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DanubeSediment

Analysis of Sediment Data Collected along the Danube

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Project Introduction

The Danube by Hainburg, Austria. (Philipp Gmeiner/IWHW-BOKU)

Sediments are a natural part of aquatic systems. During the past centuries, humans have strongly altered the Danube River. Riverbed straightening, hydropower dams and dikes have led to significant changes in the sediment load. This sediment imbalance contributes to flood risks, reduces navigation possibilities and hydropower production. It also leads to the loss of biodiversity within the Danube Basin.

To tackle these challenges, 14 project partners and 14 strategic partners came together in the DanubeSediment project. The partnership included numerous sectoral agencies, higher education institutions, hydropower companies, international organisations and nongovernmental organisations from nine Danube countries.

Closing knowledge gaps: In a first step, the project team collected sediment transport data in the Danube River and its main tributaries. This data provided the foundation for a Danube-wide sediment balance that analysed the sinks, sources and redistribution of sediment within the Danube - from the Black Forest to the Black Sea. In order to understand the impacts and risks of sediment deficit and erosion, the project partners analysed the key drivers and pressures causing sediment discontinuity.

Strengthening governance: One main project output is the Danube Sediment Management Guidance (DSMG). It contains recommendations for reducing the impact of a disturbed sediment balance, e.g. on the ecological status and on flood risk along the river. By feeding into the Danube River Management Plan (DRBMP) and the Danube Flood Risk Management Plan (DFRMP), issued by the International Commission for the Protection of the Danube River (ICPDR), the project directly contributes to transnational water management and flood risk prevention.

International Training Workshops supported the transfer of knowledge to key target groups throughout the Danube River Basin, for example hydropower, navigation, flood risk management and river basin management, which includes ecology. The project addressed these target groups individually in its second main project output: the Sediment Manual for Stakeholders. The document provides background information and concrete examples for implementing good practice measures in each field.

DanubeSediment was co-funded by the European Union ERDF and IPA funds in the frame of the Danube Transnational Programme. Further information on the project, news on events and project results are available here: www.interreg-danube.eu/danubesediment.

Project Reports

The DanubeSediment project was structured into six work packages. The main project publications are listed below and can be found here on our project website.

1) Sediment Monitoring in the Danube River
2) Analysis of Sediment Data Collected along the Danube
3) Handbook on Good Practices in Sediment Monitoring
4) Data Analyses for the Sediment Balance and Long-term Morphological Development of the Danube
5) Assessment of the Sediment Balance of the Danube
6) Long-term Morphological Development of the Danube in Relation to the Sediment Balance
7) Interactions of Key Drivers and Pressures on the Morphodynamics of the Danube
8) Risk Assessment Related to the Sediment Regime of the Danube
9) Sediment Management Measures for the Danube
10) Key Findings of the DanubeSediment Project
11) Danube Sediment Management Guidance
12) Sediment Manual for Stakeholders

Analysis of Sediment Data Collected along the Danube

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This report is a deliverable of the project **Danube Sediment Management** - Restoration of the Sediment Balance in the Danube River. DanubeSediment is co-funded by the European Union funds ERDF and IPA in the frame of the Danube Transnational Programme (Project reference number: DTP-1-1-195-2.1). The overall budget is 3 558 581.62 Euros, whereby the ERDF contributes 2 827 421.16 Euros and the IPA contributes 197 373.19 Euros.

Project duration: 01.01.2017-30.06.2019

Website: www.interreg-danube.eu/danubesediment

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1 Goal and structure of this report

This report has been prepared in the frame of the DanubeSediment Interreg DTP project. The report is one of the two deliverables within Work Package 3 (Sediment Data Collection) of the project. The goal of the report is to introduce the available sediment dataset collected within the project and to perform a preliminary analysis of the data for a follow-up, more detailed quantitative assessment for the sediment budget calculations.

An overview will be given country by country about the collected information of suspended sediment and bedload data. Besides the quantitative description a categorization of the data will be performed in terms of the quality of the data, based on the measurement and laboratory analysis methods applied at the responsible institutes. Using the available historical sediment data at shared sections of the Danube River, we perform a comparative analysis of the information to gain better knowledge about the homogeneity of the datasets and to decide which dataset can or cannot be used in the data analysis. The comparative analysis will also tackle the assessment of sediment data collected within joint field measurement campaigns in the project. Finally, we analyse the longitudinal and temporal variations of the suspended sediment and the bedload transport both on small and large scales. As a final product of this report a harmonized sediment database is established for further analysis in order to setup the sediment balance for the Danube River or, at least, for selected shorter sections.

2 Overview of available sediment data

2.1 Introduction

The goal of this chapter is to introduce the sediment data collected within the project from the partners, in terms of quantity and quality. The collected data provide a basis for the follow-up activities in the project, such as the data analysis or the set up of the sediment balance along the Danube River.

One of the most important goals within WP3 of the project, was to analyze the longitudinal variation of the long term sediment load along the Danube River both for suspended sediment and bedload. Through the results of the analysis the problematic sections, in terms of sediment continuity, can be assessed and significant data gaps can also be identified. The collected sediment data is therefore a significant pillar of the whole project. The quantity and also the quality of the sediment data strongly determine the reliability of the introduced results and the conclusions drawn from the sediment balance. The aim at this stage of the project was to collect as much information about the sediment as possible, which revealed the available datasets along the Danube river and from those tributaries, which are most relevant from a sediment input point of view. For the latter, only the data closest to the confluence with the Danube River were considered, as point sources. The available sediment data was reported in the first task of this activity by the project partners, through web-based questionnaires completed for each sediment monitoring station. Only stations, where long-term data was available have been taken into account for the follow-up tasks. These questionnaires and the actual sediment information provided by the project partners were used as input for this report.

In the followings, an overview will be provided about the methods of the data collection. Then a brief introduction will be given for every monitoring station about the related dataset both for suspended sediment and bedload. It is shown that the datasets are quite heterogeneous in terms of the covered time period as well as the time resolution of the datasets, which already imply quality issues of the information. Moreover, connecting the applied sediment monitoring methods to the data, a further qualitative discription can be linked to each dataset. In the last point, a sediment data quality characterization of the datasets will be suggested.

2.2 Data collection

The data collection was divided into two parts: suspended sediment (SS) and bedload (BL) data. In order to see temporal changes on a long-term, for instance to reveal the influence of hydropower plant operation, historical data was also collected from stations where such data was available. On the other hand, to understand the role of short-term, sudden changes in the sediment regimes, such as dynamic sediment discharge waves during flood events, fine scale, daily (or even finer) data was also gathered. Since the composition of the transported sediments can contribute to the better understanding of the morphological changes, the particle (or grain for BL) size distributions have also been looked at.

For suspended sediment, the following information was requested for each monitoring station from the partners:

- monthly minimum, mean and maximum flow discharge values for the period 1986-2016
- monthly minimum, mean and maximum suspended sediment load values for the period 1986-2016
- mean annual flow discharge for the period before 1986
- mean annual supended sediment load for the period before 1986
- daily suspended sediment load values for flood event, where available
- SS rating curves, where relevant
- Particle Size Distribution (PSD) curves for SS, where available

Regarding bedload data, the following information was requested, for each monitoring station:

- mean annual flow discharge for time period, where data is available
- mean annual bedload for time period, where data is available
- BL rating curves
- Grain Size Distribution (GSD) curves for BL material

2.3 Suspended sediment data quantity

In this point a brief description will be given for each suspended sediment monitoring station for which data were provided by the project partners, focusing on the quantity of the sediment data. The descriptions will be presented country by country from upstream to downstream along the Danube River, also for the most important tributaries.

The list of the monitoring stations, indicating the country, the river's name, the name and location of the sites is shown in Table 1 and Table 2 for the Danube and the tributaries, respectively (Figure 1).

Table 1 List of suspended sediment monitoring stations, considered in the data analysis, along the Danube

Country	**River**	**Name of monitoring site**	**Location (rkm)**
Germany	Danube	Neu-Ulm Bad Held	2 586.70
Germany	Danube	Donauwörth	2 508.13
Germany	Danube	Ingolstadt Luitpoldstrasse	2 457.85
Germany	Danube	Straubing gauging station	2 321.30
Germany	Danube	Vilshofen	2 249.50
Germany	Danube	Kachlet	2 230.70
Germany	Danube	Jochenstein	2 203.10
Austria	Danube	Engelhartszell	2 200.66
Austria	Danube	Aschach Strombauleitung	2 161.27
Austria	Danube	Linz	2 135.17
Austria	Danube	Donaukraftwerk Abwinden - Asten	2 119.20
Austria	Danube	Donaukraftwerk Wallsee - Mitterkirchen	2 094.21
Austria	Danube	Stein-Krems	2 002.69
Austria	Danube	Bad Deutsch-Altenburg (Bauleitung)	1 886.86
Austria	Danube	Hainburg Straßenbrücke*	1 886.24
Slovakia	Danube	Devín	1 878.15
Slovakia	Danube	Bratislava, Lafranconi bridge	1 871.30
Slovakia	Danube	Medveďov Bridge	1 806.30
Hungary	Danube	Vámosszabadi	1 805.60
Slovakia	Danube	Komárno Bridge	1 767.80
Hungary	Danube	Nagymaros	1 694.60
Hungary	Danube	Budapest	1 646.50
Hungary	Danube	Dunaújváros	1 580.60
Hungary	Danube	Dombori	1 506.80
Hungary	Danube	Mohács	1 446.90
Serbia	Danube	Novi Sad	1 257.10
Serbia	Danube	Stari Banovci	1 192.75
Serbia	Danube	Smederevo	1 110.40
Romania	Danube	Bazias	1 072.50
Serbia	Danube	HPP Đerdap 1/Iron Gate 1 dam	943.00
Serbia	Danube	Kladovo	932.90

Country	River	Name of monitoring site	Location (rkm)
Romania	Danube	Drobeta Turnu Severin	931.00
Romania	Danube	Gruia	858.35
Bulgaria	Danube	Lom	743.30
Romania	Danube	Corabia	624.20
Bulgaria	Danube	Svishtov	554.30
Romania	Danube	Zimnicea	553.23
Romania	Danube	Giurgiu	493.05
Romania	Danube	Chiciu Calarasi	379.58
Bulgaria	Danube	Silistra	375.50
Romania	Danube	Vadu Oii	238.00
Romania	Danube	Braila	167.00
Romania	Danube	Ceatal Izmail	80.50
Romania	Danube/Branch Chilia	Periprava	20.00
Romania	Danube/Sfantu Gheorghe	Sfantul Gheorghe Harbour	8.00
Romania	Danube	Sulina	2.50

*The data from Bad Deutsch-Altenburg (Bauleitung) and Hainburg Straßenbrücke stations are combined in the data assessment.

Table 2 List of suspended sediment monitoring stations, considered in the data analysis, at the tributaries

Country	River	Name of monitoring site	Location (rkm)
Germany	Isar	Plattling	9.12
Germany	Inn	Passau Ingling	3.10
Austria	Inn	Schärding (Schreibpegel)	16.25
Austria	Traun	Wels-Lichtenegg	33.25
Austria	Enns	Steyr (Ortskai)	30.88
Austria	Morava	Angern	31.89
Slovakia	Morava	Záhorská Ves	32.52
Slovakia	Morava	Moravský Ján	67.15
Hungary	Rába	Győr	14.5*
Croatia	Drava	Donji Miholjac	80.50
Serbia	Tisa	Titel	4.90
Serbia	Sava	Belgrade	5.20
Serbia	Velika Morava	Ljubičevski Bridge	21.83
Romania	Jiu	Zaval	8.00
Bulgaria	Iskar	Oriahovitza	340.50**
Bulgaria	Iantra	Karantzi	208.00**
Romania	Arges	Budești	2.00
Romania	Ialomita	Tandarei	29.00
Romania	Siret	Lungoci	77.00
Romania	Prut	Oancea	79.20

*River Rába flows into Danube through River Mosoni-Duna.

**River kilometer values in Bulgaria at the tributaries indicate the distance from the source instead of the mouth.

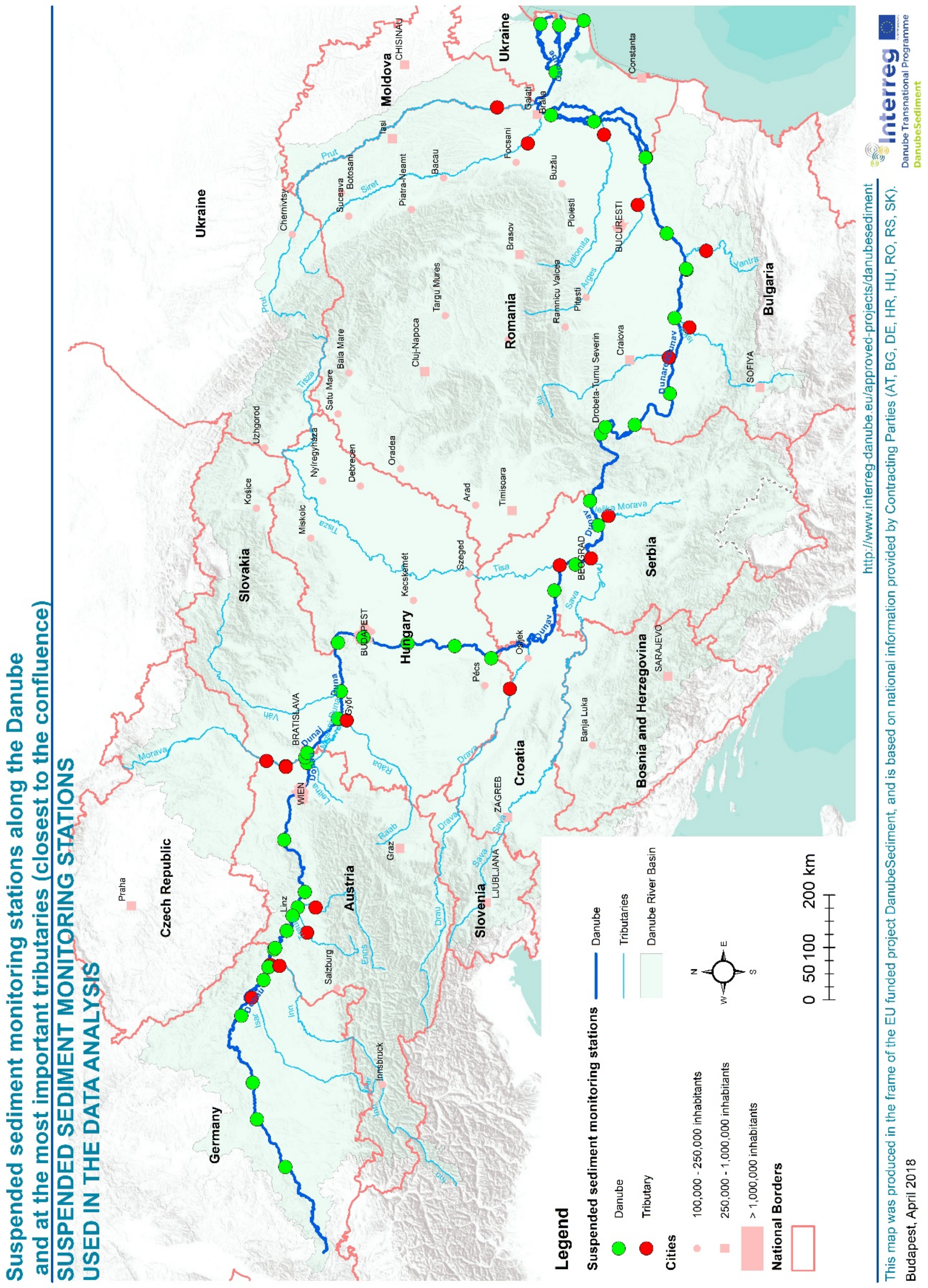


Figure 1 Suspended sediment monitoring stations along the Danube and its important tributaries, involved in the data analysis

2.3.1 Germany

SS monitoring stations involved in the data assessment from Germany (Table 3):

