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United Nations Educational, Scientific and Cultural Organization

International Hydrological Programme

International Sediment Initiative

International Research and Training Centre on Erosion and Sedimentation

Sediment Issues & Sediment Management in Large River Basins Interim Case Study Synthesis Report

International Sediment Initiative
Technical Documents in Hydrology
UNESCO Office in Beijing & IRTCES 2011

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Executive Summary

The management of sediment in river basins and waterways has been an important issue for water managers throughout history – from the ancient Egyptians managing sediment on floodplains to provide their crops with nutrients, to today's challenges of siltation in large reservoirs. The changing nature of sediment issues, due to increasing human populations (and the resulting changes in land use and increased water use), the increasing prevalence of man-made structures such as dams, weirs and barrages and recognition of the important role of sediment in the transport and fate of contaminants within river systems has meant that water managers today face many complex technical and environmental challenges in relation to sediment management.

UNESCO launched International Sediment Initiative (ISI) in 2003. ISI aims to develop a decision support framework for sediment management, in order to provide guidance on legislative and institutional solutions, applicable to various socio-economic and physiographic settings, in the context of global changes. ISI aims to further advance sustainable sediment management on a global scale. This report draws on international experience in sediment measurement and management, to provide guidance for policy makers dealing with water and river basin management.

Case studies prepared as a key component of the ISI, have been produced for the Nile River Basin, the Mississippi River Basin (USA), the Rhine River Basin, the Volga River Basin, the Yellow River Basin (China) and the Haihe and Liaohe Rivers (China). The purpose of these case studies is to:

- Increase awareness of erosion and sedimentation issues;
- Increase understanding of erosion and sediment transport processes under different conditions;
- Improve the sustainable management of soil and sediment resources, by providing examples of monitoring and data processing techniques, technical procedures, and methodologies for the analysis of environmental, social and economic impacts; and
- Ultimately assist in the provision of better advice for policy development and implementation and evaluation of management practices.

The synthesis of these case studies is intended to provide an accessible overview of sediment problems and sediment management around the world for water managers and policy makers. Key issues relating to sediment management are explored through the various case studies and recommendations for developing management strategies have been extracted from these experiences.

Contents

1. Introduction

Box 1: What is Sediment?

Sediment (sometimes called 'silt' or 'alluvium') is comprised of solid particles of mineral and organic material that are transported by water. In river systems the amount of sediment transported is controlled by both the transport capacity of the flow and the supply of sediment. The "suspended sediment load" refers to the fine sediment that is carried in suspension and this can comprise material picked up from the bed of the river (suspended bed material) and material washed into the river from the surrounding land (wash load). The wash load is usually finer than the suspended bed material. In contrast, the "bed load" comprises larger sediment particles that are transported on the bed of the river by rolling, sliding or saltation. Most rivers will transport sediment in each of these 'load' forms, according to the flow conditions.

Human activity is placing ever-increasing strain on the quality of our air, land and waters. River systems around the world are grappling with the impacts of industrial pollution, over use of water, loss of ecosystems and degradation of aquatic habitats. The time is ripe for policy makers to understand the implications of planning and management decisions for the environment. This report is intended to give an overview of different approaches to the management of sediment in river systems.

Effective management of sediment in rivers is becoming increasingly important from an economic, social and environmental perspective. Sediment carried by rivers is an important component of the global geochemical cycle. Depending on local factors, sediment can prove either beneficial or detrimental to society or the environment. For example, agriculture along the Nile floodplain historically took advantage of the seasonal flooding that deposited nutrients essential for production of crops. Today, large scale dams in many areas have removed the capacity for nutrient deposition through seasonal flooding. These dams, however, also protect the growing number of riparian settlements from the one of the most devastating natural hazards - flooding. Adverse impacts of increased sediment deposition can result in increased flooding and resulting property damage, contamination of water supplies, loss of crops, social dislocation and temporary homelessness, and even loss of life.

Sediment carried by rivers is an important component of the natural geochemical cycle and the movement of material from the land to the oceans. Natural river reaches are usually in state of morphological equilibrium, where the sediment inflow on average balances the sediment outflow. Reservoirs can upset this equilibrium by slowing or halting the movement of water and allowing sediment to settle, thereby preventing the movement of sediment downstream. This is an important issue for many rivers around the world. It is also becoming increasingly obvious that sediment loads in the world's rivers have been impacted by human development and agricultural production. A recent study of 145 major rivers with longer-term records of annual sediment loads and runoff showed that around 50% of river records demonstrated a statistically significant upward or downward trend

(Walling & Fang, 2003). The majority of these rivers demonstrated declining sediment loads due to dams and other river control structures trapping sediment.

There is also a growing body of evidence that climate change will influence the sediment loads of rivers around the world. This is by no means a new trend, with records revealing fluxes in sediment yields due to historical climate change and associated changes in rainfall and runoff. Some areas are expected to become wetter under current climate change scenarios which may increase sediment transport through erosion and runoff. Climate change impacts may also interact with other anthropogenic causes of sedimentation in rivers, such as agricultural production.

It is impossible to apply a ‘one-size-fits-all’ approach to sediment management and control, because the issues involved are frequently very regionally-specific. Local factors such as topography, river control structures, soil and water conservation measures, tree cover, and riparian land-use or land disturbance (for example agriculture, mining etc) can have a large impact on sediment loads in rivers. River control structures (such as reservoirs), soil conservation measures and sediment control programmes can cause downstream sediment loads to decrease, while factors such as land disturbance (clearing of vegetation for example) or agricultural practices can cause increase sediment loads.

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The ISI’s mission directly relates to the commitments of the international community recognized in major documents, such as the Millennium Development Goals, the Rio Declaration of Sustainable Development, the World Water Assessment Programme, World Water Development Reports, etc. The ISI also aims to uphold the importance of sustainable sediment management within the context of the United Nations “Water for Life Decade” and the “Decade for Education for Sustainable Development” in the period to 2015. With direct access to the stakeholders represented in the IHP National Committees and the Intergovernmental Council, ISI provides an effective vehicle for advancing sediment management at the global scale.

This report presents a synthesis of a series of case studies undertaken in different river basins around the world and dealing with sediment problems, sediment monitoring and sediment management and control. These case studies have been prepared as a key component of the ISI. The purpose of the case studies is to:

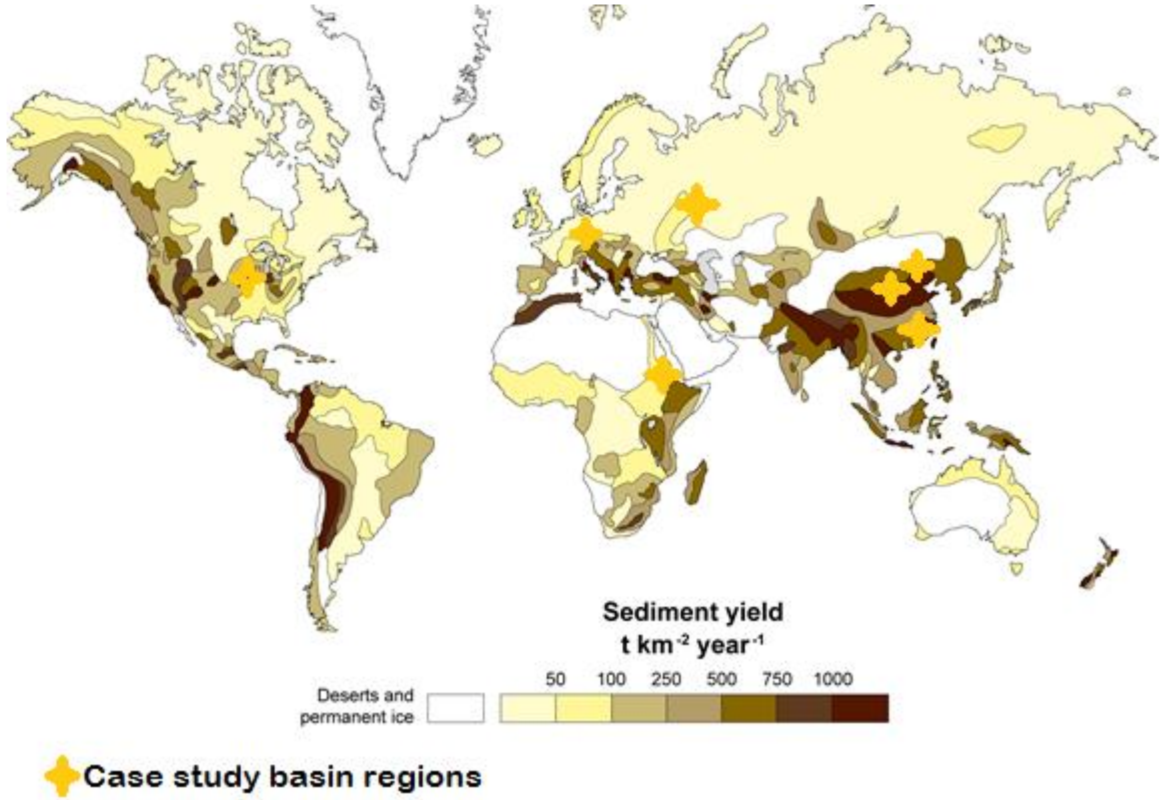
- Increase awareness of erosion and sedimentation issues;
- Increase understanding of erosion and sediment transport processes under different conditions;
- Improve the sustainable management of soil and sediment resources, by providing examples of monitoring and data processing techniques, technical procedures, and methodologies for the analysis of environmental, social and economic impacts; and

- Ultimately assist in the provision of better advice for policy development, implementation and evaluation of management practices.

Case Studies have been carried out to date for the Nile River Basin, the Mississippi River Basin (USA), the Rhine River Basin, the Volga River Basin, the Yellow River Basin (China) and the Haihe and Liaohe Rivers (China). The information provided in these case studies will be drawn together in this report.

2. Description of the Case Study River Basins

2.1 Location of the River Basins [1]



2.1. 1. Haihe and Liaohe Rivers (China)

The Haihe and Liaohe River Basins are located in northern China as shown in Maps 2 and 3. The Haihe River basin has an area of 263,400 km^2 and covers most of Hebei Province, and parts of northeastern Shanxi Province, Shangdong Province, northern Henan province, small parts of the Inner Mongolian Autonomous Region, Beijing and Tianjin. The Liaohe River Basin is located in the southwest part of northeast China. Its mainstream rises in Hebei Province, and then passes through the Inner Mongolia Autonomous Region, Jilin Province and Liaoning Province, and discharges into the Bohai Sea. The river basin incorporates two river systems. One is the East and West Liaohe River, and the other is the Hun River and the Taizi River. The total river basin area is 220,000 km^2.

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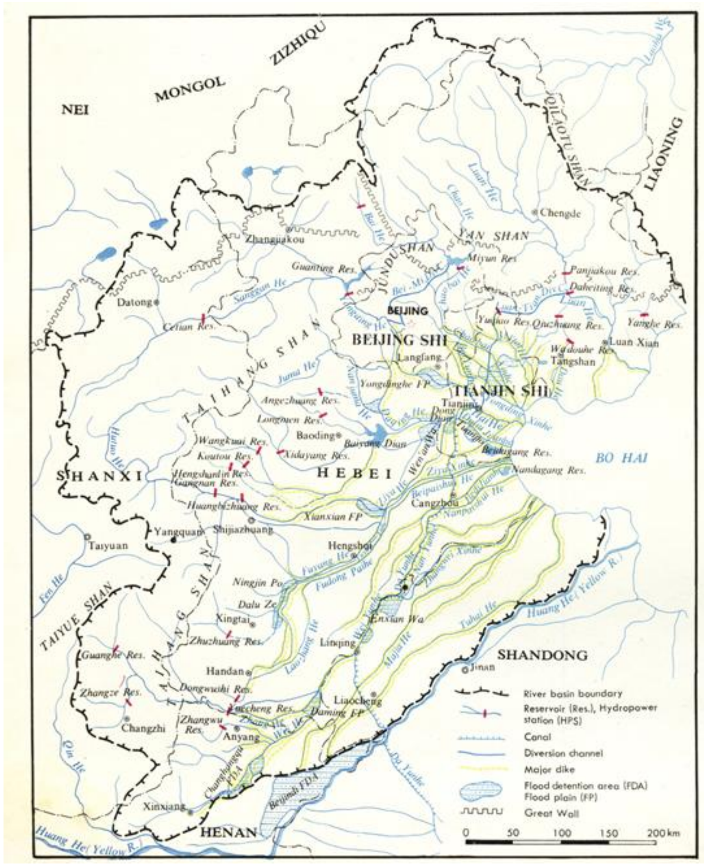
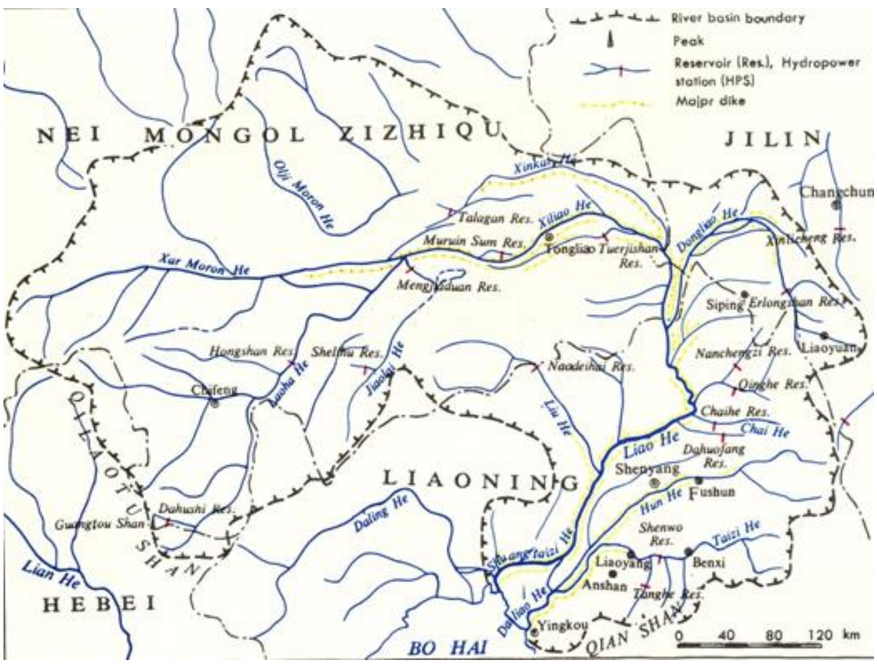
[1] Adapted from: Walling, D.E, Recent changes in the suspended sediment loads of the world's rivers: the impact of environmental Change, 3rd ISI steering Committee Meeting, 28-30 April, 2005 Vienna, Austria)

Map 2: Haihe River Basin



Map 3: Liaohe River Basin



2.1. 2. Yellow River Basin (China)

The Yellow River Basin, sometimes referred to as "the cradle of Chinese civilization", covers an area of 742,443 km^2. The Yellow River is the second longest river in China after the Yangtze River, with an estimated length of 5,464 km. It originates in the Bayan Har Mountains in Qinghai Province western China and flows through nine Provinces (which incorporate the Qinghai-Tibet Plateau, the Loess Plateau and the North China Plain) before discharging into the Bohai Sea.

Map 4: Yellow River Basin[2]

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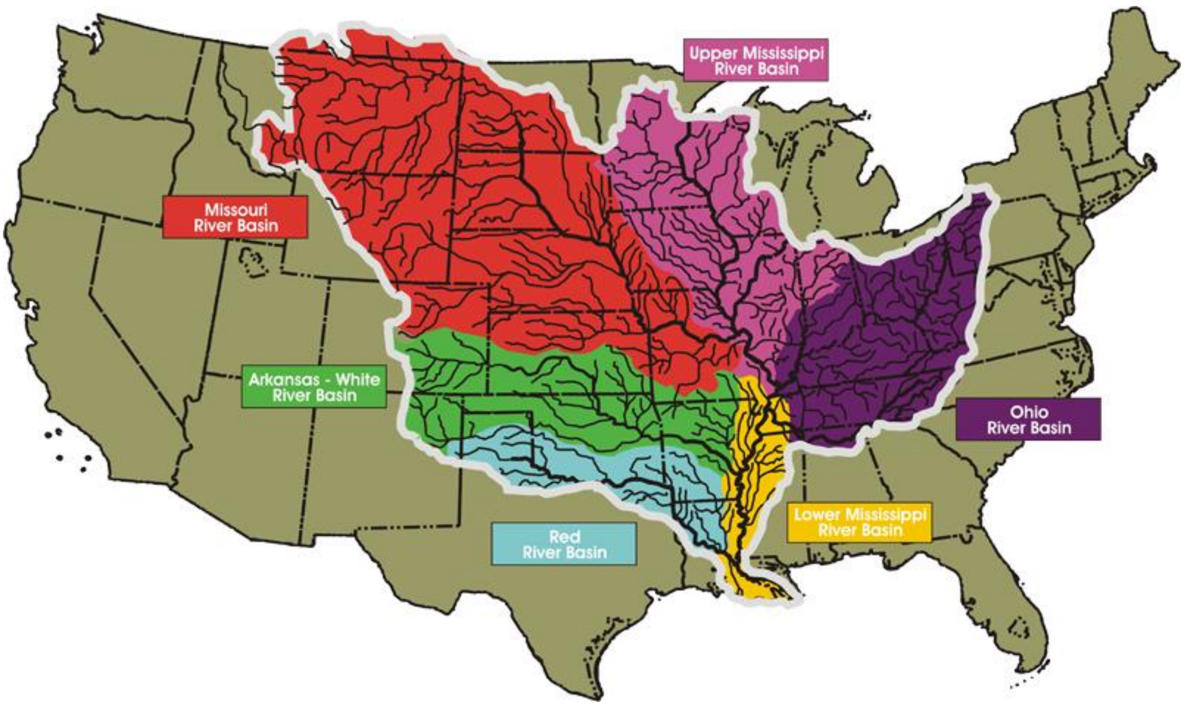
[2]Map from UN World Water Development Report 3, 2009.

2.1. 3. Mississippi River Basin (USA)

The Mississippi River Basin covers over 3.2million km^2 and is the third largest drainage basin in the world, draining the plains between the Appalachian Mountains and the Rocky Mountains. The Mississippi Basin is the source of many river systems including the two longest rivers in the United States – the Mississippi River and the Missouri River (a tributary of the Mississippi River).

Map 5: Mississippi River Basin



2.1. 4. Nile River Basin (Egypt, Burundi, the Democratic Republic of Congo, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda)

The Nile River Basin covers an area of 3.1 million km^2, or about 10% of Africa. The Nile is the largest north flowing river in Africa and is considered to be the longest river in the world. Its basin includes 10 countries – Egypt, Burundi, the Democratic Republic of Congo, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda. The Nile has two major tributaries – the Blue Nile and the White Nile.

