developed

The final deliverables of this WP are two reports on national methods and databases and one Guidance applicable to the DRB.

Sediment quality can not be considerd without considering sediment quantity also since both quantity and quality have an effect on the status of water bodies whose protection is the main objective of the project. For this reason the two Reports which represent Project Output T4.1 have been combined into one document with 2 main chapters:

- Chapter 2: Output T4.1.1 Report on national methods and databases regarding sediment quality in large lakes and reservoirs and
- Chapter 3: Output T4.1.2 Report on national methods and databases regarding sediment Quantity in large lakes and reservoirs.

Chapter 2 which covers sediment quality in large lakes and reservoirs builds on the equivalent reports from other WP of the Simona Project as the sediment quality assessment for rivers and streams and lakes and reservoirs does not differ in terms of analysis.

INTRODUCTION

Prior to any discussion about inland sediments it is important to define what sediment is. There are several definitions of sediment which are used internationally but the most common definitions are given below.

- SedNet - defines sediment in the following manner - "*Sediment is an essential, integral and dynamic part of our river basins.*"
- The WFD AMPS defines sediment as - *"Sediment is particulate matter such as sand, silt, clay or organic matter that has been deposited on the bottom of a water body and is susceptible to being transported by water"*

Sediment plays an integral role in the cycles of both nutrients and pollutants within an aquatic environment.

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. [1]

1 EU SEDIMENT POLICY FRAMEWORK

The EU Sediment Policy Framework is summarized in Figure 1. below. It is a clear from Figure 1. that sediment is hardly mentioned in the WFD despite the fact that it is an essential, integral and dynamic part of any river basin. This deficiency however can be corrected by addressing sediment as an issue in WFD river basin management plans (RBMP). However, a scan of some draft RBMPs made clear that in some plans sediment management is not addressed at all and full integration appears to be exceptional. Important reasons for this are: diverging and difficult to merge and resolve perceptions among stakeholders of risk associated with sediment, and lacking understanding of the effects of global change on sediment quality and quantity processes and the anticipated, resulting impacts on river ecosystems Too little sediment causes beaches to erode, riverbanks to erode, results in loss of wetlands, river profile degradation etc. On the other hand too much sediment causes obstruction of river channels resulting in river filling and and flooding, reefs get smothered, turbidity is increased etc. At the same time sediment is typically seen as resource (Construction material, Sand for beaches, Wetland nourishment, Soil enrichment, Habitat and food for life, etc)

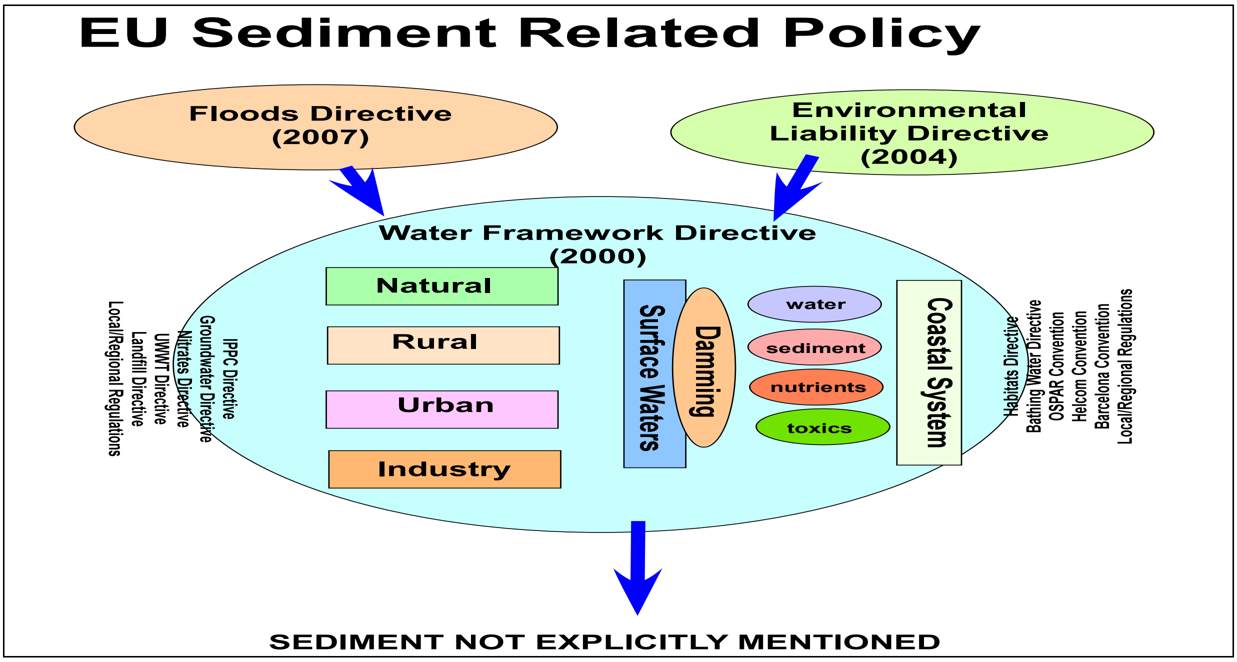

Figure 1. EU Policy Framework and Sediments (Modified from Solomons and Brils, 2004: Contaminated Sediments in European River Basins)

The Water Framework Directive WFD (Directive 2000/60/EC) aims to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwaters in Europe. It will apply to all water bodies, including rivers, estuaries, coastal waters out to a minimum of one nautical mile, and artificial water bodies such as docks and canals. The WFD provides for a new, global and integrated approach to water protection, improvement and sustainable use. It provides for a 'combined approach' of emission limit values and quality standards by setting out an overall objective of good status for all waters as well as providing for source controls. The WFD co-ordinates the application of all EU water-related legislation (e.g. Urban Waste Water Treatment, Nitrates, Integrated Pollution Prevention and Control, Seveso, Habitats Directives etc.) and provides a coherent management framework so as to meet the environmental objectives of these instruments as well as the WFD. The Directive introduces a single system of water management by river basin - the natural geographical and hydrological unit - instead of according to administrative or political boundaries.

The WFD does not adequately deal with 'sediment' and 'dredged material', although sediments are a natural and essential part of the aquatic environment and their management has to play an important role within water legislation.

The inclusion of land-water transitions zones, like wetlands, is also not yet clear. Hence there is a clear need for a more integrated approach to manage land-water interactions through specific tailor-made policy at the catchment level, including river-basin – coastal-zone interactions.

Article 16 of the WFD provides for strategies against pollution of water. Article 16(1) requires the adoption of specific measures progressively to reduce discharges, emissions and losses of priority substances, and to cease or phase out discharges, emissions and losses of priority hazardous substances. This provision can be of help to tackle existing pollution sources in European River Basins to reduce ongoing sediment contamination.

In view of the EU Sediment Policy it is clear that no clear policy framework for lake and reservoir sediment management has been established. Furthermore from information available at the time of writing this report it is also suggested that no standards are in place for sediment quantity assessment for lake and reservoir systems are available and in practice different countries use different approches.

Reservoir sedimentation is a serious consequence of soil erosion with large environmental and economical implications. On the other hand, reservoir sedimentation also provides valuable information on erosion problems and sediment transport within a drainage basin. *A reservoir can be considered as a large scale experiment, as the outlet of a giant erosion plot* (Verstraeten and Poesen, 2000).

SIMONA Project WP6 which is focussed on Large Lakes and Reservoirs has carried our literature review on different methods for the assessment of sediment yields and sediment trap efficiency of lake and reservoir cathchments seeking to establish a knowledge base for the topic which can subsequently be used for the formulation of adequate recommendations in the relevant Gudance document. Results of this literature review are presented in the remainder of this document together with examples from the Danube basin and other catchments.

It is important to note that sediment quantity for large lakes and reservoirs is not something that could easily fit into regular monitoring activities but is rather an issue that is to be considered

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through focused baseline and periodic assessment studies and the use of appropriate modelling techniques selected to provide sufficient information to answer the questions that need to be addressed within the RBMP under WFD.

It also should be noted that the SIMONA Project Partners do not contain sufficient expertise to be able to address all the topics of interest related to the subject of analysis and for this reason we rely on findings of other complementary projects such as Danube Sediment and the SedNet Project for guidance related to methods to be used in sediment sampling and sediment quantity assessments. The SIMONA Guidance document to be produced at the later phases of the project are to use the results of the mentioned projects extensivelly for the purpose of the preparation of the Guidance document.

The problem of the lake and reservoirs sediment quantity assessment is of particular interest for the purpose of estimation of the sediment trap efficiency in lakes and reservoirs and the role that the sediments traped may play in the control of the status of lake and reservoir bodies through influence on water quality and morphology of these water bodies. This knowledge is necessary in order to develop appropriate programs of meassures within RBMP within WFD aimed in acheivig good water body status/potential.

Lake/Reservoir sedimentation has been the subject of numerous studies and research in international bibliography (Walling, 1983, 1997, 1999, 2009; Verstraeten, Poesen, 2002; Syvitski et.al, 2003, 2005; Syvitski, Milliman, 2007; de Vente et.al, 2007). Many scientific papers have been published related to sediment trap efficiency in lakes and reservoirs to mention just a few (Ciaglic et.al, 1973; Ionescu, 1980; Zavati and Giurma, 1987; Apopei et.al, 1988; Ichim and Rădoane, 1986; Roşca, 1987; Roșca and Mițurcă, 1988; Pricop et.al, 1988; Roşca and Teodor, 1990; Şerban and Teodor, 1992; Scortov and Armencea, 1992; Olariu, 1992; Olariu and Gheorghe, 1999; Purnavel, 1999; Gâștescu et.al, 2003; Rădoane and Rădoane, 2004, 2005).

The first author that has paid special attention to this sediment trap efficiency was Brown (1943) who developed a model. It was then followed by others who have contributed to the knowledge of trap efficiency - TE (Churchill, 1948; Brune, 1953; Vanoni, 1977; Heinemann, 1981) and some of them even made improvements to the model (Churchill, 1948; Brune, 1953; Heinemann, 1981). Verstraeten and Poesen (2000) made a synthesis of the most used methods for calculating TE both in terms of empirical models and theoretical models.

2 OUTPUT T4.1.1 REPORT ON NATIONAL METHODS AND DATABASES REGARDING SEDIMENT QUALITY IN LARGE LAKES AND RESERVOIRS.

2.1 Introduction

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.

2.2 Current Practices in partner countries

2.2.1 Germany

In Germany the 16 federal states are responsible for water monitoring including SPM/sediments. For that reason there is no uniform monitoring at the national level of sediment quality or sediment quantity. Sediment quality is defined by the Surface Water Regulation from the 20.06.2016. Certain national guidelines, procedures, protocols, methodologies and similar are available such as the LAWA-AO -Framework concept monitoring [2] and Instructions for handling dredged material from inland waterways [3] documents.

The German Water Protection Act seeks to achieve good ecological and chemical status, establish monitoring length requirements, and detail exceptions. The Surface Waters Ordinance establishes limited target concentrations for sediment and suspended material. These targets are used to ensure that concentrations in discharges to waterways are minimized and it also allows for river-area-specific environmental quality standards. States developed requirements for sediment and suspended matter investigations based on Federal guidance. The results of these investigations can be used for the assessment of water bodies, determination of long-term trends, and the creation of an inventory of contaminated sites. These requirements are not statutory. [4]

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2.2.2 Slovakia

In Slovakia there are national laws and regulations in place which cover the fields of sediment sampling, sediment quality analysis and sediment quantity. These fields are regulated by the Guideline of the Ministry of the Environment of the Slovak Republic from 28 August 1998 No. 549/98-2 for the assessment of risks from polluted streams and reservoirs sediments, the EU WFD CIS Guidance document No. 25 on chemical monitoring of sediment and biota under the Water Framework Directive. Technical Report – 2010.3991. Luxembourg, Act No. 79/2015 Coll. on waste, Act No. 188/2003 Coll. on the application of sewage sludge and bottom sediments to soil and STN ISO 5667-12 Part 12: Guidance on sampling of bottom sediments from rivers, lakes and estuarine areas. Furthermore, there are national guidelines, procedures, protocols, methodology and similar available.

2.2.3 Serbia

In Serbia there are national laws and regulations in place which cover the fields of sediment sampling and sediment quality. These fields are covered by the Ordinance on limit values for pollutants in surface and ground waters and sediments and closing dates to reach them, („Official Gazette RS No. 50/2012.) and the Ordinance on limit values for priority and priority hazardous substances polluting surface waters and closing dates to reach them („Official Gazette RS“ No. 24/2014).

2.2.4 Slovenia

In Slovenia there are national laws and regulations in place which cover the fields of sediment sampling and sediment quality. These fields are covered by the Rules on operational monitoring of surface water status, Official Gazette of the RS, No. 91/2013 dated 5/11/2013. In addition, guidelines, procedures, protocols and methodologies are available, for example within the Program for monitoring of chemical and ecological status of water 2016-2021.

2.2.5 Bulgaria

In Bulgaria there are no national laws and regulations in place which cover the fields of sediment sampling, sediment quality or sediment quantity.

2.2.6 Montenegro

In Montenegro there are no national laws and regulations in place which cover the fields of sediment sampling, sediment quality or sediment quantity.

2.2.7 Croatia

In Croatia there are no national laws and regulations in place which cover the fields of sediment sampling, sediment quality or sediment quantity.

2.2.8 Austria

In Austria, there are currently no legally binding regulations regarding the quality of river sediments, marine sediments or soils.

2.2.9 Ukraine
No information was received at the time of writing of this report.

2.2.10 Bosnia and Herzegovina
Bosnia and Herzegovina does not have any official natioanal legislation regulating sediment quality monitoring.

2.2.11 Romania
No information was received at the time of writing of this report.

2.2.12 Hungary
No information was received at the time of writing of this report.

2.2.13 Moldova
No information was received at the time of writing of this report.

2.2.14 Republic of Srpska
No information was received at the time of writing of this report.

2.3 Sampling
2.3.1 Sampled Sediment Type
The table below shows which type of sediment is sampled in the various project partner countries.

Table1 - Sampled sediment type by country

Country	Sampled medium
Austria	Bottom sediment, suspended sediment and floodplain sediment
Bulgaria	Bottom and suspended sediment
Croatia	Bottom and floodplain
Serbia	Bottom sediment
Slovakia	Bottom sediment
Slovenia	Bottom sediment
Montenegro	No official sediment monitoring yet (Bottom sediment).
Bosnia and Hezegovina	No data available
Republic of Srpska	No data available
Ukraine	No data available
Moldova	Bottom, floodplain and suspended sediment.
Romania	Bottom sediment, dragged sediment and suspended sediment.
Hungary	No data available
Germany	Suspended sediment

From the table of above it is evident that the most commonly sampled type of sediment is bottom sediment, followed by suspended sediment whilst floodplain sediment is the least commonly sampled sediment type.

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2.4 Sampling Methods

2.4.1 Germany

No relevant data was received regarding the methodology used for sediment sample collection.

2.4.2 Slovakia

In Slovakia bottom sediment samples are collected in accordance with the requirements of STN ISO 5667-12: 2001 -Water quality – Sampling- Part 12: Guidance on sampling of bottom sediments whilst transport and handling of samples is carried out in accordance with STN ISO 5667-15.

2.4.3 Serbia

In Serbia bottom sediment samples are collected in accordance with the requirements of SRPS EN ISO 5667-12: 2001 -Water quality – Sampling- Part 12: Guidance on sampling of bottom sediments. The transport and handling of samples is carried out in accordance with SRPS EN ISO 5667 – 15: 2010; Water quality - Sampling - Part 15: Guidance on the preservation and handling of sludge and sediment samples.

2.4.4 Slovenia

In Slovenia bottom sediment samples are collected in accordance with the requirements of SIST ISO 5667 – 12:1996; Water quality - Sampling - Part 12: Guidance on sampling of bottom sediments. The transport and handling of samples is carried out in accordance with SIST ISO 5667 – 15: 2010; Water quality - Sampling - Part 15: Guidance on the preservation and handling of sludge and sediment samples.

2.4.5 Bulgaria

In Bulgaria bottom and suspended sediment samples are collected in accordance with the requirements of the following standards: БДС EN ISO 5667-13:2011 - Water quality. Sampling. Part 13: Sediment sampling guide, БДС ISO 5667-12:2017 - Water quality. Sampling. Part 12: Manual for sampling of bottom sediments from rivers, lakes and estuary areas , БДС ISO 5667-17:2012 - Water quality. Sampling. Part 17: Guidance on sampling banks and suspended material, БДС EN ISO 5667-15:2009 Water quality. Sampling. Part 15: Guidance for preparation and preservation of sediment samples.

2.4.6 Montenegro

Montenegro does not have an official sediment monitoring program, but they have some experience gained from various projects including: Geochemical reconnaissance stream sediment survey and other geochemical investigations in northeastern Montenegro in 1975 for the United Nations “Research of mineral resources in Montenegro” and Basic geochemical map of Montenegro.

2.4.7 Croatia

Sampling in Croatia is conducted in accordance with the requirements of HRN ISO 5667-12:2001 Guidance on sampling of bottom sediments.

2.4.8 Austria

Sampling of stream sediments is standardized by the Austrian norm ÖNORM G 1031.

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2.4.9 Ukraine

In Ukraine sediment samples are collected in accordance with the requirements of DSTU ISO 5667-12-2001. During ecological and geochemical studies of bottom sediments, water flow sites with oozy sediments are selected, which in most cases (if there are man-made sources of water flow contamination) correspond to the so-called "man-made" sediments (oozy fraction - <0.1 mm, most fully concentrates chemical pollution elements.

2.4.10 Bosnia and Herzegovina

Bosnia and Herzegovina does not have an official natioanal sediment quality monitoring programme and hence no information regarding the methodology used for sediment sampling in Bosnia and Herzegovina was received.