Table 3 Suspended sediment monitoring stations in Germany

River	Name of monitoring site	Location (rkm)
Danube	Neu-Ulm Bad Held	2 586.70
Danube	Donauwörth	2 508.13
Danube	Ingolstadt Luitpoldstrasse	2 457.85
Danube	Straubing gauging station	2 321.30
Danube	Vilshofen	2 249.50
Danube	Kachlet	2 230.70
Danube	Jochenstein	2 203.10
Isar	Plattling	9.12
Inn	Passau Ingling	3.10

2.3.1.1 Neu-Ulm Bad Held

The monitoring station is located at rkm 2586.7. The monitoring is performed by Wasserwirtschaftsamt Donauwörth, the sediment data is owned by the Bavarian Environment Agency (LfU) and the Bavarian Hydrological Service (GKD). Sediment monitoring started in 1966. Physical sampling was performed between 1966-2011. The sampling frequency was depending on the flow conditions, from once a week up to 8 times per day. From 2011, an optical backscatter sensor (OBS) was installed, providing a sampling interval of 15 minutes. The optical monitoring is complemented with physical sampling once a week and a multipoint measurement covering the whole cross-section, using acoustic techniques once a year. Historical data for this station in the form of annual sediment loads are reported back to 1931 from other sources.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2016)
- monthly min, mean, max SS loads (1986-2016)
- mean annual flow discharge and SS loads (1931-1985)
- 15 min resolution SS loads for the 2002, 2006 and 2013 flood events.
- SSC rating curve

2.3.1.2 Donauwörth

The monitoring station is located at rkm 2508.13. The monitoring is performed by Wasserwirtschaftsamt Donauwörth, the sediment data is owned by the Bavarian Environment Agency (LfU) and the Bavarian Hydrological Service (GKD). Sediment monitoring was started in 2014, October. An OBS is used here, providing a sampling interval of 15 minutes. The optical monitoring is complemented with physical sampling once a week and a multipoint measurement covering the whole cross-section, using acoustic techniques once a year.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2016)
- monthly min, mean, max SS loads (2015-2016)
- SSC rating curve

2.3.1.3 Ingolstadt Luitpoldstrasse

The monitoring station is located at rkm 2457.85. The monitoring is performed by Wasserwirtschaftsamt Ingolstadt, the sediment data is owned by the Bavarian Environment Agency (LfU) and the Bavarian Hydrological Service (GKD). Sediment monitoring started in 1966. Physical sampling was performed between 1966-2011. The sampling frequency was depending on the flow conditions, from once a week up to 8 times per day. From 2011, an optical backscatter sensor (OBS) was installed, providing a sampling interval of 15 minutes. The optical monitoring is complemented with physical sampling once a week and a multipoint measurement covering the whole cross-section, using acoustic techniques once a year. Historical data for this station in the form of annual sediment loads are reported back to 1931 from other sources.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2016)
- monthly min, mean, max SS loads (1986-2016)
- mean annual flow discharge and SS loads (1931-1985)
- 15 min resolution SS loads for the 2002, 2006 and 2013 flood events.
- SSC rating curve
- PSD (for different flow regimes)

2.3.1.4 Straubing gauging station

The monitoring station is located at rkm 2321.30. The monitoring is performed by Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG) and Federal Waterways Engineering and Research Institute (BAW), the sediment data is owned by the Federal Waterways and Shipping Administration. Sediment monitoring was started in 1982. Physical sampling is performed with a sampling frequency of once a day.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2016)
- monthly min, mean, max SS loads (1986-2005; 2009-2016)
- mean annual flow discharge and SS loads (1983-1985)
- 15 min resolution SS loads for the 2002, 2010 and 2013 flood events.
- SSC rating curve

2.3.1.5 Vilshofen

The monitoring station is located at rkm 2249.50. The monitoring is performed by Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG) and Federal Waterways Engineering and Research Institute (BAW), the sediment data is owned by the Federal Waterways and Shipping Administration. Sediment monitoring started in 1966. Physical sampling is performed with a sampling frequency of once a day. Historical data for this station in the form of annual sediment loads are reported back to 1930 from other sources.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2016)
- monthly min, mean, max SS loads (1986-2016)
- mean annual flow discharge and SS loads (1930-1985)
- 15 min resolution SS loads for the 2002, 2006, 2010 and 2013 flood events.
- SSC rating curve

2.3.1.6 Kachlet

The monitoring station is located at rkm 2230.70. The monitoring is performed by Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG) and Federal Waterways Engineering and Research Institute (BAW), the sediment data is owned by the Federal Waterways and Shipping Administration. Sediment monitoring was started in 1975. Physical sampling is performed with a sampling frequency of once a day.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2016)
- monthly min, mean, max SS loads (1986-2016)
- mean annual flow discharge and SS loads (1975-1985)
- 15 min resolution SS loads for the 2002, 2006, 2010 and 2013 flood events.
- SSC rating curve

2.3.1.7 Jochenstein

The monitoring station is located at rkm 2203.10. The monitoring is performed by Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG) and Federal Waterways Engineering and Research Institute (BAW), the sediment data is owned by the Federal Waterways and Shipping Administration. Sediment monitoring was started in 1974. Physical sampling is performed with a sampling frequency of once a day.

The monitoring station is located at rkm 2230.70. The monitoring is performed by Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG) and Federal Waterways Engineering and Research Institute (BAW), the sediment data is owned by the Federal Waterways and Shipping Administration. Sediment monitoring was started in 1975. Physical sampling is performed with a sampling frequency of once a day.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2010)
- monthly min, mean, max SS loads (1986-2010)
- mean annual flow discharge and SS loads (1975-1985)
- 15 min resolution SS loads for the 2002, 2006 and 2010 flood events.
- SSC rating curve

2.3.1.8 Plattling (Isar)

The monitoring station is located at rkm 9.12 in the Isar river. The monitoring is performed by Wasserwirtschaftsamt Deggendorf, the sediment data is owned by the Bavarian Environment Agency (LfU) and the Bavarian Hydrological Service (GKD). Sediment monitoring started in 1966. Physical sampling was performed between 1966-2011. The sampling frequency was depending on the flow conditions, from once a week up to 8 times per day. From 2011, an optical backscatter sensor (OBS) was installed, providing a sampling interval of 15 minutes. The optical monitoring is complemented with physical sampling once a week and a multipoint measurement covering the whole cross-section, using acoustic techniques once a year.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2016)
- monthly min, mean, max SS loads (1986-2016)
- mean annual flow discharge and SS loads (1965-1985)
- daily SS loads for the 2002 and 2006 flood events
- 15 min resolution SS loads for the 2013 flood event
- SSC rating curve

2.3.1.9 Passau Ingling (Inn)

The monitoring station is located at rkm 3.10 in the Inn river. The monitoring is performed by Wasserwirtschaftsamt Deggendorf, the sediment data is owned by the Bavarian Environment Agency (LfU) and the Bavarian Hydrological Service (GKD). Sediment monitoring started in 1970. Physical sampling was performed between 1966-2011. The sampling frequency was depending on the flow conditions, from once a week up to 8 times per day. From 2011, an optical backscatter sensor (OBS) was installed, providing a sampling interval of 15 minutes. The optical monitoring is complemented with physical sampling once a week and a multipoint measurement covering the whole cross-section, using acoustic techniques once a year.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2016)
- monthly min, mean, max SS loads (1986-2015)
- mean annual flow discharge and SS loads (1969-1985)
- daily SS loads for the 2002 and 2006 flood events
- 15 min resolution SS loads for the 2013 flood event
- SSC rating curve

2.3.2 Austria

SS monitoring stations involved in the data assessment from Austria (Table 4):

Table 4 Suspended sediment monitoring stations in Austria

River	Name of monitoring site	Location (rkm)
Danube	Engelhartszell	2 200.66
Danube	Aschach Strombauleitung	2 161.27
Danube	Linz	2 135.17
Danube	Donaukraftwerk Abwinden - Asten	2 119.20
Danube	Donaukraftwerk Wallsee - Mitterkirchen	2 094.21
Danube	Stein-Krems	2 002.69
Danube	Bad Deutsch-Altenburg (Bauleitung)	1 886.86
Danube	Hainburg Straßenbrücke*	1 886.24
Inn	Schärding (Schreibpegel)	16.25
Traun	Wels-Lichtenegg	33.25
Enns	Steyr (Ortskai)	30.88
Morava	Angern	31.89

*The data from Bad Deutsch-Altenburg (Bauleitung) and Hainburg Straßenbrücke stations are combined in the data assessment.

2.3.2.1 Engelhartszell

The monitoring station is located at rkm 2200.66. The monitoring is performed and the data is owned by via Donau - Österreichische Wasserstraßen-Gesellschaft mbH. Sediment monitoring started in 1954. Sampling frequency is dependent on the water level or discharge and varies from once every three days up to four times a day (7 am, 11 am, 3 pm and 7 pm) during flood events.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2016)
- monthly min, mean, max SS loads (1986-2016)
- mean annual flow discharge and SS loads (1956-1985)
- daily SS loads for the 2002, 2006, 2010 and 2013 flood events
- PSD for different flow regimes

2.3.2.2 Aschach Strombauleitung

The monitoring station is located at rkm 2161.27. The monitoring is performed and the data is owned by via Donau - Österreichische Wasserstraßen-Gesellschaft mbH. Sediment monitoring started in 1960. Between 1960-2011 a bottle sampling was established, with a frequency dependent on the water level or discharge and varied from once every three days up to four times a day during floods. In 2011, an optical backscatter sensor (OBS) was installed, providing a sampling interval of 15 minutes. The optical monitoring is complemented with physical sampling close to the sensor with a sampling frequency once in two weeks up to one or more times a day during flood events.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2016)
- monthly min, mean, max SS loads (1986-2016)
- mean annual flow discharge and SS loads (1960-1985)
- daily SS loads for the 2002, 2006, 2010 and 2013 flood events
- PSD for different flow regimes

2.3.2.3 Linz

The monitoring station is located at rkm 2135.17. The monitoring is performed and the data is owned by via Donau - Österreichische Wasserstraßen-Gesellschaft mbH. Sediment monitoring started in 1928, taking physical samples, with a varying sampling frequency (dependent on the water level or discharge) from once every three days up to four times a day during floods. Historical data for this station in the form of annual sediment loads are reported back to 1928 from other sources.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2016)
- monthly min, mean, max SS loads (1986-2016)
- mean annual flow discharge and SS loads (1928-1985)
- daily SS loads for the 2002, 2006, 2010 and 2013 flood events

2.3.2.4 Donaukraftwerk Abwinden - Asten

The monitoring station is located at rkm 2119.20. The monitoring is performed and the data is owned by Verbund Hydro Power GmBH (VHP). Sediment monitoring started in 1967 and is at the moment performed via automatized bottle sampling. The sampling frequency depends on flow discharge of, from 3 times a week ($Q<1100\ m^3/s$) up to 4 times a day ($Q>3700\ m^3/s$).

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2016)
- monthly min, mean, max SS loads (1986-2016)
- mean annual flow discharge and SS loads (1970-1985)
- daily SS loads for the 2002, 2006, 2010 and 2013 flood events
- PSD for different flow regimes

2.3.2.5 Donaukraftwerk Wallsee - Mitterkirchen

The monitoring station is located at rkm 2094.21. The monitoring is performed and the data is owned by Verbund Hydro Power GmBH (VHP). Sediment monitoring started in 1958 and is at the moment performed via automatized bottle sampling. The sampling frequency depends on flow discharge, from 3 times a week ($Q<1100\ m^3/s$) up to 4 times a day ($Q>3700\ m^3/s$).

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2016)
- monthly min, mean, max SS loads (1986-2004, 2009-2016)
- mean annual flow discharge and SS loads (1958-1967; 1970-1985)
- daily SS loads for the 2002, 2010 and 2013 flood events
- PSD for different flow regimes

2.3.2.6 Stein-Krems

The monitoring station is located at rkm 2002.69. The monitoring is performed and the data is owned by via Donau - Österreichische Wasserstraßen-Gesellschaft mbH. Sediment monitoring started in 1991, taking physical samples, with a varying sampling frequency (dependent on the water level or discharge) from once every three days up to four times a day during floods.

Provided sediment data:

- monthly min, mean, max flow discharges (1991-2016)
- monthly min, mean, max SS loads (1991-2016)
- daily SS loads for the 2002, 2006, 2010 and 2013 flood events
- PSD for different flow regimes

2.3.2.7 Bad Deutsch-Altenburg (Bauleitung) + Hainburg Straßenbrücke

The monitoring station is located at rkm 1886.86. The monitoring is performed and the data is owned by via Donau - Österreichische Wasserstraßen-Gesellschaft mbH. Sediment monitoring started in 1956. Between 1956-2009 bottle sampling was performed, with a frequency dependent on the water level or discharge and varied from once every three days up to four times a day during floods. In 2008, a new monitoring station was set up at Hainburg Straßenbrücke (rkm 1886.24). Here, an optical backscatter sensor (OBS) was installed, providing a sampling interval of 15 minutes. The optical monitoring is complemented with physical sampling close to the sensor with a sampling frequency once in two weeks up to one or more times a day during flood events. Approximatly twice a year, multipoint measurements covering the whole cross section are performed by IWHW/BOKU on behalf of viadonau..

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2014)
- monthly min, mean, max SS loads (1986-2014)
- mean annual flow discharge and SS loads (1956-1985)
- daily SS loads for the 2002, 2006, 2010 and 2013 flood events
- PSD for different flow regimes

2.3.2.8 Schärding (Schreibpegel) (Inn)

The monitoring station is located at rkm 16.25 in the Inn river. The monitoring is performed and the sediment data is owned by the Hydrographic service of Upper Austria (HD OOE).

Sediment monitoring started in 2008. An optical backscatter sensor (OBS) was installed, providing a sampling interval of 15 minutes. The optical monitoring is complemented with physical sampling at the sensor (from once a week up to several times a day during flood events) and a multipoint measurement covering the whole cross-section, using acoustic techniques once a year.

Provided sediment data:

- monthly min, mean, max flow discharges (2008-2014)
- monthly min, mean, max SS loads (2008-2014)
- daily SS loads for the 2010 and 2013 flood event
- PSD for different flow regimes

2.3.2.9 Wels-Lichtenegg (Traun)

The monitoring station is located at rkm 33.25 in the Traun river. The monitoring is performed and the sediment data is owned by the Hydrographic service of Upper Austria (HD OOE). Sediment monitoring started in 1950. Between 1950-2005 bottle sampling was performed, with a frequency dependent on the water level or discharge and varied from once every three days up to four times a day during floods. In 2005, an optical backscatter sensor (OBS) was installed, providing a sampling interval of 15 minutes. The optical monitoring is complemented with physical sampling at the sensor (from once a week up to several times a day during flood events) and a multipoint measurement covering the whole cross-section, using acoustic techniques once a year.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-1997; 1999; 2004-2014)
- monthly min, mean, max SS loads (1986-1997; 1999; 2004-2014)
- mean annual flow discharge and SS loads (1960-1961; 1965-1979; 1984-1985)
- daily SS loads for the 2010 and 2013 flood event
- PSD for different flow regimes

2.3.2.10 Steyr (Ortskai) (Enns)

The monitoring station is located at rkm 30.88 in the Enns river. The monitoring is performed and the sediment data is owned by the Hydrographic service of Upper Austria (HD OOE). Sediment monitoring started in 1984. Between 1984-2006 bottle sampling was performed, with a frequency dependent on the water level or discharge and varied from once every three days up to four times a day during floods. In 2006, an optical backscatter sensor (OBS) was installed, providing a sampling interval of 15 minutes. The optical monitoring is complemented with physical sampling at the sensor (from once a week up to several times a day during flood events) and a multipoint measurement covering the whole cross-section, using acoustic techniques once a year.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2014)
- monthly min, mean, max SS loads (1986-2014)
- mean annual flow discharge and SS loads (1984-1985)
- daily SS loads for the 2002, 2006, 2010 and 2013 flood events
- PSD

2.3.2.11 Angern (Morava)

The monitoring station is located at rkm 31.89 in the Morava river. The monitoring is performed and the data is owned by via donau - Österreichische Wasserstraßen-Gesellschaft mbH. Sediment monitoring started in 1988, taking physical samples, with a varying sampling frequency (dependent on the water level or discharge) from once every three days up to four times a day during floods.