Map 6: Nile River Basin

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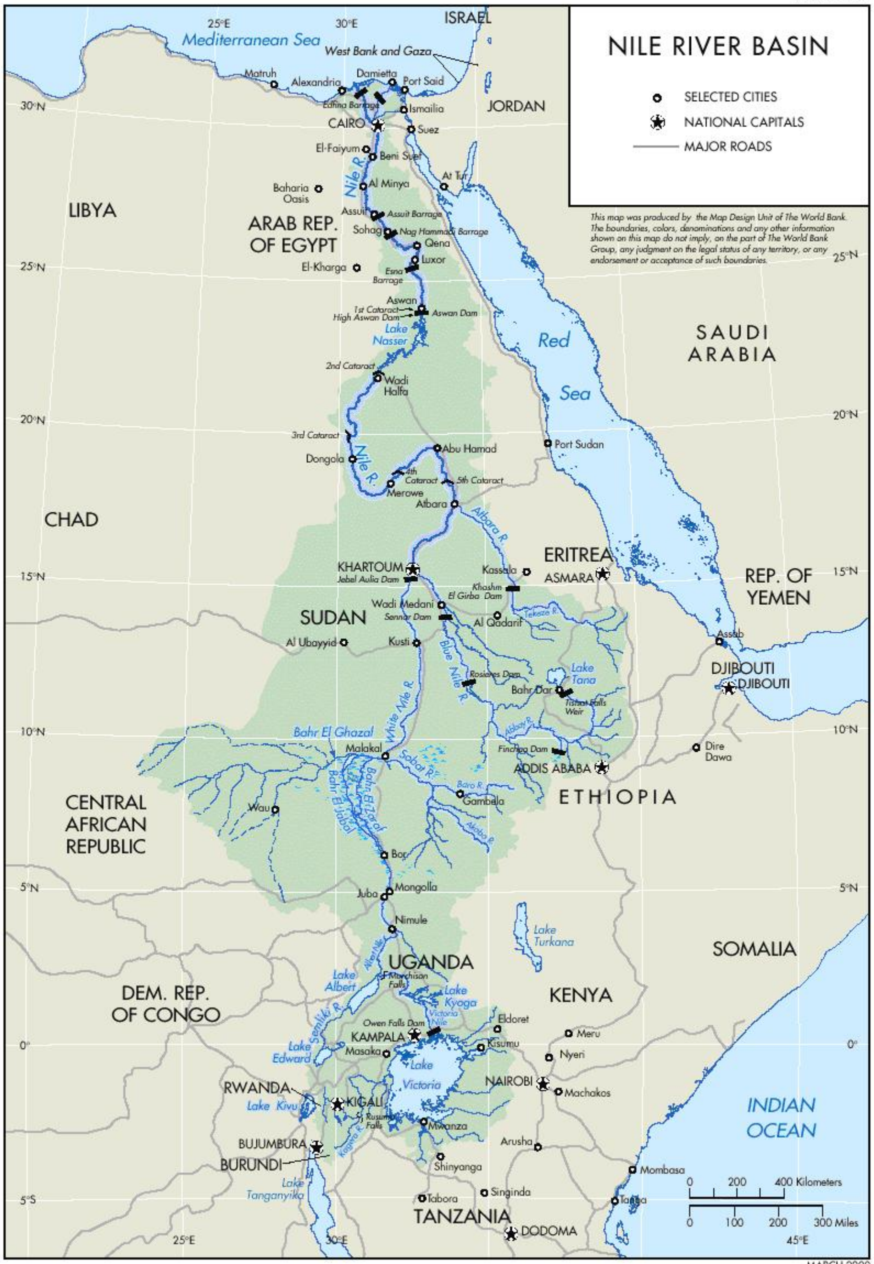

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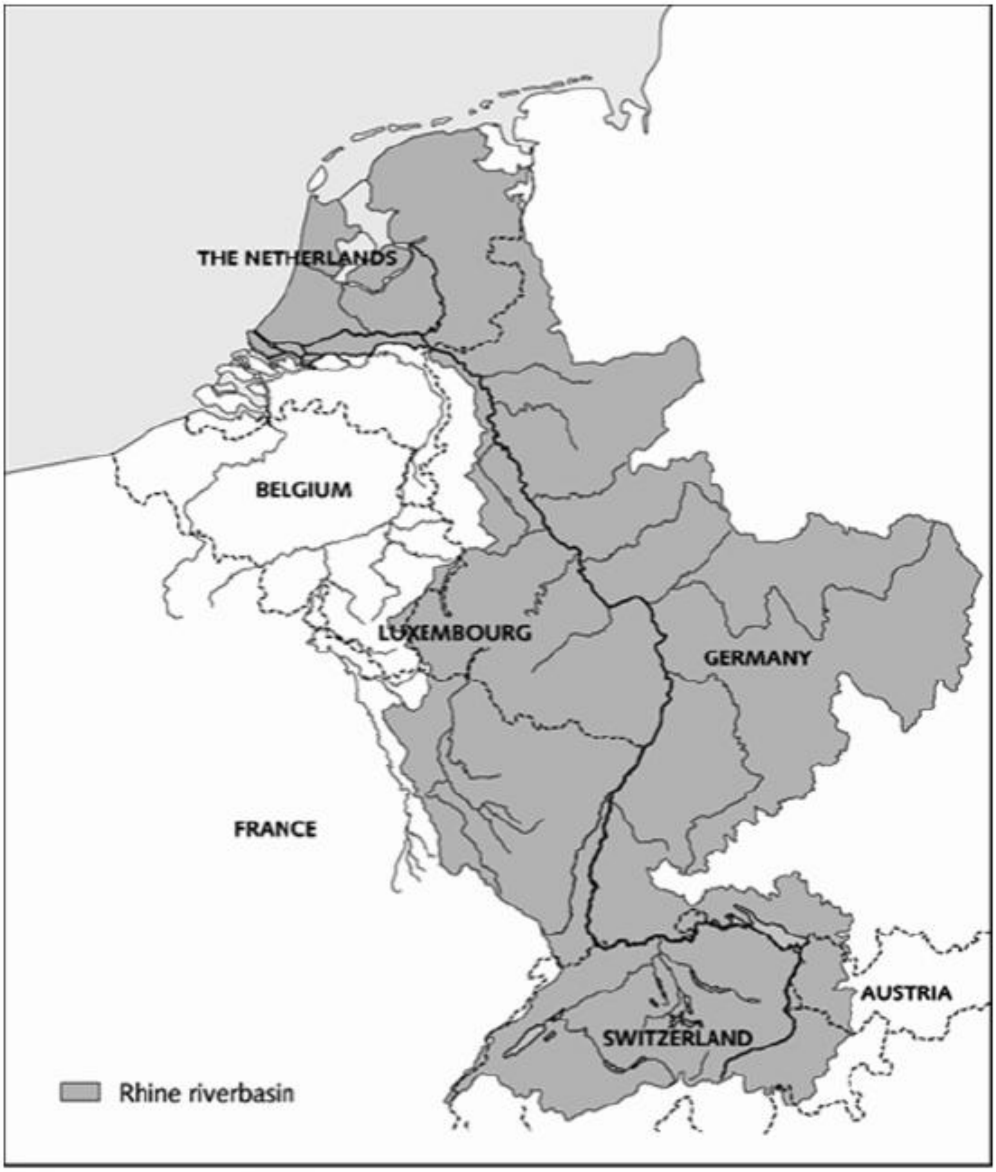
2.1. 5. Rhine River Basin (Switzerland, Austria, Germany, France, Luxembourg and the Netherlands, Belgium, Italy and Lichtenstein)

The Rhine River Basin has an area of 185,000 km^2 and is a part of 9 countries - Switzerland, Austria, Germany, France, Luxembourg and the Netherlands, Belgium, Italy and Lichtenstein. It is Western Europe's largest river basin. The length of the Rhine River is 1,320 km.

Map 7: Rhine River Basin



2.1.6. Volga River Basin (Russia)

The Volga River Basin, in central Russia, is the largest river basin in Europe. It begins in the Valdai Hills north-west of Moscow and discharges into the Caspian Sea. The total basin area is 1,380,000 km^2 and the approximate length of the Volga River is 3,701 km.

Map 8: Volga River Basin

2.2 Physiographic Characteristics of the Case Study Basins

There are a myriad of physiographic factors which can influence the magnitude of the sediment yield of a river basin and the sediment load transported by the river. The most significant factors include: climate (including rainfall intensity), basin size, topography, tectonics and geology, soil type, land use and hydrology.

Table 1 provides an overview of relevant physiographic information for each case study basin, where available in the reports. Because of information gaps, this table is intended as a summary and does not provide a basis for detailed comparisons between the case study regions.

Table 1: Comparison Table of Physiographic Conditions for River Basins

Basin	Physiographic Conditions					
	Climate	**Tectonics and geology**	**Topography**	**Soils**	**Hydrology**	**Vegetation and Land Use**
Nile River Basin ***** (please see note below)	Temperature: average from 15^{o}C to 27^{o}C. Precipitation: variable across the catchment – ranging from 1500mm per annum in southern Sudan to under 20mm per annum in Egypt. No further information available.	Nubian sandstone and granite dominate are the dominant rock types. No further information available.	The total area of the Nile Basin is estimated as 3,112,369 km^2.	Calcareous soils and soils formed by the weathering of basic volcanic rocks and sandstone. No further information available.	Runoff coefficient: 5.5% Average annual flow: 84 billion m^3 as measured at AHD. The annual hydrograph is characterized by a peak of up to 1000 millions m^3 per day (during the flood period July, August and September) and flows of less than 80 millions m^3 per day on the falling limb (recession period).	The northern part of Sudan and the Ethiopian Highlands lack any significant vegetation cover. Agricultural expansion on to steep slopes is an issue. Land use information is not available for all areas. Information is available for the Ugandan portion of basin (p 24 of Case Study Report)
Mississippi River Basin	Temperature: huge range across basin, with average of 9^{o}C winter temp and 28^{o}C	A wide variety of geological structures and rock types across the basin. No information in	The basin area is 3.1 million km^2. The region is classified as an area of "Irregular Plains"	A wide variety of soil types exist across the basin. No information included in	Flow rates on the lower Mississippi are approximately: 30,000 m3/s.	Intensive agriculture, particularly in Upper Mississippi Basin. Little information

	summer temp. Precipitation: 1250mm (in north) – 1550mm (in south)	report.	with a local relief of 300 to 500 feet and 50 to 80% of the surface gently sloping. The Mississippi River flows through three major landform regions: the Central Lowland Province, the Ozark Plateau Province and the Coastal Plain Province.	report. Sediment varieties include: Superior lobe sediment, Wadena or Des Moines lobe sediment, Lower Peoria Silt, and Lake Michigan lobe sediment.		provided in Case Study Report on vegetation coverage or land use.
Rhine River Basin	Temperature: annual mean is 10^{o}C to below 0^{o}C in the Alpine areas. Precipitation: 1100mm average mean (from 450mm in Alsace up to 4,000mm in parts of the Bernese Oberland).	The morphological structure of the Rhine basin can be divided into the high mountain area (Alps), the Alpine foothills, and the uplands.	The catchment area extends to almost 190,000 km^2 . The River Rhine, with a length of 1,320 km, can be divided into 6 major reaches. The reach extending from the main sources, the Vorderrhein and the Hinterrhein, to the point where the river discharges into Lake Constance is called the Alpine Rhine. The main tributaries of the Rhine are the Aare, Ill, Neckar, Main, Lahn, Moselle, Ruhr and Lippe.	In the uplands brown earth soils predominate, and podzolic soils are frequent in the plains The Upper Rhine Graben consists of Mesozoic strata with an overlying cover of marine, sandy-clayey Tertiary material more than 2000 m deep. The surface of the	Average runoff: 520mm Average evaporation: 580 mm. The ratio between the lowest and the highest flow in the Swiss Alps is 1:68 but at the border between Germany and The Netherlands the ratio is only 1:21.	Land use in the Rhine is dominated by intensive agriculture and forestry. A third of the basin is currently forested. Over 12.9% of the basin is urbanized.

			The mean elevation of the Rhine basin was calculated to be 483 m and the mean terrain slope 5°44'.	central basin is formed by 200-400 m thick Quaternary deposits. These deposits contain extensive and productive aquifers (more p42).		
Volga River Basin	Temperature: annual mean 3°C in north to 9°C in the south. Precipitation: 662mm (range from 150mm to 750mm in different areas).	The Volga River Basin represents a vast tectonic depression that has been in-filled by sedimentary rocks, predominantly limestones, marls and dolomites. The Carboniferous age sedimentary rocks (mainly calcareous rocks) are most widespread along the quasi-latitudinal line of the Volga River Basin western boundary. The eastern part of the Volga River Basin is dominated by continental, lagoon, lagoon-marine, terrigenous marine	The Volga River Basin is situated almost entirely within the Russian Plain, occupying about third of its total area. The basin area is 1,380,000 km^2. The length of the Volga River is about 3700 km. This is the only large river basin in Russia completely disconnected from the oceans. The Volga River Basin is dominated by plain landscapes (80% of basin area is below 200m above sea level). Mountainous terrain occupies no more than 5% of the total basin area.	Soil cover of the region is dominated by grey forest soils and soddy podzolic soils formed on glacial or glaciofluvial deposits Intensity of soil erosion on arable lands varies from <1 t/ha/year to >20 t/ha/year.	Highest average annual discharge: 8380 m3/s near Volgograd City. Annual average runoff: 179 mm. Average runoff coefficient: 27%. Rainfall erosivity coefficient of the USLE model is 6.8 estimated for the Torzhok city.	There is a wide spatial zonation of vegetation across Basin. In the north-eastern part of the basin coniferous forests occupy up to 70-80% of the area, while to the south this percentage decreases to 1-5%. More information is provided on page 30 of the Case Study Report. Steppes of the southern European Russia are at present largely cultivated. Today at least 86% of the land is owned as agricultural land.

		and calcareous evaporite sedimentary rocks of the Permian and Triassic ages.	There are more than 150000 small rivers in the Volga River Basin.			
Yellow River Basin	Temperature: annual mean temperatures vary from 1-8°C in the upper basin, 8-14°C in the middle basin and 12-14°C in the lower basin. Precipitation: the mean annual rainfall is 467mm, while the mean annual rainfall volume is about 370×10^9 m^3 , which accounts for only 6% of the total volume in China.	The Loess Plateau in the upper reaches are highly susceptible to erosion. The Yellow River is a perched river in many areas, particularly in the lower reaches, with the streambed being elevated above the surrounding terrain due to sediment deposition.	The total length of the Yellow River is 5,464 km and the drainage area is 753,000 km^2.	The Loess Plateau is the main source area of sediment in the Yellow River Basin. Loess is a deposit of coarse silt-size grains, loosely cemented by calcium carbonate. The amount of fine silt with diameters ranging from 0.002 to 0.05mm is as high as 70%. As loess is usually rather homogeneous and ill-consolidated, and as calcium carbonate is rather soluble in water, loess is highly erodible.	Average runoff: 47.38 billion m^3	The gullied-hilly zone and gullied flat ridge zones account for 43% of the basin area, and have vegetation coverage of approximately 30%. A table listing all vegetation zones is provided on page 18 of the Case Study Report. The basin has high levels of agricultural development yet figures are not provided in the Case Study Report.

Haihe River	Precipitation: the mean annual rainfall is 560mm with a distribution range from 400mm in the Yanbei region to 800mm near the Taihang and Yanshan Mountains.	No information provided.	The watershed area is 263.400 km^2. Mountainous regions and the plain each account for 50% of the total area. The northern and western areas are either mountainous region or plateaus. Eastern and southeastern parts belong to the North China Plain. The Taihang and Yanshan Mountains stretch from southwest to northeast, encircling the plain.	Red soil, loess and alluvial soil are the dominant soil types.	Water resources in the watershed are 35.3 billion m^3, of which 22.8 billion m^3 are river runoff. The total annual sediment load of the watershed is 0.15 billion ton.	No information provided.
Liaohe River	Temperature: the annual mean temperature is 4-9^{o}C. Precipitation: mean annual precipitation 350-1000mm decreasing from SW to NW.	No information provided.	The watershed area is 220, 000 km^2 Mountainous regions account for 35.7% of the total area, hilly regions 23.5%, plain regions 34.5% and sand dune regions 6.3%.	No information provided.	Average annual runoff: 2.89 billion m^3	The eastern region has good vegetation cover and the western region has poor vegetation cover. No information on agricultural production in the basin is provided in the Case Study Report.

* Although it is unclear from the Nile Case Study Report whether the report is intended to cover the whole basin. The Nile Basin covers a wide variety of geological structures and huge range of climatic zone from Lake Victoria (Tanzania, Kenya and Uganda) to Deltas in the Egypt. The information provided in this table is not comprehensive and no further information is available in the report.

2.3 Socio-economic considerations

The social demands on water management, including water supply, flood control, sediment control, navigation, environmental health and recreational use, are increasing with the growth of human populations around the world. In arid areas where water is scarce, these issues take on an increased significance. Food production and water management usually go hand-in-hand, with agricultural water use accounting for approximately 70% of the total world water use. In the recent past the area of land under agricultural production has increased sharply, reducing forest cover and increasing water use and rates of soil loss. Since agriculture is the key sector of employment in most developing countries, the allocation and management of water resources is crucial to their ongoing development. Sediment management is very important to agriculture, both in terms of minimizing erosion from farmland and also in ensuring the efficient operation of irrigation infrastructure (which may be disrupted by excess sediment in waterways).

This section considers the social and economic situation of each case study region, especially in relation to water and sediment management. It seeks to provide the basis for broader analysis of how the socio-economic conditions of each case study regions either mitigate or enhance the impacts of sediment on the local population.

2.3.1. Haihe and Liaohe Rivers (China)

The Haihe River Basin covers 3.3% of China's area (318,200km^2) and has a high population density, accounting for approximately 10% (over 122 million) of China's total population, with 28% of the population living in urban areas.[3] Two of the four provincial level municipalities directly under the control of the central government - Beijing and Tianjin - are found in the basin, together with 25 other large to medium- sized cities. The GDP of the basin in 1998 was 967.4 billion RMB, accounting for 12% of the national GDP. The GDP per capita of 7,922 RMB is about 25% higher than the national average (of 6,270 RMB). The region is very important to China from an economic perspective – hosting significant areas of manufacturing, industry and agriculture. There are also several important coal mine bases in the basin, including Datong, Yangquan, Jingxing, Fengfeng and Hebi and two oil fields - Huabei and Dagang.