2.4.11 Romania

In Romania sediment samples are collected in accordance with the requirements of SR ISO 5667-12:2001, Calitatea apei. Prelevare. Partea 12: Ghid general pentru prelevarea sedimentelor de fund and international standards ISO 5667-12:2017 Water quality — Sampling — Part 12: Guidance on sampling of bottom sediments from rivers, lakes and estuarine areas, ISO 5667-17:2008 Water quality -- Sampling -- Part 17: Guidance on sampling of bulk suspended solids, ISO/TS 3716:2006 Hydrometry -- Functional requirements and characteristics of suspended-sediment samplers, ISO 4364:1997 Measurement of liquid flow in open channels -- Bed material sampling, ISO 4364:1997/Cor 1:2000 and ISO 9195:1992 Liquid flow measurement in open channels -- Sampling and analysis of gravel-bed material.

2.4.12 Hungary

Whilst there is no official sediment monitoring programme in Hungary yet, the standards ISO 5667-12:1995 Water quality — Sampling — Part 12: Guidance on sampling of bottom sediments from rivers, lakes and estuarine areas, MSZ 21470-1:1998, MSZ EN 14899:2006 are used as guidance for sediment sampling methods.

2.4.13 Moldova

In Moldova, ISO 5667-15 -Water quality - Sampling - Part 15: Guidance on the preservation and handling of sludge and sediment samples, IAEA-TECDOC-1360 (2003) Collection and preparation of bottom sediment samples for analysis of radionuclides andtrace elements and Water Quality Monitoring - A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes, Chapter 13 Sediment measurements, are used as guidance for sediment sample collection and handling.

2.4.14 Republic of Srpska

According to the information received, Republika Srpska does not have regulations or criteria for including/excluding parameters from monitoring programme for priority substances, which would allow more efficient way to use budget resources. Systematic investigations of priority substances concentrations in samples of biota and sediment have not been conducted.

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2.5 REVIEW OF SAMPLING METHODS

A review of the above mentioned methodology which is implemented in the project partner countries or is used as guidance for the purposes of sediment sample collection 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 more than 5cm.

2.5.1 Sampling Equipment & Procedures

2.5.1.1 Germany

In Germany sedimentation boxes and high-performance centrifuges are used for suspended particulate matter sample collection. Suspended sediment sample collection is conducted with sedimentation boxes which are exposed for at least 4 weeks, if possible 1m beneath the surface, followed by wet sieving of the sample. The samples are shipped overnight in brown glass bottles and the leftover sample is stored at -20°C.

2.5.1.2 Slovakia

In Slovakia bottom sediment samples are collected using a gravity corer sampling device or using a shovel/trowel for sample collection. No information regarding the sampling procedures carried out within the official national sediment quality monitoring program was received at the time of writing of this report.

2.5.1.3 Serbia

In Serbia bottom sediment samples are collected using a grab sampler or using a shovel/trowel for sample collection. Samples of bottom sediment are collected using a Eckman or Van Veen grab sampler. The samples are then handled and transported in accordance with the requirements of the ISO 5667-15:2013.

2.5.1.4 Slovenia

No information regarding the equipment used for sediment collection was received however seeing that at the time of writing, only marine sediments were being collected and not sediments from inland waters, it is assumed that either a grab sampler or core sampler is used for sample collection. For the chemical analysis of the sediment, a granulation fraction with a grain size below 63 µm is used. The sediment sample is sieved through sieves with a screen size of 200 µm and then 63 µm. Sieves are standardized, made of inert plastics. Water from the same surface water is used for sieving.

2.5.1.5 Bulgaria

In Bulgaria bottom sediment samples are collected using spoons from what must be shallow parts of the waterbody whilst suspended sediment samples are collected using samplier bottles.

2.5.1.6 Montenegro

Seeing as Montenegro has no official sediment monitoring program no information was received about the equipment used for sediment sample collection.

2.5.1.7 Croatia

Sampling of bottom sediment for analysis of polar parameters in Croatia is conducted using a plastic spatula/spoon made of inert plastic. When sampling for all other parameter analysis a polyethylene spoon is used.

Sampling is conducted according to the parameters intended to be analyzed. Sampling for polar parameters (pesticides, pharmaceuticals, hormones, personal care products etc.) is conducted only very low water levels and as close as possible to the point where the water flow was prior to the water level dropping. Sediment samples are taken with a clean plastic spatula/spoon (inert plastics), to the depth of maximum of 2 cm. The sample is stored in a dark glass bottle.

Sampling for all other parameters is conducted directly from the watercourse, using a polyethylene spoon. The sample is taken from the sediment surface or up to 1 cm deep. The sample is stored in a glass or plastic bottle, filled with water from the sampling location before sealing the bottle.

Sample homogenization is conducted by mixing and and for some samples by sieving.

2.5.1.8 Austria

In Austria stainless steel shovels and trowels are used for bottom sediment sampling. Whilst suspended sediment is also sampled, no information regarding the equipment used for suspended sediment sampling was received. In situ parameters (electrical conductivity, pH and redox potential) are measured during sampling in water saturated sediment using portable multiparameter measuring instruments. Every 50^{th} sample is collected in duplicate for purposes of quality control. The calibration of instruments is carried out prior to every sampling campaign.

2.5.1.9 Ukraine

In Ukraine sediment samples are collected using plastic scoops or a stainless steel blade. When the thickness of sediment deposits is between 0.3 - 3.0 m a Giller peat drill is used.

2.5.1.10 Bosnia and Herzegovina

Bosnia and Herzegovina does not have an official natioanal sediment quality monitoring programme and hence no information regarding the equipment used for sediment collection was received at the time of writing of this report.

2.5.1.11 Romania

For the purposes of suspended sediment sampling a Rapid collector Nansen bottle (cylinders with flaps for sediments) is used. Sampling of bottom sediments is done with the aid of a GRAIFER or CAROTIER whilst floodplains (dry sampling) are sampled with an ordinary shovel.

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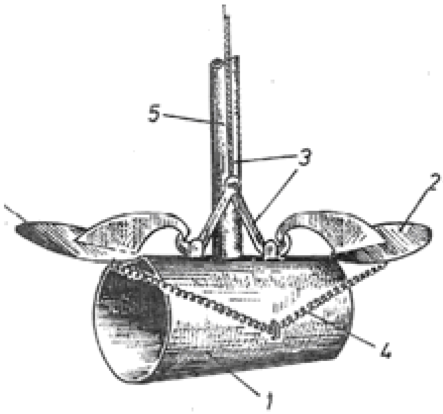
The cylinder (1) is inserted at the point of collection with the flaps (2) raised and reinforced by a simple arming-tripping system (3). By the trigger, the flaps close suddenly, pulled by the springs (4). The appliance is placed at the sampling point using a stem (5).



Picture 1. Rapid collector Nansen bottle

2.5.1.12 Hungary

Hungary has no official sediment monitoring program at the moment and therefor was unable to provide information about the equipment used for sediment sampling.

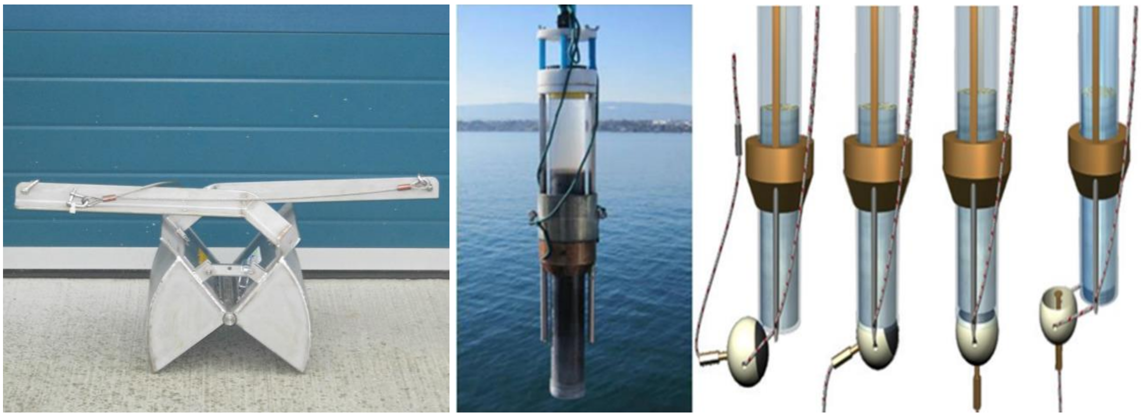
2.5.1.13 Moldova

In Moldova scoops or trowels are used for soft surficial sediment and soil samples (local producers or homemade). Scoops and trowels, which are used in soil sampling, can be used for surface sediments around shoreline for shallow and slow-moving waters. The Ekman dredge is used for soft sediments on deeper water sites. Tube samplers are used at depths of 10 – 30 cm of soft sediment or soil samples (homemade). Auger samplers are used to take deeper sediment or soil samples (Soil sampling kit Burkle 5350-1005, Germany). The water depth should to be near 1,0 m for the sediment sampling by usual auger samplers. The split-spoon sampler is used for hard sediment or soil profile. It may be used in conjunction with drilling rigs for obtaining deep core soil profiles.

2.6 Review of sampling equipment and procedures used for lakes and reservoirs

A review of the sampling equipment used in the various project partner countries shows that for the collection of bottom sediments most often spoons/trowels and shovels are used although some countries do use Eckman or Van Veen grab samplers as well as gravity corers.

For the purposes of suspended sediment sampling sedimentation boxes or sampling bottles are used most often. Below are pictures of the most commonly used sampling devices.



source: *www.uwitec.at*

Picture 2. Van Veen grab sampler and Uwitec gravity core sampler

source: *www.hyquestsolutions.com*

Picture 3. Suspended sediment sampling devices

2.7 Sampling Network and Frequency

2.7.1 Germany

In Germany the sampling locations are selected in accordance with the WFD Surveillance monitoring sites which includes 9 monitoring locations. These sampling locations are Danube river quality monitoring stations and no specific information was received about whether sediment quality is monitored at all of these locations and whether sediment quality is currently being monitored at any reservoirs. In Germany the 16 federal states are responsible for water monitoring including SPM/sediments. For that reason there is no uniform monitoring for sediments but samples are collected mostly 4 times a year in accordance with the requirements of the WFD.

2.7.2 Slovakia

In Slovakia sediment quality is monitored at 23 monitoring stations on reservoirs on 23 different waterbodies. The current frequency of sediment quality monitoring is once a year.

2.7.3 Serbia

Sediment quality is monitored on 3 catchments, the Danube, Sava and Morava catchments, on 51, 18 and 66 monitoring profiles on rivers respectively. Also, sediment quality is monitored on 3 reservoirs in the Danube basin, 4 reservoirs in the Sava basin and 10 reservoirs in the Morava basin at 5, 12 and 24 profiles respectively.

2.7.4 Slovenia

In Slovenia sediment quality is currently monitored at 6 monitoring locations on waterbody (the sea). Sediment monitoring is implemented every three years. According to the information received there are no sediment quality monitoring stations on inland waters in Slovenia at the moment.

2.7.5 Bulgaria

Sediment quality in Bulgaria is currently monitored on a total 37 stations on 37 river water bodies and 2 stations on 2 reservoir water bodies. The set of 37 river stations is split equally into 3 subgroups of stations, and each station has to be sampled once per year every 3 years. The two dam stations have to be sampled once per year from one station.

2.7.6 Montenegro

Montenegro currently does not have a national sediment quality monitoring program and no information regarding sediment quality monitoring was received at the time of writing of this report.

2.7.7 Croatia

In Croatia sediment quality is currently monitored at 17 monitoring stations on 17 different waterbodies. According to the information received the current frequency of sediment sampling for the purpose of sediment quality analysis is once per year. No information was received regarding the monitoring of sediment quality in reservoirs at the time of writing of this report.

2.7.8 Austria

No information about the number on sediment quality monitoring stations was received by the time of writing of this report. In a previous questionnaire 17 Danube river monitoring stations were listed but it was not specified whether sediment sampling for the purposes of sediment quality analysis was being conducted at each of those stations, as a matter of fact it was noted that recent information on sediment quality was available from only one of those 17 monitoring stations.

2.7.9 Ukraine

No information about the number on sediment quality monitoring stations was received by the time of writing of this report. In a previous questionnaire 5 Danube river monitoring stations were listed but it was not specified whether sediment sampling for the purposes of sediment quality analysis was being conducted at each of those stations.

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2.7.10 Bosnia and Herzegovina

Whilst a extensive list of surface water monitoring stations in the Danube river basin was received no information was received regarding sediment quality monitoring locations.

2.7.11 Romania

Whilst a extensive list of surface water monitoring stations in the Danube river basin was received no information was received regarding sediment quality monitoring locations.

2.7.12 Hungary

Whilst a extensive list of surface water monitoring stations in the Danube river basin was received no information was received regarding sediment quality monitoring locations.

2.7.13 Moldova

Whilst a extensive list of surface water monitoring stations in the Danube river basin was received no information was received regarding sediment quality monitoring locations.

2.8 SEDIMENT QUALITY ANALYSIS AND ASSESMENT

A complete and all encompassing approach to sediment qaulity assesment and it's influence on an ecosystem requires the assesment of at least five components: the physico-chemical characteristics of the sediment, the ecotoxicity of the sediment, bioaccumulation data, the composition of benthic organisms in the ecosystem and the sediment stability.

Upon review of the received answers to questionnaires and a review of existing literature it is evident that each country has a different approach to sediment quality assesment. Whilst Serbia, Slovakia, Germany, Slovenia and Hungary do have legislation in place regulating the quality of sediment in inland waters, Croatia, Montenegro, BiH, and Bulgaria do not, according to the information received from the distributed questionnaire. Although Germany does have sediment monitoring programs and legislation regulating sediment quality, the monitoring programmes differ between states and in some cases are not coordinated efficiently enough which makes a comparison of results and trends more difficult. No information about the methodology used for sediment quality assessment was received from Austria, Ukraine, Moldova or Romania by the time of writing of this report. Furthermore, whilst legislation does exist in some countries, there is a lack of uniformity of the parameters analyzed as well as the frequency of analysis. According to the information received, the bioavailable fraction of contaminants is analyzed only in Slovenia and Slovakia whilst in Serbia and Germany, the bioavailable fraction is not analyzed.

For sediment management in freshwater areas, it is difficult to form a comprehensive picture of existing European regulations or guidelines, because information on sub-basin management is hard to obtain. [5]

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2.9 INTERNATIONAL BEST PRACTICE

2.9.1 Monitoring programme formation

The Water Framework Directive (WFD) introduces a single water management system within river basins - the natural geographical and hydrological entity - instead of within administrative or political boundaries. Using management principles within a river basin provides a comprehensive and coordinated transnational approach to achieving a set of environmental goals. It requires the establishment of and updating of river basin management plans every six years, and any measures undertaken must be coordinated for the entire river basin. To provide insight into ecological processes and connections between human activities and their impact on living organisms and ecosystems such as river basins, the European Environment Agency (EEA) uses the "driving factors-pressures-condition-influences-responses / reactions" framework (drivers - pressures - state - impact - response, DPSIR ".

Seeing that few countries within the Danube river basin have national legislation regulating sediment sampling and quality/quantity analysis it is neccessary to provide examples of best practices from those countries which do have legislation regulating these fields. One such country is Serbia where national sediment quality monitoring in line with the requirements of the WFD has been taking place since 2012.

Guidance Document No 25: Guidance on chemical monitoring of sediment and biota under the Water Framework Directive gives us a list of substances that are suggested by Directive 2008/105/EC for sediment and biota trend monitoring. These supstances are highlited in the table below. The values of the Log K_{OW} are taken from the Chemical Monitoring Guidance n.19. The values of BCF are taken from the datasheets of the priority substances in the public section of the CIRCA forum.

Table 2. - Monitoring matrices for the priority substances and certain other pollutants listed by the EQS Directive
P = preferred matrix, O = optional matrix., N = not recommended, n.a. = not applicable

Priority substance	BCF	Log K_{ow}	Water	Sediment/SPM	Biota
Alachlor	50	3	P	O	N
Anthracene	**162-1440**	**4.5**	**O**	**O**	**O**
Atrazine	7,7-12	2.5	P	N	N
Benzene	13	2.1	P	N	N
Brominated diphenyl ethers a	**14350-1363000**	**6.6**	**N**	**P**	**P**
Cadmium and its compunds		**n.a.**	**n.a.**	**n.a.**	**n.a.**
C10-13-chloroalkanes	**1173-40900**	**4.4-8.7**	**N**	**P**	**P**
Chlorfenvinphos	27-460	3.8	O	O	O
Chlorpyrifos (-ethyl, -methyl)	1374	4.9	O	O	O
1,2-Dichloroethane	2-<10	1.5	P	N	N
Dichloromethane	6,4-40	1.3	P	N	N
Di(2-ethylhexyl)phthalate (DEHP)	**737-2700**	**7.5**	**N**	**O**	**O**
Diuron	2	2.7	P	N	N

Priority substance	BCF	Log K_{ow}	Water	Sediment/SPM	Biota
Endosulfan	10-11583	3.8	O	O	O
Fluoranthene	**1700-10000**	**5.2**	**N**	**P**	**P**
Hexachlorobenzene	**2040-230000**	**5.7**	**N**	**P**	**P**
Hexachlorobutadiene	**1,4-29000**	**4.9**	**O**	**O**	**P**
Hexachlorocyclohexane [b]	**220-1300**	**3.7-4.1**	**O**	**O**	**P**
Isoproturon	2,6-3,6	2.5	P	N	N
Lead and its compounds		**n.a.**	**n.a.**	**n.a.**	**n.a.**
Mercury and compounds [c]		**n.a.**	**N**	**O**	**P**
Naphthalene	2,3-1158	3.3	O	O	O
Nickel		n.a.	n.a.	n.a.	n.a.
Nonylphenols [d]	1280-3000	5.5	P	P	O
Octylphenol [d]	471-6000	5.3	P	P	O
Pentachlorobenzene	**1100-260000**	**5.2**	**N**	**P**	**O**
Pentachlorophenol	34-3820	5	O	O	O
Polyaromatic Hydrocarbons [e]	**9-22000**	**5.8-6.7**	**N**	**P**	**P**
Simazine	1	2.2	P	N	N
Tributyltin compounds	**500-52000**	**3.1-4.1**	**O**	**O**	**P**
Trichlorobenzenes	120-3200	4.0-4.5	O	O	O
Trichloromethane	1,4-13	2	P	N	N
Trifluralin	2360-5674	5.3	N	P	O
DDT (including DDE, DDD)		6.0-6.9	N	P	P
Aldrin		6	N	P	P
Endrin		5.6	N	P	P
Isodrin		6.7	N	P	P
Dieldrin		6.2	N	P	P
Tetrachloroethylene		3.4	O	O	N
Tetrachloromethane		2.8	P	N	N
Trichloroethylene		2.4	P	N	N

[a] *Including Bis(pentabromophenyl)ether, octabromo derivate and pentabromo derivate*
[b] *HCH (all isomers) - BCF (lindane)*
[c] *methylmercury*
[d] *Nonyl- and Octylphenols do not follow the classical K_{ow} partition, because they can establish hydrogen bonds by the phenolic hydroxyl.*
[e] *Including Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(g,h,i)perylene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)-pyrene. For these compounds the metabolisation in higher trophic levels should be taken into account.*

Firstly, it is necessary to define the different waterbodies and their categories at national level and to establish regulations regarding the EQS of priority and priority hazardous supstances along with a few other parameters of sediment quality which are of vital importance for the status of surface waters in large lakes and reservoirs.