Provided sediment data:

- monthly min, mean, max flow discharges (1988-2016)
- monthly min, mean, max SS loads (1988-2016)
- mean annual flow discharge and SS loads (1957-1961)

2.3.3 Slovakia

SS monitoring stations involved in the data assessment from Slovakia (Table 5):

Table 5 Suspended sediment monitoring stations in Slovakia

River	Name of monitoring site	Location (rkm)
Danube	Devín	1 878.15
Danube	Bratislava (Lafranconi bridge)	1 871.30
Danube	Medveďov Bridge	1 806.30
Danube	Komárno Bridge	1767.80
Morava	Záhorská Ves	32.52
Morava	Moravský Ján	67.15

2.3.3.1 Devín

The monitoring station is located at rkm 1878.15. The monitoring is performed and the data is owned by the Water Research Institute Bratislava (VUVH). Sediment monitoring took place between 1997-1998 in the frame of 19 detailed field measurement campaigns. Using the results of the field measurements, linear regression equations were derived for the cross-sectional mean concentration and flow discharge as well as for the sediment load and flow discharge relationships. These equations were used to calculate daily average values of suspended load for the period 1986-2016.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2016)
- monthly min, mean, max SS loads (1986-2016)
- SSC rating curve
- PSD

2.3.3.2 Bratislava (Lafranconi bridge)

The monitoring station is located at rkm 1871.3. The monitoring is performed and the data is owned by the Water Research Institute Bratislava (VUVH). Sediment monitoring took place between 1996-1998 and 2008-2016. Using the results of the field measurements, linear regression equations were derived for the cross-sectional mean concentration and flow discharge as well as for the sediment load and flow discharge relationships. These equations were used to calculate daily average values of suspended load for the period 1986-2016. Mean annual sediment load data were provided for the period 1956-1985 based on literature data.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2016)
- monthly min, mean, max SS loads (1986-2016)
- mean annual flow discharge and SS loads (1956-1985)
- daily SS loads for the 2009, 2010, 2011 and 2013 flood events
- SSC rating curve
- PSD

2.3.3.3 Medveďov Bridge

The monitoring station is located at rkm 1806.3. The monitoring is performed and the data is owned by the Water Research Institute Bratislava (VUVH). Sediment monitoring took place between 2000-2002. Using the results of the field measurements, linear regression equations were derived for the cross-sectional mean concentration and flow discharge as well as for the sediment load and flow discharge relationships. These equations were used to calculate daily average values of suspended load for the period 1993-2016. Mean annual sediment load data were provided for the period 1979-1985.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2016)
- monthly min, mean, max SS loads (1993-2016)
- mean annual flow discharge and SS loads (1979-1985)
- daily SS loads for the 2002 flood event
- SSC rating curve
- PSD

2.3.3.4 Komárno Bridge

The monitoring station is located at rkm 1767.8. The monitoring is performed and the data is owned by the Slovak Hydrometeorological Institute (SHMU). Sediment monitoring started in 1992. Daily samples are taken, based on which a linear regression equation was derived for the cross-sectional mean concentration and flow discharge as well as for the sediment load and flow discharge relationships. These equations were used to calculate daily average values of suspended load for the period 1992-2016.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2016)
- monthly min, mean, max SS loads (1993-2016)
- daily SS loads for the 2006, 2009, 2010, 2011 and 2013 flood events

2.3.3.5 Záhorská Ves (Morava)

The monitoring station is located in the Morava river at rkm 32.52. The monitoring is performed and the data is owned by the Water Research Institute Bratislava (VUVH). Sediment monitoring took place between 1992-1993 and 1995-1997. Using the results of the field measurements, linear regression equations were derived for the cross-sectional mean concentration and flow discharge as well as for the sediment load and flow discharge relationships. These equations were used to calculate daily average values of suspended load for the period 1986-2016. Mean annual sediment load data were provided for the period 1977-1985. Daily sediment load data is provided for the 1997 flood event.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2016)
- monthly min, mean, max SS loads (1986-2016)
- mean annual flow discharge and SS loads (1977-1985)
- daily SS loads for the 1997 flood event
- SSC rating curve

2.3.3.6 Moravský Ján (Morava)

The monitoring station is located in the Morava river at rkm 67.15. The monitoring is performed and the data is owned by the Water Research Institute Bratislava (VUVH). Sediment monitoring took place between 1992-1993 and 1995-1997. Using the results of the field measurements, linear regression equations were derived for the cross-sectional mean concentration and flow discharge as well as for the sediment load and flow discharge relationships. These equations were used to calculate daily average values of suspended load for the period 1986-2016. Mean annual sediment load data were provided for the period 1956-1985. Daily sediment load data is provided for the 1997 flood event.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2016)
- monthly min, mean, max SS loads (1986-2016)
- daily SS loads for the 1997 flood event
- SSC rating curve

2.3.4 Hungary

SS monitoring stations involved in the data assessment from Hungary (Table 6):

Table 6 Suspended sediment monitoring stations in Hungary

River	Name of monitoring site	Location (rkm)
Danube	Vámosszabadi	1 805.60
Danube	Nagymaros	1 694.60
Danube	Budapest	1 646.50
Danube	Dunaújváros	1 580.60
Danube	Dombori	1 506.80
Danube	Mohács	1446.90
Rába	Győr	14.5*

2.3.4.1 Vámosszabadi

The monitoring station is located at rkm 1805.60. The monitoring is performed by the North-Transdanubian Water Directorate (ÉDUVIZIG) and the data is owned by the General Water Directorate (OVF). Sediment measurements are performed 5 times a year, based on which a regression analysis is done to set up relationships between the flow discharge and the sediment load. These equations are used to estimate minimum, mean and maximum monthly sediment load using the discharge values. The data set is not used in the data analysis, but the Slovakian data is analyzed instead, which represent the same location in the Danube.

2.3.4.2 Nagymaros

The monitoring station is located at rkm 1694.60. The monitoring is performed by the Middle Danube Valley Water Directorate (KDVVIZIG) and the data is owned by the General Water Directorate (OVF). Sediment measurements are performed 5 times a year (since 1951), based on which a regression analysis is done to set up relationships between the flow discharge and the sediment load. These equations are used to estimate minimum, mean and maximum monthly sediment load using the discharge values.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2015)
- monthly min, mean, max SS loads (1986-2016)
- mean annual flow discharge and SS loads (1956-1985)
- daily SS loads for the 2002 flood event
- SSC rating curve

2.3.4.3 Budapest

The monitoring station is located at rkm 1646.50. The monitoring is performed by the Middle Danube Valley Water Directorate (KDVVIZIG) and the data is owned by the General Water Directorate (OVF). Sediment measurements are performed 5 times a year (since 1924), based on which a regression analysis is done to set up relationships between the flow discharge and the sediment load. These equations are used to estimate minimum, mean and maximum monthly sediment load using the discharge values.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2015)
- monthly min, mean, max SS loads (1986-2016)
- mean annual flow discharge and SS loads (1976-1985)
- daily SS loads for the 2002 flood event
- SSC rating curve

2.3.4.4 Dunaújváros

The monitoring station is located at rkm 1580.60. The monitoring is performed by the Lower Danube Valley Water Directorate (ADUVIZIG) and the data is owned by the General Water Directorate (OVF). Sediment measurements are performed 5 times a year (since 1950), based on which a regression analysis is done to set up relationships between the flow discharge and the sediment load. These equations are used to estimate minimum, mean and maximum monthly sediment load using the discharge values.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2015)
- monthly min, mean, max SS loads (1986-2016)
- mean annual flow discharge and SS loads (1960-1985)
- daily SS loads for the 2010 flood event
- SSC rating curve

2.3.4.5 Dombori

The monitoring station is located at rkm 1506.80. The monitoring is performed by the Lower Danube Valley Water Directorate (ADUVIZIG) and the data is owned by the General Water Directorate (OVF). Sediment measurements are performed 5 times a year (since 1968), based on which a regression analysis is done to set up relationships between the flow discharge and the sediment load. These equations are used to estimate minimum, mean and maximum monthly sediment load using the discharge values. Mean annual sediment load data were provided for the period 1968-1985. Daily sediment load data is provided for the 2010 flood event.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2015)
- monthly min, mean, max SS loads (1986-2016)
- mean annual flow discharge and SS loads (1968-1985)
- daily SS loads for the 2010 flood event
- SSC rating curve

2.3.4.6 Mohács

The monitoring station is located at rkm 1446.90. The monitoring is performed by the Lower Danube Valley Water Directorate (ADUVIZIG) and the data is owned by the General Water Directorate (OVF). Sediment measurements are performed 5 times a year (since 1949), based on which a regression analysis is done to set up relationships between the flow discharge and the sediment load. These equations are used to estimate minimum, mean and maximum monthly sediment load using the discharge values.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2015)
- monthly min, mean, max SS loads (1986-2016)
- mean annual flow discharge and SS loads (1949-1985)
- daily SS loads for the 2013 flood event

- SSC rating curve

2.3.4.7 Győr (Rába)

The monitoring station is located at rkm 14.5 in the Rába river, the tributary of the Mosoni-Duna river, which is the tributary of the Danube River. River Mosoni-Duna is a strongly regulated channel with negligible sediment transport, however, the Rába river, as a natural river, brings significant sediment load during high flows. The monitoring is performed by the North-Transdanubian Water Directorate (ÉDUVIZIG) and the data is owned by the General Water Directorate (OVF). Sediment measurements are performed 5 times a year (since 1949), based on which a regression analysis is done to set up relationships between the flow discharge and the sediment load. These equations are used to estimate minimum, mean and maximum monthly sediment load using the discharge values.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2015)
- SSC rating curve

2.3.5 Croatia

SS monitoring stations involved in the data assessment from Croatia (Table 7):

Table 7 Suspended sediment monitoring station in Croatia

River	Name of monitoring site	Location (rkm)
Drava	Donji Miholjac	80.50

2.3.5.1 Donji Miholjac

The monitoring station is located at rkm 80.50 in the Drava river. The monitoring is performed and owned by the Meteorological and Hydrological Institute of Croatia (DHMZ). Sediment monitoring started in 1993. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2016)
- monthly min, mean, max SS loads (1986-2016)
- mean annual flow discharge and SS loads (1968-1985)
- SSC rating curve

2.3.6 Serbia

SS monitoring stations involved in the data assessment from Serbia (Table 8):

Table 8 Suspended sediment monitoring stations in Serbia

River	Name of monitoring site	Location (rkm)
Danube	Novi Sad	1 257.10
Danube	Stari Banovci	1 192.75
Danube	Smederevo	1 110.40
Danube	HPP Đerdap 1 dam	943.00
Danube	Kladovo	932.90
Tisa	Titel	4.90
Sava	Belgrade	5.20
Velika Morava	Ljubičevski Bridge	21.83

2.3.6.1 Novi Sad

The monitoring station is located at rkm 1257.10. The monitoring is performed by the Jaroslav Cerny Institute (JCI) and the data is owned by the PE Electric Power Industry of Serbia. Sediment monitoring started in 1986. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2015)
- monthly min, mean, max SS loads (1986-2015)
- mean annual flow discharge and SS loads (1974-1985)
- daily SS loads for the 2006 and 2013 flood events
- SSL rating curve
- PSD for different flow regimes

2.3.6.2 Stari Banovci

The monitoring station is located at rkm 1192.75. The monitoring is performed by the Jaroslav Cerny Institute (JCI) and the data is owned by the PE Electric Power Industry of Serbia. Sediment monitoring started in 1986. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1987-2015)
- monthly min, mean, max SS loads (1987-2015)
- daily SS loads for the 2006 flood event

- SSL rating curve
- PSD for different flow regimes

2.3.6.3 Smederevo

The monitoring station is located at rkm 1110.40. The monitoring is performed by the Jaroslav Cerny Institute (JCI) and the data is owned by the PE Electric Power Industry of Serbia. Sediment monitoring started in 1986. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2015)
- monthly min, mean, max SS loads (1986-2015)
- mean annual flow discharge and SS loads (1974-1985)
- daily SS loads for the 2006 flood event
- SSL rating curve
- PSD for different flow regimes

2.3.6.4 HPP Đerdap 1 dam

The monitoring station is located at rkm 943.0. The monitoring is performed by the Jaroslav Cerny Institute (JCI) and the data is owned by the PE Electric Power Industry of Serbia. Sediment monitoring started in 1974. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2015)
- monthly min, mean, max SS loads (1986-2015)
- mean annual flow discharge and SS loads (1974-1985)
- daily SS loads for the 2006 flood event
- SSL rating curve

2.3.6.5 Kladovo

The monitoring station is located at rkm 932.9. The monitoring is performed by the Jaroslav Cerny Institute (JCI) and the data is owned by the PE Electric Power Industry of Serbia. Sediment monitoring started in 1985. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2015)
- monthly min, mean, max SS loads (1986-2015)

2.3.6.6 Titel (Tisa)

The monitoring station is located at rkm 4.9 in the Tisa river. The monitoring is performed by the Jaroslav Cerny Institute (JCI) and the data is owned by the PE Electric Power Industry of Serbia. Sediment monitoring started in 1974. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2015)
- monthly min, mean, max SS loads (1986-2015)
- mean annual flow discharge and SS loads (1974-1985)
- daily SS loads for the 2006 flood event
- SSL rating curve
- PSD for different flow regimes

2.3.6.7 Belgrade (Sava)

The monitoring station is located at rkm 5.2 in the Sava river. The monitoring is performed by the Jaroslav Cerny Institute (JCI) and the data is owned by the PE Electric Power Industry of Serbia. Sediment monitoring started in 1986. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2015)
- monthly min, mean, max SS loads (1986-2015)
- mean annual flow discharge and SS loads (1974-1985)
- daily SS loads for the 2014 flood event
- SSL rating curve
- PSD for different flow regimes

2.3.6.8 Ljubičevski Bridge (Velika Morava)

The monitoring station is located at rkm 21.83 in the Tisa river. The monitoring is performed by the Jaroslav Cerny Institute (JCI) and the data is owned by the PE Electric Power Industry of Serbia. Sediment monitoring started in 1974. Since then, daily physical sampling is performed. Provided sediment data:

- monthly min, mean, max flow discharges (1986-2015)
- monthly min, mean, max SS loads (1986-2015)
- mean annual flow discharge and SS loads (1974-1985)

- daily SS loads for the 2006 flood event
- SSL rating curve
- PSD for different flow regimes

2.3.7 Romania

SS monitoring stations involved in the data assessment from Romania (Table 9):

Table 9 Suspended sediment monitoring stations in Romania

River	Name of monitoring site	Location (rkm)
Danube	Bazias	1 072.50
Danube	Drobeta Turnu Severin	931.00
Danube	Corabia	624.20
Danube	Zimnicea	553.23
Danube	Giurgiu	493.05
Danube	Chiciu Calarasi	379.58
Danube	Vadu Oii	238.00
Danube	Braila	167.00
Danube	Ceatal Izmail	80.50
Danube/Branch Chilia	Periprava	20.00
Danube/Sfantu Gheorghe	Sfantul Gheorghe Harbour	8.00
Danube	Sulina	2.50
Jiu	Zaval	8.0
Arges	Budesti	2.0
Ialomita	Tandarei	29.0
Siret	Lungoci	77.0
Prut	Oancea	79.2

2.3.7.1 Bazias

The monitoring station is located at rkm 1072.50. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Sediment monitoring started in 1971. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2014)
- monthly min, mean, max SS loads (1986-2014)
- mean annual flow discharge and SS loads (1976-1985)

- daily SS loads for the 2001, 2006, 2010, 2013 flood events
- SSC rating curve
- PSD

2.3.7.2 Drobeta Turnu Severin

The monitoring station is located at rkm 931.00. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Sediment monitoring started in 1971. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2014)
- monthly min, mean, max SS loads (1986-2014)
- mean annual flow discharge and SS loads (1971-1985)
- daily SS loads for the 2001, 2006, 2010, 2013 flood events
- SSC rating curve
- PSD

2.3.7.3 Corabia

The monitoring station is located at rkm 624.20. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Sediment monitoring started in 1979. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2002; 2004-2014)
- monthly min, mean, max SS loads (1986-2002; 2004-2014)
- mean annual flow discharge and SS loads (1973-1985)
- daily SS loads for the 2001, 2006, 2010, 2013 flood events
- SSC rating curve
- PSD