The management plan for the Haihe River Basin went through expert review in June 2010, with the intention of improving water management in the Basin and making it the third 'Growth Pole' after the Yangtze River delta and Pearl River delta. [4]

The Liaohe River Basin covers 2.196×10^5km^2 and includes 15 cities and 56 counties with a population of around 35 million (based on 2005 data). The total cultivated area is approximately 4.95×10^6hm^2. [5]The area hosts significant heavy industry, energy production and commodity grain production centres and is highly urbanized. Within Liaoning Province, urban areas accounted for 60.3% of the population in 2005, much higher than the national

[3]Haihe River Conservancy Commission, Ministry of Water Resources, PRC, 1998 http://www.hwcc.gov.cn/pub/hwcc/static/lygk/lyzs.htm

[4] Speech of the Vice Minister, Ministry of Water Resources, PRC http://www.gov.cn/gzdt/2010-06/03/content_1619942.htm

[5] Pollution Prevention and Management Plan of Liaohe River http://cn.chinagate.cn/economics/2010-10/27/content_21213043.htm

average of 45.68%. The GDP of the area of 600 billion RMB and is slightly higher than the national average in terms of GDP per capita.

The highly urbanized Liaohe River Basin faces challenges for ensuring water supply to the residents in the cities. [6] The water management authorities have been calling for water saving for urban and industrial development as well as for ecological restoration[7].

2.3.2. Yellow River Basin (China)

The Yellow River Basin accounts for approximately 7% of China's area (752,000 km^2), 11% of its population (136 million people), and 13% of the total cultivated area (12.9 million hectares). There are over 50 cities in the Basin with a population of more than half a million people which are reliant on the river as a source of water. In the year 2000, 26.4% of the Basin was urbanized. The area of irrigated agricultural development has increased almost ten-fold since 1950, covering 7.5 million (or 75,000km^2) hectares in 2000. Irrigation accounts for 84% of water use, industry for 9% and households for 5%. Despite the population's heavy reliance on the river for domestic use, agricultural use and industrial use (in particular chemical and oil production in the middle and lower reaches) the river only accounts for 3% of China's water resources. [8]

The population and living standards in the basin are both increasing, placing increased pressure on land and water resources. The GDP of the basin is $8.8 billion US which is mainly industrial and agricultural production. Shandong has the highest intensity of industrialization yet Henan and Shanxi are also increasing. The North China Plain in Henan and Shandong has experienced huge increases in the intensity of agricultural production in recent years because of its flat land, few employment prospects outside the agricultural sector, and increased food demand from both the north and south of China.

The Yellow River Provinces have lower 'human development index' scores and a lower GDP per capita than most other areas of China. Poverty is generally concentrated in areas with few non-agricultural income opportunities, and is most severe in the upstream areas of the basin, where rain-fed agriculture is dominant. Farmers are the most sensitive group in relation to water issues.

2.3.4. Mississippi River Basin (USA)

The Mississippi River Basin has an area covering 3.1 million km^2, or 40% of continental USA, and a population of over 30 million. Nearly 80% of the population lives in urban areas (with 50 cities relying on the Mississippi for urban water supply) yet over 60% of the basin is cropland or pasture. Major crops include corn and soya beans. Agriculture in the basin accounts for over 90% of the countries agricultural exports and most of the USA's livestock. The river is

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[6] Evolutional Trend of Water Resource in Liaohe River (journal paper of 2006 by researchers of Changchun Institute of Geography，Chinese Academy of Sciences，Changchun 130021，Jilin Province，PRC
http://www.66wen.com/06gx/shuili/shuiwen/20061020/46097.html

[7] Speech of the VM, Ministry of Water Resources, PRC
http://ghjh.mwr.gov.cn/ldjh/201003/t20100302_181067.html

[8]http://www.unesco.org/water/wwap/wwdr/wwdr3/case_studies/pdf/Case_Studies_AsiaPacific.pdf#page=6 (Ref Li,2005 and YRCC for figures for irrigation/water use).

the major shipping route to the Port of New Orleans and the Ports of South Louisiana with the main goods being petroleum, iron, grain, rubber, paper, wood, coffee, coal, chemicals and edible oils.

There are over 3,000 reservoirs in the basin which are mainly used for flood storage and water supply, and over 2,580km of levees. The Mississippi is both a source of freshwater and also an outlet for industrial and municipal waste. Water pollution is a serious issue for the Mississippi. This is compounded by the fact that the river is also a key site of recreational use by residents – used for swimming, boating, fishing etc.

2.3.5. Nile River Basin

The Nile River Basin has a population of approximately 170 million people from 10 countries and is home to most of Egypt's 78 million people. There are 25 large cities in the basin with over 100,000 people. The Nile River Basin is expected to be water scarce by 2025.

The few dams in the Basin contribute significantly to socio-economic development, providing hydropower generation, flood control and irrigation water storage. The area includes sections of five of the poorest counties in the world, where per capita income is less than $250 US per year. Economic development is essential to the improving the living conditions of people in these regions, and for future generations.

Despite the importance of water resource development to the population of the Nile River Basin, there are still many hurdles to achieving effective management. These include: a lack of skilled manpower and implementation capacity, poor management of water resource schemes (especially small-scale schemes), traditional irrigation methods, inadequate legislation to govern conflicts between different sectors and users of the common resource, and lack of effective monitoring and evaluation of projects and programs.

2.3.6. Rhine River Basin

The Rhine River Basin has an area of 170,000 km^2 and a population of approximately 50 million. The majority of major cities in the Basin are located on the Rhine River. Both the cities and agricultural regions in the Basin are heavily dependent on the river for their water supply (the Rhine supplies 20 million people with drinking water), energy production and disposal of waste water. Industrial developments, in particular chemical production plants, are prevalent along the Rhine. The Rhine is also Europe's busiest shipping route, connecting Rotterdam with the world's largest inland port of Duisburg.

2.3.7. Volga River Basin

The Volga River Basin contains eleven of the twenty largest cities in Russia, including Moscow, and covers 10% of Russia's total land area. Its reservoirs provide a reliable source of water and hydroelectric power for the region, which is home to over 60 million people. Water from all large reservoirs is used for drinking water supply of large cities located along the main channels of the Volga and the Rama rivers. Also it is used for industrial needs. Two middle size reservoirs are located in the canal between the Moscow River and the Upper Volga River. Water for given reservoirs are delivered from the Volga river and it is used as drinking water for the citizens of the Northern part of Moscow.

The Volga and its tributaries provide important shipping routes throughout Russia – connecting the White Sea, the Baltic Sea, the Caspian Sea, the Sea of Azov and the Black Sea.

The Basin is highly fertile, with wheat as the main crop. Fishing (including caviar mainly at Astrakhan), mining, salt mining, timber, natural gas production and petroleum are also major industries in the Volga valley. The population has serious concerns about the safety of drinking water – with around 42 million tonnes of toxic waste being generated within the basin each year and only 3% of the river's water being a safe source for drinking.

2.4 Hydraulic works and reservoirs

The presence of hydraulic works and reservoirs will both impact upon the sediment regime and be influenced by the sediment regime. For example, the presence of river control structures such as reservoirs will attenuate the flow of water and result in the deposition of sediment. Excessive sediment accumulation in reservoirs may reduce the useful lifespan of these structures for water supply and flood control purposes, and reduced sediment loads in rivers below reservoirs may result in erosion and channel degradation and subsequent damage to river infrastructure (bridges, culverts etc.). A summary of the available data on numbers of hydraulic works and reservoirs in each area is provided in Table 2.

The construction of reservoirs is usually based on considerations such as the suitability of local topography and the need for water storage or flood control in the area. The number, size and design of hydraulic works on a river may be useful in considering the water/sediment storage potential, the scale of disruption of the natural sediment regime, and therefore also the downstream impacts of these structures.

The estimate of the number of river control structures (mainly dams and reservoirs) per basin area would be more usefully compared if the economic and physiographic conditions of each region were more similar. The high ratio of river control structures per square kilometer in the Chinese River Basins is mainly due to the inclusion of available data on the large number of small reservoirs. Considering only the large reservoirs (as shown in the brackets in the table) would make the figures more comparable to other basins.

Box 2: The Aswan High Dam on the River Nile

Construction of the Aswan High Dam began in 1960. Prior to this, the River Nile experienced summer flooding, which had both positive and negative consequences. The positive aspects of the flooding were that it deposited essential nutrients on the floodplains, increasing soil fertility and agricultural productivity. The negative effect of flooding was that it had the potential to cause a danger to human populations as well as destroying crops and damaging infrastructure. The dam was built to regulate annual flooding, provide storage of water for agriculture and permit the generation of hydroelectricity.

Today the Aswan High Dam traps vast quantities of sediment which both reduces the storage capacity of Lake Nasser and results in problems downstream of the dam. Such problems include: the increased use of chemical fertilizers to replace nutrients once carried in sediment deposited during floods, erosion of farmland on the river banks, erosion of the coastline and degradation of the Nile Delta (including the fertility of ecosystems in the region), a decline in Mediterranean fishing due to a reduction in nutrients from upstream, and seawater intrusion in the northern portion of the delta.

Table 2: Major hydraulic words and reservoirs in the case study regions

*= incomplete information in Case Study Reports

River Basin	Large Reservoirs/ Dams [9]	Small dams	Weirs/ Locks/ Other	Total	Total number of river control structures/km^2
Haihe	25 (Total capacity of 18.1 billion m^3)	1350	Not available	1375	0.0052
Liouhe	17 (Total capacity of 13.2 billion m^3)	64 medium sized, 607 small sized.	Not available	688	0.0031
Yellow River Basin[10]	22	159 medium sized, 559 small sized.	Not available	740	0.001
Mississippi River	Upper River has 29 locks and dams	Not available	Not available	29	0.000009*
Nile River	10 (plus two under construction)	Not available	Series of barrages near the delta in Egypt	10	0.000003*
Rhine River	10	Not available	Not available	10	0.00005*
Volga River	11 (8 large hydropower on Volga, 3 large dams on Kama River)	9 medium-sized, approx 900 small	12 locks	932	0.0007

[9]A 'large dam' is usually defined by ICOLD as one measuring 15 m, or more from foundation to crest, i.e. taller than a four-storey building, or with reservoir capacity greater than 1.0 million m^3. The reports have not defined how they classify large dams so this has been assumed where they refer to 'large' dams.

[10] The Yellow River Case Study provides a detailed analysis of the sediment-storage and other characteristics of major reservoirs in the Basin.

3. Sediment Regimes

3.1 Inter-basin contrasts in erosion and sediment yield

The river basins being considered in this report are all very different in terms of sediment load and erosion characteristics. The following table facilitates comparison of estimated sediment loads and yields and whether sediment loads are increasing or decreasing.

Table 3: Comparison of sediment yields and trends in sediment discharge

River Basin	Sediment load – mean annual load in lower basin	Mean annual sediment yield/basin area (km^2)	Annual average runoff	Sediment discharge increasing/ decreasing	Reason for increase/decrease in discharge & other comments
Haihe	0.15 billion tonnes	569.4 tonnes	22.8 billion m^3	Decreasing	Dam construction trapping sediment.
Liaohe	39.19 million tonnes (Pre-dam[11]) 11.43 million tonnes (Post-dam)	51.95 tonnes (post-dam)	5.67 billion m^3 (Pre-dam) 2.89 billion m^3 (Post-dam)	Decreasing	Dam construction trapping sediment (except in flood season where sediment is released from reservoir)
Yellow	1.63 [12]billion tonnes (1919 – 1960) 0.8392 billion tonnes (1952~2000)	1130.3 tonnes (post-dam)	47.38 billion m^3	Decreasing (land is still accumulating at river mouth)	Low flow to ocean and large reservoirs trapping sediment.
Mississ ippi	205 million tonnes	64.01 tonnes	-	Decreasing	Levees, reservoirs trapping sediment.
Nile	160 million tonnes (at Aswan High Dam)	51.61 tonnes	-	Decreasing	Aswan Dam trapping sediment upstream
Rhine	7.3 million tonnes[13] [2.75 million t for German portion]	39.46 tonnes	-	Decreasing	Reservoirs trapping sediment.
Volga	26 million tonnes (Pre-dam) 8 million tonnes (Post-dam)	5.80 tonnes	254 km^3	Decreasing	Reservoirs trapping sediment.

[11] The Naodehai Reservoir was built in 1971.
[12] Table 1.4 on page 7 of Yellow River Case Study Report says that total sediment load is 16.3 billion m^3 yet it is unclear which time period this is for.
[13] Van Dijk, P &Kwaad, F. (1998) Modelling suspended sediment supply to the River Rhine drainage network; a methodological study. *Modelling Soil Erosion, Sediment Transport and Closely Related Hydrological Processes.* IAHS Publ. no. 249, 1998.*Amsterdam, The Netherlands*

Soil erosion rates are likely to be almost as variable within basins because of local conditions as between basins. Since a discussion of the influence of particular local soil types on soil erosion rates is likely to be of limited value in terms of transferring sediment management strategies to other areas of the world, it will not be explored in this report. The Yellow River Basin, however, deserves special mention because it has the highest sediment yield of any river in the world. This reflects the severe soil erosion occurring within the Loess Plateau, where the soils are highly erodible. The sediment regime of this river is somewhat unique in that up to 80% of the sediment load originates from a relatively small (110,000km^2) area of serious soil erosion in the Hekouzhen-Longmen catchment (the majority of the runoff comes from the area upstream of Hekouzhen, whereas the majority of the sediment comes from the area downstream of Hekouzhen). The highest recorded sediment concentration of 128 kg/m^3 was measured in this area. The Chinese water management authorities have been able to target their efforts in reducing soil erosion to this area and, as discussed later in this report, have made good progress in reducing sediment mobilization and delivery within the Loess Plateau area, through a number of measures. As shown in Table 3, the sediment load has decreased significantly since the 1950's, which is when the Yellow River Conservancy Commission began implementing erosion control Measures.

In the Volga River Basin, the intensity of soil erosion on arable land varies from <1t/ha/year to >20 t/ha/year.The greatest impact on water quality and suspended sediment concentrations is generally a result of soil erosion in the middle part of the Volga River Basin. Under natural conditions, the Volga River exported large amounts of sediment to the Caspian Sea, and it has been estimated that annual loads were about 26×10^6 tonnes. At present the entrapment of sediment by large reservoirs along the Volga River has resulted in a significant decrease of the suspended sediment yield at the basin outlet to 8×10^6 tonnes per year.

Table 3 indicates that all rivers in the case study reports are experiencing decreasing downstream sediment loads, primarily due to the impact of large reservoirs. Although estimates of pre-dam sediment loads are not provided for all river basins, an example from the Mississippi River will be provided. For the lower Mississippi River, the pre-reservoir suspended sediment load is estimated to have been 400 to 500 million tonnes per year. Recent measurements and estimates demonstrate a reduction of sediment load by approximately 50% since the construction of reservoirs.[14] In some areas, success has been achieved in reducing the amount of sediment trapped by dams, with specially designed structures permitting sediment to be discharged with the water. In other areas, reservoir management strategies allow sediment-rich water to be discharged downstream. Since 1971 the Naodehai Reservoir, on the Liaohe River in China, has had special management arrangements in place, aiming to discharge muddy water in the flood season while impounding clear water in the dry season.

[14]Kesel, R. H. *et al*. (1992) An approximation of the sediment budget of the lower Mississippi River prior to major human modification. *Earth Surf.Process.Landf.*17, 711.

4. Sediment Issues

4.1 Overview of sediment issues, their causes and their impacts

Sediment transport, as a natural component of river geomorphology, is generally not in itself a problem. Sediment plays an important role in maintaining fluvial environments such as channel systems, floodplains, wetlands and estuaries, and equilibrium between erosion and deposition usually occurs along a river's course in natural, undisturbed, systems. Equally, soil erosion must be seen as a natural process and in undisturbed landscapes, rates of soil loss or surface lowering are generally balanced by rates of soil formation. However, natural equilibria are readily disrupted by extreme climatic events and human activities, such as land clearance which cause increased inputs of both runoff and sediment to river systems. The resulting imbalances can have a range of detrimental impacts on society, economies and the environment. Neglecting to manage sediment in a sustainable way, through effective sediment management strategies or policies, could lead to a higher operational costs and significant adverse impacts on society and the environment. It is therefore important to evaluate the socio-economic and environmental impacts which necessitate sediment management.

Studies of longer-term sediment loads undertaken in some areas have demonstrated that sediment loads are dependent on many factors. These include reservoir construction, land use change (tree clearing or different forms of agricultural production), mining, and any soil or water conservation techniques employed in the region. In the Yellow River Basin, historical comparisons have been made of erosion rates, in an attempt to compare natural and man-made processes contributing to soil erosion. In this study, shown on page 21 of the case study report, it can be seen that erosion rates have increased dramatically since the early 1900's, in line with increases in population and the intensification of agriculture in the region.

Sedimentation in reservoirs is perhaps the most pressing concern facing river managers today, and has the potential to cause both upstream and downstream impacts. For the purposes of this report, sediment problems and issues will be divided into those resulting from changes in sediment regimes due to the construction of reservoirs (which will be further divided into 'upstream' impacts of sediment which are mainly issues relating to the storage of sediment in reservoirs, and 'downstream' impacts as a result of sediment being trapped in reservoirs), and the impacts of excessive sediment loads more generally.

This section seeks to provide an overview of key impacts relating to the mismanagement of river basins and sediment in river systems. The main sediment issues are:

4.1.1. The upstream negative effects of reservoir sedimentation

<u>Loss of reservoir storage capacity:</u>

The key impact of reservoir sedimentation is a reduction in the useful life of the reservoir. Sediment deposition is a key factor reducing the life of dams around the world. Reservoirs are expensive to build and their construction usually also entails high social and environmental costs. Entire communities may be forced to relocate and ecosystems destroyed in their construction. However, it is recognized that dams also bring many benefits

– such as water storage, power generation and flood mitigation. Extending the life of dams through careful management of sediment, therefore, should be a key priority.

Effects of sediment on hydropower operations and reservoir operations:

The build-up of sediment in front of power intakes may result in significant costs for hydropower operations. Dredging is often required to remove excess sediment and allow a full flow of water through the intakes. Costly engineering solutions are sometimes employed as an alternative.

If the sediment accumulation is high, the reservoir outlet works (intake and bottom outlet structures) may also become clogged. Abrasion of hydraulic machinery may also occur, decreasing its efficiency and increasing maintenance costs.

4.1.2 The downstream negative effects of reservoir sedimentation resulting from bed degradation or sediment deficiency

The downstream impacts of the trapping of sediment by reservoirs are quite different from the upstream effects. The problems generally result from shortages of sediment and the consequences for the equilibrium of the fluvial system and environment. When water enters a reservoir, most of incoming sediment load is usually deposited. Water is then usually released from the top of the reservoir and contains very little sediment. The lack of sediment flowing downstream combined with the natural erosive force of the flow of the river creates erosion in the form of a widening and deepening of the river channel. The distance over which erosion takes place, and the scale of this erosion, depends heavily on the flow and morphological characteristics of the river. For example, below the Danjiangkou Reservoir on the Lower Yellow River, erosion due to the trapping of sediment behind the dam extended for over 800km downstream.