Once the different waterbody categories have been determined it is neccessary to identify representative sampling locations.

The percentage of waterbodies covered by monitoring and the spatial coverage of waterbodies monitored is conditioned by financial resources as well as human resources. During the selection of waterbodies which are to be monitored special attentian and priority should be given to those waterbodies which experience the most intense pressures from anthropogenic activities (population number, industrial production, quantity of sewage system wastewater discharged, significant diffuse pollution, transboundary leaks etc.).

The monitoring programmes must be tailored to the actual operational capacity for fieldwork and analysis. The list of parameters analyzed should be compliant to international standards so as to allow for the inter-comparison of the results.

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2.9.2 Sediment quality criteria

Over the past decades, more specifically since the 1980s, several criteria for assessing sediment quality have been developed in an effort to define boundary values that will help with the management of sediments. Setting EQS for sediment quality allows us to grade sediment quality relative to a desirable or benchmark standard. The chemical contamination of sediment is determined by measuring the concentrations of individual elements or compounds in bulk sediment and comparing them to the reference values. Generally, analytical chemical methods are standard procedure so the determination of concentrations of pollutants or compounds is fairly simple.

All international criteria used so far can be systematized into two groups which emerged from two different approaches. The first, which relies on sediment chemistry and which requires the comparison of measured concentrations with the EQS and benchmarks so that a quality assessment is obtained, and the second, where sediment contamination is compared with the adverse effects which it causes on the living organisms. An example of the criteria in the first approach are the regulations applicable in the Republic of Serbia, which has established limit values for pollutants in sediment. Another example are the ICPDR recommendations. Serbian regulation defines a target value, maximum allowable concentration (MAC) and remediation value for concentrations of individual pollutants or a group of pollutants. The target value is the limit value for a pollutant concentration below which the negative impacts on the environment are negligible and it represents a long-term goal for sediment quality, while maximum permissible concentration (MAC) of pollutants are the values above which negative environmental impacts are likely.

The second approach of defining criteria for sediment quality generally sets two levels of tolerance to polluting supstances in sediment, the first below which negative effects on macroinvertabrates are rarely observed and a second level above which negative effects on macroinvertabrates are commonly observed.

2.9.3 Sediment quality assessment

The interpretation of the results of laboratory analysis of sediment quality can be conducted in a number of different ways. With the aim of sediment quality assesment, the measured concentrations pollutants should be compared to the MAC values or EQS standards for sediments as well as the „Quality targets“ defined by the ICPDR. The definition of sediment quality in this manner requires the correction of the MAC values for metal concentrations depending on the physical characteristics of the sediment, that is, the percentage of clay and percentage of organic matter present. This in turn means that granulometric analysis of the sediment samples is required for adequate sediment quality assesment.

When assessing the degree of metal contamination of the sediment at a basin level, we can use contamination indicators, enrichment factors, geoaccumulation indices, contamination factors and degrees of contamination to identify possible factors or sources of pollution.

In addition to the above mentioned methods of analysis, the interpretation of monitoring results of sediment quality with the aid of statistical methods for trend analysis should also be applied. For example the Mann-Kendall test can be used for trend analysis, multivariate statistical analysis or cluster analysis for simillarity can be used by applying the Ward method.

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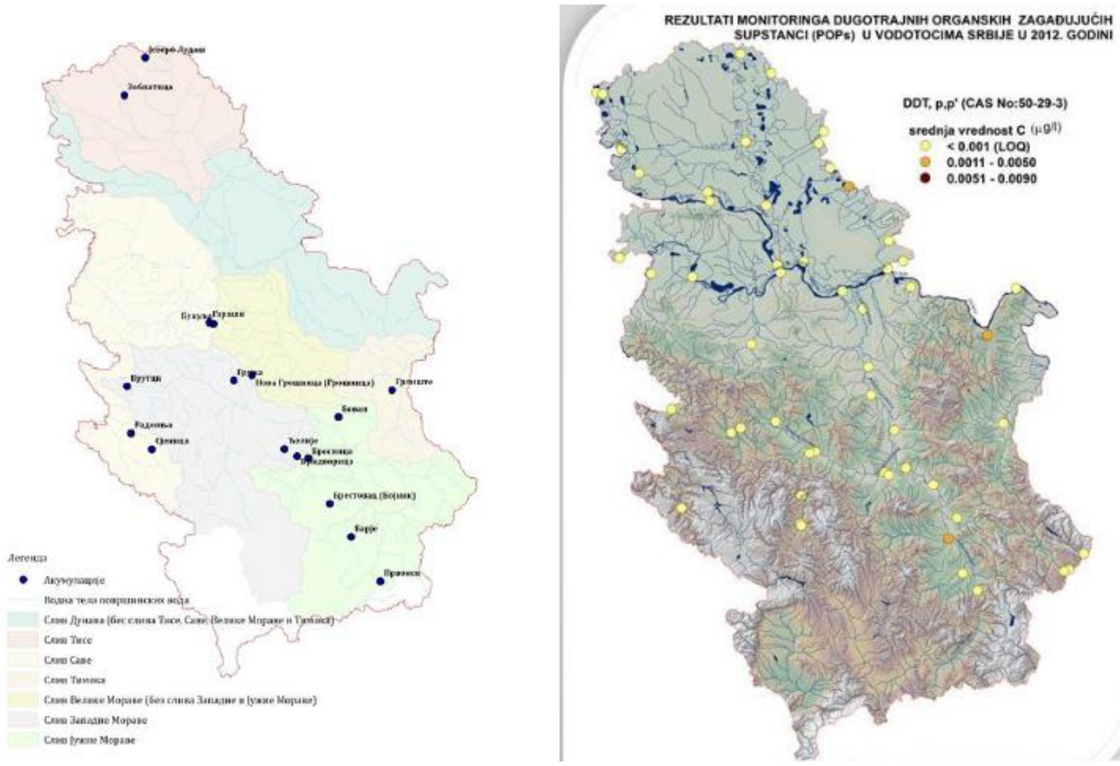
Seeing that it might not be possible to obtain more than one sample at every given monitoring profile within the 6 year period that the river basin management plans specify, it is important to specify that for single samples, measured concentrations should be used whilst for locations where more than one sample was collected during the monitoring period, a mean value should be used.

It was mentioned above that when assesing the quality of sediment in large lakes and reservoirs, in addition to the priority and priority hazardous substances taht we are dealing with, it is crucial that total phosphorus (TP) and total nitrogen (TN) concentrations are also monitored. This is because of their potential for rerelease into the water column, their influence on the potential for eutrophication and the internal load of the reservoir.

2.9.4 Reporting

In addition to tables with the results of the laboratory analyses, graphical representations of the results should also be given.



Picture 1. - The locations of sediment quality monitoring in lakes in reservoirs in the Republic of Serbia (2012-2017) and the results of persistant organic pollutant (POPs) monitoring in surface waters in Serbia during 2012.

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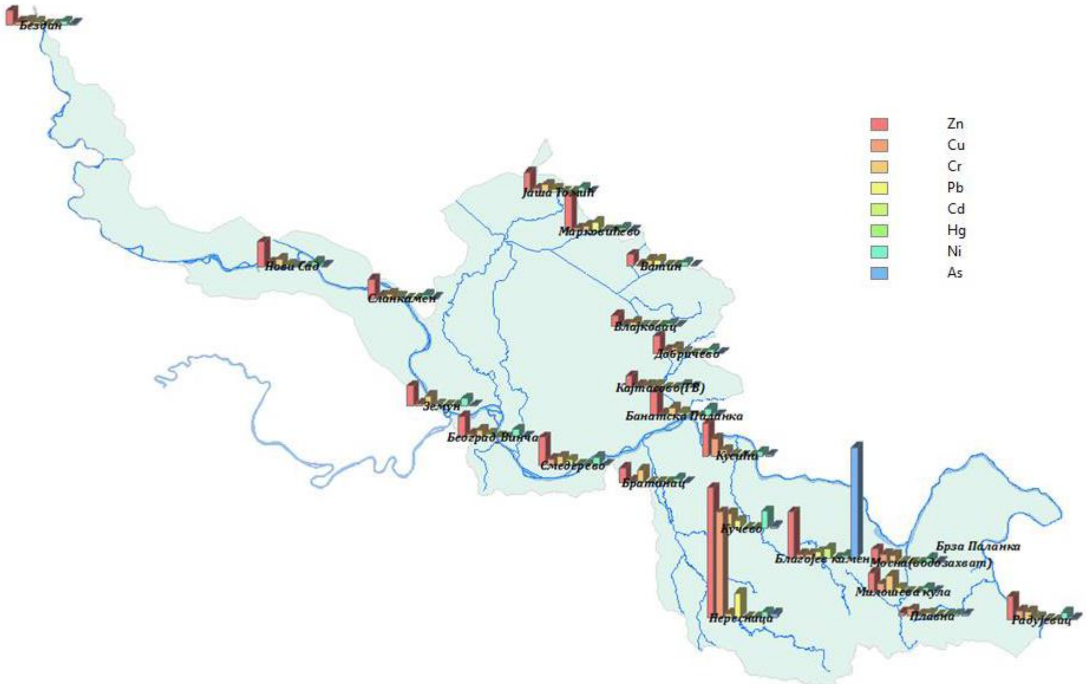

Picture 2. - The spatial distribution of monitoring profiles in the river basin along with histograms of metal content at the various monitoring stations.

Picture 3. - The concentration of polycyclic aromatic hydrocarbons in surface waters in the Republic of Serbia

2.10 Gaps Identified

Whilst the WFD does give relevant EQS values for water, the same does not apply to sediments. However, Article 3 of the Directive 2008/105/EC does state that Member states should have the possibility to establish EQS for sediment and/or biota at national level. This has not been the case though as many member states still do not have national legislation regulating the concentration of polluting supstances in sediment in inland waters.

Many of the potentially toxic components in the sediments of European waters are not priority pollutants yet they need to be monitored.

At the moment there is no simple methodology which can follow and estimate all the influences of polluted sediments on different organisms and ecosystems at the same time. This is partially a result of the fact that different organisms have different tolerances to different pollutants, not all pollutants which are present are analyzed, the bioavailability of analyzed polutants is not always analyzed and pollutants can appear in different forms which can affect their toxicity.

2.11 Data availability

In countries where a national monitoring program is in place, the amount of data collected varies as does it's availability. In Serbia, for example, some of the sediment quality data is available as open source data whilst Slovakia and Slovenia apply an open source data policy regarding sediment quality data. It is however important to note that whilst Slovenia does have national legislation regulating sediment quality in inland waters, currently sediment quality is monitored only at sea so the amount of available data about inland sediment quality is not known.

2.12 Recommendations

Regarding sampling equipment it is important to note that for the purposes of sediment quality monitoring, the recommendations of the ISO standards which most countries have either adopted or are using as guidance are that composite samples should be collected. Furthermore, these standards specify that grab samplers are not always adequate for the collection of composite samples due to their varying penetration depth with each lowering of the sampler. This leads us to the notion that for the purposes of bottom sediment sampling in deeper waters core samplers should be used and the actual portion of the entire sample collected which is used for analysis should be the top layer which represents newly deposited sediment.

If we are to compare and adequately monitor changes in sediment quality and the effects of these changes, it is important to develop a set of defined quality criteria with limit values/ranges for specific parameters.

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In a number of countries in Europe and around the world, lists with such SQCs for contaminant concentrations are in use, often in the form of lower and upper action values [6]. These values were not developed in a standardised way but on the basis of the respective scientific considerations and national objectives. Therefore, they vary considerably from country to country and are far from offering a firm basis for decision making. For this reason, scientists warn against a simplified application of these action values as the only basis for "pass-fail" decisions in dredged material management [7].

Consequently it follows that standardisation of sampling and analysis beyond regional borders is a prerequisite for successful sediment monitoring. The same holds true for the development of standardised action values as a joint basis for the subsequent quality assessment. [5].

The selection of analytes, standards and approaches should be driven by site conditions, regulatory context and assessment objectives.

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3 OUTPUT T4.1.2 REPORT ON NATIONAL METHODS AND DATABASES REGARDING SEDIMENT QUANTITY IN LARGE LAKES AND RESERVOIRS.

3.1 INTRODUCTION

In view of the EU Sediment Policy it is clear that no clear policy framework for lake and reservoir sediment management has been established. Furthermore from information available at the time of writing this report it is also suggested that no standards are in place for sediment quantity assessment for lake and reservoir systems are available and in practice different countries use different approches.

Reservoir sedimentation is a serious consequence of soil erosion with large environmental and economical implications. On the other hand, reservoir sedimentation also provides valuable information on erosion problems and sediment transport within a drainage basin. *A reservoir can be considered as a large scale experiment, as the outlet of a giant erosion plot* (Verstraeten and Poesen, 2000).

SIMONA Project WP6 which is focussed on Large Lakes and Reservoirs has carried our literature review on different methods for the assessment of sediment yields and sediment trap efficiency of lake and reservoir cathchments seeking to establish a knowledge base for the topic which can subsequently be used for the formulation of adequate recommendations in the relevant Gudance document. Results of this literature review are presented in the remainder of this document together with examples from the Danube basin and other catchments.

It is important to note that sediment quantity for large lakes and reservoirs is not something that could easily fit into regular monitoring activities but is rather an issue that is to be considered through focused baseline and periodic assessment studies and the use of appropriate modelling techniques selected to provide sufficient information to answer the questions that need to be addressed within the RBMP under WFD.

It also should be noted that the SIMONA Project Partners do not contain sufficient expertise to be able to address all the topics of interest related to the subject of analysis and for this reason we rely on findings of other complementary projects such as Danube Sediment and the SedNet Project for guidance related to methods to be used in sediment sampling and sediment quantity assessments. The SIMONA Guidance document to be produced at the later phases of the project are to use the results of the mentioned projects extensivelly for the purpose of the preparation of the Guidance document.

The problem of the lake and reservoirs sediment quantity assessment is of particular interest for the purpose of estimation of the sediment trap efficiency in lakes and reservoirs and the role that the sediments traped may play in the control of the status of lake and reservoir bodies through influence on water quality and morphology of these water bodies. This knowledge is necessary in order to develop appropriate programs of meassures within RBMP within WFD aimed in acheivig good water body status/potential.

Lake/Reservoir sedimentation has been the subject of numerous studies and research in international bibliography (Walling, 1983, 1997, 1999, 2009; Verstraeten, Poesen, 2002; Syvitski et.al, 2003, 2005; Syvitski, Milliman, 2007; de Vente et.al, 2007). Many scientific papers have been published related to sediment trap efficiency in lakes and reservoirs to mention just a few (Ciaglic et.al, 1973; Ionescu, 1980; Zavati and Giurma, 1987; Apopei et.al, 1988; Ichim and Rădoane, 1986; Roşca, 1987; Roşca and Mițurcă, 1988; Pricop et.al, 1988; Roşca and Teodor, 1990; Şerban and Teodor, 1992; Scortov and Armencea, 1992; Olariu, 1992; Olariu and Gheorghe, 1999; Purnavel, 1999; Gâștescu et.al, 2003; Rădoane and Rădoane, 2004, 2005).

The first author that has paid special attention to this sediment trap efficiency was Brown (1943) who developed a model. It was then followed by others who have contributed to the knowledge of trap efficiency - TE (Churchill, 1948; Brune, 1953; Vanoni, 1977; Heinemann, 1981) and some of them even made improvements to the model (Churchill, 1948; Brune, 1953; Heinemann, 1981). Verstraeten and Poesen (2000) made a synthesis of the most used methods for calculating TE both in terms of empirical models and theoretical models.

Sediment trap efficiency (TE) is the proportion of the incoming sediment that is deposited, or trapped, in a reservoir or pond. In situation when sediment data downstream the reservoir is available this parameter is effective in calculating the sediment yield of the upstream catchment of the reservoir. The TE of reservoirs and ponds is dependent on several parameters (an overview of these processes taking places in a reservoir is given by Heinemann, 1981, cited by Verstraeten and Poesen, 2000). Since TE is dependent on the amount of sediment deposited, parameters controlling the sedimentation process are very important.

Trap efficiency of the reservoirs is an important parameter in the analysis of sedimentation in the reservoirs and thus the transport of sediments in a river basin (Verstraeten et. al, 2006; Vanmaercke et.al, 2011). Although the complexity of this parameter determined by many controlling factors control as numerous authors mentioned (Brown, 1943; Brune, 1953; Heinemann, 1981; Verstraeten and Poesen, 2000) complicate this parameter calculation and theoretical models are more accurate in calculating TE, both Brown and Brune have adapted an empirical model that facilitates more computing TE (equations 1 and 2). These two formulas (equation 1 and 2) were used also by us for TE calculation in this paper.