2.3.7.4 Zimnicea

The monitoring station is located at rkm 553.23. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the

National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Sediment monitoring started in 1931. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2002; 2004-2014)
- monthly min, mean, max SS loads (1986-2002; 2004-2014)
- mean annual flow discharge and SS loads (1931-1985)
- daily SS loads for the 2001, 2006, 2010, 2013 flood events
- SSC rating curve
- PSD

2.3.7.5 Giurgiu

The monitoring station is located at rkm 493.05. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Sediment monitoring started in 1931. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2014)
- monthly min, mean, max SS loads (1986-2014)
- mean annual flow discharge and SS loads (1966-1985)
- daily SS loads for the 2001, 2006, 2010, 2013 flood events
- SSC rating curve

2.3.7.6 Chiciu Calarasi

The monitoring station is located at rkm 379.58. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Sediment monitoring started in 1931. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2002; 2004)
- monthly min, mean, max SS loads (1986-2002; 2004)
- mean annual flow discharge and SS loads (1931-1985)

- daily SS loads for the 2001 flood event
- SSC rating curve

2.3.7.7 Vadu Oii

The monitoring station is located at rkm 238.00. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Sediment monitoring started in 1931. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2003; 2005-2010)
- monthly min, mean, max SS loads (1986-2003; 2005-2010)
- mean annual flow discharge and SS loads (1931-1985)
- daily SS loads for the 2001, 2006 and 2010 flood events
- SSC rating curve
- PSD

2.3.7.8 Braila

The monitoring station is located at rkm 167.00. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Sediment monitoring started in 1931. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2013)
- monthly min, mean, max SS loads (1986-2013)
- mean annual flow discharge and SS loads (1956-1985)
- daily SS loads for the 2001, 2006, 2010 and 2013 flood events
- SSC rating curve
- PSD

2.3.7.9 Ceatal Izmail

The monitoring station is located at rkm 80.50. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National

Administration "Apele Romane"/National Institute of Hydrology and Water Management. Sediment monitoring started in 1931. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2014)
- monthly min, mean, max SS loads (1986-2014)
- mean annual flow discharge and SS loads (1968-1985)
- daily SS loads for the 2001, 2006, 2010 and 2013 flood events
- SSC rating curve
- PSD

2.3.7.10 Periprava (Branch Chilia)

The monitoring station is located at rkm 20.00. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Sediment monitoring started in 1961. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2015)
- monthly min, mean, max SS loads (1986-2015)
- mean annual flow discharge and SS loads (1931-1985)
- daily SS loads for the 2001, 2006, 2010 and 2013 flood events
- SSC rating curve

2.3.7.11 Sfantul Gheorghe Harbour (Branch Sfantu Gheorghe)

The monitoring station is located at rkm 8.00. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Sediment monitoring started in 1979. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-1997; 1999-2015)
- monthly min, mean, max SS loads (1986-1997; 1999-2015)
- mean annual flow discharge and SS loads (1979-1985)
- daily SS loads for the 2001, 2006, 2010 and 2013 flood events
- SSC rating curve

2.3.7.12 Sulina

The monitoring station is located at rkm 2.50. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Sediment monitoring started in 1979. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2014)
- monthly min, mean, max SS loads (1986-2014)
- mean annual flow discharge and SS loads (1979-1985)
- daily SS loads for the 2001, 2006, 2010 and 2013 flood events
- SSC rating curve

2.3.7.13 Zaval (Jiu)

The monitoring station is located at rkm 2.50 in the Jiu river. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Sediment monitoring started in 1963. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-1992; 1994-2014)
- monthly min, mean, max SS loads (1986-1992; 1994-2014)

2.3.7.14 Budești (Arges)

The monitoring station is located at rkm 2.00 in the Arges river. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Sediment monitoring started in 1956. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-1988; 2006-2014)
- monthly min, mean, max SS loads (1986-1988; 2006-2014)

2.3.7.15 Tandarei (Ialomita)

The monitoring station is located at rkm 29.00 in the Ialomita river. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Sediment monitoring started in 1956. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (2005-2014)
- monthly min, mean, max SS loads (2005-2014)

2.3.7.16 Lungoci (Siret)

The monitoring station is located at rkm 77.00 in the Siret river. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Sediment monitoring started in 1956. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2014)
- monthly min, mean, max SS loads (1986-2014)

2.3.7.17 Oancea (Prut)

The monitoring station is located at rkm 79.20 in the Prut river. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Sediment monitoring started in 1977. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2014)
- monthly min, mean, max SS loads (1986-2014)

2.3.8 Bulgaria

SS monitoring stations involved in the data assessment from Bulgaria (Table 10):

Table 10 Suspended sediment monitoring stations in Bulgaria

River	Name of monitoring site	Location (rkm)
Danube	Lom	743.30
Danube	Svishtov	554.30
Danube	Silistra	375.50
Iskar	Oriahovitza	340.50*
Iantra	Karantzi	208.00*

*River kilometer values in Bulgaria at the tributaries indicate the distance from the source instead of the mouth.

2.3.8.1 Lom

The monitoring station is located at rkm 743.30. The monitoring is performed and the sediment data is owned by the National Institute of Meteorology and Hydrology-BAS (NIMH-BAS). Sediment monitoring started in 1971. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1986-2014)
- monthly min, mean, max SS loads (1986-2014)
- mean annual flow discharge and SS loads (1976-1985)
- daily SS loads for the 2001, 2006, 2010, 2013 flood events
- SSC rating curve
- PSD

2.3.8.2 Svishtov

The monitoring station is located at rkm 554.30. The monitoring is performed and the sediment data is owned by the National Institute of Meteorology and Hydrology-BAS (NIMH-BAS). Sediment monitoring started in 1989. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1989-2007; 2011-2015)
- monthly min, mean, max SS loads (1989-2007; 2011-2015)
- daily SS loads for the 2001, 2006, 2010, 2013 flood events
- SSC rating curve
- PSD

2.3.8.3 Silistra

The monitoring station is located at rkm 375.50. The monitoring is performed and the sediment data is owned by the National Institute of Meteorology and Hydrology-BAS (NIMH-BAS). Sediment monitoring started in 1989. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1989-2015)
- monthly min, mean, max SS loads (1989-2015)
- daily SS loads for the 2002, 2006, 2010, 2013 flood events
- SSC rating curve

2.3.8.4 Oriahovitza (Iskar)

The monitoring station is located at rkm 340.50 in the Iskar river (this is the distance from source). The monitoring is performed and the sediment data is owned by the National Institute of Meteorology and Hydrology-BAS (NIMH-BAS). Sediment monitoring started in 1961. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1961-2015)
- monthly min, mean, max SS loads (1961-2015)
- daily SS loads for the 2002, 2006, 2010, 2013 flood events
- SSC rating curve
- PSD

2.3.8.5 Karantzi (Yantra)

The monitoring station is located at rkm 208.0 in the Yantra river (this is the distance from source). The monitoring is performed and the sediment data is owned by the National Institute of Meteorology and Hydrology-BAS (NIMH-BAS). Sediment monitoring started in 1964. Since then, daily physical sampling is performed.

Provided sediment data:

- monthly min, mean, max flow discharges (1964-2015)
- monthly min, mean, max SS loads (1964-2015)
- daily SS loads for the 2002, 2006, 2010, 2013 flood events
- SSC rating curve
- PSD

2.4 Bedload data quantity

In the followings an overview, similar to the one in the previous Chapter, will be given for each bedload monitoring station, focusing on the quantity of the sediment data, provided by the project partners. The descriptions will be presented country by country from upstream to downstream along the Danube River, also for the most important tributaries.

The locations and a few characteristics of the bedload monitoring are presented in Table 11 and Figure 2.

Table 11 List of bedload monitoring stations along the Danube and its important tributaries

Country	River	Name of monitoring site	Location	Comment
Germany	Danube	Straubing1	2 329.30	campaigns
Germany	Danube	Straubing2	2 321.00	campaigns
Germany	Danube	Pfelling	2 305.50	campaigns
Germany	Danube	Deggendorf	2 283.20	campaigns
Germany	Danube	Halbmeile	2 280.00	campaigns
Germany	Danube	Hofkirchen	2 256.39	campaigns
Austria	Danube	Vienna	1 930.80	campaign (past)
Austria	Danube	Hainburg Straßenbrücke	1 886.24	monitoring
Austria	Danube	Bad Deutsch-Altenburg	1 885.90	campaign (past)
Slovakia	Danube	Devín	1 878.15	campaigns
Hungary	Danube	Vámosszabadi	1 805.60	monitoring
Slovakia	Danube	Klizska Nema	1 795.58	campaigns
Romania	Danube	Bazias	1 072.50	monitoring
Romania	Danube	Corabia	624.20	monitoring
Romania	Danube	Zimnicea	553.23	monitoring
Romania	Danube	Giurgiu	493.05	monitoring
Romania	Danube	Chiciu Calarasi	379.58	monitoring
Romania	Danube	Vadu Oii	238.00	monitoring
Romania	Danube	Braila	167.00	monitoring
Romania	Danube	Ceatal Izmail	80.50	monitoring
Slovakia	Morava	Moravský Ján	67.15	campaigns

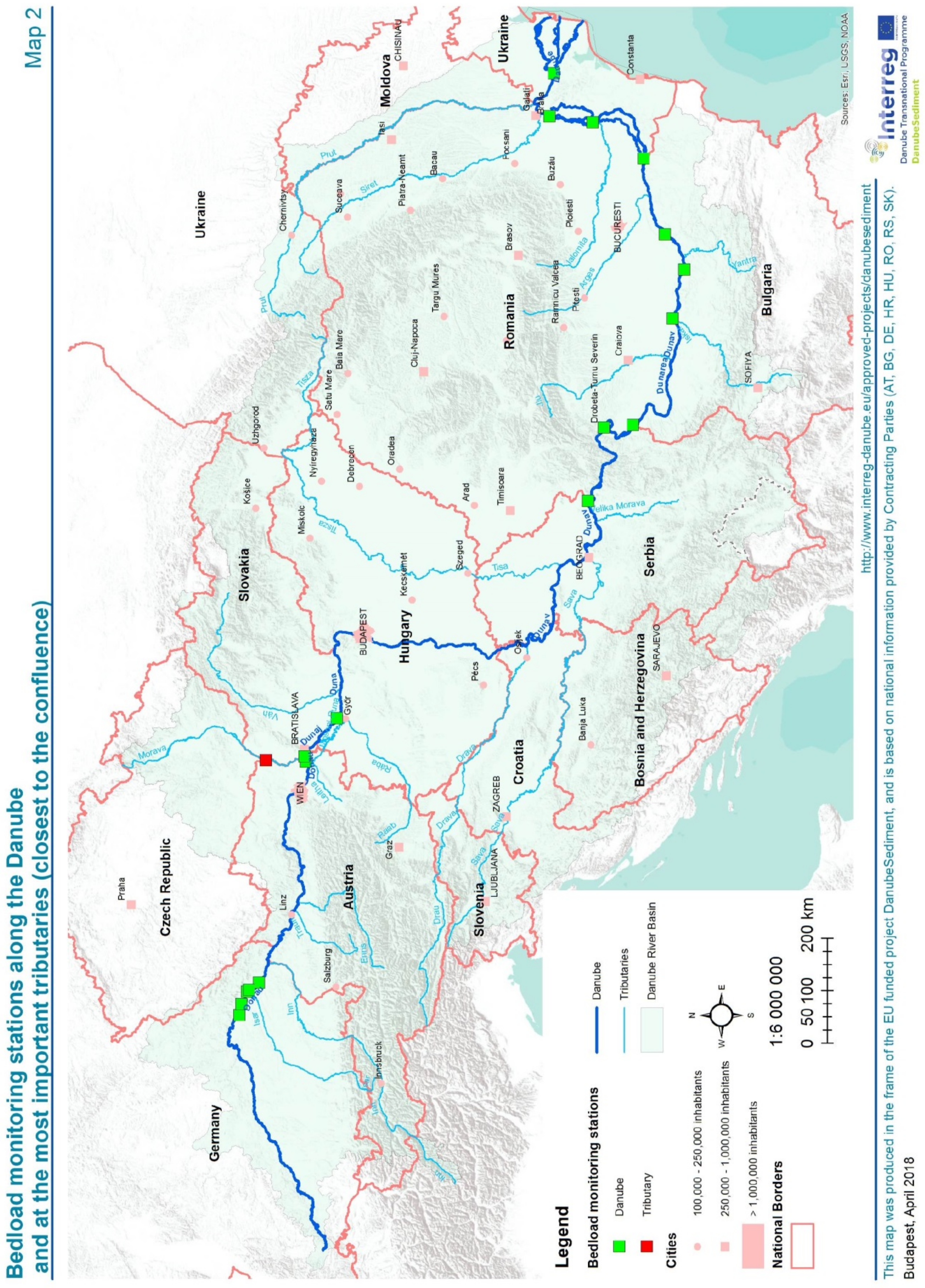


Figure 2 Bedload monitoring stations along the Danube and its important tributaries

2.4.1 Germany

BL monitoring stations involved in the data assessment from Germany (Table 12):

Table 12 Bedload monitoring stations in Germany

Station	Location (rkm)	Measurements
Straubing1	2 329.30	campaigns
Straubing2	2 321.00	campaigns
Pfelling	2 305.50	campaigns
Deggendorf	2 283.20	campaigns
Halbmeile	2 280.00	campaigns
Hofkirchen	2 256.39	campaigns

2.4.1.1 Straubing 1

The monitoring station is located at rkm 2329.3. The monitoring is performed by Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG) and Federal Waterways Engineering and Research Institute (BAW), the sediment data is owned by the Federal Waterways and Shipping Administration. The provided data consists of two flow disharge and bedload discharge data pairs and two GSD curves.

2.4.1.2 Straubing 2

The monitoring station is located at rkm 2321.0. The monitoring is performed by Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG) and Federal Waterways Engineering and Research Institute (BAW), the sediment data is owned by the Federal Waterways and Shipping Administration. The provided data consists of two flow disharge and bedload discharge data pairs and two GSD curves.

2.4.1.3 Pfelling

The monitoring station is located at rkm 2305.5. The monitoring is performed by Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG) and Federal Waterways Engineering and Research Institute (BAW), the sediment data is owned by the Federal Waterways and Shipping Administration. The provided data consists of a bedload rating curve (prepared from 15 campaigns) and several GSD curves.

2.4.1.4 Deggendorf

The monitoring station is located at rkm 2283.2. The monitoring is performed by Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG) and Federal Waterways Engineering and Research Institute (BAW), the sediment data is owned by the Federal Waterways and Shipping Administration. The provided data consists of a bedload rating curve (prepared from 8 campaigns) and several GSD curves.

2.4.1.5 Halbmeile

The monitoring station is located at rkm 2280.0. The monitoring is performed by Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG) and Federal Waterways Engineering and Research Institute (BAW), the sediment data is owned by the Federal Waterways and Shipping Administration. The provided data consists of a bedload rating curve (prepared from 9 campaigns) and several GSD curves.

2.4.1.6 Hofkirchen

The monitoring station is located at rkm 2256.39. The monitoring is performed by Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG) and Federal Waterways Engineering and Research Institute (BAW), the sediment data is owned by the Federal Waterways and Shipping Administration. The provided data consists of a bedload rating curve (prepared from 16 campaigns) and several GSD curves.

2.4.2 Austria

BL monitoring station involved in the data assessment from Austria (Table 13):

Table 13 Bedload monitoring station in Austria

Station	Location	Measurements
Vienna	1 930.80	campaign (past)
Hainburg	1 886.24	monitoring
Bad Deutsch-	1 885.90	campaign (past)

2.4.2.1 Vienna

In the past 4 full-profile measurements at rkm 1930.80 in Vienna were performed by the Staatliche Versuchsanstalt für Wasserbau (today IWB - Institut für Wasserbau und hydrometrische Prüfung) in 1930/1931 in Vienna (Ehrenberger, 1931 and Ehrenberger, 1942) with the Ehrenberger sampler. The measurements covered a discharge range between ~1000 m³/s and ~2200 m³/s (according to Ehrenberger (1931) bankfull discharge at that time was around 3400 m³/s). Some of the bedload values were taken directly from Ehrenberger (1942), were he reported bedload transport values for the years 1910, 1921, 1925 and

1930/1931. Additional annual loads were calculated based on the published rating curve which uses mean annual gauging levels at the Reichsbrücke in Vienna.