Damage to wetland, floodplain and estuary ecosystems reliant on sediment:

Many wetland areas are reliant on a continuous supply of sediment to maintain their ecological functioning and biological diversity. Estuary areas are also often reliant on the deposition of nutrient-rich sediment to support fish breeding. When dams trap sediment upstream these ecological assets may become deprived of sediment and nutrients and may eventually disappear.

Reservoirs designed for flood mitigation often have the unintended consequence of depriving downstream floodplains of deposited sediment. After reservoir construction, these areas no longer receive the periodic sediment-recharging floods that are important for their functioning. Under natural conditions, floods carrying suspended sediment would spill onto river floodplains, leaving behind both sediment and associated nutrients. This sediment can play an important role in nourishing both natural ecosystems and agricultural land. Today, agriculture on floodplains which are no longer subject to natural flooding regimes often relies entirely on artificial fertilizers to replenish soil nutrients. This can have serious implications for downstream water quality as such fertilizers often cause increased nutrient inputs to rivers.

Impacts on infrastructure:

Too little sediment, especially downstream of dams, may encourage accelerated erosion around structures on/in riverbeds or riverbanks due to a lack of sediment recharge. In extreme cases, excessive erosion has led to incidents such as bridge collapses. Cracks in infrastructure such as bridges and other structures are typical results of such erosion.

4.1.3 Excessive sediment accumulation on river beds and in river environments

Flooding:

Flooding occurs when a watercourse is unable to convey the quantity of runoff flowing downstream. The frequency with which this occurs is described by a return period. Flooding is a natural process, which maintains ecosystem composition and processes, but it can also be altered by land use changes including river engineering. Increased sediment accumulation in river systems can raise the level of the riverbed, subsequently increasing water levels. This deposition can have significant implications for flooding, and may cause floods which would otherwise be contained by banks and levees to pose a risk to human settlements.

As an example, in the Mississippi Basin, many of the backwater lakes along the Illinois River have lost 30 to 100% of their capacity to sediment deposition. On the average about 18.7 million tonnes of sediment are deposited annually over the entire river valley, with a deposition rate of 20.5-53.3 mm/yr. These conditions pose a serious risk to flooding.

Navigational issues:

The sedimentation of water courses can also make them unsuitable for navigation without regular dredging work. This dredging is often costly to operate.

Impacts on wetlands and in-stream ecosystems:

Where dams do not exist to trap sediment, excessive sediment inputs may have negative impacts on wetland areas. This is especially the case where wetlands occur close to agricultural areas where land use change has resulted increased rates of soil loss, increased downstream sediment loads and increased rates of sedimentation in wetland areas.

The impact of excessive sediment deposition in wetlands may create ecological disruption. Sediment may smother primary producers and invertebrates and this may result in alteration of aquatic food webs, nutrient cycling and biogenic processes that transform and sequester pollutants. Eventually sediment deposition may entirely smother wetlands resulting in limited biological diversity.

Impacts on infrastructure:

Aside from dams, sediment can have impacts on other man-made infrastructure. Too much sediment can disrupt the normal functioning of irrigation pump house intakes and can also disrupt irrigation when excess sediment is deposited in canal systems. Deposition in canal systems can lead to high costs for those reliant on these systems as a water supply. Dredging may be required to remove surplus sediment. Sediment deposition may also result in blockages or inefficiencies in irrigation infrastructure (including pumps and distribution networks) and may even impact upon the produce.

Sediment also has negative impacts on domestic water supplies – causing problems in both water treatment plants and distribution networks. Failure of water treatment plants, especially in poor regions, can mean that water is unsuitable for human consumptions. Populations may suffer from health effects as a result. In the Nile River Basin, for example, the turbidity during the flood season can reach 23,000ppm, disrupting water treatment and meaning that only 50% of the population has access to safe drinking water. In some Sudanese rural areas, this can drop to 25% of the population in the dry season. Chemical treatment of water is often used and can create its own health impacts on the population.

Sediment impacts on water quality (turbidity and sediment-associated pollutants):

Sediment is a pollutant in its own right. Even where sediment is uncontaminated by agricultural fertilizers and pesticides and industrial or human waste, they cause turbidity in the water which limits light penetration and prohibits healthy plant growth on the river bed. The accumulation of sediments on the river bed can smother or disrupt aquatic ecosystems by reducing food sources, and degrading spawning grounds (such as gravel and rocky environments) and the habitats of desirable fish species. Turbidity may also result in eutrophication where nutrient rich sediments are present (particularly sediments from agricultural land with high fertilizer contents). Eutrophication creates a situation where the oxygen present in the water system is reduced to the point where fish species may be unable to survive in the water column. Eutrophication, where it results from toxic algal blooms, can also be a serious risk to human health.

Sediments in areas with high human activity often contain chemical pollutants which may pose a risk to human health and the health of surrounding ecosystems. Potable water supplies can be compromised by the presence of excess sediment (whether contaminated by toxins or not) as purification facilities may not be able to cope with the sediment in the water – leading to temporary breakdowns and subsequent risks to the safety of the drinking water. Contaminated surface waters also risk altering the metabolic processes of the aquatic species that they host. These alterations can lead to fish kills or alter the balance of populations present. Other specific impacts are on animal reproducing, spawning, egg and larvae viability, juvenile survival and plant productivity.[15]Some areas have been very active in improving water quality in relation to sediment management and control. In the Rhine River Basin, for example, the “Rhine Action Programme” has significantly improved water quality by reducing point source pollution, including sediments. Today river water quality results are required to meet certain target values and polluters are punished for infringements.

4.2 Identification of priority issues and discussion of inter-basin contrasts in the type and scale of sediment problems

Erosion and sedimentation are natural phenomena which can be greatly affected by human activities. Natural factors such as highly erodible soils, steep unstable slopes and high rainfall intensities often play an important role in increasing rates of erosion and sediment loads. However, natural erosion is generally a very slow process which takes place over centuries or even millennia. Human induced or accelerated erosion and associated increases in sediment inputs to rivers can result in major increases in sediment flux and important impacts on water

[15] Lin, B & Cleveland, C. (2010) "Surface runoff". In: Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment). [Retrieved September 28, 2010 <http://www.eoearth.org/article/Surface_runoff>]

quality and sediment t loads. Understanding the causes of human induced or accelerated erosion is very important when studying sediment transport and managing sediment loads in rivers.

The principal factors which influence the significance and magnitude of accelerated erosion rates are the size of the area under cultivation, and changes of land use, crop rotation and agricultural practices. The key anthropogenic driver of high sediment loads in most of the river systems considered in this report is agricultural practices. The clearing of vegetation to promote agricultural expansion, as well as tillage techniques which leave the soil unprotected by crops and loosened, during periods of high erosivity can greatly increase rates of erosion by both rainfall and runoff and wind. In particularly vulnerable areas, unsustainable farming practices may result in highly destructive forms of erosion – such as the formation of gullies – which can often render farmland useless and further compound the siltation problems in nearby streams and waterways and storage reservoirs.

The other major human-induced changes which disrupt the natural processes of erosion and sediment transport involve the construction of dams and other river-control structures, such as locks, weirs, meander cutoffs, river-training structures, and bank revetments. In some areas, sediment problems reflect a lack of sediment, rather than too much sediment, as a result of sediment being held back by these structures upstream. This can have serious impacts downstream in terms of erosion and lack of sediment recharge to wetlands and estuaries. There are no easy solutions to overcome the impact of river control structures on the flow of sediment. However, since the deposition of sediment in reservoirs is usually the greatest factor influencing the useful life of these structures, in recent times engineering solutions have been developed to increase dam life and allow the transfer of sediment downstream. The initial location, design, and management of river control structures should consider their potential impacts on downstream environments and infrastructure – especially in terms of sediment.

The nature and scale of the sediment problems faced by different river basins are frequently unique due to specific combinations of controlling factors such as topography, surface conditions and land use patterns. Furthermore, as indicated above, the importance or significance of the problems will also often be influenced by the socio-economic conditions in a river basin. Making comparisons between basins or ranking them according to the 'seriousness' of their sediment problems is therefore difficult (if not impossible). Due to the large amount of data that would be required from a usually large basin area, the case studies do not provide sufficient information to conclusively determine the impact of sediment on the economy (e.g. in terms of dollar-values), society (e.g. in terms of flooding impacts) or the environment (e.g. in terms of overall reductions in water quality or loss of habitat/species).

Table 4 attempts to 'rank' the case study river basins, based on the sediment problems within the river basin which have the most serious impacts on society, the economy and the environment. The case study reports provide more detailed information about each of the issues listed in the table.[16] The table does, however, serve to provide a summary of the key problems or issues in each basin.

[16] Please note that the rankings are subjective and based on the limited information in the case study reports. The table is not intended as a comprehensive overview of sediment issues in each Basin.

Table 4: Priority Sediment-related Issues in each River Basin.

Basin	Priority Issues	Case Study Page References for Further Information/Description of Priority Issues		
		Social Impact	**Economic Impact**	**Environmental Impact**
Haihe and Liaohe	Flood control	Page 7, 13	Page 7, 13	Page 7, 13
	Reservoir sedimentation		Page14	
Yellow River Basin	Evolution of the Yellow River Delta	Page 32	Page 32	
	Reservoir sedimentation		Page 36	
	Flood control	Page 7	Page 7	
Mississippi River	Decreased sediment loads – wetland loss & coastal erosion	Page 40	Page 40	Page 40
	Water quality	Page 42	Page 42	Page 42
	Coastal land loss in the delta	Page 32	Page 32	Page 32
Nile River	Decreased sediment load downstream of Aswan dam	Page 82	Page 82	Page 82
	Reservoir sedimentation		Page 76, 80	
	Canal system sedimentation & growth of aquatic weeds	Page 71-72, 82	Page 73-74	Page 71
Rhine River	Water quality	Page 26	Page 26	Page 26
	Reservoir & channel sedimentation		Page 62	
Volga River	Water quality	Page 19	Page 19	Page 19
	Decreased sediment load downstream	Page 105	Page 105	Page 105

Note: Page numbers refer to descriptions of the problems in the Case Study Reports which can be consulted for more information.

It is very difficult to assess which of the case study basins has been impacted the most by changes in erosion and sedimentation brought about by human activities, because the significance of particular problems will be different due to different economic and development pressures in different regions. One of the most widely cited, however, is likely to be the Nile Basin. The construction of the Aswan High Dam has virtually cut off sediment transport and deposition to downstream areas by trapping vast quantities of sediment. Agriculture in the lower Nile Basin has relied upon the deposition of nutrient-rich sediment on floodplains for thousands of years. Today, huge quantities of artificial fertilizers are used to sustain the fertility of the land. This has imposed extra costs on farmers, caused disruption to agricultural production and increased diffuse source pollution. The situation is likely to worsen into the future.

The reduction of downstream sediment transport, due to reservoirs trapping sediment, can also have serious impacts on estuarine ecosystems, and the populations and industries reliant upon them. The Mississippi Delta, for example, has been facing the loss of 65-104 km^2 of marshland each year. [17] The loss of habitat has been devastating for local plant and animal species, and also to the fishing industry in the area which relies on the marshlands as fish breeding grounds. The situation in the Mississippi Basin is by no means unique – most of the case study rivers will have experienced delta-retreat due to a decrease in sediment loads.

For all the benefits that reservoirs bring, it is evident that their construction also brings serious costs. Assessment of the 'downstream' impacts of reservoirs should be seen as an essential prerequisite for any decision making involving the construction of new dams.

Flood control also appears to be a major issue which is often hampered by excessive sediment deposition. The consequences of floods can include loss of life, and massive damage to property and agriculture. Careful planning of flood control must be undertaken to mitigate their impacts. The building of levees, for example, has worsened flooding in some instances. In the Mississippi River basin the narrowing of the river channel by the construction of levees can actually increase the impact of severe floods (for example, the 1993 flooding at St. Louis which killed 50 people and left thousands homeless). The Yellow River Basin is also a serious priority in terms of the contribution of sediment load to flooding. Sediment is a key influence on flood control along the Lower Yellow River and the failure of existing flood control measures would be catastrophic in terms of both loss of life and disruption of agriculture and the economy. The perched nature of the river channel which is itself the result of the excessive sediment loads and associated deposition is a very important driver of the flood problems.

4.3 Stakeholders affected

The identification of key stakeholders in sediment issues needs to be a primary step in the development of sediment management plans. People may be affected by sediment issues in a number of different ways and bringing their insight into management efforts will not only create a way forward for solving sediment issues, but may also bring about better management of the entire system in which sediment is only a small part. Key stakeholder concerns can be grouped into the following main categories (please note this is not an exclusive list and the unique situation of each management area should be considered in deciding who to consult):

<u>Agriculture including irrigation:</u>

Irrigated agriculture is generally the largest water user in river basins around the world. The needs of agriculture should be considered in water use and sediment decision-making. Agricultural practices which disturb the soil are also increasingly a cause of sediment issues in many areas, particularly where agriculture occurs in areas with highly erodible soil conditions or on steep slopes or other marginal land.

<u>Mining and industrial uses:</u>

Mining and industry also have a role to play as both a water user and also as a source of sediment in many cases. Where mining/industrial uses impact upon the sediment regime or

[17] Please note that this loss is also due to other human impacts, such as the cutting of new waterways for petroleum exploration etc. and cannot be solely explained by a lack of sediment deposition.

are impacted by reductions in water quality due to sediment, their concerns should also be taken into consideration.

Communities in flood-prone areas:

Floods pose a serious threat to those living in flood-prone areas. These people will often be of low economic status and living on marginal land, and deserve to be considered in decision making. Their safety should be a priority in decisions relating to sediment management. Preventing flood disasters and the protection of human life and property should be the paramount consideration in flood management, yet the aspirations and needs of people living in these communities should also be factored into the decision-making processes so their engagement is essential.

Reservoir managers:

Those responsible for river control structures such as reservoirs usually have a lot of expertise concerning the impact of sediment on the operation of their infrastructure. Engaging them in any decision-making relating to sediment control is crucial as their decisions about sediment management also impact downstream environments.

Wetland and environmental organizations:

The environment is rarely given a ‘voice’ in natural resources decision-making, so efforts should be made to engage with environmental organizations which seek to protect environmental assets. Wetlands, estuary environments, riparian areas and in-stream biota all suffer due to sediment imbalances in river systems. Changes in natural flow patters can eliminate environments and cause the disappearance of many species unable to adapt to new conditions.

Recreational users of rivers/lakes/reservoirs/estuaries:

For the Mississippi River alone, thousands of visitors come each year to visit the river to enjoy activities such as fishing, hunting, boating, water skiing, hiking, camping and simply enjoying the natural sites. The government considers sedimentation to be the most serious concern to the health and amenity of the river – not only in terms of visual amenity but also for fish reproduction and pollution.

5. Extent of information collection, analysis and reporting

The amount of information and data presented in the case study reports varies quite substantially between the individual river basins, but does necessarily provide a good indicator of the extent of data collection in the country/region involved. Background information on data collection programmes and data analysis and reporting was not always provided due to space considerations or because the documents were intended to inform non-technical audiences. Where essentially the same information was collected in different river basins, the data were often collected using different methodologies and at different spatial and temporal scales. This introduces difficulties when comparisons are attempted and emphasizes the need for common data collection methodologies around the world, a key recommendation of this report.

A report published by the World Meteorological Organization in 2003 – the *Manual on Sediment Management and Measurement (Operational Hydrology Report No. 47)* [18] – provides an overview of commonly used methods of data collection and analysis for sediment monitoring. Where appropriate, references will be made to information in this report. This information is provided on the basis that it provides guidance to sediment managers around the world and is not intended as an authoritative manual on sediment management and control. The methods used in case study basins may be more appropriate for local conditions (including natural, economic and technical).

5.1 Sediment measurement methodologies and assessment strategies including measurement and computational techniques

Methods and equipment for measuring sediment in rivers are becoming increasingly sophisticated. New techniques and technologies are continuously being developed, to improve the measurement parameters such as: flow velocity and turbulence, suspended sediment concentration and particle size composition, suspended sediment loads, bed load transport, and sediment accumulation in reservoirs and on floodplains, as well as methods for the measurement of landscape features influencing sediment loads, such as runoff and rates of erosion.

This section will focus on the key sediment measurement techniques considered in the case study reports. In most cases there are no agreed ‘best practice’ approaches to sediment measurement methodologies. The World Meteorological Organization’s *Manual on Sediment Management and Measurement (Operational Hydrology Report No. 47),* however, strives to identify the most useful sediment measurement techniques for river managers. This manual is referred to frequently in this section and should be consulted for further technical detail relating to the majority of the methods used in the case study reports.

<u>Measuring water movement:</u>

Water movement, i.e. stream flow, flow velocity or water discharge, will have an impact on the transport of sediment in river systems. Water levels and flow rates will vary at different points in the stream transect and along its course. The flow of a river can be measured in several

[18] Available online at: http://www.whycos.org/rubrique.php3?id_rubrique=11

different ways, using current meters and calibrated channel cross sections. Such measurements of water discharge are frequently coupled with water level readings to generate a stage/discharge relationship which can be used in conjunction with a continuous record of stage to generate a continuous record of water discharge. A report on 'Field Measurement of Soil Erosion and Runoff' published by the Food and Agriculture Organization of the United Nations, does however provide detailed methods for measuring stream flow. [19]

Measured data can then be used to calibrate and validate mathematical models used for predicting or forecasting river flows under a variety of conditions. A key application of such modeling is for flood forecasting. Computer models (such as the Dynamic Stream Simulation and Assessment Model - DSSAM) have been developed to route storm runoff through a river system. This is particularly useful for determining pollution levels in receiving waters as a result of storm runoff.

Measuring erosion rates on a basin scale:

Differences in measurement methodologies can be due to the perceived significance of the impacts of soil loss – either on agricultural land or on receiving waters. Agronomists, on the one hand, are concerned with the on-site impacts of soil loss on particular land areas. Hydrologists, on the other hand, are concerned with the off-site effects of soil loss on rivers and river infrastructure. Many measures of erosion, in tonnes/hectare, for example, do not account for the soil that is re-deposited during transfer across the landscape and does not end up in rivers. The 'sediment delivery ratio' (defined as the proportion of the soil or sediment mobilized by erosion that reaches the basin outlet) should be a key focus of hydrological investigations of erosion rates.

Erosion rates can be difficult to measure accurately, because they are highly variable spatially and influenced by many factors. Modelling is, therefore, a very useful tool for extrapolating available measurements and predicting sediment inputs to river systems under different conditions.

The Universal Soil Loss Equation (USLE) has been used extensively in the case study reports to estimate erosion rates in a particular area. It is explained in detail in the World Meteorological Organization's *Manual on Sediment Management and Measurement (Operational Hydrology Report No. 47).* The manual also includes a table on Page 15, also copied below, which classifies the intensity of soil erosion rates on a basin scale.