Verstraeten and Poesen (2000) make a briefly overview of the high number of the factors that influence the trap efficiency of pond and reservoirs. Starting from the fractions of incoming sediments they relate this parameter with the settling velocity of sediment particles and with the retention time of runoff and sediment particles. They also marked the importance of the incoming sediment characteristics (particle size distribution), inflow characteristics (runoff volume, peak discharge, base flow) and pond characteristics (pond typology, surface area, shape, outlet dimension, outlet type, location of the outlet, initial storage volume).

Taking in consideration the many parameters that influences the sedimentation process and, hence the TE of reservoirs and ponds, it is very difficult to predict TE in a simple manner. The most accurate predictions will be those based on theoretical relations that incorporate all the influencing factors. However this requires not only the use of complex models but also the availability of a great deal of input data. Simple models relating TE to a single reservoir parameter are, on the other hand, easy to implement but are far less accurate (Verstraeten and Poesen, 2000).

Different empirical relations have been developed to estimate the trap efficiency. Usually the relation proposed by Brown (eq. 1)(Brown, 1943) and Brune (eq. 2)(Brune, 1953) are applied, as these relations are suited for large reservoirs, and is relatively easy to apply.

Brown relation (1943)

$$TE = 100 * \{1 - 1 / [1+D*(C/A)]\}$$

In this relation TE, stands for trap efficiency (%), C for the capacity of the reservoir (m3) and A for the drainage are of the basin (km2). D is a constant between 0.046 and 1, with a mean value of 0.1 and depends on the reservoir type. Brown (1943) suggest that values for D are close to 1 (i.e. high TE) for reservoirs in regions with smaller and more variable runoff and for those that hold back and store flood flows.

Brune (1953) replaced the C/A (capacity/catchment area) ratio with C/I (capacity/inflow) ratio because he stated that in the catchments with the same area the hydrological characteristics might be different.

Brune relation (1953)

$$E = 100 * \{1 - 1 / [1+D*(C/I)]\}$$

Even if the second relation is more accurate we used both in our study because for some reservoirs we didn't have inflow values.

Verstraeten and Poesen (2000), citing Heinemann (1981) indicate that TE of reservoirs is dependent on several parameters. Since TE is dependent on the amount of sediment deposited, parameters controlling the sedimentation process are very important. Therefore, the particle-size distribution of the incoming sediments controls TE in relation to retention time (the average time the incoming runoff remains in the reservoir). Coarser material will have a higher settling velocity, and less time is required for it to be deposited. Very fine material, on the other hand, will need long retention times to deposit. The particle-size distribution of the incoming sediment is dependent on the soils in the catchment that are being eroded and on the sediment delivery processes. The retention time of a reservoir is related to the characteristics of the inflow hydrograph and the geometric characteristics of the reservoirs or pond, including storage capacity, shape and outlet topography. The location of the principal spillway can also control the retention time. If located at the bottom, the water will flow out directly while, if it is located at the top of the embankment, the runoff water will, first, have the opportunity to mix with the water already present in the reservoir. The size of the spillway (which regulates the discharge) must be taken into account. Permanent poop storage (in contrast to completely dry reservoirs) also controls the average retention time (Verstraeten and Poesen, 2000).

Box 1: Siret River Catchment Example:

The Siret River is the biggest river in Romania. It springs from the Paleogene flysch of the Wooded Carpathians (in Ukraine) at an altitude of approximately 1238 m (Ujvari, 1972) and drains, within its catchment the central-eastern part of the Eastern Carpathians and a part of the South-Eastern Carpathians, the Moldavian Sub-Carpathians and the northern part of South- Eastern Sub-Carpathians, the Moldavian Plateau and the Lower Siret Plain. The catchment area of the Siret River covers an area of 44 871 km2 from which 42 890 km2 in Romania. The total length of this river in Romania is 548 km, while there are another 110 km from its springs to the point it enters Romania.

The main relief lines decrease in height from west to east and from north to south. The morphographical and morphometrical features depend on lithology. This way in the Carpathians area, from west to east, there aligns the main morphological units (Olariu et.al, 2009): -Volcanic mountains, with massive forms and hard rocks. In this area the runoff is high (15 – 20 l/s/km2) and the sediment yield is low (0,5 – 0,7 t/ha/yr).

Crystalline mountains, also with massive forms, and very high, because of the hard rocks, and with limestone intrusion. The runoff is still high (12 – 16 l/s/km2) while the sediment yield is low (0,8 – 1,2 t/ha/yr). -Flysch Mountains are characterized by a great lithological variability, because of the overthrust layers. Here the runoff has values between 8-14 l/s/km2, and the sediment yield become high (20 – 25 t/ha/yr in the South-Eastern Carpathians).

The Sub-Carpathians are located on the eastern part of the Carpathians, characterized by the presence of some depressions bounded by anticline hills. In this area the runoff is between 8 – 10 l/s/km2, and the sediment yield between 5 – 15 t/ha/an, but there are a lot of variations. The main relief units from the platform region are the Moldavian Plateau, the Lower Siret Plain and the north-east part of the Baragan Plain. In the plateau, the runoff has values between 2 – 6 l/s/km2, and the sediment yield between, 2 –5 t/ha/yr. In the plain area the values of the runoff and the sediment yield are much smaller.

During 1960-2001 in the Siret Basin were constructed 35 dams with a height of at least 10 m behind which were made reservoirs for various purposes which include water supply to municipalities, irrigation, electricity or fish and leisure (Rădoane and Rădoane, 2004, 2005). Siret Basin is characterized by the highest use of hydrological potential in Romania, resulted in the number of reservoirs designed and put into operation. Among the other rivers and river basins in Romania, only Olt River poses a much bigger number of reservoirs than Siret (Dăscălescu, 2000). Regarding capacity of the reservoirs in the Siret Basin there is a dominance of small reservoirs with capacities below 20 million m3. Only one reservoir has capacity over 200 million m3 - Izvorul Muntelui on Bistrita River.

Capacity and operating mode lakes are important factors controlling the degree of retention of silt from the source area. As we mentioned above sedimentation within reservoirs is a problem as it decrease the storage capacity and, hence, makes the structure less efficient. For small reservoirs, sedimentation can become a severe problem as the rate of siltation is generally much higher in comparison to large dams (Rădoane and Rădoane, 2005).

Table 1. Total reservoir capacity in catchments of main tributaries of the Siret River (2012)

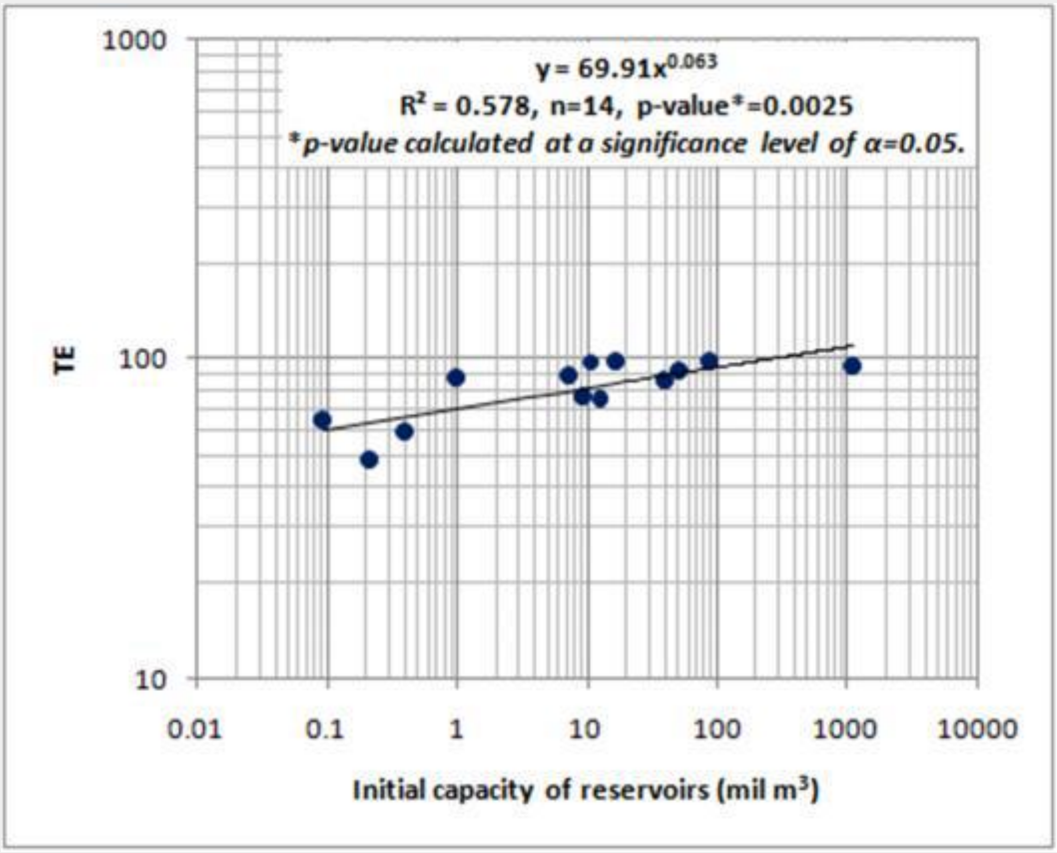
River	Reservoir storage (mil m^3)
SIRET	442
SUCEAVA	7.7
SOMUZU MARE	25.0
SOMUZU MIC	3.0
MOLDOVA	1.0
VALEA NEAGRA	5.9
BISTRITA	1280
TROTUS	104
PUTNA	0
BARLAD	95
BUZAU	170
TOTAL	**2134**

Table 2. Sediment Trap Efficiency TE and other characteristics of reservoirs in the Siret Basin

River	Reservoir	C –initial (mil m^3)	C-last measured (mil m^3)	Year of last measure	SV (t/yr)	Source	TE (%)	Method TE
Siret	ROGOJESTI	38.4	34.9	2004	220000	Siret Water Adm.	85	Brune
Siret	BUCECEA	8.73	4.97	2009	208889	Siret Water Adm.	-	-
Siret	GALBENI	40	16	1988	2000000	Siret Water Adm.	86	Brune
Horodnic	HORODNIC	1	0.55	2011	15000	Siret Water Adm.	87	Brown
Solca	SOLCA	0.096	0.04	2002	3136	Siret Water Adm.	64	Brown
Somuzul Mare	SOMUZ II MOARA	7.4	6	2011	41000	Siret Water Adm.	88	Brown
Bistrita	IZV MUNTELUI	1123	1100	1998	570000	Siret Water Adm.	94	Brune
Bistrita	PANGARATI	6.7	3.5	1987	139130	N.Radoane, 2002	-	-
Bistrita	VADURELE	5.6	4.96	1982	40000	N.Radoane, 2002	-	-
Bistrita	B. DOAMNEI	10	7.28	1990	340000	N.Radoane, 2002	-	-
Bistrita	RACOVA	8.6	4.27	1983	206190	Olariu, 1992	-	-
Bistrita	GARLENI	5.1	3.81	1982	75882	Olariu, 1992	-	-
Bistrita	LILIECI	7.4	6.61	1983	46471	Olariu, 1992	-	-
Bistrita	BACAU	7.4	6.04	1986	68000	Olariu, 1992	-	-
Uz	POIANA UZULUI	90	85.6	2009	191304	Olariu, 1992	97	Brune
Tazlau	BELCI	12.5	4.5	1991	350000	Olariu, 1992	74	Brune
Barlad	PUSCASI	17.2	6.65	1998	422000	Purnavel, 1999	97	Brown
Barlad	ANTOHESTI	0.22	0.13	1995	8182	Purnavel, 1999	48	Brown
Barlad	GAICEANA	0.41	0.24	1995	15455	Purnavel, 1999	59	Brown
Barlad	CUIBUL VULTURILOR	9.5	6.4	1992	221429	Purnavel, 1999	76	Brown
Barlad	RAPA ALBASTRA	10.6	8.5	1993	150000	Purnavel, 1999	98	Brown
Barlad	SOLESTI	52.7	52.1	1985	54545	Purnavel, 1999	91	Brown

TE was calculated as mentioned above in two ways (Brown method, Brune method). Values of this parameter are between 42-98%. Wide spread of ratios can be attributed to high number of factors that influence this parameter (Table 2).

The correlation between initial capacity of reservoirs considered (m3, n = 14) and trap efficiency (TE %) has a coefficient of determination of approximately 0.600, which indicates that the capacity of the reservoirs explains almost 60% of the variations of TE. In reservoirs with higher capacity the values approach to 100% while in small reservoirs, the value of TE is decreasing (Brown, 1943; Brune, 1953).



Picture 4. - Correlation between TE and capacity of reservoirs in the Siret Basin.

The results of the analyses indicate that the relationship is statistical significant at p-value of 0.0025 which is lower than the significance level α (α = 0.05).

The relation from figure 4 indicates that the capacity of reservoirs is a very important controlling factor in retaining and silting the sediments transported by the rivers through the reservoirs. However, the lack of any other information regarding other controlling factor at the moment makes the analyses of the TE factor impossible. Data regarding incoming sediment characteristics (particle size distribution), inflow characteristics (runoff volume, peak discharge, base flow) and pond characteristics (pond typology, surface area, shape, outlet dimension, outlet type, location of the outlet, initial storage volume) need to be obtain and gathered together for a more accurate analyses.

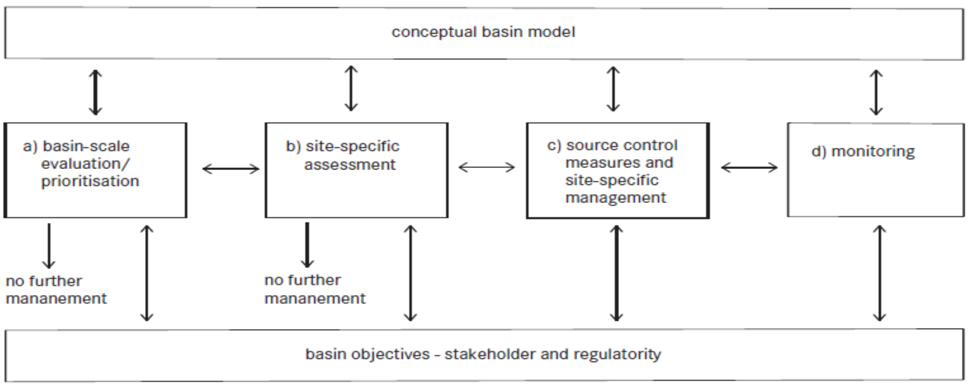
Siret Basin is one of the most developed river basins in Romania in terms of reservoirs. A detailed analysis on this parameter (TE) provides an overview of the process of sedimentation in reservoirs. TE values can then be used in the calculation for SY upstream reservoirs. The calculated values for the reservoirs for which we had data in the Siret Basin vary between 42 - 98%. This correlates well with the capacity of reservoirs ($r2=0.578$, p-value=0.0025, α=0.05). For reservoirs with large volumes TE value approaches 100%, while for those with lower volumes the value reduces.

3.2 Sediment Quantity Monitoring

Within the SedNet Project the definition and objective of sediment risk-management was debated intensely. The following risk-management objective was agreed upon: 'to reduce risk posed by contaminated sediments to humans and ecological receptors to a level deemed tolerable by society and to control and monitor sediment quality and ensure public communication with the final aim of complying with the EU WFD and Habitats Directive' If by any process within the river-basin sites pose such a risk, reduction of that risk should be a vital part of an effective sediment management action-plan (to be a part of the RBMP).

Long-term risk reduction requires a basin-scale decision framework that takes into account the entire sediment-cycle including the interactions between soil, sediment and suspended material. Figure xxx illustrates a conceptual diagram of the interrelationship between basin scale and site-specific assessment and management actions. A basin-scale risk management framework should comprise two principal levels of decision making. The first being a basin scale evaluation, comprising the development of a Conceptual Basin Model (CBM, Apitz and White 2003). CBM integrates an inventory and description of the mass-flow of contaminants and particles, and the prioritisation of sites considering their potential impact on other areas within the river system. The second level is a detailed assessment of environmental risks at specific sites, and the evaluation of the risks and benefits of management options (site-specific risk ranking and management).

If a site is identified as high risk during the basin-scale prioritisation, then it should be subject to a management process, which includes site-specific risk ranking. Because evaluation at the basin scale may be at a screening level, or may be based upon generic criteria, risk-ranking at the specific sites comprises a more detailed risk analysis in the form of a tiered approach, comprising different methods such as chemical, ecotoxicological and sediment community data. The objective then is to assess the *in situ* risks and, if deemed necessary, to predict those risks that are connected with proposed management activities. The selection of risk management or disposal approaches requires a comparative risk assessment that identifies (and possibly compares) the risks to the environment due to proposed management options, such as dredging.



Picture 5. - Conceptual diagram on the relationship between basin-scale and site-specific assessment and management in a river basin.

The main recommendations resulting from SedNet activities are structured as follows:

- Recommendations towards EU policy development
- Generic recommendations towards sustainable sediment management
- Specific management recommendations:
- towards river-basin management plans
- towards sediment treatment
- Recommendations towards sediment monitoring under the WFD
- Research recommendations

Of particular interest to SIMONA Project are the recommendations in relation to sediment monitoring and especially.