2.4.2.2 Bad Deutsch-Altenburg / Hainburg Straßenbrücke

In the past the Bundesstrombauamt (predecessor company of the viadonau) performed bedload measurements between April 1956 and April 1957 at Bad Deutsch-Altenburg (rkm 1885.90) with an Ehrenberger sampler (Moosbrugger, 1957 and Schmutterer, 1961). According to Schmutterer (1961) 115 full-profile measurements were performed covering a discharge range from ~1000 m³/s up to ~5000 m³/s. The bedload transport for the period 1956/1957 at Bad Deutsch-Altenburg was 1.07 Mt (Moosbrugger, 1957 and Schmutterer, 1961). Additional annual loads were calculated for the years 1951-1955 based on an adjusted rating curve published in Gruber (1969).

Currently, the monitoring station is located at rkm 1886.24 near Hainburg. The monitoring is performed by IWHW/BOKU on behalf of viadonau and the data is owned by via donau - Österreichische Wasserstraßen-Gesellschaft mbH. Sediment monitoring started in 2006, performing direct bedload transport measurements with a BfG-sampler (pressure difference sampler) three times a year on average. The 55 full-profil measurements cover the full discharge range from low-flow up to a 200 years flood event. The daily and annual bedload amounts have been calculated with a combination of a sigmoid and a linear function to account for deviations of the bedload transport from a power function above bankfull discharge.

Provided sediment data:

- mean annual bedload transport (1910; 1921; 1925-1931; 1951-1957; 2005-2015)
- bedload rating curves
- GSD for different flow regimes

2.4.3 Slovakia

BL monitoring stations involved in the data assessment from Slovakia (Table 14):

Table 14 Bedload monitoring stations in Slovakia

Station	**Location (rkm)**	**Measurements**
Devín	1 878.15	campaigns
Klizska Nema	1 795.58	campaigns
Moravský Ján (Morava River)	67.50	campaigns

2.4.3.1 Devín

The monitoring station is located at rkm 1878.15. The monitoring is performed and the data is owned by the Water Research Institute Bratislava (VUVH). 46 full-profile measurement campaigns were carried out between 1997-2003 and relationships have been set up between flow discharge and bedload transport. Daily or annual bedload transport amounts were estimated based on these relationships.

Provided sediment data:

- mean annual bedload transport (1991-2016)
- bedload rating curve
- GSD

2.4.3.2 Klizska Nema

The monitoring station is located at rkm 1795.58. The monitoring is performed and the data is owned by the Water Research Institute Bratislava (VUVH). 54 full-profile measurement campaigns were carried out between 2000-2002 and relationships have been set up between flow discharge and bedload transport. Daily or annual bedload transport amounts were estimated based on these relationships.

Provided sediment data:

- mean annual bedload transport (1992-2016)
- bedload rating curve
- GSD

2.4.3.3 Moravský Ján

The monitoring station is located at rkm 67.50. The monitoring is performed and the data is owned by the Water Research Institute Bratislava (VUVH). Field campaigns were performed during the flood discharges in 1996 then bedload monitoring continued during period 2004-2005. Data from both periods are used to develop regression type equation.

Provided sediment data:

- mean annual bedload transport (1990-2016)
- bedload rating curve
- GSD

2.4.4 Hungary

BL monitoring station involved in the data assessment from Hungary (Table 15):

Table 15 Bedload monitoring station in Hungary

Station	Location (rkm)	Measurements
Vámosszabadi	1 805.60	monitoring

2.4.4.1 Vámosszabadi

The monitoring station is located at rkm 1805.60. The monitoring is performed by the North-Transdanubian Water Directorate (ÉDUVIZIG) and the data is owned by the General Water Directorate (OVF). Bedload measurements are performed 5 times a year, based on which a regression analysis is done to set up relationships between the flow discharge and the sediment load.

Provided sediment data:

- bedload rating curves
- GSD

2.4.5 Romania

BL monitoring stations involved in the data assessment from Romania (Table 16):

Table 16 Bedload monitoring stations in Romania

Station	Location (rkm)	Measurements
Bazias	1 072.50	monitoring
Corabia	624.20	monitoring
Zimnicea	553.23	monitoring
Giurgiu	493.05	monitoring
Chiciu Calarasi	379.58	monitoring
Vadu Oii	238.00	monitoring
Braila	167.00	monitoring
Ceatal Izmail	80.50	monitoring

2.4.5.1 Bazias

The monitoring station is located at rkm 1072.50. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water

Management. Bedload monitoring took place in the period 1971-1984, with a sampling frequency of 4 times a year.

Provided sediment data:

- bedload rating curve

2.4.5.2 Corabia

The monitoring station is located at rkm 624.20. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Bedload monitoring started in 1992. Since then, the sampling is performed 4 times a year.

Provided sediment data:

- bedload rating curve

2.4.5.3 Zimnicea

The monitoring station is located at rkm 553.23. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. The data series are not continual, several years are missing. The measurements were done in the following periods: 1985-1996, 2007-2008, 2010-2012,2014-present

Provided sediment data:

- bedload rating curve

2.4.5.4 Giurgiu

The monitoring station is located at rkm 493.05. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Bedload monitoring started in 1970. Since then, the sampling is performed 4 times a year.

Provided sediment data:

- bedload rating curve

2.4.5.5 Chiciu Calarasi

The monitoring station is located at rkm 379.58. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Sediment monitoring started in 1980. Since then, the sampling is performed 4 times a year.

Provided sediment data:

- bedload rating curve

2.4.5.6 Vadu Oii

The monitoring station is located at rkm 238.00. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Sediment monitoring started in 1970. Since then, the sampling is performed 4 times a year.

Provided sediment data:

- bedload rating curve

2.4.5.7 Braila

The monitoring station is located at rkm 167.00. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Sediment monitoring started in 1971. Since then, the sampling is performed 4 times a year.

Provided sediment data:

- bedload rating curve

2.4.5.8 Ceatal Izmail

The monitoring station is located at rkm 80.50. The monitoring is performed by the National Administration "Apele Romane"/Jiu River Basin Administration and owned by the National Administration "Apele Romane"/National Institute of Hydrology and Water Management. Sediment monitoring started in 1969. Since then, the sampling is performed 4 times a year.

Provided sediment data: bedload rating curve

2.5 Sediment data quality

As shown in the report entitled “Sediment monitoring in the Danube River” of this project, the sediment monitoring methodologies can significantly vary along the Danube river country by country, or even within countries. Moreover, besides the sediment sampling methods, the laboratory analysis techniques as well as the sediment discharge calculation methods can differ. This inhomogeneity of the methods inherently results in differences of sediment data quality. The quality of the information used in the data analysis can influence the reliability of the data assessment and the conclusions drawn from the analysis, e.g. when the sediment balance of the Danube is to be set up within Work Package 4 of this project. Also, when suggesting improvements for the sediment monitoring methodologies along the Danubian countries, the limitations and uncertainties of the currently applied methods have to be known.

It is, therefore, of great importance to have an idea about the representativeness of the sediment data collected in the first stage of this project. The quantification of the possible errors resulted by e.g. the sampling method, the operation of the instruments, the calibration of surrogate methods, the laboratory analysis technique is quite a challenging task and calls for scientific research. The time and cost demand of such an analysis is far beyond the scope of this project, therefore a simpler way had to be found for the sediment data characterization.

Our proposal was to define a classification of the different methods, considering the applied technique, the sampling frequency, if the provided sediment data is directly measured or estimated based on statistics, also taking into account the experiences of sediment experts. Instead of quantifying the uncertainty in the datasets, a qualitative evaluation will be performed, eventually providing three classes for the sediment data quality. The assessment is carried out both for suspended sediment and bedload monitoring.

2.5.1 Suspended sediment data quality

In order to implement the classification on the data quality the applied methods have been overviewed. As presented in a connecting report of this activity (see the “Report on Sediment Monitoring Methods), the following field measurement techniques are currently applied at the institutes responsible for the sediment data collection:

1. Calibrated Optical Backscatter Sensor (OBS) based continuous (15 min sampling frequency) suspended sediment concentration monitoring (in one point of the cross-section), together with isokinetic physical sampling and acoustic suspended sediment concentration mapping over the whole cross-section (complementary multipoint measurements). The multipoint measurements are performed 1-5 times a year and are used to calibrate the near-bank suspended sediment concentration with the cross-sectional mean concentration. The daily suspended sediment load is calculated using the calibration curves.
2. Automatized pump or physical sampling with a flow discharge dependent sampling frequency (from 4-6 times a day to 3 times a week) in one point of the cross-section. When estimating the suspended sediment load, it is assumed that the measured sediment concentration is representative for the whole cross-section.
3. Isokinetic, depth-integrating physical sampling on daily basis in one point of the cross-section. The sampling is performed in a carefully chosen vertical, which provides suspended sediment concentration representative for the whole cross-section. The daily suspended sediment load is calculated based on the product of the measured concentration and the actual flow discharge.
4. Physical, non-isokinetic sampling on daily basis in one point of the cross-section, with complementary multipoint measurements 4-6 times a year. The multipoint measurements are used to calibrate the near-bank suspended sediment concentration with the cross-sectional mean concentration. The daily suspended sediment load is calculated based on the product of the mean cross-sectional concentration and the actual flow discharge.
5. Physical, non-isokinetic sampling on daily basis in one point of the cross-section When estimating the daily suspended sediment load, it is assumed that the measured sediment concentration is representative for the whole cross-section. The daily sediment load is calculated based on the product of the concentration and the actual flow discharge.
6. Physical, non-isokinetic multipoint sampling 4-6 times a year. A regression curve is set up for the mean cross-sectional concentration and the flow discharge, then the monthly suspended sediment load is calculated based on this regression and the characteristic flow discharge.

As to the suspended sediment concentration determination methods, there are basically three methods applied by the responsible institutes:

Filtering method: the suspended sediment concentration is determined by vacuum filtration using cellulose acetate or cellulose nitrate filters with pore diameters of 0.45 µm. Before filtering, the filter is weighed and the sample volume is determined. The whole sample volume is filtrated. After filtering, the filter and contents are removed and dried for nearly 2 hours at 105° C. The filter, including the content, is weighed with an analytical balance of an accuracy of ± 0.1 mg. The suspended sediment concentration is calculated by dividing the filter content by the volume.

Evaporation method: This method uses a sample of 10 l. After a settling process (at least a few days long), 1-1.5 l of concentrated sediment is decanted and transported into the sediment laboratory. After 24 hours of sediment settling, a sample of 100 ml of sediment is taken. The settling process is repeated for another 24 hours, and then all of the sediment dried on 105°C for 4 hours and weighed. The sediment concentration is calculated on the basis of known volume of sample and the weight of sediment. For the PSD analysis a sedimentation instrument and a sieving instrument is used.

Turbidity method: a portable turbidity meter provides the concentration values of the water samples directly in mg/l. To perform the calibration of the equipment, a blank sample of distilled water is used. Then the specific glass of the equipment is filled with the collected water sample and the SSC will be given. The water sample is shaken well before being placed in the equipment for reading. After the first reading, the glass is shaken, rotated 180 degrees and the reading is repeated. At least two readings are performed, and the final value is obtained as the arithmetic mean of the readings.

The decisive parameter at the classification of the above presented methods was the sampling frequency. Sediment data collected on a daily basis or even with higher frequency (the optical sensors collect data in every 15 minutes) provides high time resolution datasets and contributes to a more accurate sediment load calculation on a long term, compared to monthly or less frequent data collection frequency. With daily datasets it is ensured that the widest range of flow regimes is measured in contrast with less frequent sampling, when extreme situations can be easily missed. Also, the influence of dynamic flood waves, and the hysteresis effect can be captured with frequent sampling. Besides the sampling frequency, the cross-sectional representativeness of the collected data was taken into account, because at many stations the near-bank data is used without cross-sectional calibration, which inherently decreases the accuracy of the calculated sediment load. It was also considered if the calculated sediment load is based on measured data or derived from statistical analysis, where the former is considered to be more accurate.

As to the laboratory analysis, the experiences suggest that the filtering method provides more reliable data compared to the evaporation method. In fact, the latter can easily consist of dissolved parts, which can bias the resulted concentration values. The turbidity method can be an acceptable and straightforward manner of sample analysis, however, the proper calibration of the applied instruments is of primary importance.

Combining the above aspects, the following classification was established. In Table 17, the green boxes indicate the good practices of suspended sediment monitoring. The methods indicated with yellow provide less accurate datasets and improvement is suggested for those. The improvements, as discussed in the report entitled "Sediment monitoring in the Danube River", should focus on the sampling technique (upgrade from non-isokinetic to isokinetic), the cross-sectional calibration and/or the applied laboratory analysis method. The methods indicated with red boxes need significant improvement. At these monitoring stations, the sediment load calculation is based on a regression analysis, set up from data collected in the past. This method, therefore, does not consider the long-term temporal changes of the sediment transport dynamics and neglects the unsteady effects of dynamic flood waves.

Table 17 Classification of suspended sediment monitoring methods

	Filtering method	**Evaporation method**	**Turbidity method**
Continuous point OBS (4/hour) + complementary multipoint sampling with isokinetic physical and acoustic methods (1-5/year)	DE: Wasserwirtschaftsamt Donauwörth, Wasserwirtschaftsamt Ingolstadt (Neu-Ulm Bad Held, Donauwörth, Ingolstadt Luitpoldstraße) AT: viadonau (Aschach Strombauleitung, Hainburg Straßenbrücke), Hydrographic Service of Upper Austria (HD OOE) (Schärding, Wels-Lichtenegg, Steyr (Ortskai))		
Automatized pump sampling in a point (Flow-dependent, from 3/week to 6/day)	AT: Verbund Hydro Power (VHP) (Abwinden-Asten, Wallsee-Mitterkirchen)		
Physical sampling, isokinetic sampling in a	SK: Water Research Institute		

	Filtering method	**Evaporation method**	**Turbidity method**
vertical (depth-integrating) Flow-dependent, from 1/day to 1+/day	Bratislava (VUVH) (Bratislava)		
Physical point sampling 1/day + complementary physical, multipoint sampling (1-3/year)		RS: Jaroslav Černi Institute for the Development of Water Resources (JCI) CR: Meteorological and Hydrological Institute of Croatia (DHMZ)	RO: National Administration "Apele Romane"/River Basin Administrations
Physical point sampling ~1/day (from 4-6 times a day to 3 times a week depending on the flow conditions)	DE: Wasserwirtschaftsamt Donauwörth, Wasserwirtschaftsamt Ingolstadt, Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG), Federal Waterways Engineering and Research Institute (BAW) (Straubing gauging station, Vilshofen, Kachlet, Jochenstein) AT: viadonau (Engelhartszell, Aschach Strombauleitung, Linz, Stein-Krems, Bad Deutsch-Altenburg, Angern) SK: Slovak Hydrometeorological Institute (SHMU) BG: National Institute of Meteorology and Hydrology-BAS		

	Filtering method	**Evaporation method**	**Turbidity method**
	(NIMH-BAS)		
Physical, multipoint sampling (4-6/year)	SK: Water Research Institute Bratislava (VUVH) (Devín, Medveďov Bridge, Záhorská Ves, Moravský Ján)	HU: North-Transdanubian Water Directorate (ÉDUVIZIG), the Middle Danube Valley Water Directorate (KDVVIZIG), Lower Danube Valley Water Directorate (ADUVIZIG)	

2.5.2 Bedload data quality

Characterizing the bedload data quality is even more difficult than for the suspended sediments. There is no generally well-applicable method, which would provide high accuracy and representative bedload data (Habersack et al., 2017) and in fact, the development of proper bedload monitoring techniques is still an active research topic. Therefore it is highly recommended to integrate (combine) the existing monitoring methods to overcome the limitations of the current monitoring techniques. Based on the experiences of the sediment experts involved in this project it can be stated that the bedload samplings performed with well-tested, pressure difference samplers, such as the Helley-Smith or the BfG-sampler provide reliable information in the gravel bed sections. In sandy environment, however, the bedload transport can be characterized with very complex dynamics, which can hardly be detected by physical samplers (e.g. Kleinhans et al., 2001). In such conditions, the bedload transport can mainly be represented by the movement of bedforms and therefore, a bedform tracking should be used instead, or the combination of different techniques (e.g. Gray et al., 2010). In case of the Danube River, currently only physical bedload samplers are applied both in the gravel and sand bed reaches.