[19]Chapter 4 of the following book provides several methods for this: Hudson, N. (1993) 'Field Measurement of soil erosion and runoff'. Food and Agriculture Organization of the United Nations. Available at: http://www.fao.org/docrep/t0848e/t0848e00.htm

Table 5: Classifications of degrees of erosion by area

Degree	Mean Annual Erosion Modulus ($t\ km^{-2}.a$)	Mean lost thickness (mm/a)
Slight	<200, 500, 1000	<0.15, 0.37, 0.74
Light	200, 500, 1000-2500	0.15, 0.37, 0.74-1.9
Moderate	2500-5000	1.9-3.7
Intensive	5000-8000	3.7-5.9
Utterly intensive	8000-15000	5.9-11.1
Severe	>15000	>11.1

In the Volga Basin, since much of the erosion is from soil loss during snow-melt, an adapted version of the USLE has been developed by the Russian State Hydrological Institute (1979) to deal with this. These models are usually verified by measurements in the field. In general, the intensity of soil erosion on arable lands within the Volga River Basin varies from <100 t/km^2/year to >2000 t/ km^2/year.

There are various methods other than the USLE for estimating and documenting rates of soil loss in river basins. These include: soil surveys, aerial mapping (as carried out in the Nile River Basin), the use of fallout radionuclide tracers (Walling & He, 1999a and Walling & He, 1999b) and the soil-morphological method (Larionov *et al.*, 1973).

In the Volga Basin it was found that soil erosion rates estimated using the USLE-based prediction model and obtained from soil profile morphology and ^{137}C tracer technique had a coefficient of correlation about 0.8. Page 49 of the Volga Basin Case Study Report provides a methodology for carrying out a basin-scale investigation of soil erosion using the soil-morphological method, radionuclide tracers, and USLE-based modeling (Larionov *et al.*, 1998; Krasnov *et al.*, 2001). Another study, on page 54 of the report, provides more detail about radionuclide tracing.

Intensity of erosion ultimately also depends on soil characteristics such as infiltration capacity. The methods discussed in the reports for determining soil resistance to erosion include:

- Field surveys to determine average and maximum stream bank retreat rates and areas/volumes of erosion; and
- An approach developed by Bastrakov (1983), and discussed in the Volga Case Study report, which measures the impact of a single water jet with a known hydraulic power onto an undisturbed soil sample placed in a cylindrical steel container.

<u>Measuring sediment grain size:</u>

Measurements of sediment grain size are important for many different applications. As with most methods of measurement, a compromise will frequently need to be made between accuracy and the simplicity of the method used. The World Meteorological Organization's *Manual on Sediment Management and Measurement (Operational Hydrology Report No. 47)* discusses errors which may be introduced by the use of simplified methods. It is also important to recognize that different approaches to measuring grain size distributions (e.g. via particle settling and Stokes's Law or via Laser Diffraction techniques can produce different results.

Measuring bed load:

The movement of sediment as ‘bed load’ is an important component of sediment transport by rivers. Bed load consists of larger particles than suspended sediment that cannot be transported in suspension. Bed load is difficult to measure accurately.[20] There are both direct and indirect methods of measuring bed loads.

Direct methods involve taking trapping the sediment moving along the river bed and measuring the weight of sediment collected over a specific time period. There are many samplers that have been specially designed for this purpose and these can be grouped into basket-type samplers, pressure-difference-type samplers, pan-type and pit-type samplers. The Rhine Case Study Report, on page 93, explains the use of hydrophones and sediment retention basins in obtaining measurements for bed load transport in the Swiss portion of the river. In the Netherlands portion of the Rhine Helley Smith Bedload samplers are used.

Indirect methods include the use of tracers, including fluorescent tracers, radioactive tracers and stable isotope tracers. Where the bed is composed mainly of fine sand, silt and clay, however, radioactive tracers are often the only method which is suitable.

Because sediment bed loads will vary over the cross section of a stream, bed load measurements are usually taken along the cross section of the stream (the Rhine report, on page 110, recommends 5 to 8 verticals per cross section). By integrating these measurements the bed load transport rate for the whole cross section discharge can be derived for the time of measuring.

Measuring suspended sediment load:

The suspended sediment concentration in the water column (sometimes referred to as ‘turbidity’) is the most important parameter when measuring suspended sediment loads. The suspended sediment load transported by a river at a particular moment in time (kg s^{-1}) represents the product of the mean suspended sediment concentration in the cross section (g L^{-1} or kg m^{-3}) and the water discharge sediment (m^3 s^{-1}).

The morphology of the river section plays a large role in the distribution of suspended sediment within the cross-section. Because sediment concentration and sediment particle size, as well as flow velocity will vary in the cross-section, there is a need to collect samples at various points within the cross section of the river. Suspended sediment concentrations will also vary through time in addition and to obtain accurate measurements of the suspended sediment load of a river over longer periods (e.g. a day, month or year) detailed records of both water discharge and suspended sediment concentration are required. The Rhine Case Study Report provides more detail on cross-sectional methods for sampling from page 100.

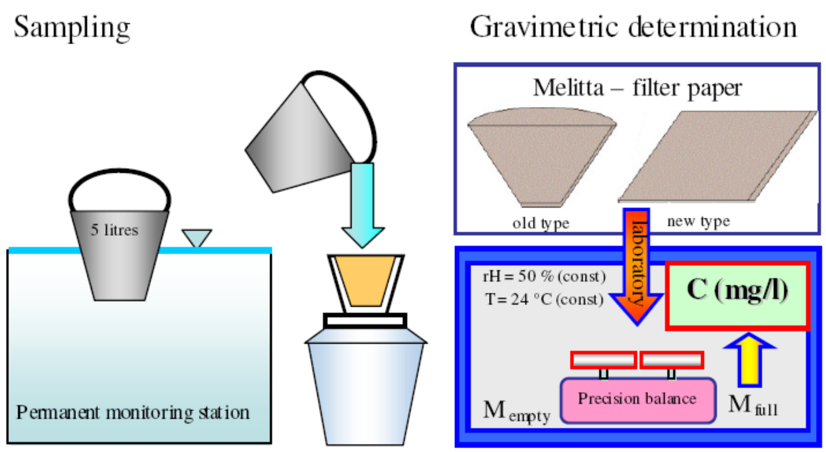
The usual methods used for measuring the concentration of sediment at various points are either sampling by point or depth integration and/or in-situ measurements. The sampling devices are either time-integration samplers or instantaneous samplers. For more information about sampling devices and detail on sampling methods used by other countries, please see from page 119 of the World Meteorological Organization’s *Manual on Sediment Management and Measurement (Operational Hydrology Report No. 47)*.

[20] More research into improvement of sampling methods for bed load is required.

The methods used for measuring suspended sediment load in the basins considered in the case studies include:

- Direct sampling and gravimetric determination by filtering suspended sediment in the laboratory (see Figure 1 below, from Rhine Report);
- Simple measuring devices based on the diffusion or obscuration of light;
- Continuous sampling by a nephelometric (turbidity probe) device;
- The Acoustic Sand-Transport-Meter used in the Netherlands portion of the Rhine, which measures the concentration of suspended sand grains by means of sound waves;

Figure 1: Showing gravimetric determination of suspended sediment (from page 100 of the Rhine Case Study Report)



In the Volga River Basin, suspended sediment yield has been estimated using empirically established relationships between water and suspended sediment discharges measured at certified gauging stations of the Russian Hydrometeorological Service. The Rhine Report provides further information about the analysis of samples using the methods given above. The Rhine River has a permanent network of monitoring stations – with each station taking 5L samples of water at approximately 50cm below the water surface on a daily basis. The Mississippi River has a similar network where daily data is stored in a database.

Measuring Total Sediment Load:

Procedures for measuring total sediment load mainly use other available sediment data to estimate the unmeasured suspended sediment and bed load discharge. The World Meteorological Organization's *Manual on Sediment Management and Measurement (Operational Hydrology Report No. 47)* is a good source for information on calculating total sediment loads. It describes the use of the 'modified Einstein procedure' which is based on the Einstein total load transport formula and is useful for computing the total sediment discharge over the entire cross-section of streams. A computer program has been designed to facilitate computation.

Calculating Sediment Budgets:

The following simplified equation has been used for representation of fluvial sediment budget in the Volga River Basin[21]:

$$W_{es} – W_{ds} + W_{ed} + W_{eg} – W_{db} – W_{dss} – W_{dsr} – W_{dmr} – W_{dlr} = W_{olr}$$

where *W* is a volume of sediment, first indexes *e*, *d* and *b* stand for erosion, deposition and output respectively. Second indexes stand for: *s* – slope; *d* – slope depression; *g* – gully; *b* – *balka*(small dry valley); *ss* – small stream valley; *sr* – small river valley; *mr* – medium river valley and *lr* – large river valley.

Page 111 of the Volga report also provides methods for calculating the sediment budget based on the Zusha River Basin and pages 111 – 113 of the Rhine Case Study Report provides more detail on the calculation of sediment budgets for the German portion of the Rhine.

<u>Measuring sediment deposition on floodplains:</u>

In many areas monitoring networks are in place to accurately measure sediment deposition and inundation of floodplains. The density of these networks, however, is not always sufficient to fully evaluate sediment deposition trends. Sediment delivery ratios are often estimated to 'fill the gaps' in measured data. This strategy is applied in the Volga Basin where the long term monitoring has been undertaken in small, medium and large valleys by the Russian Hydrometeorolgical Service gauging station network, and results are used to extrapolate findings to other parts of the river system.

Aerial photography, remote sensing and GIS may also be used to monitor sediment deposition (especially where it is deposited or eroded in large quantities by floods and storms).

<u>Measuring sediment accumulation in reservoirs:</u>

The rate of accumulation of sediment in reservoirs is usually one of the most pressing sediment issues facing water managers. Representative repeat surveys aimed at documenting the change in the level of the reservoir bed in response to sediment deposition are the most common method of estimating sediment accumulation. The volume of deposition, converted to weight and divided by the duration between sampling, will give the average rate of accretion. Estimates of sediment accumulation rate can also be obtained by combining measurements of the sediment load entering a reservoir at its upstream end with an estimate of the trap efficiency of the water body.

<u>Measuring vessel-induced re-suspension of sediment:</u>

In the Mississippi River Basin, new technologies have been employed to measure the impact of vessel-induced sediment re-suspension. Computer-based FORTRAN programs have been developed to consider vessel induced erosion and deposition, independent of natural river

[21] See page 99 of the Volga River Basin Case Study Report for further information about the application of the study.

current conditions. The Mississippi report has more information about this as does the study completed by McAnally et.al. 2001.

Measuring the geometry of the river bed:

Surveying of the river bed morphology is an important aspect in understanding sediment distribution, composition and processes in the river bed. In the German section of the Rhine River, the riverbed is surveyed using multi-beamed echo-sounding techniques. A specially designed watercraft (diving-bell) is also used to collect information on the sedimentological features of the river bed.

5.2 Information/data available on sediment

The amount of information available for each case study basin varies significantly. The table below provides a summary of the data made available through the case study reports. As indicated previously, the quantity of data presented in the reports is not in itself indicative of the amount of information available for the study basin due to the intentionally limited scope of the case study reports. Determining what information is available in each country where this information is not provided in the case study reports is outside the scope of this study.

Table 6: Data Available in Case Study Reports

Basin	Information Available in Case Study	Page reference
Haihe	Statistics for river runoff, sediment load, storage capacity and hydropower potential.	4
	Annual runoff and sediment loads	5
	Floods of major tributaries	5 - 6
	Flood carrying capacity of major tributaries	7
Liaohe	Annual runoff and sediment loads	11
	Floods of major tributaries	11
	Statistics for annual runoff, flood peak discharge, sediment load, sediment concentration and percentage of sediment load in flood season.	12
	Pre-dam and post-dam annual runoff and sediment loads	12
	Pre-dam and post-dam sediment deposition and erosion in river channels.	13
	Features of main channels – gradient, width etc	13
	Levees	14
Yellow River	Annual mean soil erosion, sediment yield and area of zones of soil loss for different areas in Yellow River Catchment	15, 18, 19
	Runoff, sediment load, sediment concentration and maximum flood discharge for Lower Yellow River	52
	Experimental data for slope soil loss	20
	Comparison table of historical soil loss	21
	Maximum and minimum annual sediment loads at different gauging	22

	stations	
	Annual load of different particle sizes at different regions	24
	Soil delivery ratios for different areas in the region	25
	Reservoir sedimentation rates (detailed descriptions of large reservoirs are also given in Chapter 3 of the report p 36-50)	30
	Sediment deposition in river channels (upper and lower reaches)	31 - 32
	Measurements for deposition rates in Lower Yellow River and longitudinal profiles	54 - 55
	Cross sectional profiles for Lower Yellow River	56 - 62
	Sediment deposition at river mouth	32 - 33
	Sediment budgets	33 - 35
	Measurements for scouring and silting in different time periods in Lower Yellow River	63 - 74
	Sedimentation for seasons distributed by particle size	104
	Hyper concentrated floods	104, 114, 116
Mississippi River	Overview of data collected in Mississippi Basin and databases	2
	Measured suspended sediment discharge since 1946	4
	Sediment accumulation on Lower Mississippi lakes	10
	Floodplain and backwater lakes sedimentation rates	12 - 13
	Migration of meander bends	19
Nile River	Long-term average flow discharge	14 - 18
	Sediment erosion rates and runoff data by country	23 - 26
	Sediment loads and bed loads in Nile tributaries	29
	Suspended sediment concentration in Aswan High Dam	30
	Rainfall, discharge and sediment yields	31
	Monthly average discharge of Aswan High Dam before and after construction	55
	Sediment deposition in Aswan High Dam Reservoir	58
	Capacity loss of Nile Reservoirs	60
Rhine River	Mean annual change in river bed level	17
	Water storage capacity of Rhine River Basin reservoirs	22
	Runoff rates at Rhine monitoring stations	33
	Flood discharges and water balance components of an extreme flood	35
	Average annual suspended sediment load - Switzerland	59
	Overview of Swiss approach to sediment data collection	77 - 80
	Overview of German approach to sediment data collection	81 – 82, 88 - 89

	Bedload distribution in German Rhine	84
	Average annual suspended sediment load - Germany	85
	Average diameter of bedload sediment particles - Germany	86
	Overview of The Netherland's approach to sediment data collection	89
	Grain size distribution – The Netherlands	90
	Various sediment studies – sediment balance, sediment yield, reduction of erosion, bedload management, selective transport and dispersion, suspended sediment transport and sediment budget	Section 11 (from 135)
Volga River	Intensity of soil erosion on arable lands	40 - 41
	Mean annual rate of sheet and rill erosion by area	43
	Sheet and rill erosion in different time periods	46
	Results/data for soil erosion in two sub-basin case studies	47 - 59
	Mean annual rate of gully erosion by area	63
	Gully growth rates according to land-use type	64
	Rate of gully formation over time	64
	Total volume of erosion for different sub-basin areas	80, 130
	Average annual rate, volume and area of bank retreat	93 - 94
	Case studies on calculating sediment yield and budgets for sub-basins	105 - 115
	Average annual suspended sediment concentration and yield	118 - 119
	Contribution of bedload to total sediment load	121
	Reservoir sedimentation rates in basin	131

5.3 Modelling and prediction strategies

Due to the uncertainties involved in the science of water management, modelling is an important tool used by water managers around the world to predict likely outcomes of management options. This is particularly useful for sediment management, because control structures are often used to manage sediment loads in rivers.

Identifying common methods is difficult, since most river managers use their own unique models. Even where modelling is based on similar methods, changes are usually made to the models to account for local features or parameters unique to the particular river basin being studied.

The table below shows the extent to which modelling and prediction techniques and real-time forecasting procedures have been developed to support sediment-related catchment management and control in the case study basins. Unfortunately not all case study basins provided the same level of detail on modelling techniques used and this list is by no means exhaustive. The modelling techniques discussed in the case study reports, and others known to be used in each case study region, are included in the table.

Table 7: Modelling Techniques referred to in each Case Study Report

Basin	Issue for which modelling applied	Modelling Techniques Used
Haihe and Liaohe	-	No information provided
Yellow River Basin	-	No information provided
Mississippi River	Channel deepening and widening	Diffusion model and hyperbolic models for channel degradation, using a Laplace transform approach
	Effectiveness of structural modifications	Physical hydraulic modelling
	Effectiveness and effects of dredging	Numerical models - TABS-1 and TABS-2
	Prediction of changes in river profiles due to deposition and scour	HEC-6 model (Barbe et al. 2000)
Nile River	Estimation of erosion	• Universal Soil Loss Equation (USLE) or its modified versions • Sediment yield as a function of drainage area and drainage characteristics
	Hydrology, soil erosion and sediment transport	SWAT model
	Hydrodynamic sediment transport (temporal and spatial based visualizations)	MOHID (using SWAT model result as an input)
Rhine River	Re-suspension risk of contaminated sediments	Mentions - but no model name given.
	Sediment balance	MORMO („MORphological MOdell“).
	Bed load sediment budget	Simulation models based on the program MORMO
	Prediction of future development	Simulation models based on the program MORMO
Volga River	Soil loss from rainfall	Modified version of Universal Soil Loss Equation (Larionov et al., 1998)
	Soil loss from snow melt	Model of the Russian State Hydrological Institute
	Estimations of soil redistribution rates	• Soil-morphological method (Larionov *et al.*, 1973) • ^{137}Cs technique

* See Index at Appendix A for a list of page references for models.

Modified versions of the Universal Soil Loss Equation (USLE) appear to be the most commonly used approach to predicting erosion and soil loss in the case study basins. Pages 17 – 23 of the World Meteorological Organization manual provides a detailed overview on the application of the USLE. The Volga report outlined the use of USLE-based modelling for estimating the volume of sediment eroded from slopes. Physical data have been used to verify the USLE modelling undertaken in the Volga Basin and it was found that soil erosion rates calculated by the USLE-based model and obtained from soil profile morphology and ^{137}Cs radioactive tracer technique had a coefficient of correlation about 0.8 (Yakimova, 1988).

6. Current management strategies and options

6.1 Approaches to sediment management and control

Over the years there have been many studies carried out, and many management options proposed for dealing with the impacts of sediment. There is lots of work being carried out worldwide, yet there are few true sediment success stories. Reducing erosion and sediment delivery within the Loess Plateau in the Yellow River Basin is, however, one example of such success. Since the mid 1950's the Yellow River Conservancy Commission has implemented widespread land management change in the Yellow River Basin (in particular the Loess Plateau region) – including major dam construction, afforestation, terracing, construction of check dams and conversion of crop land on slopes into grazing land. The project was successful in reducing sediment loads transported by the Yellow River. See pages 80 and 94 of the Yellow River Case Study Report for more information on this, with page 94 providing areas of land converted for each management category.