1. The frequency of sediment monitoring should range from once or twice per year to once every 5 to 10 years depending upon the sedimentation rate. Sediment samples could be collected randomly at the designated sampling point and the location of each should be recorded. Samples shall be collected at the same time of the year for each sampling occasion, the time being chosen according to local circumstances, bearing in mind the aim of monitoring trends in the concentration of contaminants. The purpose of sediment monitoring guidelines is to assess long-term trends in impacts of anthropogenic pressures and to ensure no deterioration limit is reached and that comparable data are collected.
2. In case ecological criteria of the EU WFD are not met, a check may be needed on the role of sediment contamination. This requires sediment-quality assessment approaches (cause-impact analysis) that can be linked to the WFD.
3. SedNet recommends criteria to select the target compounds to be monitored in sediments. The selection of target compounds to be monitored in sediments should be based on: 1) Persistence; 2) Bioaccumulation/adsorption; 3) Toxicity; 4) Relevance at the large scale (river basin); 5) High fluxes (tendency to increase concentrations/fluxes on a long-term basis); 6) Addition or replacement of pollutants will be based on the results of present and future monitoring programmes and on the results achieved by RTD projects where the identification of new or emerging contaminants takes place.
4. Include sediments and/or suspended solids in river monitoring plans. Substances which tend to accumulate in the geosphere and are transported bound to particles may better be measured in the suspended matter than in the water phase, which is particularly important for some new groups of compounds included in WFD, such as flame retardants (PBDEs). It is clear that transfer of contaminants from the sediments to the water column through processes of diffusion, advection and sediment resuspension is a major factor. SedNet recommends that a river monitoring plan should necessarily include monitoring of the suspended matter, in order to obtain a holistic picture of the contamination status of the whole river basin. In this respect, we should add that contaminants in suspended sediment generally represent 'current' rather than historical pollution, as they will ultimately lead to 'new' deposits of contamination, and newly settled material is the main food source for detritivorous benthic organisms.
5. Monitoring should include assessment of the bioavailable fractions of contaminants, in both the laboratory and the real field situations. The relation between sediment quality and risks is complex and site specific, requiring assessment methods based on bioavailable contaminant fractions and bioassays results rather than on the traditional total contaminant concentrations.

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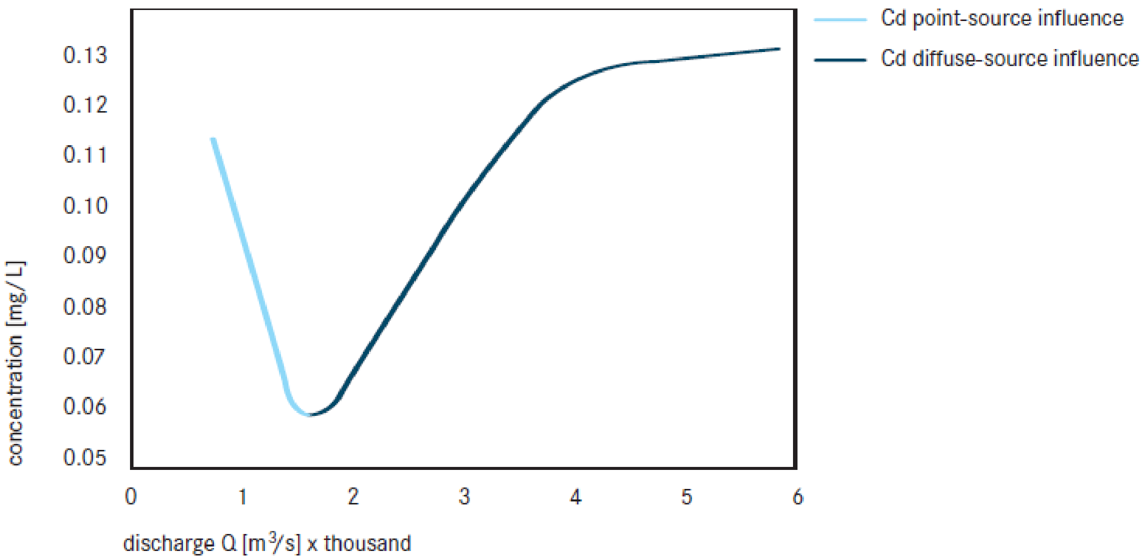
In view of the recommendations given by SedNet it is interesting to note the relationship between sediment quality and hydrological conditions as shown for the case of Cd *Other substances show similar relationships.



Picture 6. - Relationship between discharge and Cadmium concentration in the Rhine river (Vink and Behrendt 2001)

3.2.1 Similarities and differences in the river basins

A recurring theme in discussions of the different case studies was that each case was unique, for natural, socio-economic and political reasons. At the same time, sediments are an issue of importance in all of the river basins that were discussed. Different uses and ecological targets are connected through sediments. While sediment challenges become evident in defined areas they may have to be tackled on a broader scale, from water bodies to regions to whole catchment areas.

Some discussion focused on issues of sediment balance. Often in the same river basin, different areas had contrasting sediment quantity issues. Too much sediment makes dredging or reservoir flushing necessary, which may cause ecological impacts like smothering of habitats or even habitat loss. Downstream sediment loss due to sand and gravel extraction, for example, may cause erosion or loss of wetlands and create problems for habitat or coastal protection. At the same, time human interventions such as dredging or hydropower generation have to be acknowledged in order to support economic activities. In all case studies, there was recognition that this would require intense communication and collaboration between various sectors. Solutions need to be both ecologically and economically sustainable. Although not all objectives may be achievable, winwin situations should be sought. Beneficial use of the dredged sediment should be sought, e.g. for conservation purposes etc. Sediment quality due to contaminants and nutrients was a focus of concern in three of the case studies. There was recognition of the need for better understanding and control of current and historical sources of contaminants, which may involve international and cross-regional cooperation. Approaches for risk identification are being used.

Not only are there differences between the rivers, but also within river basins different regions often need to be identified because they have special characteristics that need to be evaluated. For example, sediment delivery, erosion, contaminant and nutrient emission in mountainous regions have to be differentiated from lowland river stretches.

Looking at the differences between river basins the following issues were raised:

- Sediment management has to consider the natural and artificial variations in a river basin.
- The areas within basins with the most important issues differ between river basins.
- In some river basins quality issues appear to be the most important, whereas in others the focus is more on the quantity issue or a mixture of both. Quality often becomes an issue through the need of quantity management (e.g. maintenance dredging). Quantity management often means sediment transport management• (supply and transfer) and also aspects such as river bed stabilisation.

3.2.2 Better system understanding

A general conclusion that was reached is a need to respect wide variation in sediment processes. Because of the highly dynamic nature of most river basins, both quantity and quality issues require a good understanding of the basin system to support management actions and plans. There is a clear need to better understand sediment sources and dynamics and their interactions with both human management and ecosystem functioning and services. It is necessary to collate all available data and information to enhance understanding and to identify knowledge gaps.

To manage sediment from a quantitative point of view, it is essential to have data on morphological and sedimentological change. This could be an element of the WFD monitoring programme. Data on aggregate extraction and dredging could be supplied in the characterisation of the river basin.

Hydromorphological alterations - like dams, river deepening, etc. - are often linked to sediment management, which may be necessary to maintain the functioning of the alterations. It may be not only an issue of sediment transport (quantity), because if sediments are contaminated it may become a quality issue as well. Quantity and quality issues often cannot, and should not, be separated.

Flood protection and sediment management are interrelated as well. Giving more room to rivers means extended inundation areas (such as floodplains), which generally are also sedimentation areas. This may mean areas which are subject to sedimentation of contaminants, which may impact on agriculture in these areas.

3.2.3 Need for guidance

Sediment management is an issue which should be considered in the context of WFD river basin management. Because each river basin has its specific characteristics and challenges, then river basin sediment management will have different focal points. A systematic approach which can be used throughout Europe is very much needed.

There is a need for scientific and practical guidance on how to consider sediment management issues at a river basin scale which should draw on existing information and guidance and experience from other places. Available scientifically based approaches and practical experience in Europe should be shared. Sediments are subject to different European policies and regulations. A European approach should also clarify existing uncertainties in legislation otherwise integration of the requirements of different directives will be difficult for river basin managers and users.

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Such integration is essential if the objectives are to be met. Even conflicting objectives and activities may arise when EU policies are implemented independently.

It has to be emphasized that a "one size fits all" approach would not be an adequate management solution. Development and delivery of guidance and frameworks have to allow for variability.

3.2.4 Environmental Quality Standards for sediments

The difference between EQS for water and those for sediment is that various types of sediment matrices and different contaminant levels act very differently in river basins. Therefore EQS should only be regarded as high-level screening values and be used accordingly:

- as a start of diagnostics (using tiered approaches);
- using different lines of evidence, and linking sediment state to impacts;
- for certain measures (such as source control) then target values and a good understanding of the system are necessary;
- the role of EQS is different in upstream parts of the river basin compared to that in downstream parts (estuaries);
- EQS may not be appropriate for sediments in highly variable situations where measurable state-impact links are not well understood.

3.2.5 Sediment Management

Sediment management in terms of quality and quantity should receive due attention in River Basin Management Plans (RBMP). Exceptions from including sediment management into the RBMP should be justified.

There is a need for wide recognition that the current "at risk" classification within the WFD is a screening level, which should trigger spatial discrimination, further study of effects and tests of the significance of impacts. This requires an evidence-based approach to link sediment state to impacts, and integrated thinking about rivers and transitional waters.

An adaptive management approach is required; there is not a one-size-fits-all solution, it has to be tailor-made to the specific situation. At the same time it is important to make use of experience from other river basins and to develop common basic approaches.

Achieving good ecological status of water bodies requires a proper attention to sediment issues, with an awareness of natural variation and differences between river basins.

- Issues differ in the different stretches of the Danube, which are: Upper; Middle; Lower; delta; tributaries and reservoirs;
- Measures supporting navigation (river training works & dredging) are pressures which can conflict with natural/dynamic rivers, demanding adaptive management;
- Sediment (fine material) deficit/river bed degradation is mainly perceived as an issue in the lower part (Romania) and some sections of the upper part (bed load/bed incision) of the Danube. However, over the longer term the average sediment load has remained the same due to flushing (upstream), but the temporal variability has increased;
- In general sediment quantity is perceived as the main issue, however in the main channel/lower part of the Danube there are also quality related issues (DDT and other persistent pollutants). Furthermore there are indications that sediment quality in (some) tributaries is much worse than in the Danube main channel. This may pose a risk of secondary poisoning/food chain effects;

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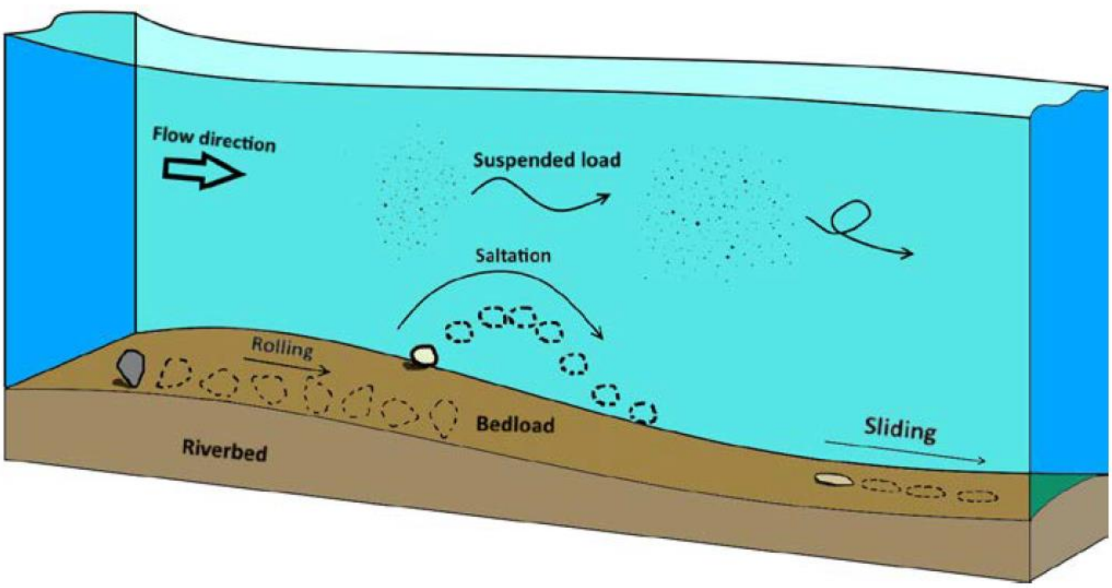
- Agriculture in the Danube has more impact on ground water quality than (contaminated) sediment in the flood plains. In general the flood plains have good ground water quality;
- Nutrient loading is perceived as an up-down stream issue. However, the nutrient load is quickly diluted by rain. But in general a significant load comes from upstream countries. Last but not least the participants to the discussion indicated that they would like to see solutions for existing problems before focusing on new issues.
- *Define the sediment balance*: i.e. actions undertaken to collate and synthesise the available information related to the current status in quality and quantity of sediment in the Danube riverbasin. The actions are aimed at coming to a (preliminary) estimation of the sediment balance for the Danube and its main tributaries.

3.3 Sediment Monitoring Methods In The Danube Countries

In order to understand, to assess and to give potential solutions for sediment related problems in rivers, lakes and reservoirs the amount of the transported sediments, varying both in time and space, has to be known. For this purpose, sediment monitoring stations are operated along the Danube River and its main tributaries in all the countries that the river flows through. Based on the nature of sediment transport in rivers, the monitoring methods can be divided in two larger groups, focusing on either suspended sediment (SS) or bedload transport (BL). Suspended sediment is the finer fraction, which is moved with the water, and mixed up in the whole water column. Bedload transport takes place at the riverbed, where the coarser particles are rolling, sliding or saltating . In the case of the Danube River, the relatively high number of suspended sediment monitoring stations stands in contrast to the few stations where bedload monitoring is continuously performed. In total, there are 55 SS stations in the Danube and 20 in the tributaries, whereas for BL, there are 19 and one, respectively.

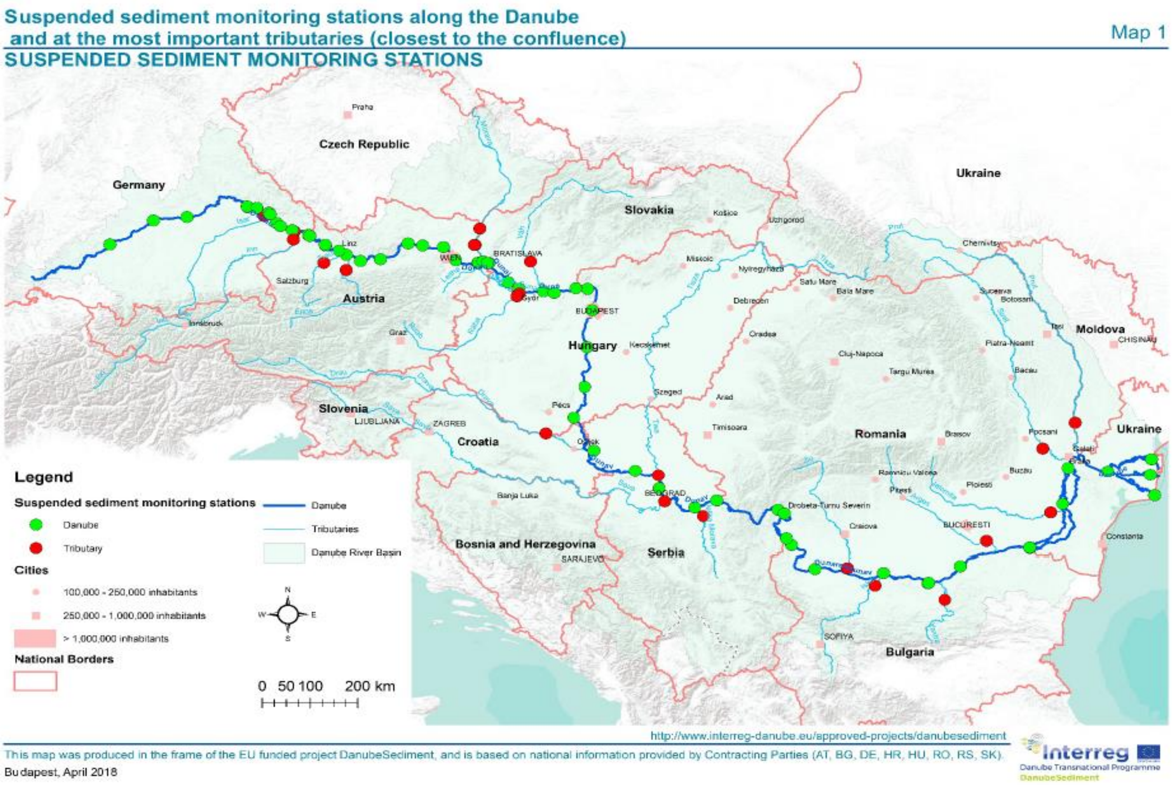


Picture 7. - Sediment movment in river channels. In lakes and reservoirs bed load is not seen as significant (Adopted from Danube Sediment Project)

In general, the main purpose of the sediment monitoring stations is to determine the sediment load at characteristic sections of the Danube River as well as in the tributaries. The Danube countries use different techniques for both suspended sediment and bedload transport. Suspended sediment monitoring stations can be found in all Danubian countries, whereas bedload monitoring is not performed everywhere. There are differences in sediment sampling methods of the countries along the river in terms of applied technique, sampling frequency, sediment analysis and the resulting data quality. This inhomogeneity of monitoring methods makes it clear that a harmonized sediment monitoring system is needed. This system must provide consistent and comparable sediment datasets that serve as a basis for assessing sediment-related problems in the Danube Basin.

According to the assessable data provided by the project partners, the suspended sediment monitoring system consists of 55 stations along the Danube and 20 in the tributaries (considering only the ones closest to the Danube confluence, except at the Inn and Morava Rivers, where two stations were taken into account from the neighbouring countries). In terms of applied methods, several different techniques are used, such as physical sampling with bottle, physical sampling with point-integrating sampler, physical sampling with depth-integrating sampler, pump sampling, optical sensors as well as acoustic sensors. The frequency of the sampling as well as the laboratory analysis methods also differ between countries. These characteristics, together with information about the sediment data owners are summarized in Table xxx for each country.

Note that only the tributaries, which play a major role in the sediment balance of the Danube, are listed here.



Picture 8. - Suspended sediments quantity monitoring in the Danube basin

3.3.1 Good practice examples for Suspended Sediment

The following parameters can be used for the reliable characterization of suspended sediment transport:

- suspended sediment concentration (mg/l),
- suspended sediment load (kg/s),
- suspended sediment yield (t),
- spatio-temporal variability,
- particle size distribution,
- characteristic particle size.

Concentration is defined as the ratio of the mass of total solid particles in a water sample, and the volume of the sample itself. The mass of the solid particles is determined after the sample is dried and has reached a constant mass.