Bedload data was provided from five countries: Germany, Austria, Slovakia, Hungary and Romania. The dataset provided by the German partners come from expeditionary bedload measurement campaigns and in most of the cases the data cannot be considered representative in terms of the measured flow range as high flow conditions were not sampled. Even though the sampling technique (using BfG sampler) would suggest reliable data, an improvement of the monitoring, to cover high flow regimes, is necessary. The bedload monitoring performed in Austria is based on a well-tested methodology (using BfG sampler) and covers wide range of flow conditions from low flow to extreme floods. This data is considered as good-quality information. Only one monitoring station is operated and therefore the only local behaviour of the bedload transport can be assessed. The bedload data provided by Slovakian and Hungarian partners represents also a shorter reach of the Danube River. Also, the measured flow regimes do not cover high flow conditions, where most probably a significant sediment transport takes place. Furthermore, there are substantial data discrepancy issues between the datasets of the two countries, despite the fact that the monitoring stations are located close to each other. The applied monitoring methods therefore need further improvements and the data provided by the partners are questionable. The bedload data from Romania covers a large time period, i.e. decades, which results in bedload rating curves for adequately large flow range. At the Romanian section of the Danube the bedload transport consists of sand and the representativity of the available data is questionable due to the fact that physical sampling of bedload in large, sand bed rivers can generally be characterized with high uncertainty. Nevertheless, an order of magnitude assessment of the bedload transport can be performed. The quality of the bedload data is therefore based on the applied monitoring methods (Table 18), where green is considered to be good and yellow as moderate quality.

Table 18 Classification of bedload monitoring methods

Country	**Applied technique**	**Comments**
Germany	BfG sampler	Well-tested pressure-difference sampler. The measured flow range does not cover high flows. Field campaigns in high flow conditions are needed.
Austria	Ehrenberger sampler	Basket sampler. Bedload sampling in the past was performed with this type of sampler.
Austria	BfG sampler	Well-tested pressure-difference sampler. The measured flow range covers low flow to extreme flood
Slovakia	Swiss-type sampler	Basket sampler. The measured flow range does not cover high flows. Data shows significant discrepancy with HU data. Further tests and improvement are needed.
Hungary	Károlyi-type sampler	Pressure-difference sampler. The measured flow range does not cover high flows Data shows significant discrepancy with SK data. Further tests and improvement are needed.
Romania	IMH bedload equipment	The provided data covers a wide flow range. Due to the complex nature of bedload transport in sand bed rivers, this technique might not be suitable here. Further tests and improvement are needed.

3 Comparative analysis

3.1 Introduction

When analysing the sediment balance of a longer river section, or in this case, the whole Danube River, the harmonization of sediment data provided by the countries is of primary importance. However, due to the different monitoring techniques applied by the countries, it is far not straightforward how the unification of the measurement data can be done. An attempt is made here to see the major differences in the sediment data performing an extensive comparison.

The comparative analysis is carried out for the cross-border sections of the Danube River: German-Austrian, Austrian-Slovakian, Slovakian-Hungarian, Serbian-Romanian and the Romanian-Bulgarian sections. The comparative assessment includes a brief presentation of the suspended sediment monitoring methods used by the different countries and organisations along the Danube River. The basic steps of the measurement methods are also summarized briefly.

The comparative analysis of the historical data can give a more direct information about the differences between the measurement methods. The monthly suspended sediment load and flow discharge data have been available so the effects of the differences of the measurement methods (sampler, sampling frequency), the laboratory analysis and the suspended sediment discharge calculation could be looked into.

Within the project, three joint measurement campaigns were also carried out in the Romanian-Bulgarian and Serbian-Romanian cross-border sections and one at the section close to the boarder Austrian Danube near Bad Deutsch-Altenburg. The collected data will also be compared and conclusions are drawn for the follow-up data analysis.

Note that the comparative analysis could only be carried out for the suspended sediment data as no concurrent bedload transport information was available for shared sections of the Danube River.

3.2 Comparative analysis of historical data

3.2.1 German-Austrian cross-border section

The Jochenstein (Germany) and Engelhartszell (Austria) monitoring stations are relatively close to each other (Table 19). At both stations continuous physical sampling is performed on a daily basis at the German stations and from three times a week to four times a day, depending on the flow regime, at the Austrian station. The filtration method is used at both monitoring stations to provide sediment concentration values from water samples. Both of the stations are located downstream of the Jochenstein hydropower plant.

Table 19 Summary table about the monitoring methods (Germany-Austria)

Name of the monitoring site	**Location of the monitoring site**	**SS measurement method**	**Frequency**	**SSC analysis method**
Jochenstein (Germany)	2203.10 rkm	Physical sampling	1 times per day	Filtration
Engelhartszell (Austria)	2200.66 rkm	Physical sampling	Flow-dependent, from 3/w to 4/d	Filtration

Monthly mean suspended sediment load values against the monthly mean flow discharges are illustrated for both stations in Figure 3.

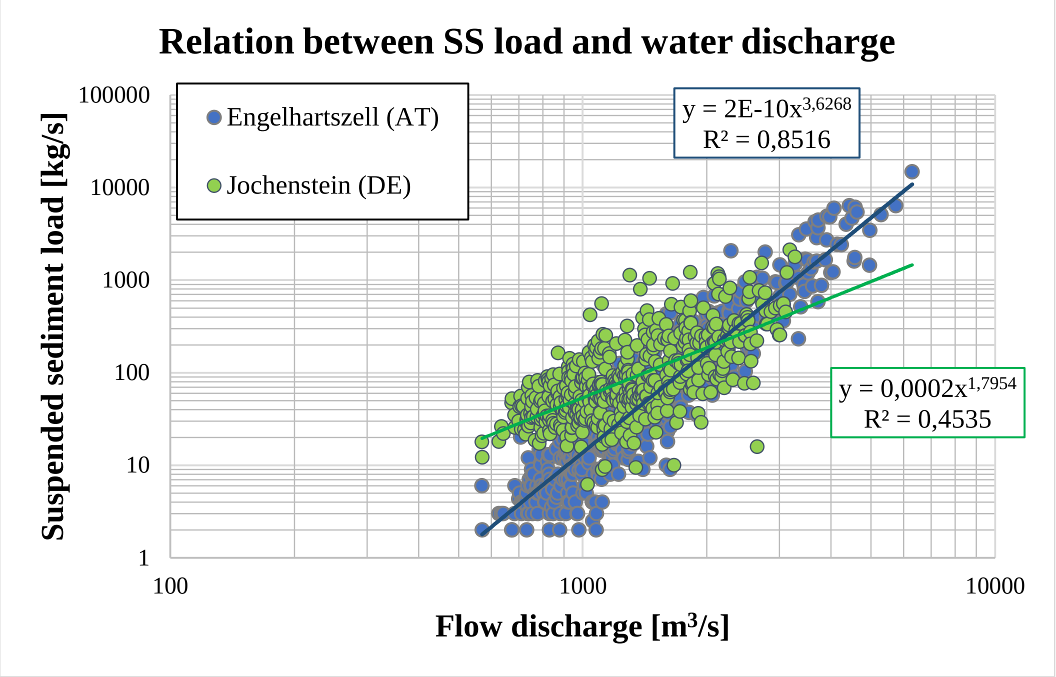


Figure 3 Relation between monthly mean SS load and flow discharge values (Germany-Austria) (data source AT: viadonau)

Overall, the agreement between the two datasets is reasonable. It has to be noted that data from high flows is hardly available for the German station. In the low-flow range the sediment load values from the German station overestimates the ones at the Austrian station. Based on the calculated annual sediment load values, however, this data discrepancy seems to have low influence (Figure 4). The evolution of annual suspended sediment load values from 1975-2010 is shown in Figure 4. The differences between the two stations are not significant, the highest differences occur during „wet years”, when the Austrian values can be higher up to 25% compared to the German values. The total sum of the suspended sediment load between 1975 and 2010 differs by approx. 9%, with the higher value for the Austrian station at Engelhartszell. The year 2005 was excluded from this comparison, because at the German station 5 months were missing, during which a considerable amount of suspended load was measured in the Austrian part of the Danube.

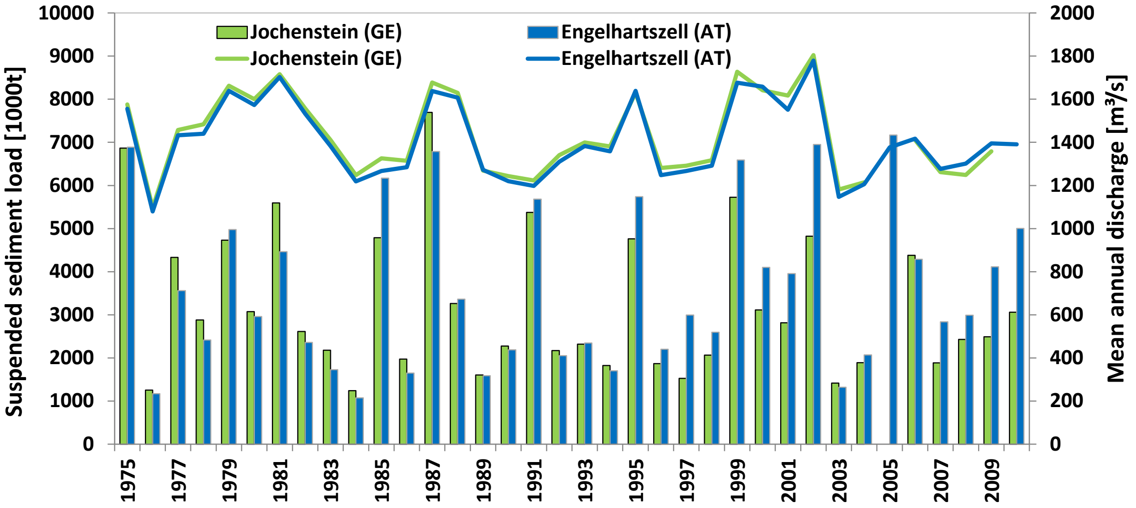


Figure 4 Annual suspended sediment load values between 1975 and 2010 (data source AT: viadonau)

Daily sediment load values have also been compared for a flood event in 2002 (Figure 5). It can be seen that only the peak values differ, which might be resulted by the different time of the samplings, otherwise the values show very good agreement.

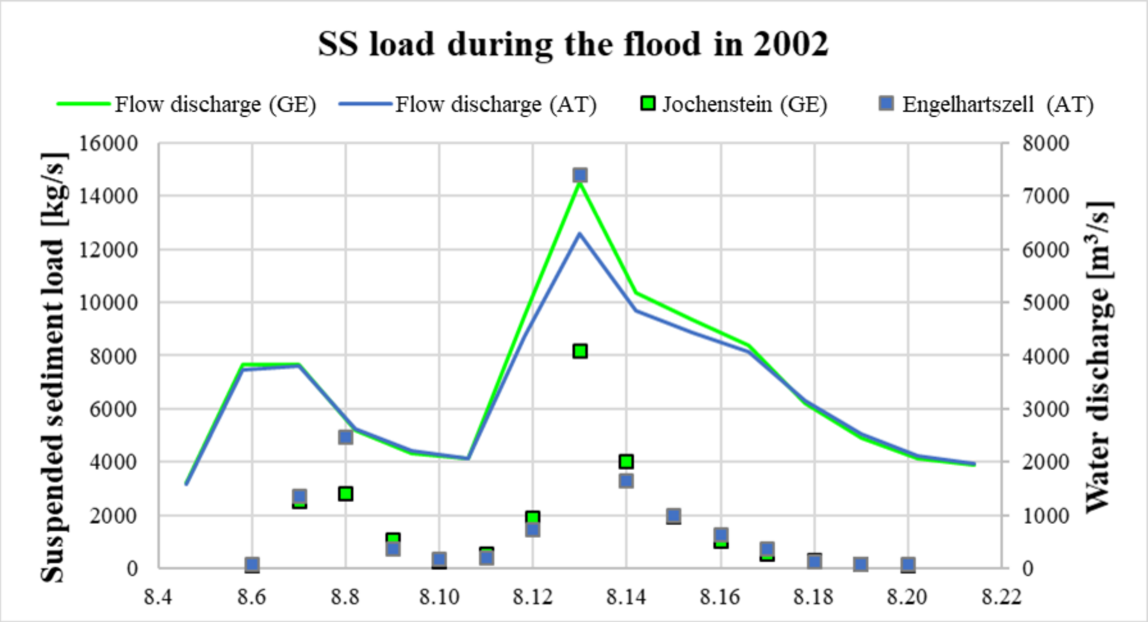


Figure 5 Daily suspended sediment load values during the flood in 2002 (Germany-Austria) (data source AT: viadonau)

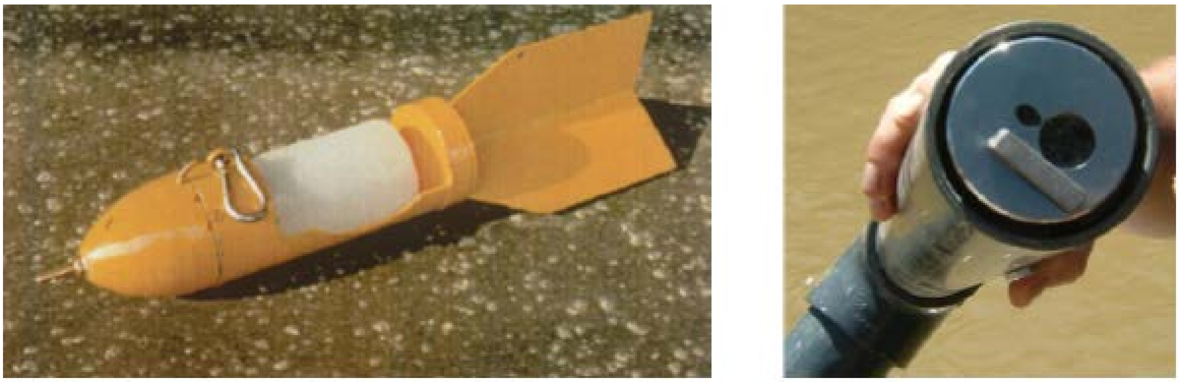
3.2.2 Austrian-Slovakian cross-border section

A recent study (Holubová and Lukáč, 2016) was carried out on the comparison of suspended sediment concentration values in the Danube River obtained by different methods at Slovak and Austrian sites. A brief summary is presented here.

The common cross-border section (~ 7 km) is located between the Hainburg Bridge, Austria and the Lafranconi Bridge, Slovakia (Figure 6). The suspended sediment regime has been monitored at both monitoring sites since 2008.

Figure 6 The Slovak-Austrian cross-border section

At the Austrian monitoring site, a Solitax ts-line turbidity sensor (Figure 7) is used for continual turbidity measurements. These measurements are calibrated by samples taken close to the sensor plus cross sectional measurements. The advantage of this method is the continual recording and the determination of the cross-sectional variation of the suspended sediments. Data on average daily sediment loads were used for the purpose of the study.



a) WRI sampler for depth-integrating sampling

b) Solitax ts-line sensor

Figure 7 Measurement devices; a) WRI - sampler (SK), b) Solitax ts-line sensor (AT)

At the Slovakian monitoring site, a depth-integrating, so called WRI sampler, is used to collect a water-sediment sample, while it is lowered to the river bed and raised to the surface at a uniform rate. The recording is not continuous; the frequency of the measurements varies from 3 times per week to 1 (or few) times per day.

The methods differ in their basic technical solutions and sampling frequency. For both stations, the filtration method is applied for the SSC analysis method. See below the summary table (Table 20) about the different monitoring methods.