Consensus on a well-defined procedure for dealing with sediment problems remains elusive, mainly because applying an approach suitable to one area may not always be of benefit to another area with different conditions. Different types of erosion (for example, sheet erosion, rill erosion, gully erosion, stream-bank erosion etc.) will require location-specific solutions which cannot usually be successfully applied on a broad scale. Adapting methods to suit the conditions of the area represents a key component of sediment control and management. This section deals with various sediment management methods, solutions for dealing with reservoir sedimentation and downstream sediment issues, and their application in the case study regions.

6.1.1 Reservoir Sedimentation Management

Reservoirs are a key part of water management, providing many human benefits including a reliable water supply, flood control, power generation, navigation and recreation. Reservoir sedimentation occurs concurrently with the impounding of water, and is a threat to the useful life of reservoirs. Natural river reaches are usually in state of morphological equilibrium where the sediment inflow on average balances the sediment outflow. Sediment deposition occurs as the flow enters the impounded reach of a reservoir due to a decrease in flow velocity and a reduction in the transport capacity of the flow. The impounded reach will accumulate sediment and lose storage capacity until a new balance with respect to sediment inflow and outflow is again achieved. Declining storage volume reduces and eventually eliminates the capacity for flow regulation and with it all water supply, energy and flood control benefits (International Committee on Large Dams, 1989).

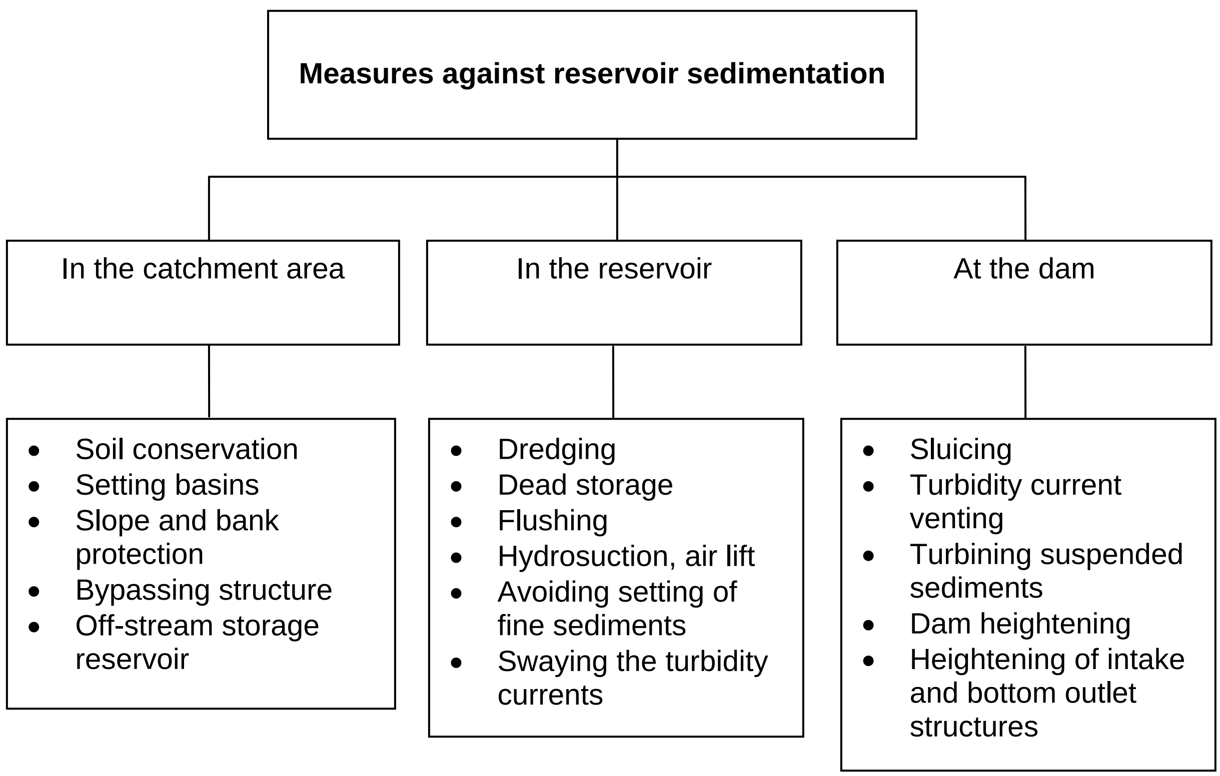
Some reports estimate that on a global scale, reservoirs intercept up to 25% of sediment which would otherwise flow to the ocean (Walling, 2002; Vorosmarty et al, 1997). Approximately 1% of the world's water storage capacity in reservoirs is lost every year through sediment deposition. The life of reservoirs is usually limited by the accumulation of sediment behind the upstream reservoir wall. Reservoirs have traditionally been planned, designed, and operated on the assumption that they have a finite lifespan, frequently as short as 100 years, which will eventually be terminated by sediment accumulation. However, the sustainability criterion was recently introduced by the United Nations (UN) towards the end of the last century to suggest a minimum of 1000 years of operation for new reservoir projects.

However, for existing reservoirs, sustainable sediment management should seek to balance sediment inflow and outflow across the impounded reach while maximizing long-term benefits.

Reservoirs also create downstream disturbances to natural sediment regimes by trapping sediment. The Aswan Dam on the Nile River effectively eliminated the downstream passage of sediment.

Although there are now technologies available to extend dam life through the removal of sediment, sediment still poses a great technical challenge to engineers around the world.The Rhine Case Study Report summarizes possible practical measures to deal with sediment management in reservoirs on page 64, with a particular focus on managing sedimentation in Alpine reservoirs. Please note that control of sediment from upstream areas will be considered in the section below on land management and soil conservation techniques.

Figure 2: Measures against reservoir sedimentation[22]



[22]From Rhine Report p 64. (Schleiss and Oehy, 2002)

The diagram above is helpful in showing that there are several levels at which management effort can be targeted to reduce sediment retention by reservoirs – either using broad-scale land management type strategies (which will be considered further in 6.1.2 below), or targeting the reservoir itself or the dam. Some further information on key strategies linked to the latter two approaches is provided below.

Flushing [23]: Sediment Flushing is a technique whereby previously accumulated and deposited sediments in a reservoir are hydraulically eroded and removed by accelerated flows created when the bottom outlets of the dam are opened. Flushing can be further divided into flushing under pressure and free-flow flushing. During flushing under pressure water, is released through the bottom outlets while the water level in the reservoir is kept high. For free-flow flushing the reservoir is emptied and the inflowing water is routed through the reservoir, resembling natural fluvial conditions. If flushing is carried out under pressure, only a very limited area in the reservoir is cleared. Free-flow flushing can transport a much greater sediment load (sometimes even consolidated sediments) than flushing under pressurized conditions. Flushing is often associated with a host of adverse environmental impacts.

Dredging [24]: One obvious alternative to flushing or routing sediments through a reservoir is underwater dredging or dry excavation of the deposited material. The drawback of dredging is the high cost for sediment removal, but reservoir level drawdown for flushing and sluicing may not solve all sediment-related problems. The impounded reach may need to be dredged due to continued accumulation of gravels. Dredging requires less drawdown of the reservoir water level. Another concern is the disposal of the sediments after dredging. Depending on the legal framework, disposal of sediment stored for many years in the reservoir may raise problems and ecological concerns. Returning the sediment to the river downstream of the dam will frequently not be possible due to the adverse ecological impact of adding large amounts of fine sediment, potential contamination of that sediment and the difficulty of controlling suspended sediment concentrations downstream. Furthermore, muddy reservoir deposits, mainly composed of silt and clay, are not easy to remove or use because of their high water and organic matter contents.

Avoiding the in-reservoir settling of fine sediments: methods for achieving this include structures which exploit the movement of turbidity currents (using obstacles, screens, water jets and bubble curtains[25]), turbidity current venting, and turbining of suspended sediments. The venting of turbidity currents has been carried out in the Liujiaxia Reservoir in the Yellow River Basin since 1974, successfully decreasing reservoir deposition. Venting of turbidity currents means that the incoming sediment-laden flow is routed under the stored water and through the bottom outlets in the dam.

Dead storage and dam heightening: the solution of dam heightening is usually a last-resort for sediment management within the reservoir as it is a generally very costly and unsustainable as a long-term option. Any raising of the dam will usually also involve raising of intake and bottom outlet structures. Where sediment issues are anticipated they should taken into account in the original design, where provision can be made for an increased amount of 'dead storage', or over sizing of the reservoir.

[23] This section extracted from Rhine Report page 66.
[24] This section is extracted from Rhine Report page 66.
[25] For more information please see Rhine Report page 66.

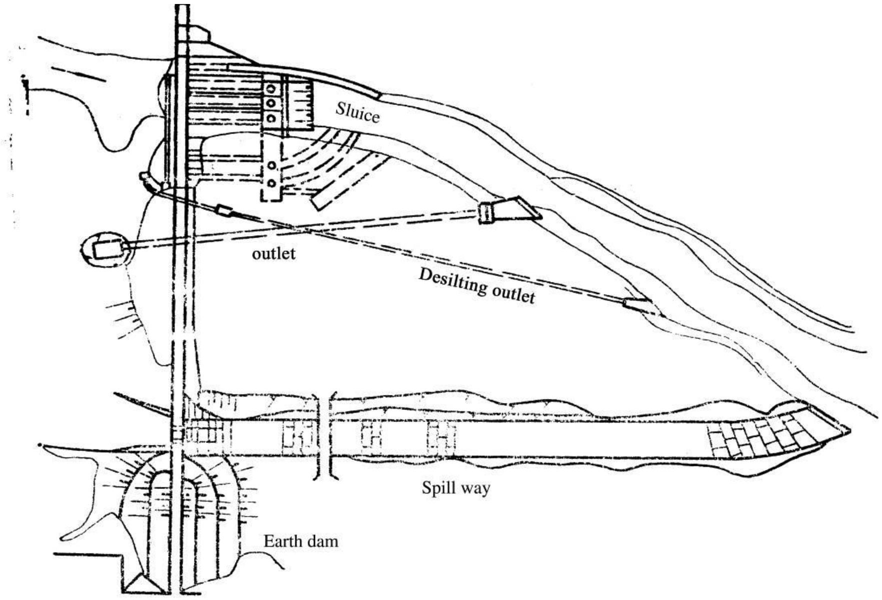
By-pass tunnels [26]: Worldwide, limited numbers of sediment bypass tunnels have been constructed because of topographical, hydrological or economical conditions. Bypass tunnels, however, have many advantages, including the possibility that they can be constructed at existing dams and prevent a loss of stored reservoir water caused by the lowering of the reservoir water level. They are also considered to have a relatively small impact on the environment downstream because the inflow discharge diverted through the tunnel during a flood essentially replicates a natural event downstream (Sumi, 2004).

Hydrosuction[27]: Hydrosuction systems remove deposited sediments by using the available energy head due to the difference between water levels upstream and downstream of a dam. These techniques try to return the system to more natural pre-dam conditions by releasing sediment in accordance with the downstream transport capacity. The pumping device is equipped with a drill head in order to facilitate the disintegration of the deposits. The pumped mixture can be diverted into decantation basins or into the downstream river using a controlled discharge.

Sluicing[28]: During sluicing of sediment, the water level in the reservoir is drawn down to allow for sediment-laden inflow to pass the reservoir with a minimum of deposition. Typical of sluicing in a flood-detention reservoir is that during a rising water level of a flood the out flowing sediment discharge is always smaller than that of the inflow. During the lowering of the water level, the out flowing sediment discharge is greater than the inflow, due to erosion in the reservoir (Fan 1985). Since inflowing sediment concentration during a flood tends to be highest during the rising limb of the hydrograph, the reservoir can be filled with less turbid water following the flood peak (Fan and Morris 1992). Sluicing operations should be timed to accommodate the higher sediment concentrations brought in by flood flows. By opening bottom gates fast enough, the rate of the increase of the outflow can be made equal to the rate of increase of an incoming flood. The detention effect and alteration of the sediment hydrograph are then minimized. Thus, the sediment outflow approaches the natural flow condition. Figure 3 shows the location of sluice outlets at the Liujiaxia Reservoir in the Yellow River. In 2002, the Yellow River Conservancy Commission carried out regulation of sediment load in the Xiaolangdi reservoir, lasting 11 days. Average controlled discharge in the lower channel was 2649m^3/s while the average sediment-laden concentration was 13.3kg/m^3. The result of this activity was that the lower channel was scoured, and 0.0562 billion tonnes of sediment was flushed to the sea. Scour depth was 0.07-0.26m and discharge carrying capacity increased to 90-500 500m^3/s.

[26]Further information available on Rhine Report page 65.
[27] This section extracted from Rhine Report page 66.
[28] This section is extracted from Rhine Report page 66.

Figure 3: Layout of Liujiaxia Reservoir on the Yellow River showing the location of de-silting and sluice outlets [29]



6.1.2 Land Management and Soil Conservation Techniques

Erosion control has a long history. In medieval times farmers used contour farming to conserve soil. Recently there have been advances in technology and knowledge which have made soil conservation practices more efficient. Methods such as barriers on slopes to slow runoff, silt fences etc have been used in the construction industry in the United States to minimize erosion on building sites. The agricultural sector, however, is primarily responsible for sediment runoff in most areas of the world, and will be the focus in this section. Soil conservation strategies to mitigate sediment runoff, and build-up in reservoirs, will be considered below.

Engineering solutions: Applying engineering solutions to manage sediment in a catchment can be very effective. However, these measures are often very complex and usually rely on the application of other forms of sediment control to be sustainable in the long term. The main engineering solutions are: gully control, as well as slope and bank protection works on rivers.

In the Yellow River basin engineering measures for sediment control have been widely used and include the construction of structures to trap sediment on slopes, and within pond and dam systems in gullies (sometimes called 'check' or 'warping' dams) which intercept sediment discharged from the slope. In many cases these dams also provide sources of water for local residents and agricultural enterprises. Terracing of fields is used extensively in the Yellow River Basin to mitigate soil loss from crop lands. The success of these measures in specific basins is discussed in more detail in the United Nations World Water Development Report 3. [30]

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[29] From Yellow River Case Study Report page 38.

[30] Wallling, D.E (2009) 'Scientific Paper: The Impact of Global Change on Erosion and Sediment Transport by Rivers: Current Progress and Future Challenges'. United Nations World Water

Settling basins [31]**:** Settling basins are often constructed in catchments to limit gully erosion. These small dams trap only the coarser sediment particles and the sediment load quickly builds up again downstream. Therefore, this measure rarely has a major impact on the sediment yield. The construction of such debris trap dams in the upper catchment areas may be a solution; but, without proper regular maintenance, such dams will be quickly filled through bed load transport and in the long term they serve no purpose. A further problem with upstream sediment trap dams is finding a place for the continuing long-term disposal of the incoming sediments, which will continue to accumulate indefinitely. Often the settling basins are also too small to significantly affect the sediment yield into the reservoir.

Vegetation cover: The clearing of native vegetation is a well-documented cause of increased soil erosion (Walling/Morgan, 1986). Where the climatic conditions permit manipulation of the vegetation cover, the soil can be protected from erosion by afforestation or vegetation screens. Placing moratoriums on the clearing of native vegetation in erosion-prone areas is a good strategy for areas which are experiencing increasing erosion due to land clearing for agricultural expansion. This can have a significant impact on sediment reduction in waterways.

In the Yellow River Basin, vegetative controls have been used extensively in the Loess Plateau Region. Afforestation and vegetation protection on the banks of terraced fields and erosion-prone land (such as slopes, gully beds and riverbanks) has been implemented with good results for sediment control in these regions. Other benefits from afforestation, such as environmental quality improvement and creation of habitat for different species have also been acknowledged as significant in the Basin.

Agricultural practices: Today's modern agricultural practices, and the increasing demand for agricultural products, often puts undue pressure on agricultural land – by increasing tillage, use of heavy machinery and increasingly intensive land use (crop rotations and stocking density). This pressure is resulting in risks for sediment management due to the degradation of agricultural land.

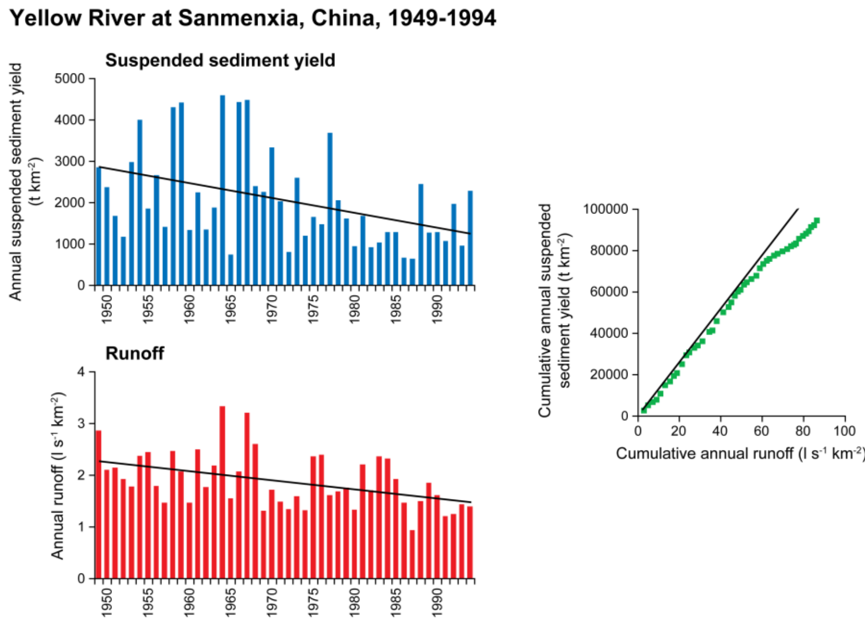
Tillage has the most significant impact on soil structure, by breaking up the soil and leaving it vulnerable to wind and water erosion. In the Yellow River Basin there has been significant progress in banning tillage on almost 5% of all farmland in the Loess Plateau. This 5% accounts for the farmland designated as unsuitable for tillage, because its slope is greater than 25^0 and it is often converted into forest or improved pastures for livestock. Terracing of farmland and the building of horizontal ditches to trap sediment are other ways in which agricultural soil loss is being reduced in China.

The graph below (Figure 4) shows the progressive decrease in the suspended sediment yield from the Yellow River basin above Sanmenxia, starting from the 1950's, when significant soil conservation work began in the Loess Plateau Region. These soil conservation works also resulted in a significant decrease in runoff, although increasing water use could also be expected to contribute to this decline.

Development Report 3. Available online at:
http://unesdoc.unesco.org/images/0018/001850/185078e.pdf

[31] This section extracted from the Rhine Report page 65.