Suspended sediment load is the flux of the suspended sediments through a selected cross-section per unit time. The suspended sediment load may significantly change over time. Integrating the suspended sediment load over a specific period of time (e.g. a year) gives the total amount of sediment transported through the studied cross-section.

Suspended sediments not only change significantly over time, but in space as well i.e. the cross-sectional distribution of the suspended sediments is rather inhomogeneous.

Suspended materials consisting of particles of different particle sizes can be characterized with specific particle sizes (e.g. mean grain size) or with the particle size distribution curve as well.

3.3.2 Monitoring methods/strategies

Various methods are available for the determination of suspended sediment concentration (Wren et al., 2000; Gray and Gartner 2009). It can be stated, that a single method is not sufficient for the characterization of all relevant parameters. Developing and maintaining reliable suspended sediment monitoring calls for the parallel implementation of both direct and indirect methodologies (Haimann et al., 2014) and their combination during post processing.

The temporal variation of the suspended sediment transport can be assessed with methods/devices which offer continuous operation, such as turbidity sensors installed in a vertical close to the bank. As the turbidity values measured by these sensors strongly depend on the size and shape of suspended particles, the preliminary calibration of these devices is necessary with water samples taken in the close proximity of the vertical where the sensors operate. Optimal sampling interval depends on the concentration and on the flow velocity as well.

Another important monitoring task is to reveal the cross-sectional distribution of the suspended sediment yield, which can be achieved through multi-point samplings usually combined with ADCP measurements. This combined methodology offers the determination of the cross-sectional distribution of suspended sediment concentration and its load as well. Due to the temporal variations, it is recommended to perform such combined measurements multiple times a year, preferably in different flow conditions.

By combining these measurements with conversion factors, a time series of mean suspended sediment concentration can be established. Taking the discharge into account, the suspended sediment transport can be determined. By integrating the time series of suspended sediment transport over time, the suspended sediment load can be determined for any period of time (years, months, events).

Table 4. - Suspended sediment measurement methods (BMLFUW, 2008;2017)

Parameter	Method	Sampling frequency
Turbidity	Turbidity sensor	Continuous
Suspended sediment concentration	Single-point sampling with bottle sampler or pump (close to the probes for calibration)	High water – daily; mean water – 1-2 times per week; low water – less often
Cross-sectional distribution of suspended sediment concentration	Multi-point sampling, or sampling combined with ADCP measurements	Several times per year, at different flow rates
Particle size	Water sample with sufficient amount of suspended solids	Recommended: at least every year during high water condition.

3.3.3 Monitoring site selection and infrastructure

Permanently operating suspended sediment monitoring stations shall be constructed and operated in a way that the monitoring of suspended sediments is possible throughout the whole year and that the measurement results can be considered as representative for the section of the river. Therefore, even when selecting the monitoring location as well as the positioning of the equipment in the water, flow conditions, tributaries or inlets, sedimentation and erosion tendencies, ice formation, (bio-) fouling and weeds have to be taken into account. Equipment that is permanently installed at the monitoring site shall be accessible for e.g. maintenance throughout the whole year.

For the calculation of the suspended sediment load, the flow discharge must be determined continuously at the measurement site too.

3.3.4 Continuous data recording

In order to assess the temporal variability of turbidity or concentration, indirect measurement devices are required which are capable to conduct measurements at least with the temporal resolution of 15 minutes (mean or instantaneous). In order to obtain reliable data, the measurement device must be chosen carefully, according to the local concentration and grain size characteristics. The regular cleaning and maintenance of the device most be ensured. In addition to locally storing the collected data, their remote transmission is recommended.

3.3.5 Calibration measurements

Since the continuous monitoring of suspended sediments is only feasible with indirect methods, their calibration must be conducted with water samples taken from their close proximity.

It is advised to generalize a consistent measurement report sheet on which one can record the identification number of every sample with the date and time of the sampling and the relevant turbidity measurement as well. It is also recommended to record every maintenance work done on the probe e.g. cleaning or change of sensor.

Calibration measurement conducted with a sampler on a rope

Based on previous experiences the calibrating measurements are advised to be conducted from a bridge.

3.3.6 Determination of cross-sectional (spatial) distribution of sediment concentration

Devices necessary for the assessment of spatial concentration distribution:

- Sampling device (e.g. US-P61-A1 type sampler or pump sampler; *Figure 75*) + necessary accessories
- Reel, crane
- Clear, closable bottles to store water samples (volume of min. 1 litre)
- Waterproof marker to make labels
- Stopwatch
- Measurement protocol and writing tool
- Calibrated device for velocity measurements (ADCP, ADV, etc.)
- Power supply (generator, battery)

In order to calibrate the indirect device employed for the assessment of temporal changes the followings are needed:

- Sampling device (e.g. hand sampler)
- Clear, closable bottles to store water samples (volume of min. 1 litre)
- Waterproof marker to make labels
- Measurement protocol and writing tool

Picture 9. - Example suspended sediments samplera) US P61 A1, b) Pump sampler

3.3.7 Cross-sectional measurement

In order to obtain a reliable estimation of the suspended sediment flux in a cross-section, one must determine the spatial distribution of suspended sediment concentration and flow velocities in the assessed cross-section. It is advised to conduct such measurements several times per year, preferably in different flow conditions. It can be done with multi-point sampling measurements or with its combination with ADCP measurements. Figure shows an example of a cross-sectional measurement plan, with the sampled points (5 verticals, 4 points in each vertical).

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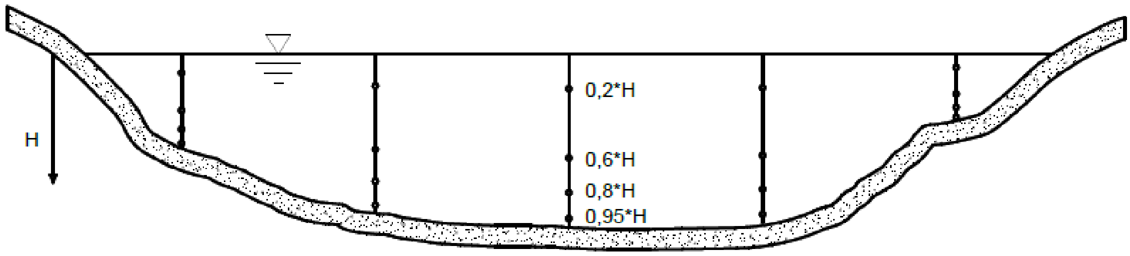


Picture 10. - Scheme of a cross-sectional measurement in 5 verticals and 4 measuring points per vertical (based on BMLFUW, 2008; 2017)

The cross-section must be divided into several segments of equal width. The number of verticals shall not be less than seven for a water surface width larger than 300 m and not less than five for a surface width smaller than 300 m (ISO4363; 2002). The measurement verticals are then in the midpoint of these sections. In the case when ADCP measurements are conducted as well, a fewer number of verticals is sufficient.

The determination of the water depths in the verticals can be done with the velocimeter (ADCP) or with the suspended sediment sampler. In case when the cable of the sediment sampler is used for the estimation of the water depth, the sweeping effect of the flow should be taken into account (the measured depth can be larger than the actual), hence the use of ADCP is justified. All designated verticals must be logged in the measurement protocol.

Determination of measurement points along the verticals: in general, it is suggested to measure 3-5 points in the same relative depths. The relative depths in which measurements have to be conducted based on the total depth (H) with different number of points are the following:

- 5-pointed method: 0.05×H, 0.20×H, 0.60×H, 0.80×H, 0.95×H
- 4-pointed method: 0.20×H, 0.60×H, 0.80×H, 0.95×H
- 3-pointed method: 0.20×H, 0.60×H, 0.80×H
- 2-pointed method: 0.20×H, 0.80×H
- 1-pointed method: 0.60×H

The sampler is lowered to the depths determined in the previous step. It is recommended to use an isokinetic sampler, so the measurement is the most representative and reliable as possible. It is not necessary to fill the sampler bottle entirely, however, it is advised to take a sample of at least 0.5 l. The stopwatch is used the measure the net time of the measurement.

The sampling bottle most be labelled for clear identification (sample ID; place and time of sampling).

The time, location (distance from bank, depth), time and the length of the measurement must be logged on the protocol along with the ID of the sample. If possible, turbidity and water stage must be noted as well.

Determination of flow velocity in the sampled point.

Relevant steps are repeated to all the verticals.

3.4 Lake And Reservoir Sedimentation Assessment

Reservoir and lake survey methods have been used for many years to estimate the expected life of the reservoir/lake and catchment sediment yields (cf. Brown, 1944). A comprehensive range of survey and resurvey techniques have been developed to calculate the sediment volumes deposited (Bruk, 1985; Pemberton & Blanton, 1980; Rausch & Heinemann, 1984; Vanoni, 1975). Many studies based on resurvey and/or remote sensing methods report average yields for the entire life of the reservoir/lake (e.g. McManus & Duck, 1985) but developments in the Cs dating of reservoir sediments reported by Ritchie *et al.* (1973) have enabled some estimate to be made of variations in deposition rate through time (cf. Batten & Hindall, 1980).

Despite these and other technical developments, and the strengthening of conceptual links between lakes and their contributing catchments (Oldfield, 1977), a number of important practical difficulties still remain in utilizing the bottom sediments of lakes and reservoirs for reconstructing sediment yield histories (sediment quantity). These include the identification and/or quantification of sediment source, trap efficiency, resuspension processes, sediment density changes, autochthonous and allochthonous contributions to the sediment and the significance of mixing processes.

3.4.1 Sources of lake/reservoir sediment

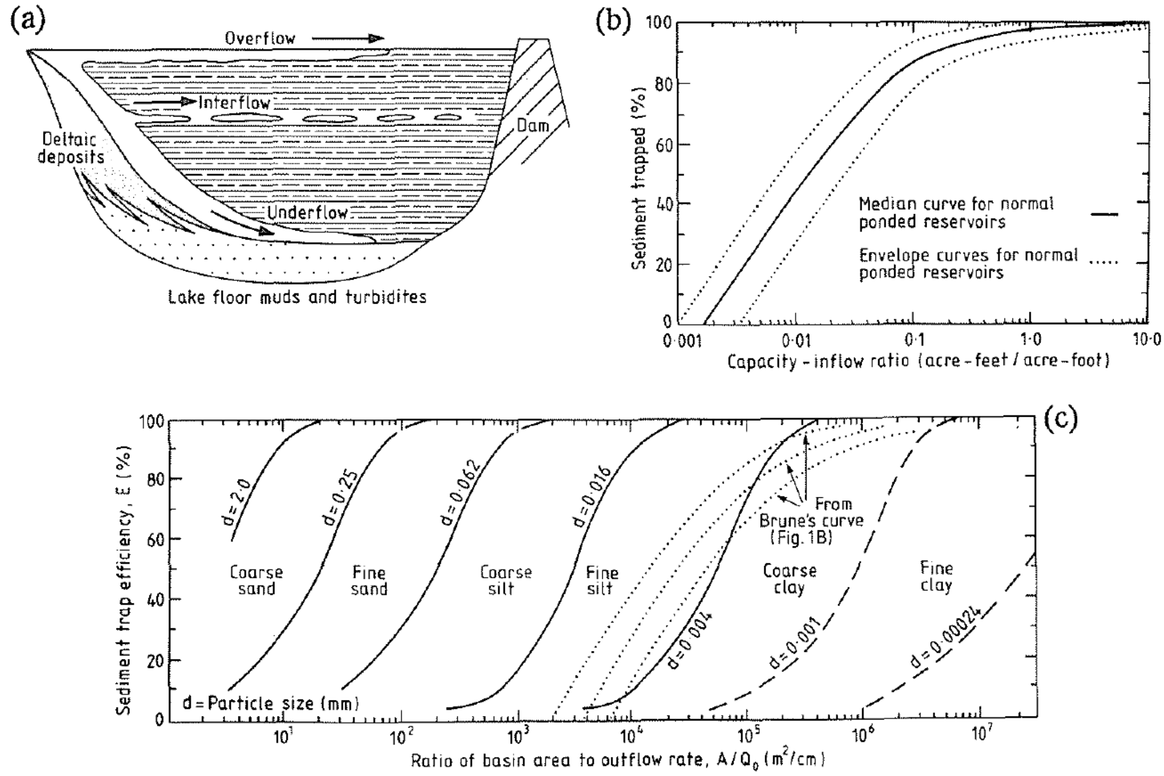
Hakanson & Jansson (1983) identify four major factors which control sedimentation in lakes and reservoirs.

1. A depositional factor which expresses the capacity of a lake to act as a sediment trap (all other things being equal, larger lakes tend to be more efficient sediment traps).
2. The lake or reservoir will have its own internal productivity which will contribute towards the accumulation of sediment at the lake bed.
3. Pretrapping of sediment in upstream lakes and reservoirs will limit sediment supply.
4. The natural load factor derived from allochthonous inputs (direct drainage basin derived inputs or atmospheric contributions to the lake surface).

Any attempt to utilize the lake sediment record must be capable of distinguishing the respective contribution of autochthonous and allochthonous material and the relative contribution derived from the drainage basin and the atmosphere.

3.4.2 Trap efficiency

Sediment trap efficiency has attracted considerable attention from hydrologists. Graf (1983), for example, has shown that the general pattern of sedimentation is a function of changing hydraulic conditions, with the relatively high velocity turbulent inflow being transferred to slow flowing water within the lake or reservoir. Coarser particles, including the bedload, are usually deposited as a delta whilst the lighter particles, especially fine silts and clays, are distributed further into the water body. The exact distribution of the sediment will depend on factors such as the relative densities of the inflowing river and lake waters and the position of the thermocline (or pycnocline) if one exists (Pic. 10(a)). Furthermore, the chemical properties of the water in which settling takes place may enhance or inhibit settling through the impact of the sodium adsorption ratio on flocculation (e.g. Trujillo, 1982).



Picture 10. - Lake and reservoir trap efficiency: (a) mechanics of sediment delivery and distribution; overflow, interflow and underflow rates depend on the relative density of inflowing water and the presence of a thermocline; (b) trap efficiency as related to the capacity-inflow ratio (based on Brune, 1953); (c) trap efficiency as related to particle size and the ratio of basin area to outflow rate (based on Chen, 1975). The Brune curve is included for comparative purposes.

The efficiency with which lakes/reservoirs trap sediment can be predicted in a number of ways. Brown (1944) suggests that trap efficiency *(Te)* can be determined from:

$$Te(\%) = 100 \times 1 - \frac{1}{1 + 0.1C/DA}$$

where *C* = reservoir capacity; and
DA - basin area.

The drainage area parameter, however, seems to be a relatively poor substitute for inflow volume, and Brune (1953) developed the use of the capacity inflow ratio in preference to the capacity drainage area ratio (Fig. 1(b)).

In his survey of 44 reservoirs, Brune found a range of trap efficiencies. Reservoirs/lakes with low capacity inflow ratios may fill and scour depending on the pervading streamflow conditions, whereas high retention capacities are to be found in reservoirs with high capacity inflow ratios, where continuous sedimentation is experienced and clear water is released downstream. In small basins, the trap efficiency curve developed by Heinemann (1981) may be more appropriate or, where a particle size differentiation is seen to be important, the capacity inflow/particle size relationship may be relevant (see Fig. 1(c); Chen, 1975; Heinemann, 1984; and Rausch & Heinemann, 1984).

Trap efficiency, although a vital component for quantitatively estimating sediment yield, may vary in the same lake or reservoir depending on inflow conditions. For example, the trap efficiency of the Aswan high dam for a 15 year period between 1964 and 1979 varied from 84.8% to 99.9% (based on data in Shalash, 1982). For the purposes of sediment yield estimation, lakes and reservoirs with trap efficiencies approaching 100% will provide optimum sites for sediment yield studies.

3.4.3 Resuspension

Despite the relatively efficient trapping of sediments in some lakes and reservoirs, the resuspension, redeposition and sediment focussing process has a significant bearing on the methods which may be employed to estimate sediment yield.

These problems have been investigated in limnological research, for example by Davis (1974) and Davis & Ford (1982) in Mirror Lake, New Hampshire and in Esthwaite Water in the UK (Hilton, *et al.,* 1986). Resuspension appears to be most relevant to the use of seston traps for estimating sediment accumulation rates in lakes and reservoirs (cf. Bloesch & Burns, 1980; Blomqvist & Hakanson, 1981), although it may also have implications for the preservation of the radioisotope record as discussed below.

In a more general review of the problem, Hilton (1986) suggests that four processes dominate the resuspension and potential focussing of lake sediments. These include peripheral wave attack, random redistribution, intermittent complete mixing and slumping and sliding on slopes. Indeed, Davis *et al.* (1984) have argued that little information is as yet available on the understanding of the hydrodynamic and sedimentological processes which control sediment deposition in lakes, although some attempts to model the process have been made on the basis of lake morphology (e.g. Lehman, 1975). An inability to predict the process of sediment focussing has implications for the design of sediment survey techniques, since basic morphometric properties cannot be used to predict the points of maximum, muiimurn and, more importantly, average sedimentation for a lake basin. As Dearing (1983) has shown in a small Scanian lake, the point of average se«diment accumulation at the lake bed may vary over time depending on changes in exposure conditions or in response to local depositional processes.

3.4.4 Sediment density

In many cases, reservoir resurvey techniques have been used to estimate the volumetric accumulation of sediment for economic as well as geomorphological reasons (e.g. Stromquist, 1981; Bruk, 1985; McManus & Duck, 1985). Although the survey technique may be of value in assessing lake/reservoir life, it is suboptimal for assessing sediment yield for a number of reasons.

- Firstly, sediment density may not be measured directly and may be assumed or estimated from one of the available empirically-derived formulae.
- Secondly, without sediment cores for analysis, the relative proportions of the autochthonous/allochthonous components cannot be estimated.
- Thirdly, the sediment yield estimate may span the entire life of the reservoir covering several periods of human impact or change.

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- Fourthly, initial surveys following construction may be inadequate to provide a baseline against which to adequately assess subsequent deposition, since early adjustments might involve a greater proportion of bank derived sediments.