Table 20 Summary table about the monitoring methods (Slovakian-Austrian)

Name of the monitoring site	Location of the monitoring site	SS measurement method	Frequency	SSC analysis method
Hainburg Bridge (Austria)	1886.24 rkm	Continuous point OBS + calibration samples and complementary multipoint sampling with isokinetic physical and acoustic methods (cross-sectional corrected)	OBS: Continuous (4/hour) Calibration samples: flow dependent (from 1/2w to 1+/d) Cross sectional measurements: 1-5/year	Filtration
Lafranconi Bridge (Slovakia)	1871.30 rkm	Isokinetic sampling (depth-integrating)	Flow-dependent, from 3/w to 1+/d	Filtration

The regression relation between the SSC and the water discharge is shown in Figure 8. The equations are similar and showing high values of the coefficient of determination (R^2). The almost uniform difference is slightly higher for the lower range of water discharge. It suggests that the results may be influenced by several factors associated with the differences between the two methods used for the measurements.

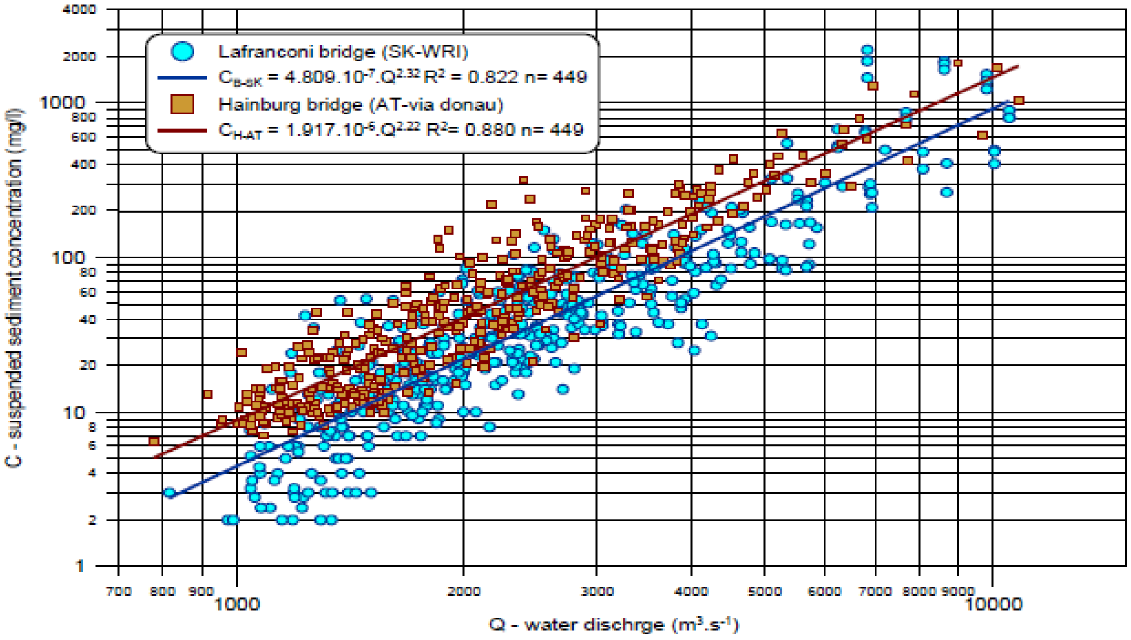


Figure 8 Relation between SSC and water discharge

Comparison of the SSC during extreme discharges is shown on (Figure 9). The measurements were carried out during the flood in 2013. The methods indicate a rather good agreement for higher discharges. The differences are greater in the lower range of water discharge.

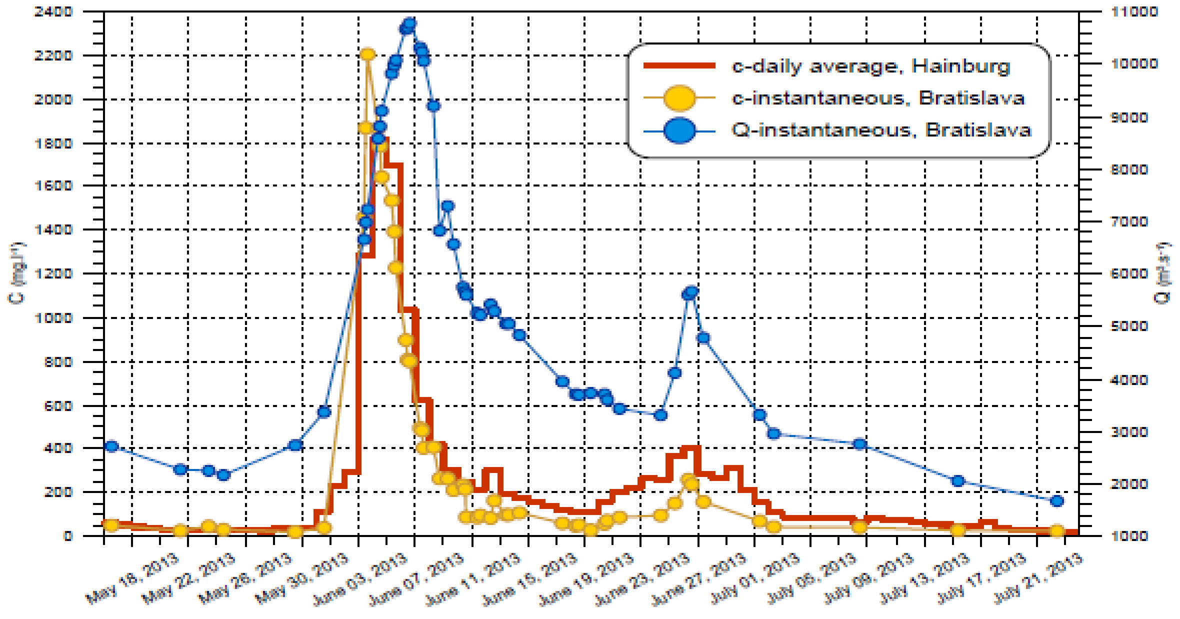


Figure 9 SSC values during the flood in 2013

The main conclusions of the Slovakian-Austrian study were that there is still need to improve the SSC measurements to increase the reliability of the results and that the monitoring of cross-border river sections requires a unification of the used suspended sediment monitoring methods. At the same time, it was confirmed that no significant data discrepancy characterises this section of the Danube River and the provided dataset is adequate for the follow-up analysis.

3.2.3 Slovakian-Hungarian cross-border section

The Medved'ov (Slovakia) and Vámosszabadi (Hungary) monitoring stations are within 1 km distance. The Slovakian institute uses an isokinetic depth-integrating sampler, the frequency of the sampling depends on the flow regime, but on average, daily sampling is performed. The laboratory analysis is done with the filtration method. On the other hand, the North-Transdanubian Water Directorate (ÉDUVIZIG) in Hungary performed five cross-sectional suspended sediment sampling campaigns with a pump sampler annually (Table 21).

Table 21 Summary table about the monitoring methods (Slovakian-Hungarian)

Name of the monitoring site	**Location of the monitoring site**	**SS measurement method**	**Frequency**	**SSC analysis method**
Medved'ov (Slovakia)	1806.30 rkm	Physical sampling, isokinetic sampling (depth-integrating)	Flow-dependent, from once a day to more than 1 time per day	Filtration
Vámosszabadi (Hungary)	1805.60 rkm	Physical sampling, pump sampling	five times per year	Evaporation

Monthly mean values were calculated for both stations. In case of the Hungarian monitoring station, however, first, a regression curve was fitted on measured long-term mean concentration and flow discharge values, and then this regression was used to calculate mean monthly sediment load values using the monthly mean flow discharge. This means that the Hungarian sediment load values are derived from long-term dataset and not calculated from daily load values. Even though, the agreement between monthly mean sediment load values is acceptable for the two stations (Figure 10). The Hungarian dataset shows somewhat higher values in the low-flow range and on the contrary, lower values during floods.

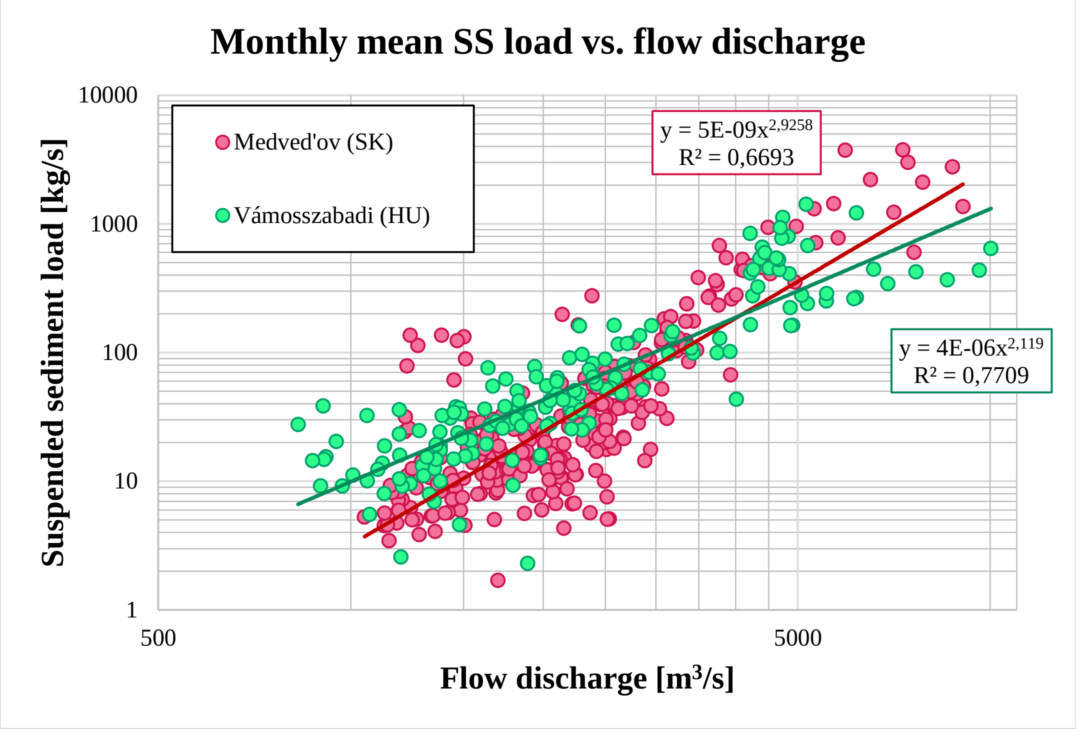


Figure 10 Relation between monthly mean SS load and flow discharge (Slovakia-Hungary)

The annual suspended load values have also been calculated from the monthly SS load values. The compared period is between 1996 and 2014. The results of the comparison of the annual SS loads are shown in Figure 11. The registered flow discharges values can be considered identical, consequently only the differences of the SS monitoring methods have effects on the results. On long term, calculating the differences between the mean annual suspended load values for the period 1996-2014, a discrepancy of 36 % can be observed (with higher values for the HU station). It is also important to note, that in dry years a larger portion of the SS load is transported during low and mean water regimes, which underlines the necessity of performing sediment measurements at different water regimes. Considering the results from the comparison of the Austrian and Slovakian datasets and the significant sampling frequency applied by the two countries, it is suggested that the values based on daily sediment samplings at the Slovakian institute are more reliable. Therefore, in the later data analysis, the sediment load values derived for the Hungarian monitoring station at this section of the Danube will not be taken into account.

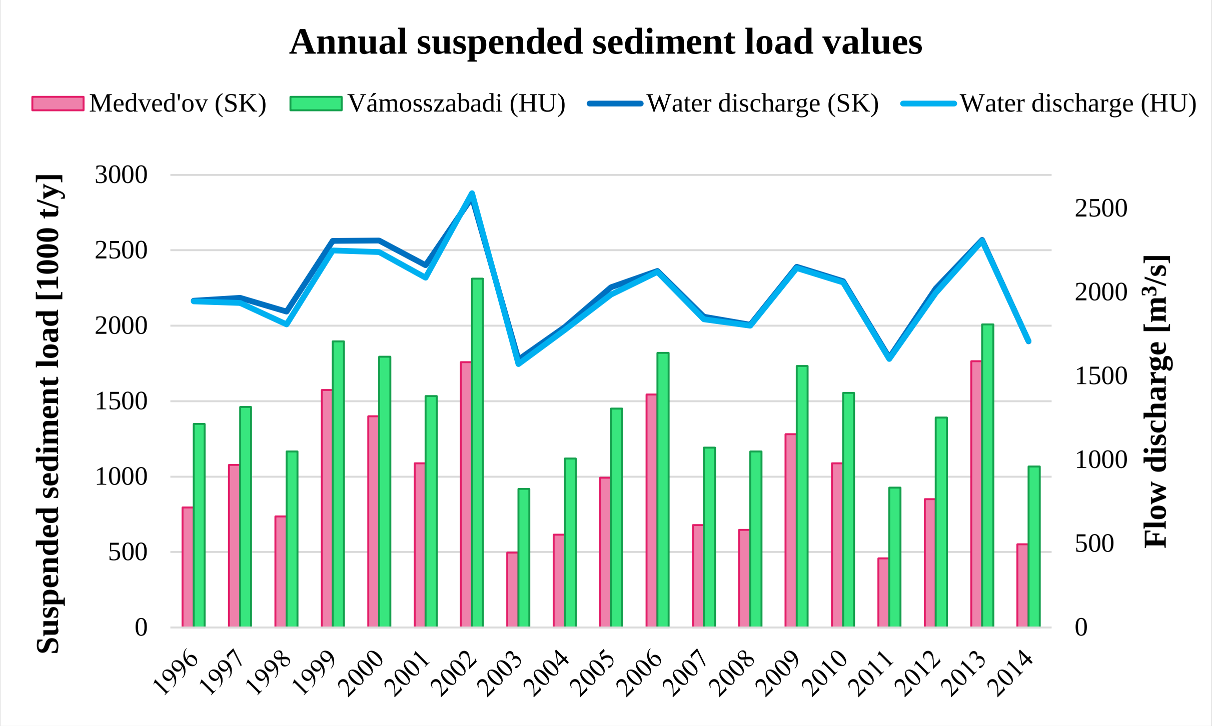


Figure 11 Annual suspended sediment load values 1996-2014 (Slovakia-Hungary)

3.2.4 Serbian-Romanian cross-border section

The HPP Đerdap 1 (Serbia), Kladovo (Serbia) and Drobeta Turnu Severin (Romania) monitoring stations are investigated in the Serbian-Romanian cross-border river section. The suspended sediment monitoring is done by physical sampling at all monitoring sites. There are no tributaries, which could explain significant disagreement between the datasets. Sampling at Kladovo and Turnu Severin are done on a daily basis and cross-sectional correction is done based on multipoint measurements, performed 1-3 times a year. At HPP Đerdap 1 the daily sampling is also done. When estimating the daily suspended sediment load, it is assumed that the measured sediment concentration is representative for the whole cross-section. The SSC is determined with the evaporation method at the Serbian side and by filtration (until 2003) and turbidity meter (after 2003) by the Romanian partner. See Table 22 about the differences of the methods used at the investigated monitoring stations.

Table 22 Summary table about the monitoring methods (Serbian-Romanian)

Name of the monitoring site	**Location of the monitoring site**	**SS measurement method**	**Frequency**	**SSC analysis method**
HPP Đerdap 1/Iron Gate 1 dam (Serbia)	943.00 rkm	Physical sampling	Once per day	Evaporation
Kladovo (Serbia)	932.90 rkm	Physical sampling	Once per day (+1-3 times a year multipoint sampling)	Evaporation
Drobeta Turnu Severin (Romania)	931.00 rkm	Physical sampling	Once per day (+4-6 times a year multipoint sampling)	Filtration (until 2003), Turbidity meter (from 2003)

The mean monthly SS load rating curves can be seen in Figure 12. The data shows consequently lower values at the Serbian station, however, higher discrepancy can only be observed in the low-flow range. Moreover, a group of the points from the Romanian station indicates good agreement in the mean and high flow range as well, whereas another group of points indicate higher values compared to Serbian data. A better understanding of the differences can be gained from the mean annual SS load values for the time period 1986-2014 (Figure 13). Here, the agreement is reasonable until 2001 and from 2002 a consequent overestimation of the RS values, by a factor of ~150% is found for the Romanian dataset.