Figure 4: Changes in suspended sediment load and annual runoff at Sanmenxia, Yellow River, from 1949 – 1994 [32]



Different crops also have different properties in terms of their potential for erosion control, and although decisions on the crops to be grown are generally made by individual farmers in most parts of the world, regulation of crop varieties in erosion-prone areas may also provide a basis for reducing erosion and controlling sediment delivery from agricultural land.

6.1.3 Bedload management

Bedload management focuses on maintaining the continuity of bed load transport. Active management is usually undertaken to preserve river depth for navigation purposes. It includes:

Bedload relocation: dredging is undertaken in areas where excess sediment is deposited, increasing the flooding risk of the area and also possibly creating a hazard for navigation.

Artificial bedload supply: this is usually undertaken where erosion is excessive and poses a risk to human infrastructure and river integrity. It involves the regular dumping of coarse material into the river in an attempt to reduce bed erosion.

6.1.4 Flood Control Programs

Floods are a potentially dangerous consequence of sediment accumulation on river beds and in reservoirs. In the Yellow River Basin alone, millions of lives have been lost due to flood events. From 206BC to 1949AD, 1,092 major flood events were recorded. Flood control programs are generally designed to cope with maximum recorded flood levels or model predicted extreme events. Today, flood control programmes are capable of predicting peak flows in rivers and involve advanced flood forecasting and warning systems. Strategies have

[32] Graph from: Walling, D.E. & Fang, D. (2003) Recent trends in the suspended sediment loads of the world's rivers. Global and Planetary Change.39; 111– 126.

been developed around the world to minimize peak flows and reduce channel velocities, including:

Detention basins: act as holding ponds to mitigate peak flows. The most extreme example of a detention basin is a large reservoir specially designed for flood control purposes. Specially-designed reservoirs that discharge sediment in the form of turbid water are particularly useful for flood mitigation as they are able to protect the area downstream of the reservoir for longer by effectively discharging sediment that would otherwise reduce the useful life of the reservoir for flood control and other purposes.

Energy dissipaters in channels: these are engineering works used to reduce stream velocity and the erosive capacity of the stream. Common examples include: culvert outlet controls, forced hydraulic jumps, drop structures, stilling wells etc.

Land use controls: these are used to reduce storm runoff. See section above on 'engineering solutions' for reducing reservoir sedimentation. Warping dams in low-lying areas are a particularly effective method to reduce flood peaks by holding water back in steep areas.

Embankments/dyke/levee construction: The construction of embankments and levees along river channels can provide some relief from flooding by increasing the height the water must reach before flooding surrounding areas. Despite their effectiveness, levee breaches can be devastating as they occur suddenly and water generally moves at high velocities (with the river level during flood being higher than the surrounding land). In the Yellow River Basin only 25% of the sediment load is carried to the sea, while the rest is deposited in the riverbed and in reservoirs. The riverbed is estimated to rise between 5-10cm per year due to sedimentation, and as a result, dykes have to be periodically raised. This phenomenon creates difficulties for the management of dykes in sediment-laden rivers.

Periodic flushing of rivers: where water is stored in reservoirs and downstream accumulation of sediment is an issue, particularly in low-lying coastal areas, periodic 'flushing' of rivers brought about by releasing large quantities of water can assist in the removal of sediment to reduce flooding risk. This flushing may also bring about environmental benefits.

6.1.5 Environmental management

Wetlands and estuaries require a certain level of sediment in order to maintain their ecological functions. Sediment provides many environments with a supply of nutrients that they would otherwise not receive. Reservoirs usually interrupt the flow of sediment downstream and this can have devastating consequences for aquatic life as well as wetland and estuary ecosystems.

Ensuring environmental water requirements: Flushing of sediment is a key concern for water managers in areas where water is held back by reservoirs and other river control structures. Regular 'flushing' of rivers is important for maintaining bedload transport at sustainable levels, and also to prevent sediment accumulation in wetlands and at the mouths of estuaries. In the Yellow River Basin, the Yellow River Conservancy Commission has made flushing of sediment its most critical environmental priority due to the reliance of wetland biodiversity and dependent fisheries on wetlands that are not choked with sediment. The minimum flow requirement in the Yellow River is 14 billion m^3 which is difficult to provide with the myriad of other demands on water resource use. Ensuring such environmental flows are considered in water allocation exercises is also a significant management challenge for river managers.

Deposition of silt downstream by dredging and other works: In extreme cases, sediment may be transported to downstream areas to maintain wetlands and estuaries.

6.2 Legal, Administrative and Organizational aspects of sediment management

The increasing importance of river management has led to the implementation of laws and regulations governing land and water use in many regions of the world. More and more countries are recognizing the importance of healthy rivers – for the health of communities and the environment. Regulation of sediment is, however, a relatively new concept in some areas. In Australia for example, laws were only quite recently passed to protect the Great Barrier Reef from excessive sediment runoff from sugar cane farms in adjacent river systems. [33]

Where river basins extended over different countries, some areas have established management bodies that transcend national boundaries. In the Nile Basin, for example, nine of the ten Nile River riparian countries have started the 'Nile Basin Initiative'. This initiative has helped the countries to build a shared vision and focus on key actions to improve management of water resource in the basin. The table below provides an overview of legal and administrative structures governing sediment control in each basin area.

[33] See http://www.gbrmpa.gov.au/corp_site/info_services/publications/sotr/latest_updates/water_quality/issues.html for more information about sediment issues in the Great Barrier Reef.

Table 8: Overview of Legal and Administrative structures in each Basin

Basin	Organizations Responsible for Management	Legal Structures in Place to Manage Sediment	Administrative Structures in Place to Manage Sediment
Haihe	The Ministry of Water Resources of the People's Republic of China is a department of the State council that is responsible for water administration. The Haihe River Water Resources Commission is the responsible agency under the Ministry of Water Resources for water resource management in the Haihe River Basin.	Water Law of The People's Republic of China (2002); Flood Control Law of The People's Republic of China (1997); Law of the People's Republic of China on the Prevention and Control of Water Pollution (1996); Law of The People's Republic of China on the Conservation of Soil and Water (1991); Hydrology Regulation of the People's Republic of China (2007);Rules For Implementation Of The Law Of The Peoples Republic Of China On The Prevention And Control Of Water Pollution (1989); Regulation of Water Drawing Permit and Water Resources fee (2006); Regulations for River Course Management of the People's Republic of China (1988); Management Measures for Water Function Zone(2003). Relevant regional and local regulations, rules, methods and guidelines implemented by Haihe River Water Resources Commission, Tianjin City, Hebei, Shandong and Henan Provinces.	The Haihe River Water Resources Protection Bureau, the Haihe River Soil and Water Conservation Monitoring Station, the Zhanweinan River Administration Bureau, the Lower Haihe River Administration Bureau, the Upper Zhanghe River Administration Bureau, and the Haihe River Hydrology Bureau under the Haihe River Water Resources Commission are responsible for sediment related management in different aspects.
Liaohe	The Ministry of Water Resources of the People's Republic of China is a department of the State Council that is responsible for water administration. The Songliao Water Resources Commission is the	Water Law of The People's Republic of China (2002); Flood Control Law of The People's Republic of China (1997); Law of the People's Republic of China on the Prevention and Control of Water Pollution (1996); Law of The People's Republic of China on the Conservation of Soil and Water (1991); Hydrology Regulation of the People's Republic of China (2007);Rules For Implementation	The Department of Planning, Department of Water Resources, Department of International River and Researches, and Department of Water and Soil Conservation of the Songliao River Water Resources Commission, and the Songliao River Hydrology Bureau

	responsible agency under the Ministry of Water Resources for water resource management in the Liaohe River Basin.	Of The Law Of The Peoples Republic Of China On The Prevention And Control Of Water Pollution (1989); Regulation of Water Drawing Permit and Water Resources fee (2006); Regulations for River Course Management of the People's Republic of China (1988); Management Measures for Water Function Zone(2003). Relevant regional and local regulations, rules, methods and guidelines implemented by Songliao River Water Resources Commission, Hebei, Inner Mongolia, Jilin and Liaoning Provinces.	and the Songliao River Soil and Water Conservation Monitoring Station under the Songliao River Water Resources Commission are responsible for sediment related management in different aspects.
Yellow River Basin	The Ministry of Water Resources of the People's Republic of China is a department of the State council that is responsible for water administration. The Yellow River Conservancy Commission (YRCC)[34] as an agency under the Ministry of Water Resources takes, on behalf of the Ministry of Water Resources, the responsibilities of water administration in the Yellow River basin and the inland river basins in several provinces of Xinjiang, Qinghai, Gansu and Inner Mongolia.	Water Law of The People's Republic of China (2002); Flood Control Law of The People's Republic of China (1997); Law of the People's Republic of China on the Prevention and Control of Water Pollution (1996); Law of The People's Republic of China on the Conservation of Soil and Water (1991); Hydrology Regulation of the People's Republic of China (2007);Rules For Implementation Of The Law Of The Peoples Republic Of China On The Prevention And Control Of Water Pollution (1989); Regulation of Water Drawing Permit and Water Resources fee (2006); Regulations for River Course Management of the People's Republic of China (1988); Management Measures for Water Function Zone(2003) relevant regional and local regulations, rules, methods and guidelines implemented by Yellow River Conservancy Commission, Shanxi, Shaanxi, Shandong and Henan Provinces.	The Water and Soil Conservation Bureau of the YRCC takes charge of management of soil and water conservation works in the basin, guides and coordinates preservation and supervision of soil and water conservation and ecological management, organizes establishment of modern soil and water conservation supervision system, supervises implementation of related laws and regulations of soil and water conservations and carries out key projects of soil and water conservations, etc. The Office of the Chief Engineer, Department of Planning and Programming, Department of Water Resources Management and Regulation,

[34] For more information on the main duties of the YRCC see page 122 of the case study report. Also a section covering links to international organizations on p 124.

			Department of Construction and Management, Department of Water and Soil Conservation, Yellow River Committee of Agricultural, Forestry and Water Conservancy Workers Union of China of the YRCC, and the Yellow River Basin Water Resources Protection Bureau, Yellow River Shandong Bureau, Yellow River Henan Bureau, Upper and Middle Yellow River Bureau, Heihe River Bureau, Hydrological Bureau, Yellow River Institute of Hydraulic Research, Yellow River Xiaobeiganliu Shanxi Bureau, and Yellow River Xiaobeiganliu Shaanxi Bureau under the YRCC are responsible for sediment related management in different aspects.
Mississippi River	Most river management authority lies with the US Army Corps of Engineers.	Water Resources Development Act (2007), Fish and Wildlife Coordination Act (1934) which requires consideration of habitat of wildlife in water resources management. Wild and Scenic Rivers Act protection of amenity of river. National Environmental Policy Act (1969), Endangered Species Act,	No information.
Nile River	The Nile Basin Initiative (nine of the ten Nile Basin countries are represented). There is also an Eastern Nile Subsidiary Action Program (ENSAP) which comprises of Egypt, Ethiopia and Sudan.	There are few legal instruments to govern sediment in Nile riparian countries.	Nile Basin Capacity Building Network. Nile Basin 'Shared Vision' Programme which has involved key stakeholders and the public more generally.

	The Equatorial Lakes Regions, comprising of Burundi, Democratic Republic of Congo, Egypt, Kenya, Rwanda, Sudan, Tanzania, and Uganda have Councils of Ministers. [35]		
Rhine River [36]	The International Commission for the Hydrology of the Rhine Basin – promotes data exchange and collects sediment and flood data. The International Commission for Protection of the Rhine – investigates sources of pollutants and is governed by a convention against pollution (The Bern Convention, 1963 and resigned in 1999).	Laws and regulations in each jurisdiction will cover sediment control and management. These are covered in the case study report on page 119-123. There also exist action plans for the Rhine including: • Rhine Action Plan Against Chemical Pollution, 1987 • Rhine Action Plan on Flood Defense, 1998	Each jurisdiction will have its own unique administrative structures to deal with sediment control and management. These are covered in the case study report on page 119-123. The European Environment Agency governs environmental issues in the region.
Volga River	State Water Resources Management is the overarching body while four Basin Commissions (Verkhnevolzskoe, Niznevolzskoe, Oksskoe and Kamskoe are the next level of management.	The Water Code of the Russian Federation (2006) contains information about water quality, but there are no references to sediment. The Code of Inland Water Transport of the Russian Federation (2001) includes some information about sediment management.	Mostly local hydropower companies are responsible for sediment management for large reservoirs with hydropower capacity, local units of Basin Commissions are responsible for middle size dams and reservoirs.

[35] There is no information on management structures or legal arrangements in the case study. For more information about these arrangements, please see the Nile Basin Region website: http://www.nilebasin.org/index.php?option=com_content&task=view&id=106&Itemid=120

[36] More information can be found in the following report: http://webworld.unesco.org/water/wwap/pccp/cd/pdf/case_studies/rhine2.pdf

7. Policy recommendations based on this study

Each river basin has specific natural characteristics, uses, history, challenges and is unique for natural, socio-economic and political reasons. Therefore, a one-size-fits-all approach would not be an appropriate solution for managing sediment in international river basins.

It is important that guidance allows for variability, and the following recommendations are intended as a guide for river basin managers:

Recommendation 1: Sediment management (quantity and quality) should become a part of all river basin management plans.

Recommendation 2: Encourage soil conservation initiatives, in particular on steep agricultural land.

- Soil conservation is vital not only for reducing soil erosion but also for increasing the development of the local economy and for raising the living standards of the local people. As soil conservation is demanding work and may require a long period of time to achieve its full effect, it must be persisted with to achieve its goals.
- Substantial water quality improvement can result from the use of economically achievable sediment-reduction practices on farmland. One of these practices is conservation tillage, defined as tillage systems that leave at least 30 percent of the field surface area covered by crop residue after planting. Leaving the surface rough and partially covered with crop residue reduces sedimentation at its origin by preventing the detachment of soil particles by raindrops, and retarding their transport across the field surface by water runoff. Soil erosion reduction does not necessarily translate into an equal reduction of sediment entering surface waters, however. Erosion refers to the mobilization of sediment from the land surface by water or wind, while sedimentation refers to the deposition of sediment in surface water bodies. A reduction in erosion usually corresponds to a much smaller reduction in sedimentation.

Recommendation 3: There is a need to work with international agencies such as the ISI in developing a commonly accepted international protocol for measuring erosion, sediment transport and sedimentation in river systems.[37]

- There is a need for a common international protocol for measuring sediment mobilization, transport and deposition in river systems, including data collection methodologies and units for results. The reports synthesized in producing this synthesis report demonstrate that different river basins can employ very different monitoring and data collection techniques and procedures.

Recommendation 4: It is important that efforts should be made to Involve the community in sediment control and management and to provide sufficient information on how they can improve river health and contribute to sediment management.

- Discussion of the involvement of stakeholders – does this need to be improved or the community better informed about decision making or what they can do to reduce sediment in rivers?

[37] Note that the WMO report intends to summarize methods as a guide for river mangers, however, a commitment to commonality in the practical application of these methods is what is required.

Recommendation 5: Sediment management must be based on a sound understanding of the sediment dynamics of the river basin involved. There is a need to clearly define the sediment budget or balance of a river system and collate available data to identify knowledge gaps and further enhance understanding of sediment issues on a global scale.

Recommendation 6: Sediment management plans should be periodically reviewed to ensure that they are in line with international best-practice.

Recommendation 7: The potential downstream impacts of any river structures and sediment management strategies must be considered.

- The sedimentation of reservoirs built on sediment-laden rivers is a serious problem. It should be seriously considered in the planning and design of such reservoirs

Recommendation 8: There is a need for investment in capacity building to ensure that water management personnel understand and engage with sediment issues effectively.

- Capacity building is an essential requirement for efficient water resources management.

Recommendation 9: Further investment in sediment research must be encouraged, particularly in developing countries.

- There is a need for international support to irrigation and drainage research in the Nile Basin countries, especially for those rivers used for irrigation that carry high sediment loads. Despite the great progress in irrigation research in developed countries, few of the results have been transferred to the developing world.
- To justify the additional cost of a sediment control or storage recovery strategy, an evaluation of the economic impact of sedimentation on agricultural irrigation schemes and reservoirs is needed.
- A list of topics for further research/study is included in Appendix 2.

Recommendation 10: There is a need to increase institutional cooperation and collaborate with international partners to share research and experiences.

- Worldwide, relevant institutes, agencies and researchers in this field need to combine their effort and collaborate in coordinated research programmes to deal with sediment problems. This should help international community's achieve practical and effective solutions. Joint and coordinated effort entails partnership, pooling of resources, focused science, and sharing of information and experiences.
- Information on sediment data is important when comparing river basins in different areas of the world. Without adequate monitoring and reporting, and transparency in these processes, in order to permit comparison of methodologies employed, meaningful comparisons between different river basins cannot be easily made. This will impact on the promotion and implementation of sediment management in different countries. Encouraging countries to make an effort to share data is an important part of international cooperation in river basin management. Many rivers cut across national boundaries and the sharing of data is vital for their effective management. In the USA, water and sediment data are made publicly available by the US Geological Survey. Such data include precipitation, river levels, water discharge, reservoir and lake levels, suspended sediment loads and other water quality indicators. More information is available from http://co.water.usgs.gov/sediment/ .

Recommendation 11: The ISI network should include representatives from all regions of the world (with perhaps one representative who is a key expert in sediment from each of the major sediment-laden river systems of the world).

- Progress could be discussed via an online forum/interactive website for sediment managers which would include information from this report, data, and an interactive forum to post questions and discuss issues.

Recommendation 12: The precautionary principle should be applied in sediment management.

- Where there is a lack of information or uncertainty in relation to sediment issues, the precautionary principle should be applied on the basis of perceived threats.

- The complexity of sediment transport processes and associated uncertainties makes the application of the precautionary principle important to management. For example, to ensure flooding does not impact on society/economy and to protect the environment.

8. Conclusion

Humans are currently placing more pressure on the environment and the earth's resources than at any other time in history. Water resources, in particular, are under increasing strain in many regions of the world. Water availability is commonly the key concern for policy makers, with water quality and sediment control issues often receiving less attention in water management policies and programmes. Sediment issues are often ignored due to a lack of information or understanding on behalf of policy makers who drive the water management process, or because the scale of the problem seems too overwhelming to be tackled in a meaningful way by regional water managers. This report has sought to provide river managers with an overview of sediment issues, methods for collection of sediment data, and management strategies to help overcome any issues in catchments under their control.

It is difficult to determine a future outlook for sediment issues on a global scale, mainly due to the variety of location-specific causes and impacts of sediment. It appears that many rivers around the world are experiencing declines in sediment loads (Walling, 2002) mainly due to the construction of dams and other control structures. The environmental, social and economic impacts of poor management of sediment cannot be ignored by policy makers. Wetland health, irrigation infrastructure, estuaries, and farmer's livelihoods are just some of the things being put at risk by inappropriate sediment management practices. The good news is that many countries around the world have begun to take these issues seriously and information on 'sediment success stories' are slowly becoming available.