Of particular importance in sediment yield estimation is the change in density which can occur either during deposition or in post-depositional diagenesis. The density of sediment can be estimated from one of two major approaches. Reservoir engineers, for example, frequently consider the compaction of sediment in terms of the removal of pore water through time, assuming that the increase in compaction is time and/or particle size dependent. The methods most commonly used, according to Vanoni (1975), include that of Lane & Koelzer (1953) where the sediment density *(p)* after / years is given as:

$$p = p_1 + k \log t$$

where: *p1* is the sediment density after 1 year, *k* is a constant and *t* is time since deposition in years.

The detailed considerations given by Bolton (1986) to the above and other equations are too lengthy to be presented in detail here, but after reviewing a range of models based on inadequately formulated hydraulic principles, Bolton suggests that a mathematical formulation of the density profile, such as:

$$p = p_f - a\ e^{by}$$

where: *p* is a sediment density, *a* and *b* are constants which can be obtained from curve fitting techniques, *p* - is a hypothetical maximum density value and *y* is depth; may be more appropriate.

The limitations of this approach are seen in hydraulic terms to relate to inadequate pore pressure dissipation during consolidation, although the problem may not manifest itself in slowly sedimenting basins where this process may equilibrate through time. However, the assumption that the density will tend towards a finite maximum is invalidated by the observations in a 500 000 year continuous sedimentary sequence in Lake Biwa, Japan (Yamomoto, 1984) where density increases with depth through over 200 m of sediment. Such records may form an important basis for the evaluation of a variety of models of sediment density.

An alternative approach to the density problem is presented by Hakanson & Jansson (1983). They assume that water content is the key component which they define as:

$$W = \frac{gws - gds}{gws}$$

where *gws* and *gds* are wet and oven dry masses respectively from a known sample volume.

Water content will decline with depth in the form of a negative exponential. More importantly, water content is also related to wet bulk density *(pw),* organic content and the density of organic material. Although humus may have a density close to water (1.3 to 1.5 g cm"), the density of minerogenic sediments may exceed 5.0 g cm". Clearly, the mixture of sediments of various types affect the final density, not simply because of pore pressure and particle size differences, but also as a result of differential organic:inorganic loadings. Analyses of the organic matter content of lake sediments have shown that values may range from a few percent to over 30% by weight (Engstrom & Wright, 1984) and may reflect the organic productivity in the epilimnion of stratified lakes receiving high nutrient loadings. A recent investigation by Foster & Dearing (1987) has shown that in two morphologically and geologically similar reservoir basins in the Midlands of England, the average organic matter content of the sediments in the two basins ranged from 8 to 15% of dry sediment mass. The accuracy of sediment yield estimates for whole lake basins may be inadequate, not only because of errors in estimating the vertical variations in density but also because spatial variations in density over the lake or reservoir bed will relate to inflow and secondary sorting processes as well as to local variations in erosion and deposition. For example, Smith *et al.* (1960) have show that dry densities of surficial sediments in Lake Mead ranged from 0.53 to 0.91 t m"3 (excluding deltaic deposits). Such a range of densities would produce a significant variation in the estimated sediment mass and any consequent calculation of sediment yield.

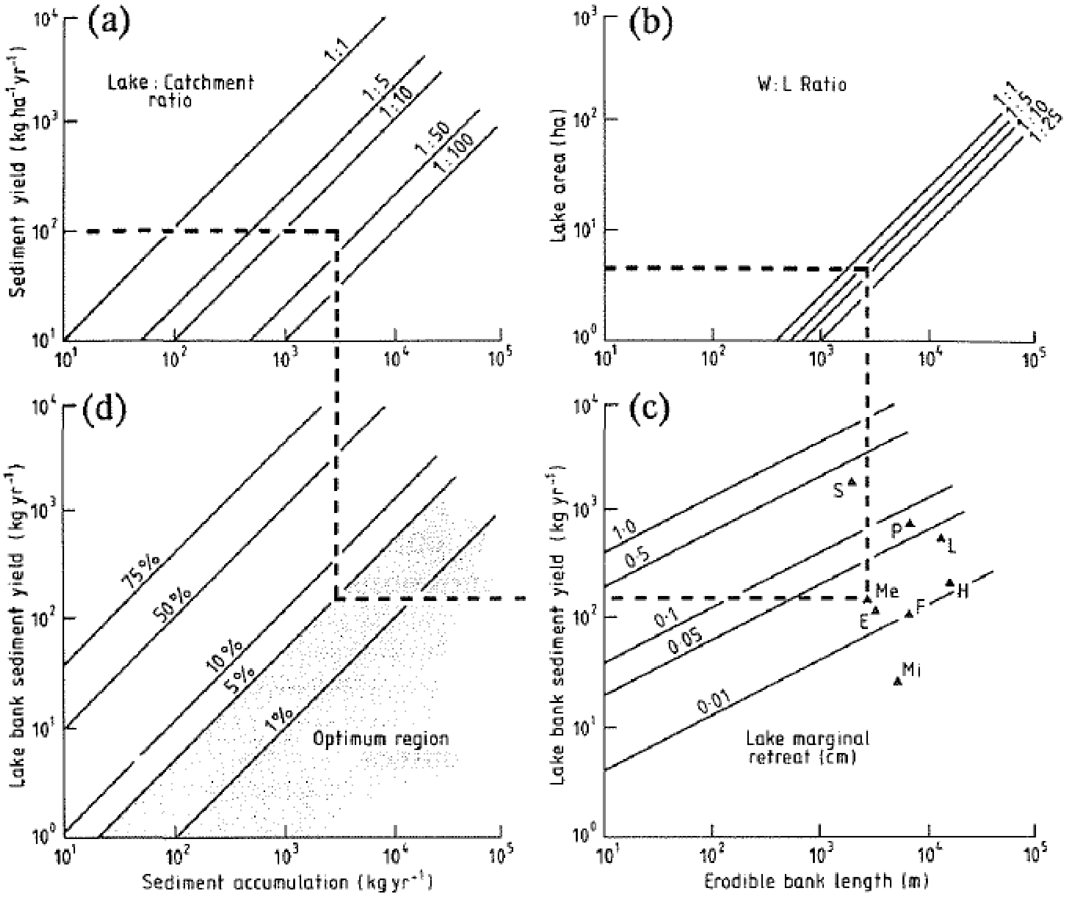
Clearly, the range of factors is responsible for controlling sediment density, which will also include particle size considerations, and this precludes the prediction of density with any degree of certainty.

At the present time, there appears to be little substitute to the application of coring methods to quantify accurately spatial and post-depositional variations in sediment density.

3.4.5 Autochthonous and allochthonous sources

Lake sediments will comprise material derived from erosional processes within the upstream drainage basin, lake marginal erosion processes, atmospheric sources and biotic processes within the circulating water body which may selectively assimilate elements delivered to the lake in solution. Some attempt to distinguish these sources must be made where they are likely to contribute significantly to the accumulating sediment.

Little has yet been done on the possible significance of lake marginal erosion processes, where imperceptible backwearing may make significant contributions to the accumulating sediment. This problem has been investigated theoretically by Dearing & Foster (1986) who produced the nomogram shown in Fig. 7 in an attempt to quantify the maximum acceptable bank erosion rate in a range of recent lake sedimentbased estimates of sediment yield. The factors controlling bank erosion rates will include wave height, height of erodible shoreline, fetch, local water level lowerings and the magnitude of currents capable of transporting eroded sediments to the central part of the lake or reservoir. Water level lowering is more problematic in reservoirs, and many studies have evidenced the secondary erosion/depositional sequences associated with the reworking of deltaic or other sediments (cf. Bruk, 1985; Szechowycz, 1973). Particularly problematic is the deliberate use of scour valves to remove reservoir bottom sediments. Such disturbances are likely to invalidate the lake sediment based method of sediment yield estimation. It is recommended that some attempt be made to monitor contemporary rates of bank retreat in order to quantify the magnitude of this problem in a variety of locations. Erosion pin studies are currently being carried out by the authors on a reservoir site in Midland England in order to quantify this problem. The contribution derived from atmospheric inputs is usually assumed to be negligible. Records from Midland England have, however, shown that localized dust fallout could exceed 30 t/km^2 year 1 in recent times. Undoubtedly, these fallout records are unlikely to represent regional rates of deposition, but attempts by Foster *et al.* (1985) to quantify this component in a slowly sedimenting Midland England reservoir suggests that the atmospheric input could contribute up to 9% of the gross sediment accumulation in recent years.



Picture 11. - The impact of lake bank erosion on yield estimate:(a) relationship between lakex-atchment area ratio and sediment yield to estimate dry sediment accumulation (kg yr'1); (b) relationship between lake area and lake width to length (W:L) ratio to give estimate of erodible bank length; (c) relationship between erodible bank length, rate of retreat and sediment yield derived from bank erosion (assuming a bank height of 40 cm and a sediment density of 2.65 g cm'3); (d) relationship between lake bank sediment yield, sediment accumulation and the % contribution to total yield by bank erosion.

The nomogram requires two sets of input, a regional rate of sediment yield (Fig. 3(a)) and lake area and the W:L ratio (Fig. 3(b)). The example of its use, given for the dashed line ofMerevale Lake, Warwickshire, shows a regional estimate of sediment yield of 100 kg ha year . In order for the lake marginal retreat to have less than a 5% contribution to sediment yield, a retreat of between 0.01 and 0.05 cm year must be assumed. The following lakes are plotted: Merevale Lake (Me, Foster et al, 1985); Seeswood Pool (S, Foster et al., 1986b); Frains Lake (F, Davis, 1976); Loe Pool (L, O'Sullivan et al., 1982); Llyn Peris (P, Dealing et al., 1981); Havgardssjon (H, Oldfield et al., 1983); Mirror Lake (Mi, Likens & Davis, 1975); and Lake Egari (E, Oldfield et al, 1985) (based on a diagram in Dearing & Foster, 1986

Estimation of the contribution made by internal productivity can be made by an analysis of the organic content of the accumulating sediment, which may be compared with the organic content of contemporary inflowing sediments.

Hakanson & Jansson (1983) have empirically modelled the relationship between density and organic matter content, based on the weight loss recorded when sediments are ignited in a muffle furnace at low temperatures (540°C). Such analyses may only record a small component of the productivity controlled deposition, since diatom frustules composed of silica may constitute a large proportion of the sediment mass. Here, the contribution may be estimated by analysis of the accumulating sediments by an alkaline digestion procedure (cf. Engstrom & Wright, 1984 and Foster *et al*, 1985, 1986b).

Midland reservoirs in the UK may have as much as 30% of their sediment mass accounted for by organic matter and biogenic silica. Another particularly problematic area relates to the secondary precipitation of calcite in lake waters in lakes of high salinity or where soils are carbonate-rich. Extraction techniques seem unable to differentiate between autochthonous and allochthonous calcium carbonate and as far as is currently known, no lake sediment based estimate of sediment yield has yet attempted to deal directly with this problem.

Several approaches may be adopted, such as to undertake comparative extractions in soils and lake sediments to assess the gross changes in calcium carbonate content, to undertake XRD analysis to quantitatively distinguish between calcite and dolomite in the sediments and sources, or to adjust for all CaC03 contents by expressing yields on a carbonate free basis.

3.4.6 Authigeruc and mixing processes

Of less significance for sediment accumulation studies, but of great relevance to the preservation of chemical and radiometric stratigraphies, is the variable nature of the combined effect of bioturbation and chemical diffusion. These processes are relevant here in that the separation of the sedimentary record into intervals approaching a decade in resolution is wholely dependent upon the mechanisms responsible for the delivery, adsorption and diagenesis of those isotopes which form the basis of radiometric chronologies.

The two isotopes most commonly employed for short core studies are "'Cs and 210Pb. For timescales exceeding 100-200 years, varved, 14C and/or palaeomagnetic chronologies may be more appropriate

Few models as yet exist to quantify the significance of these components, but Fisher *et al.* (1980) in a series of laboratory experiments have shown how *Tubifex tubifex* incubated at different levels in the sediment could affect the movement and diffusion of 137Cs in a laboratory tank experiment and Davis (1974) demonstrated that feeding depths of tubificids reached 15cm in the profundal sediments of Messalonskee Lake, Maine.

Hakanson & Jansson (1983) have proposed a dynamic model of the process, which incorporates parameters such as sediment depth, rate of sedimentation, water content, bulk density, compaction, biotransport, substrate decomposition and bioturbation limit. Such a model may form the basis for assessing the importance of density variations as well as the bioturbation process on sediment yield estimation.

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3.5 Bottom Sediment Sampling

The selection of an appropriate sampling framework in order to provide accurate and precise estimates of sediment quantities and yields in considerations of lake/reservoir sediment loads involves several problems.

To date, most studies have performed multiple corings in order to account for the spatial variation in deposition rate.

The sampling framework is usually arranged on a rectangular grid to improve the speed of sample point location and to ensure that a representative range of sedimentary environments is sampled. On lakes which are seasonally frozen, cores may be retrieved through the ice and traditional land survey techniques and/or GPS systems may be used to locate sampling positions.

3.6 Sediment retrieval

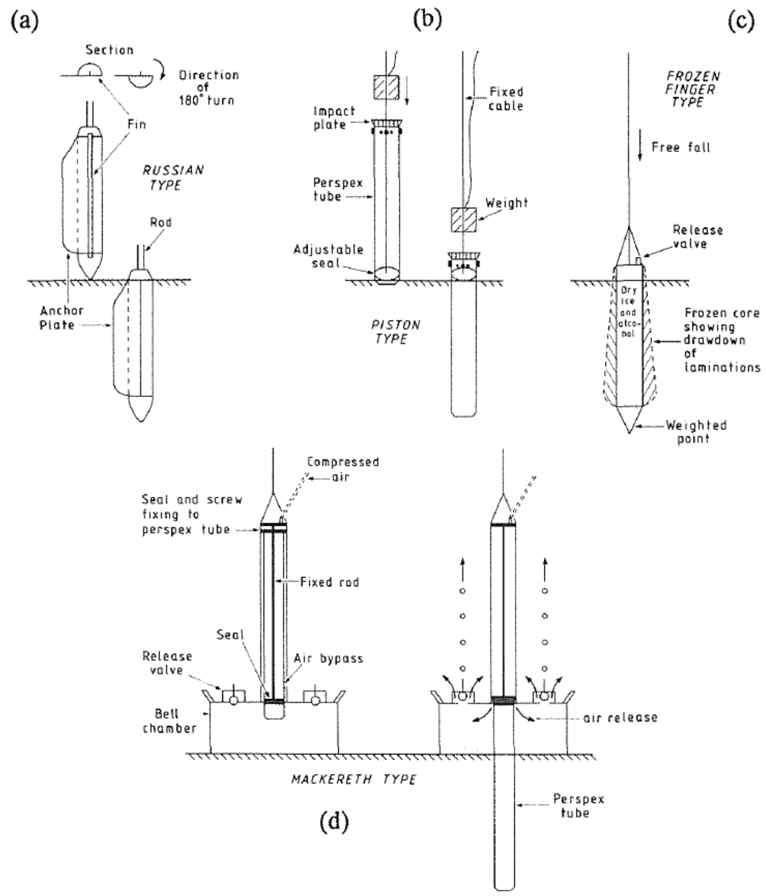
Numerous techniques have been developed in order to retrieve bottom sediments from lakes and reservoirs. The exact method selected will depend on the following criteria:

- depth of water;
- whether the water surface is frozen;
- stability of the coring platform;
- thickness of the sediment to be cored;
- cohesive properties of the sediment;
- whether an undisturbed surface is to be retrieved;
- whether undisturbed samples are to be subsampled in the field;
- mass of sediment required for subsequent analysis; and
- whether sediments are laminated.

Various sampling methods have been reviewed, for example, by Wright (1980) and Aaby & Digerfeldt (1986). Figure 4 illustrates some of the basic principles of corer operation.

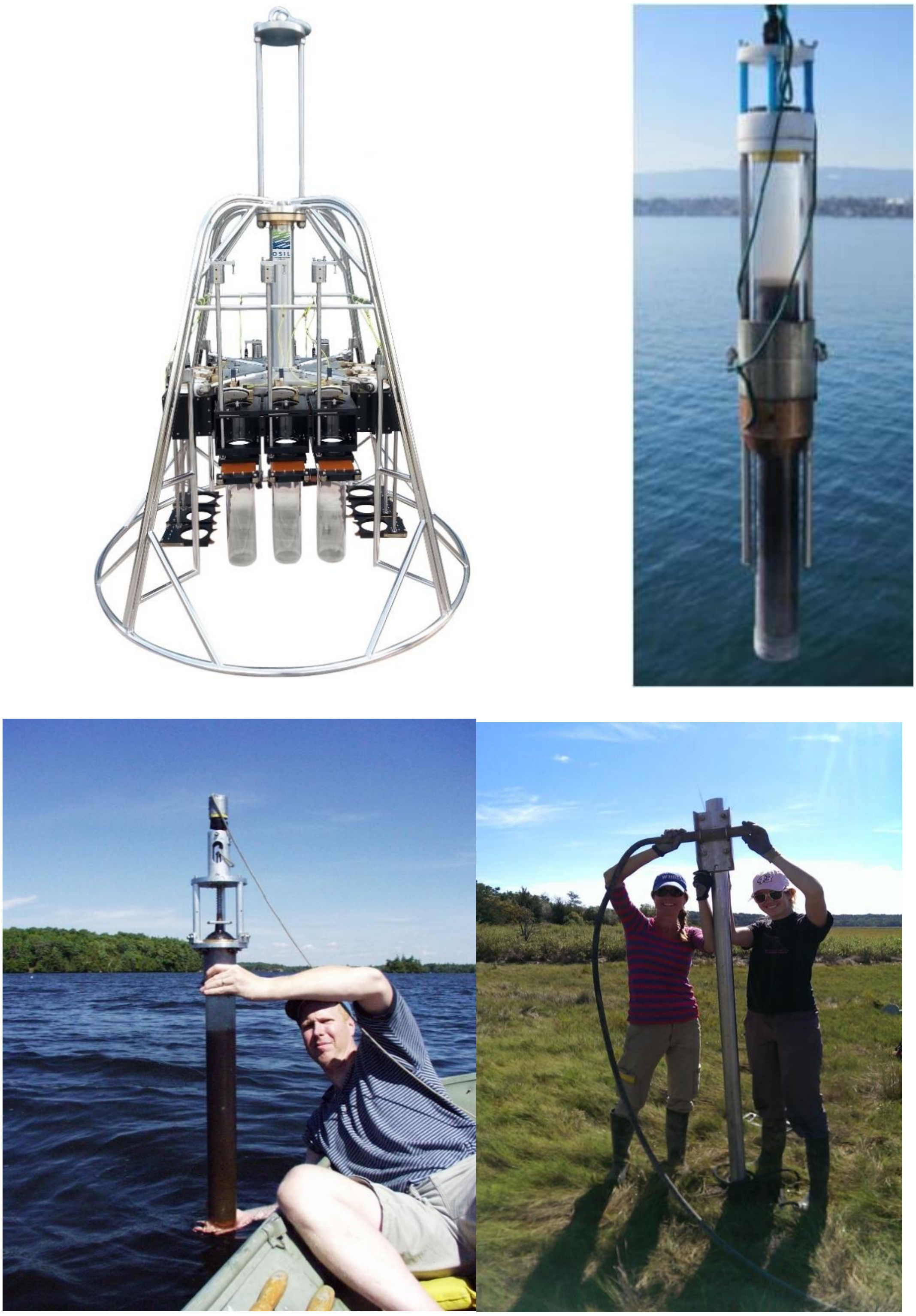
For example, Fig. 4(a), the "Russian" corer, is a chamber corer which samples undisturbed material. However, it can only be operated from a frozen surface or a stable raft or platform and, with deep water (>3-4 m), it requires guide tubes to avoid bending the rods. It is unsuitable for low density surface sediments, but in higher density materials it may retrieve a sufficiently undisturbed sample for density and palaeomagnetic determinations. In deeper water where rod operation is impractical, a line operated piston type sampler may be more appropriate (Fig. 4(b)). The fixed line holds a Kullenberg (1947) seal above the sediment surface and the piston is driven past the seal into the sediment with a line operated weight. The partial suction created by the seal prevents the sample falling out of the piston as it is raised to the surface. The "frozen finger" type sampler (Fig. 4(c)) is a gravity operated device which is filled with dry ice and alcohol. The sediment freezes to the outer surface of the corer which is retrieved with the hand line. Although the sampler may be unsuitable for density analysis, the technique is particularly suitable for the study of laminated sediments (cf. O'Sullivan *et al,* 1982), One of the most important developments has been the availability of compressed air driven samplers (cf. Mackereth, 1969) which are capable of retrieving an undisturbed sediment surface as well as continuous cores of up to 6 m of undisturbed material from a variety of depths and, theoretically, in any depth of water exceeding the length of the corer. The principle of operation of the "mini corer" is shown in Fig. 4(d).

A bell chamber provides a stable platform for the coring operation and the piston is pushed past a seal with compressed air pumped into the corer from the boat. The corer penetrates the sediment and air bubbles released through the release valves indicate completion of coring at the water surface. The corer is retrieved by hand. For 3 and 6 m versions of this sampler, the system is modified to "suck" the corer chamber into the sediment in order to improve stability and, once coring is complete, this chamber fills with compressed air to provide lift. Both corers can be operated from small boats. One of the greatest limitations of the piston samplers, including those driven by compressed air, is that they are unreliable in sediments with low cohesion and high water contents. Estimates of density are subject to error in the Mackereth and similar types of piston corer because some compaction, foreshortening and even sediment loss may occur during sampling (Blomqvist, 1985) and vertical extrusion of cores with a piston may also lead to some compaction.



Picture 12. - Coring devices for sediment retrieval: (a) the Russianc type; (b) the piston type; (c) the frozen finger type; and (d) the Mackereth (pneumatic) type.

Picture 13. - Example of modern sediment corer samplers



Picture 14. - Example of modern sediment corer samplers

3.6.1 Core correlation and dating

Since sedimentation rates vary across the lake or reservoir bed, an important aspect of sediment yield reconstruction is the identification of time synchronous layers within the sediments, in order to calculate sediment volume. The solution to this problem demands some means of both core correlation and dating. Although dating methods may be applied to all cores, the prohibitive cost and time consuming nature of the analysis will frequently preclude more than one or two dated cores per lake. The techniques of core correlation have recently been reviewed by Dearing (1986) who suggested that correlation of synchronous levels between sediment cores demands that the property used for correlation should be areally continuous and synchronous. Various methods of core correlation have been used in lake and reservoir studies and these are summarized in Table 2. One of the more important developments in core correlation in recent years has been the measurement of the magnetic properties of lake sediments (see Thompson & Oldfield, 1986). These properties were shown to be particularly useful because of the speed of measurement in the first study of this type (Bloemendal *et al.,* 1979) and a range of magnetic properties have been used in many subsequent lake sediment based studies of sediment yield (e.g. Dearing *et al.,* 1981; Dearing, 1986; Foster *et al.,* 1985, 1986b).

More recent investigations by Hilton & Lishman (1985) have, however, shown that some properties, such as magnetic susceptibility may be controlled by a diagenetic process under differing redox conditions and may not be controlled by allogenic inputs to the lake basin. Some care should be exercised in selecting the most appropriate basis for magnetic or other core correlation methods, in order to adhere to the principles of areal continuity and areal synchroneity. Provision of an accurate chronology is undoubtedly the most important aspect of sediment yield reconstruction and a variety of techniques have now been developed. These techniques may be based firstly, on the preservation of palaeomagnetic properties of inclination, declination and intensity, calibrated on a regional basis with radioisotope ages; secondly, on the production of natural isotopes in the environment which decay at a known rate relative to a stable form, such as 14C and 210Pb; thirdly, on the presence of an isotope such as 137Cs which was introduced into the environment from atmospheric weapons testing; and, fourthly, on the existence of rhythmic or annual laminations or varves (cf. O'Sullivan, 1983). Space does not permit a full discussion of the technical problems involved and a number of recent reviews have dealt with palaeomagnetic methods (Thompson & Oldfield, 1986; Thompson, 1986) and radiometric dating including weapons testing isotopes (Cambray *et al.,* 1982; Lowe & Walker, 1984; Oldfield & Appleby, 1984; Olsson, 1986).

For reservoirs constructed over the last 200 years or less, a combination of 210Pb and 137Cs analyses seem to be most appropriate in providing resolution of a decade or less over the appropriate time period. Given the half life of 210Pb of 22.26 ± 0.22 years, this radionuclide is particularly suited to this timescale and can potentially give accurate age determinations for up to 150 years. Recent investigations by Flower *et al.* (1989) in North Africa have, however, experienced some difficulty in obtaining a reliable chronology older than 30 years BP from this isotope in a lake basin which is accumulating at a particularly rapid rate. One of the most important problems recently identified is the potential unreliability of the 137Cs record and its apparent dependence not only on the bioturbation and mixing processes outlined above, but also on the potential downward molecular diffusion and adsorption of this ion. This problem was highlighted by Davis *et al.* (1984) in a number of Scandinavian and New England lake sediment cores which were dated by pollen marker horizons as well as by the 210Pb method. The latter appears to be little affected by downward diffusion through the sediment column.

Some examples of the application of 137Cs and 210Pb for dating cores are given in Fig. 5 for two Midland England reservoirs. The degree of coincidence between the atmospheric and lake sediment records in Figs 5(a), 5(b) and 5(c) is variable and the correlation of these records with the *10Pb record shown in Figs 5(d) and 5(e) depends on the model used to calculate the depth:age relationship in the sediment. At least two dated cores seem to be necessary to overcome the problems of sediment focussing discussed above and other independent means of core correlation between the two dated cores should be used in order to "fine tune" the depth:age curve in different parts of the basin (cf. Oldfield & Appleby, 1984; Fig. 5(e)).

3.7 Sediment Quantity Calculation And Interpretation

The total influx of sediment to a lake or reservoir for each synchronous and dated horizon can be obtained by multiplying the associated mean wet sediment volume of each core by the percentage weight loss measured by oven drying at 110°C, in order to obtain total dry sediment mass. A more accurate method is to use the dry sediment density data for all cores within each synchronous zone. A map of the dry sedimentation rate for each area of the basin can then be produced for each time zone, such as that shown in Fig. 6. The total mass of dry sediment over the lake bed is then calculated after measuring the area of lake bed receiving different amounts of dry sediment. This procedure not only accounts for the spatial variability in sedimentation rate across the lake bed but enables examination of how the patterns of sedimentation have changed through time. In the two examples shown in Fig. 6, early sedimentation in both reservoirs is restricted to the old river channels and valley floors. As time proceeds and these zones fill with sediment, the area receiving material expands towards the more marginal zones where later accumulation occurs.

As described above, the total mass of accumulating sediment is only partly a function of processes operating in the drainage basin and some attempt should be made to account for losses due to changing trap efficiency, and increases in mass caused by atmospheric input, lake marginal erosion and autochthonous and diagenetic contributions. These adjustments frequently demand chemical and other determinations on the retrieved sediment.

3.7.1 Interpretation

Having subtracted the mass of sediment which is non-denudational, the remaining fraction should represent a value close to that calculated from river based sediment yields. Some attempt has been made to evaluate the correspondence between sediment yields calculated from river discharge and turbidity measurements and from reservoir sedimentation in Midland England (Foster *et al.,* 1985). This study has shown that within the likely variability in annual sediment yields demonstrated by the turbidity record, the adjusted lake sediment-based estimate of yield produces comparable results for the most recent time period. To date, however, insufficient emphasis has been placed on the comparison of lake sediment based estimates with estimates derived from river based studies.

To date, less than 10 continuous reconstructions of sediment yield, based on multiple coring of bottom sediments, have been published. These records cover a range of environments from Tropical lakes in highland Papua New Guinea (Oldfield *et al.,* 1985) to lowland lakes in seasonally cold environments of Southern Sweden (Dearing, 1986). Some of these records are reproduced in Fig. 7(a). Two types of lake are represented in this diagram. First, Frains Lake and Lakes Egari, Havgârdssjôn and Bjâresjô are lakes receiving no channel inflow, where all inflowing sediments are presumably derived from surface erosional processes and/or lake marginal erosion. In contrast, the three lakes with lower sediment yields all have at least one and, in the case of Seeswood Pool, two major channel inflows. (The apparent decline in the sediment yield in Bjâresjô through the period of record appears to relate to a change in contributing catchment area).

In addition to the historical picture given by the published lake sediment based estimates of sediment yield, resurveys of reservoirs have provided average yield estimates over varying timescales. Some of these latter data have been used with the more detailed reconstructions to construct Pic. 14(b), which shows the relationship between the catchment to lake area ratio (CLR) and the estimated basin sediment yield. Two trends emerge from this relationship. First there is a general increase in yield with decreasing CLR. Secondly, two subsets appear in the data which distinguish forested basins with a lower yield than other basins for the same CLR. The upper relationship (Curve 1: Pic. 14(b)), which is statistically significant at the .001 level, includes a wide diversity of environments and land use types and the two patterns may be interpreted in a number of ways. First, the relationships suggest that the impact of deforestation on sediment yields is significantly affected by basin size, with smaller basins being more sensitive to change (the ratio between forested and non forested basins with a CLR approaching 1.0 is around a factor of 10 whereas in basins with a CLR of 100, the factor is less than 5). Secondly, not only can this relationship be demonstrated for different environments, but comparison of the trends shown by Frains Lake, and Lakes Egari and Bjâresjô demonstrates the same magnitude of change appropriate to their CLRs. Furthermore, comparison of Merevale Lake and Seeswood Pool, which are both in Midland England and have almost identical CLRs but contrasting land uses, indicates a ratio of forested to deforested basins in accordance with the general relationships obtained. The CLR parameter is dominated by the influence of catchment size and it is suggested that it may closely relate to the sediment delivery ratio in fluvial studies (cf. Walling, 1983).

An ability to reconstruct patterns of sediment yield for a single environment is valuable for a number of reasons. Firstly, it is possible to exert some experimental control on the influence of catchment size on the computed result. (A paired lake catchment based study should account for the changing sensitivity of the environment at different CLRs). Secondly, careful selection of the basin enables testing of various models of the fluvial environment and general models of landscape sensitivity to change by using historical data to conduct experiments on our behalf (cf. Deevey, 1969). The contemporary analogue model produced by Wolman (1967) is frequently reproduced in fluvial texts, yet the quantitative reconstruction of sediment yields following deforestation presented by Davis (1976) rarely appears in the hydrological literature. This latter study evaluates not only the equilibrium conditions under forest and clearance but also quantifies the response to and recovery from a period of change. Conceptually, the latter is to be preferred and one might argue that the Wolman model should be modified in the light of these data More recently, the lake sediment based record of sediment yield has been used to evaluate the important controls on sediment production in contrasting environments through an analysis of the relationship between historical rainfall records and sediment yield for the last two centuries (Bearing & Foster, 1987) and in association with tephra layers, the technique has been used by Thompson *et al,* (1986) to calculate changes in the sediment input to Icelandic lake sediments.

The lake sediment based record of sediment yield is undoubtedly suboptimal for a detailed evaluation of contemporary process dynamics, but it has already been shown to add a significant dimension to the interpretation of sediment yield and sediment source data at a timescale relevant to the testing of hydrological and fluvial models of landscape change.

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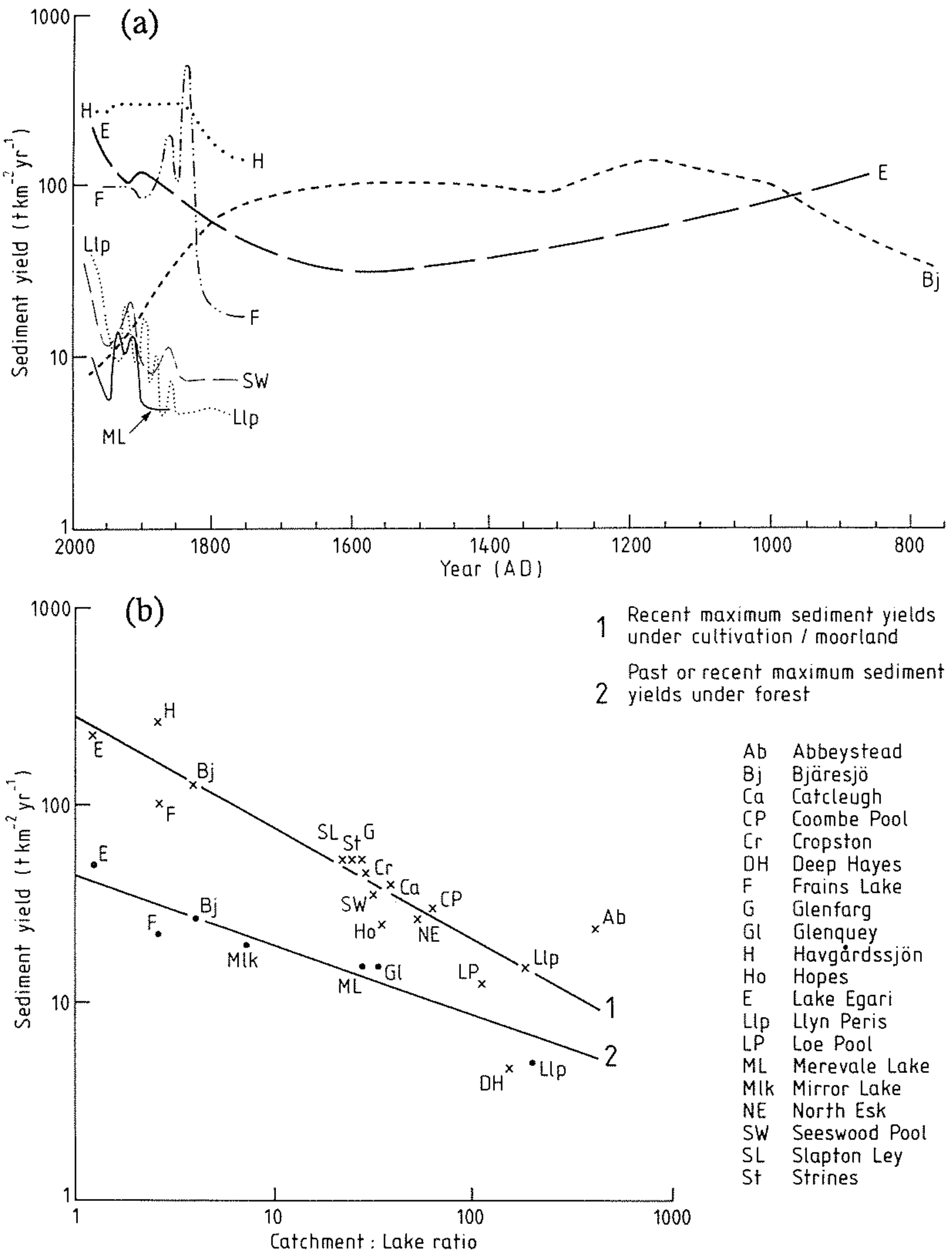

Picture 14. - Sediment yield estimates from lake and reservoir based studies: (a) some long term trends in sediment yield from lake sediment based studies; (b) sediment yields as related to the catchment to lake ratio (CLR). These include both lake sediment based and reservoir resurvey data, making allowance for water content and density. Data from the following published sources: Crick (1985), Davis (1976), Dealing (1986), Dealing et al. (1981), Cummins & Potter (1972), Foster et al. (1985), Foster et al. (1986), Hall (1967), Ledger et al. (1974), Likens & Davis (1975), McManus & Duck (1985), Oldfield et at. (1985), O'Sullivan et al. (1982), Rodda et al. (1976) and Young (1958).

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4 CONCLUDING REMARKS

This document is a PROPOSAL which is to be revised once all the inputs from the project partners are received. In addition to this it may prove to be necessary to add additional material specific to Lakes and Reservoirs depending on the material to be received.

In this context this is a working version which is deanmed sufficient to kick start the work on the preparation of the Guidance document but is not a final version for the Project.