The case studies referred to in this report represent a useful first step towards the global sharing of knowledge and experiences essential for best-practice sediment control and management. The hope is that these case studies will encourage further information exchange and sharing of data, and promote international dialogue on sediment control issues.

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Appendix 1: Index of Case Study Reports by topic

Note: Liaohe and Haihe Basins are part of the same report.

Topic	Information Available in Case Study	Basin	Page reference
Agricultural practice change	Yellow River cultivation measures	Yellow River	84, 94
	Contribution of tillage on hill slopes to gully erosion	Volga	37 -39
Alpine watersheds	Torrents and small alpine watersheds as a challenge for sediment management	Rhine	51, 105
Bank Erosion	Bank erosion in the Nile	Nile	32
	River bank erosion case study in Volga Basin	Volga	91 - 97
Bed degradation	Bed degradation processes in Rhine River	Rhine	52 - 53
Bed load	Bed load distribution and management in the Rhine River	Rhine	84
	Bed load monitoring in Swiss portion of Rhine		93
	Bed load monitoring in German portion of Rhine		98, 110
	Bed load monitoring in the Netherlands portion of the Rhine		101, 116
Climate change	Influence of climate change on runoff regime	Rhine	36
Data (Sediment)	Statistics for river runoff, sediment load, storage capacity and hydropower potential.	Haihe	4
	Annual runoff and sediment loads		5
	Floods of major tributaries		5 – 6
	Flood carrying capacity of major tributaries		7
	Annual runoff and sediment loads	Liaohe	11
	Floods of major tributaries		11
	Statistics for annual runoff, flood peak discharge, sediment load, sediment concentration and percentage of sediment load in flood season.		12
	Pre-dam and post-dam annual runoff and sediment loads		12
	Pre-dam and post-dam sediment deposition and erosion in river channels.		13
	Features of main channels – gradient, width etc		13
	Levees		14
	Annual mean soil erosion, sediment yield and area of zones of soil loss for different areas in	Yellow River	15, 18, 19

	Yellow River Catchment		
	Runoff, sediment load, sediment concentration and maximum flood discharge for Lower Yellow River		52
	Experimental data for slope soil loss		20
	Comparison table of historical soil loss		21
	Maximum and minimum annual sediment loads at different gauging stations		22
	Annual load of different particle sizes at different regions		24
	Soil delivery ratios for different areas in the region		25
	Reservoir sedimentation rates (detailed descriptions of large reservoirs are also given in Chapter 3 of the report p 36-50)		30
	Sediment deposition in river channels (upper and lower reaches)		31 – 32
	Measurements for deposition rates in Lower Yellow River and longitudinal profiles		54 – 55
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	Sedimentation for seasons distributed by particle size		104
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	Overview of data collected in Mississippi Basin and databases	Mississippi River	2
	Measured suspended sediment discharge since 1946		4
	Sediment accumulation on Lower Mississippi lakes		10
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Appendix 2: Recommendations for Future Studies

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.

The current state of data availability and the quality of these records is not always sufficient to provide a basis for sound management decisions.

Some suggestions for future studies include:

- A project on standardizing sediment data collection methods and units. Uniformity is required for sediment data collection and reporting around the world, in order to assist in the drawing of comparisons and learning from the situations in other regions. Sediment data collection methods are an area where uniformity would greatly assist in comparing sediment data between regions. When data are collected in different ways this often creates significant hurdles to comparison.

- Expanding sediment case studies to other regions - including South America, Australia, SE Asia or southern Africa

- Collecting more data about the contribution of extreme events in erosion and sediment redistribution for different landscape zones (highlighted in the Volga report). Also, there is a need to know in more details about the dynamic of deposition rates on river floodplains in different river basins and we already have a methodology to study this problem.

Appendix 3: Comparison Table of Management Approaches

3.1 Current Management Approaches – Strategies, Future Outlook and Barriers to Implementation

Basin	Management Approaches			
	Strategies Implemented	**Resources Required for Effective Management**	**Future Strategies**	**Barriers to Implementation**
Nile River Basin	**For water bodies:** • De-silting and aquatic weed clearance to restore canal systems (since 1925). • Application of canal design systems to reduce sedimentation for minor and major canals. For example, the use of settling basins at the head of the main canals to reduce sediment deposition in irrigation systems. **For reservoirs:** • Managing sediments within the reservoir by controlling water levels. • Evacuating sediment from the reservoir by sluicing or flushing. **For both canal systems and reservoirs:** • Reducing sediment inputs by land/catchment management practices or by providing upstream storage.	• It is usually more cost – effective to reduce sediment entering canal systems with sediment control than relying on silt removal in canals. However, most of the sediment in the Nile system occurs in the form of 'wash loads' which are more difficult to manage. • The use of expensive sediment control structures, (e.g. sediment extractor), can be justified where it would accommodate an increase in the cropped area and reduce costs associated with silt removal.	No information.	Little is known about the contribution of wind erosion to sedimentation in the Nile River. Wind deposition increases flood risk by elevating river beds. Further studies in this area are highly recommended.

Mississippi River Basin (USA)	**For water bodies:** • The placement of flood control structures and other channel improvement features • The implementation of improved land management practices throughout the basin • Management of cutoff bends focuses on sequencing construction activities and modification of the upstream bend entrance geometry to reduce the quantity of bed material diverted into the bend. • Construction of blockage structures to top-bank elevation in upstream entrances of cutoff bends has been recommended for systems with average suspended bed-material concentrations greater than about 50 ppm.	No information.	• The use of wetlands in future wastewater assimilation due to ecological and economic benefits. • Goal to mitigate new sedimentation issues, while continuing to sustain the mitigation of old sedimentation issues, all while minimizing social, environmental and economic impacts.	No information.
Rhine River Basin	The Rhine River Basin employs different planning and sediment management techniques depending on the type of water course (small alpine rivers and large river systems for example). Common to each are the following: • Stabilization works of river beds and banks, • Dredging (permissions have been treated more restrictively recently due to lack of sedimentation downstream	No information.	• To stop bed degradation and to improve navigation, a strategy has been developed combining sediment management measures with conventional river training measures (Gölz 1994). Besides local dredging and re-dumping activities six major bed-load management measures	• Dredging and disposal of sediments is sometimes a major problem where sediments are in parts contaminated by hexachlorobenzene (Koethe et al. 2004). There is a heightened risk of remobilization of contaminated sediments during floods (Witt et al., 2003).

	causing increased bed erosion and associated infrastructure damage) • planning of traffic routes (river crossings etc), • sanitary engineering, • sediment and wood retention in hydropower operations, • watershed management and conservation (drainage, afforestation, landscape protection, risk detection and hazard mapping, evaluation of danger zones for flooding) **For reservoir silting:** Page 65-7 measures for dam silting. **For contaminated sediment:** For the assessment of contaminated sediment, there is not one ‘best’ method available. Chemical analysis can be used to determine concentrations of selected, hazardous chemicals and then it can be checked if the concentrations exceed pre-defined standards or guideline values. The toxic effects of sediment on organisms can be tested by using bioassays.		primarily artificial bedload supply provide the base for achieving a dynamic equilibrium over a length of 530 km. • Mandated by the ICPR, the ICPR expert group “SEDI” since 2005 elaborates a comprehensive strategy for sediment management in the Rhine basin. Main objectives are a sediment management plan for contaminated sediments addressed to competent authorities in the watersheds for implementation in measure programs according to WFD and the “improvement of sediment quality in order to relocate dredged material without harm” (Art. 3 of the ICPR Rhine Convention). • The development of strategies both to reduce dredging of sediments and to dispose them in an ecologically friendly and economically acceptable manner is one of the important tasks of	

			sediment management at the Rhine waterway.	
Volga River Basin	**For discharge into water bodies:** • There appears to be a focus on land management and agricultural practices to mitigate soil erosion.	No information.	• Quantitative assessment of erosion rates, especially during warm period of year, should be seriously improved for elaboration of effective soil conservation measures. • To evaluate the fate of different pollutants, which are transported through the fluvial system with sediment, is one of the most important tasks. • Quantitative assessment of trap effectiveness of small ponds and reservoirs should be improved for understanding of their role in sediment redistribution processes. • Changes of erosion and deposition rates associated with climate changes are also very essential issue of future studies.	No information.
Yellow River Basin	**For discharge into water bodies:** • Soil and water conservation is the	No Information	• Soil and water conservation works	• The Yellow River has a naturally high sediment

(China)	strategic measures for improving the ecological environment and reducing the amount of sediment, discharged into the Yellow River. Specific strategies included gully management and sloped land management (engineering, afforestation and cultivation measures). • A policy of ‘widening the floodplain and strengthening the levees’ was adopted as a temporary measure to prevent flooding. • The creation of ‘warping dams’ in particular the check dam is an important measure for soil and water conservation in serious soil erosion areas, with the purpose of flood detention and soil conservation while allowing agriculture to take place. • Dredging is used to widen and deepen shrinking river channels and to raise the elevation of surrounding ground to reinforce levees. Various dredgers have been used: dredge vessels; agitating dredgers; dipper dredgers; hauling scarpers; excavators and bulldozers, and trailer dredgers. **For reservoirs:** • Establishment of a sediment balance between sediment inflow		should be strengthened in the middle and upper Yellow River to reduce the amount of sediment entering into the Lower Yellow River. • Regulation of water flow and sediment load to control floods – a regulation system of water flow and sediment load should be built to ultimately form an integrated regulation system composed of Longyangxia Reservoir, Liujiaxia Reservoir, Daliushu Reservoir, Qikou Reservoir, Guxian Reservoir, Sanmenxia Reservoir and Xiaolangdi Reservoir to enhance the capability in artificial interruption and control of floods and sediment load. • Reducing the extension rate of the river mouth is also an important goal of sediment management in the Lower Yellow River as land is created in a speed of 20~30km^2 annually in the Yellow River mouth.	load. Environmental issues are not a direct result of high sediment loads in the basin yet heavy soil losses have other ramifications for social/economic reasons. • Barriers to dredging: issues have to be solved before employment of dredging as a main strategy for river training: (1) effects of dredging on flow and sediment carrying capacity; (2) how to avoid or reduce resiltation in the dredged channel; (3) efficiency of dredging at different places; (4) disposal of dredged silt to prevent it from becoming a source of pollution.

	and outflow and controlling the bed elevation. • Enlarge sluicing capacity of the dam • Change operation rules to maintain the lowest pool level for flushing before the arrival of floods in the period between July and October (this allows the pool level to be controlled lower than the elevation of the floodplain to preserve storage capacity in extreme flood events).			
Haihe and Liouhe Rivers (China).	**For water bodies:** • Bypass channels have been excavated to reduce the burden on the main channel of the Haihe and allow for the rapid release of floods from the main tributaries. • 26 depressions have been prepared as flood detention areas. • Non-structural measures include: soil conservation measures (particularly in the mountainous regions) should be emphasized to reduce soil erosion and to promote local economic development and dredging of estuaries to maintain flood carrying capacity. **For reservoirs:** • Mitigation measures to reduce	No information.	• In the upper reaches, especially in the western region of the basin, soil conservation works should be prioritized. • Detailed catchment management planning. • Considering inter-basin water transfer to maintain normal flow conditions (however this would be very expensive). • Further regulation of estuaries to improve their flood capacity and ecology.	• Incomplete flood control system and low standard of flood control works: The standard of flood control of many reservoirs, including large-size reservoirs, does not comply with the national standard of flood control. The quality of the levees, totaling 20 thousand km long, is poor. • Difficulty in operation of flood detention areas: There are 26 planned flood detention areas with a total storage volume of 17 billion m3. 4.61 million people live in those areas, but 80% of them are without guarantee of safety. The warning system of flood control is

	incoming sediment load.			still not complete. It is quite difficult to use those flood detention areas when it is necessary. • River flows are an issue to to limited water availability – so sediment and flood carrying capacity will be an ongoing issue, especially in the middle reaches.

3.2 Comparison Table of Sediment Issues

Basin	**Sediment Issues**			
	Social	**Environmental**	**Economic**	**Geo-political/other**
Nile River Basin	• Flood risk due to sand deposition places lives at risk. • Soil erosion and land degradation (as the main causes of sediment in river systems) have had reduced agricultural yields. FAO (1985) estimated that the average annual yield declined from (1 to 3%) on cropland (average 2.2 % for	• Excessive weed growth caused by sedimentation results in problems for aquatic health of waterways. Weed growth also further compounds sedimentation issues, trapping sediment.	• Land degradation could cost Ethiopia over 2.0 billion US$ in 25 years, and the soil nutrient depletion reduces crop production by approx 885,330 t/yr, which is about 14% of the agriculture contribution to Ethiopian GDP. • Irrigation canal silting. Such practices of sediment removal enlarge the debt	No information.

	the Ethiopian Highlands) and up to 1% on grassland. • Sediment contributes to the increased growth of weeds which cause problems for irrigation. Until recently manual labor was used for weeds removal which caused health hazards (such as bilharzias). • Excavators with special weed-cutting are used to remove weeds from the canals, but they face lack of funds for maintenance to keep them working. • Sediment causing problems for domestic water supply (water treatment and distribution networks) leading to reduction in plant capacity, problems in water delivery and efficiency. As a result up to 50% of Nile residents have access to safe drinking water. Chemical treatment is the only alternative to these people – and the related health effects are unknown.		burden, which is facing GS now, following many years of unprofitable performance. • The existing Sudanese and Ethiopian reservoirs lost about 50% of their storage capacity in the last 40 years, AHD lost about 4% taking into consideration the total amount of sediment reaching the reservoir, about 140 million tons annually. It was found that, a sediment control facility with capital cost as high as the cost of the total project would be economically justified if only the active storage of the reservoir would have been preserved.	
Mississippi River Basin (USA)	• Major tributaries and the delta area have been susceptible to significant changes in river discharge,	• The sedimentation issues have had broad effects upon several aspects of life, both terrestrial and aquatic.	• Loss of land at the delta (loss of tourist amenity?) • Reduced water quality impacts on fisheries?	-

	cross section, width, mean bed elevation, water surface elevation, and sediment concentration. • Water quality issues are also a concern.	• Reduced sediment deposition at the delta is resulting in loss of wetlands.		
Rhine River Basin	• Dredging is carried out to ensure safety and ease of navigation. Navigation is influenced by bed level alteration by erosion or accumulation of sediments. Outgrowing bedrock-sills at the river bed hamper navigation and falling water levels in the inland harbors force both lowering of the harbor bed by dredging and subsequent enhancing of the vertical harbor walls. • Sediment also acts as a potential sink for many hazardous chemicals. Since the industrial revolution, human-made chemicals have been emitted to the Rhine surface waters.	• Whereas water quality at most places in the Rhine is improving, the legacy of the past is still present in sediments hidden at the bottom of the Rhine river, behind dams, estuaries and on the Rhine floodplains. These sediments may become a secondary source of pollution when they are eroded (e.g. due to flooding) and transported further downstream. • The relation between sediment quality and risks is complex and site specific. However, at a certain level contaminants in sediment will start to impact the ecological or chemical water quality status and complicate sediment management. In the end, effects may occur such as the decreased abundance of sediment dwelling (benthic) species or a decreased reproduction or health of	• The economic and ecologic consequences of continuous bed degradation (lowering of water levels due to erosion of bed) have been described by Gölz (1994). • Dredging is costly and yet is necessary where navigation channels fill with sediment. • Sediment accumulation in reservoirs reduces the economic lifetime of the reservoir. • Dredging often has downstream impacts due to a lack of sediment downstream causing bed erosion which can result in damage to hydraulic works, walls, bridge foundations etc.	-

		animals consuming contaminated benthic species. • Turbidity and excessive sedimentation have a physical effect on benthic life • Dams and barrages decrease the supply of sediment needed to support downstream wetlands, estuaries and other ecosystems (Salomons & Brils, 2004).		
Volga River Basin	• Ground dams are often constructed in small river valleys, in order to maintain water supply in summer months. During spring floods many such dams can be breached by intensive runoff, flow velocities increase greatly and erosion accelerates. • For example, significant bank downcutting has been observed on the Agrizka River (the Izh River Basin) in 2003 as a result of earthen dam breach (Fig.4.8). The maximum value of the bank retreat was more than 8 m in this instance.			

Yellow River Basin (China)	• The main channel in the reach from Taohuayu to Gaochun, having a river length of 194 km is a wide and shallow wandering channel, which is the most dangerous stretch for flood control. The reach from Aishan to Lijin, having river length of 282 km is a meandering river with stable narrow main channel. It is also a dangerous stretch for flood control and ice jam due to its narrow channel and floodplains. • The floods with high sediment concentration usually occur in the months from June to September • The perched nature of the river makes it a risk for flood control. The river bed elevation of the Lower Yellow River channel is commonly 3m~5m higher than that of the ground behind the river, the maximum of which is 10m.	• The Yellow River has a naturally high sediment load. Environmental issues are not a direct result of high sediment loads in the basin yet heavy soil losses have other ramifications for social/economic reasons. • A series of inland lakes and swamps, such as the Dongping Lake, Northern Five Lakes and Yongan Swamp, etc located on the floodplains, are continually drying up due to sediment aggradation and human activities. These play an important role in flood retention.	• Engineering impacts of erosion and sedimentation. There are 740 reservoirs with 54.3 billion m^3 with storage capacity. Based on incomplete statistics, until 1990 (some reservoirs until 1987), the total deposition in these reservoirs was about 11.55 billion m^3, among which 9.6 billion m^3 in large-scale reservoirs and 1.4 billion m^3 in medium-scale reservoirs. After the large scale reservoirs were constructed, until 1990, the cumulative siltation was 2.27 billion m^3. • In the tributaries and trunk of the Yellow River, there are 740 reservoirs. Expensive solutions are required to guarantee the normal operation of reservoirs (to reduce silting and limit turbine abrasion)– such as intake screens (for heavy sediment load and floating materials) etc. • Sediment diversion for irrigation	• In 1976 a new outlet channel was artificially diverted into the Bohai Sea. Since then about one billion tons of sediment has been deposited in this region, forming annually new ground of 25-30 km^2 in average. • Reducing the extension rate of the river mouth is also an important goal of sediment management in the Lower Yellow River even though local residents consider the sediment as resource by taking advantage of the newly formed land for agriculture, oil fields, fisheries and modern cities.
Haihe and Liouhe Rivers	• Flood control to protect human life is the key sediment issue. The total	• The flood carrying capacity of the rivers and bypass channels have been reduced	• Two of China's largest cities – Beijing and Tianjin – are located in the	None.

(China).	population in the watershed is about 100 million and is one of the densely populated areas in China.	significantly due to sedimentation and vegetation. The total design flood carrying capacity was 24680 m^3/s, but now the flood carrying capacity is 15040 m^3/s.	watershed. • There are also several important coal mining bases and the Huabei and Dagang oilfields.	

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