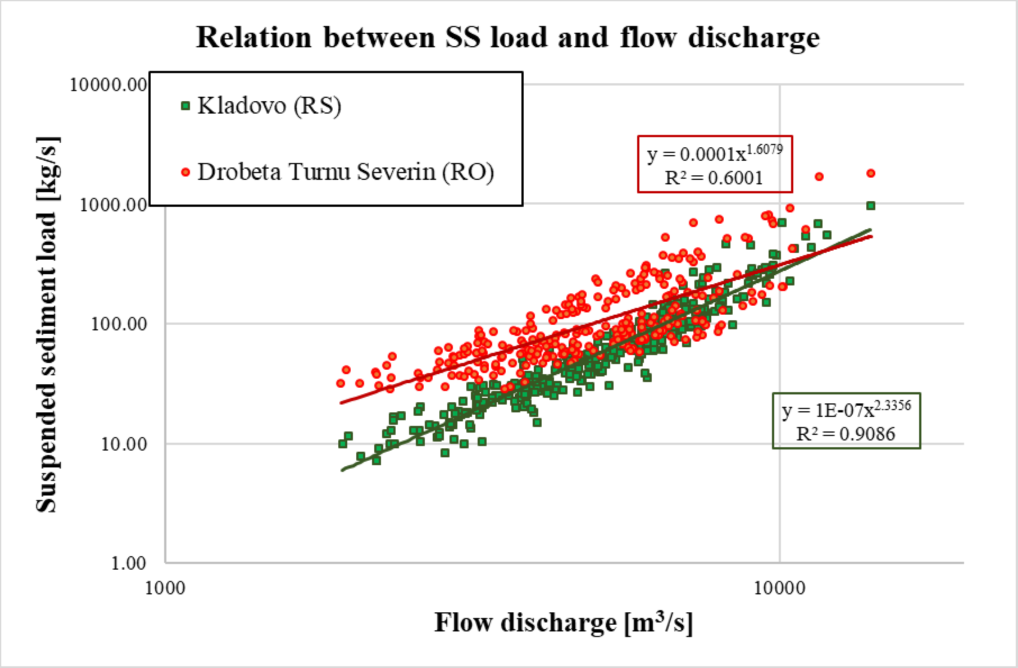


Figure 12 Relation between SS load and water discharge in log-log plot (Serbia-Romania)

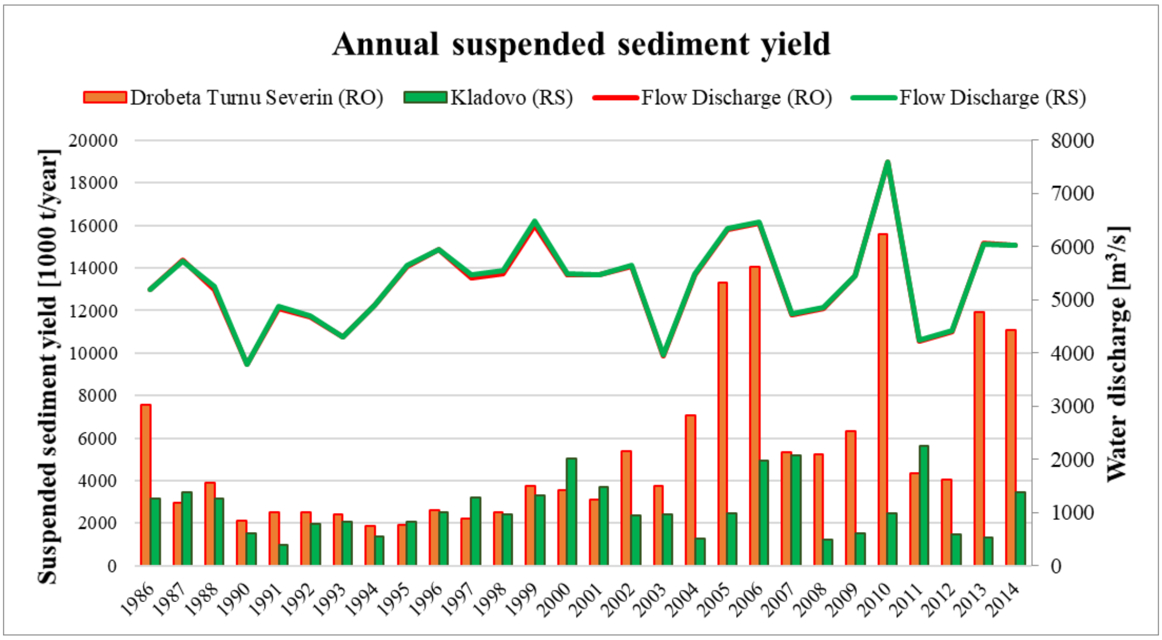


Figure 13 Annual suspended sediment yield in 1986-2014 (Serbia-Romania)

The indicated high difference between the two datasets can be even better seen for the daily sediment load values measured during the 2006 flood (Figure 14). The measured flow discharge values overlap, meaning that the disagreement between the sediment load can only be caused by the measured sediment concentration data. The peak values of the sediment load indicate more than five times higher loads from the Romanian dataset (~2600 kg/s) compared to the values provided by the Serbian partner (~500 kg/s).

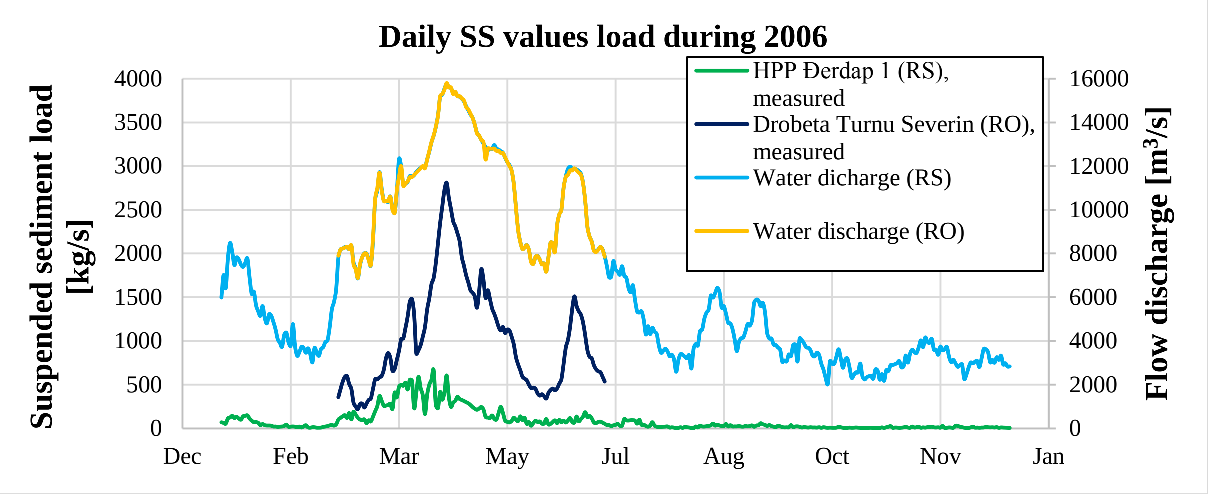


Figure 14 Suspended sediment load during 2006 (Serbia-Romania)

The found data discrepancy not only influences the short term sediment load values, but as shown in the graph of the annual sediment load values, it certainly affects the long-term sediment load, which will serve as input data for the establishment of the sediment balance. In order to reveal the possible explanation for this issue a more detailed analysis was performed, focusing on the temporal variation of the sediment load rating curves. As shown in Figure 15 the mean monthly SS load values follow two different behaviours before and after 2002 at the Romanian station, which suggests that either the sediment regime changed or some sort of methodological changes took place in the sediment measurement. In fact, the operation of the Iron Gate 1 reservoir, which has a decisive influence on the sediment regime, has not changed since the 1985, according to the information received from the responsible partners. At the same time, it was indicated by the Romanian partners in the project, that an improvement of the sediment monitoring was carried out around 2001, i.e. the conventional physical sampling together with the laboratory analysis of the water samples using the filtration method has been replaced with in-situ turbidity based evaluation of the sediment concentration.

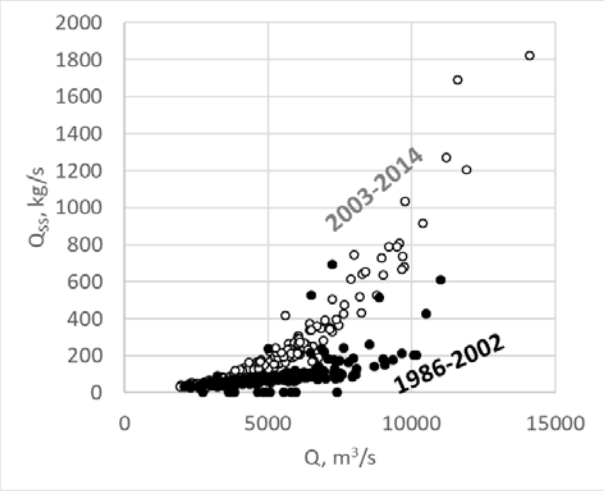


Figure 15 SS load rating curves at Drobeta Turnu Severin (RO)

Very similar behaviour of the sediment load rating curves was found for two more neighbouring stations in the Romanian monitoring network, at Bazias (rkm 1072.5) and at Gruia (rkm 858.35) (Figure 16), but not for all the other stations towards downstream. Considering the fact, that there was a change in the monitoring methodology in 2003, i.e. changing the filtering analysis of the water samples to in-situ turbidity sensor based analysis, it is presumable that this influenced the sediment data for the recent period. Moreover, it has to be enhanced that the turbidity sensors applied for the determination of the concentration values are not calibrated against information from laboratory analysis, which can inherently bias the concentration values.

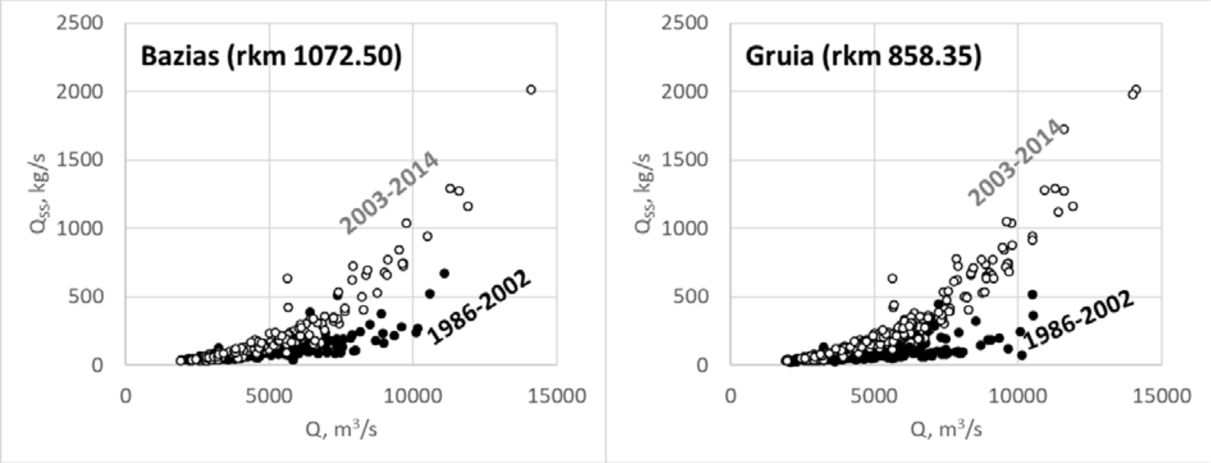


Figure 16 SS load rating curves at Bazias and Gruia (RO)

Based on these significant data discrepancies, and considering that data is available along the common Romanian-Serbian section of the Danube by the Serbian partners, the data at the three Romanian monitoring stations were neglected in the follow-up data analysis procedure.

3.2.5 Romanian-Bulgarian cross-border section

The Zimnicea (Romania) and Svishtov (Bulgaria) monitoring stations are located close to each other (within 1 km) and both of them apply daily physical samplings at a nearbank point of the monitoring section. As mentioned above, the Romanian institutes apply cross-sectional calibration of the nearbank data, performing 4-6 cross-sectional measurements during the year. The method applied by the Bulgarian partners does not involve cross-sectional calibration, but it is assumed that the measured concentration at the bank is representative for the whole cross-section of the river. See Table 23 about the differences of the methods used at the investigated monitoring stations.

Table 23 Summary table about the monitoring methods (Romanian-Bulgarian)

Name of the monitoring site	**Location of the monitoring site**	**SS measurement method**	**Frequency**	**SSC analysis method**
Zimnicea (Romania)	553.23 rkm	Physical sampling	Daily (+cross-sectional measurements 4-6 times per year)	Turbidity meter
Svishtov (Bulgaria)	554.30 rkm	Physical sampling isokinetic sampling (depth-integrating),	Daily	Filtration

The mean monthly SS load values fall in the same range from the two stations and in general, the agreement seems to be adequate between the two datasets (Figure 18). In this case the comparison of these values can, however, be misleading. When determining the annual sediment load values for the time period 1989-2014, a much higher data discrepancy shows up (Figure 19). In contrast to the measured mean annual flow discharge, where the values are actually overlapping, there is continuous disagreement between the annual loads indicating an average factor of two. The sign of the difference is, however, also changing, which at the end results in a reasonable match for the long-term mean annual sediment load values (around ~10% difference).

For the follow-up data analysis three facts were considered: i) the sediment data provided by the Romanian partners, at the common Romanian-Bulgarian section, do not show such unreasonable temporal variation due to the methodological change on the sediment measurements as was found for the stations close to the Iron Gate HPP; ii) cross-sectional calibration is continuously performed for the Romanian dataset in contrast with the Bulgarian datasets; iii) The four Bulgarian monitoring stations are located within the operating Romanian stations, and two of them are actually in front of the Romanian ones (Zimnicea-Shvistov and Chiciu Calarasi-Silistra). Based on these considerations, it was decided to exclude the sediment data of the Bulgarian stations from the data analysis.

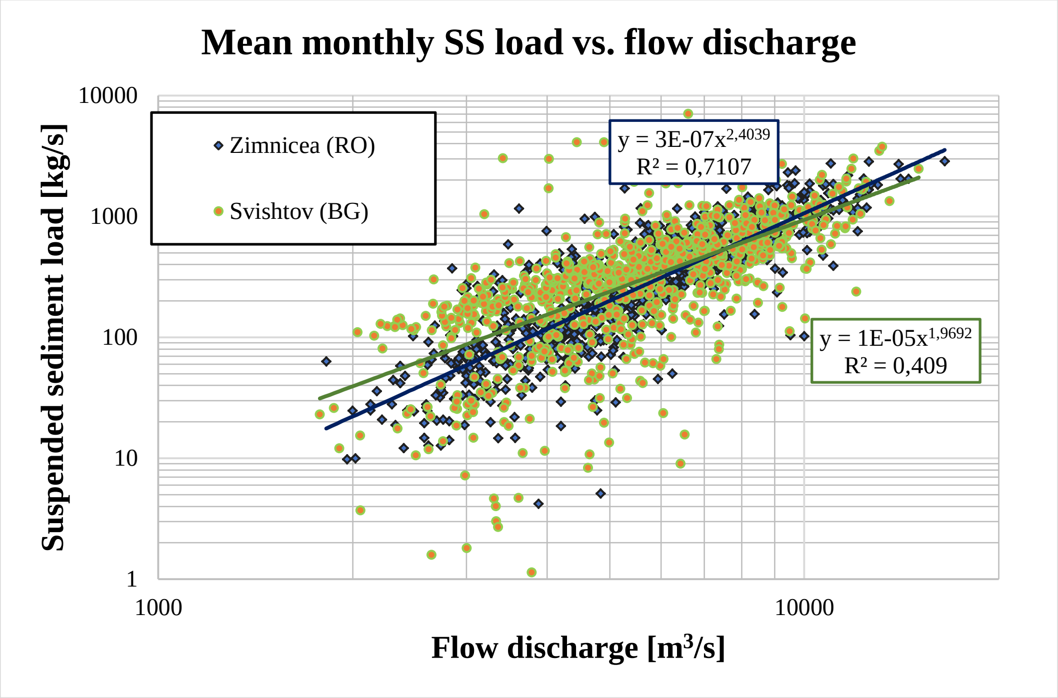


Figure 17 Relation between SS load and water discharge in log-log plot (Romania-Bulgaria)

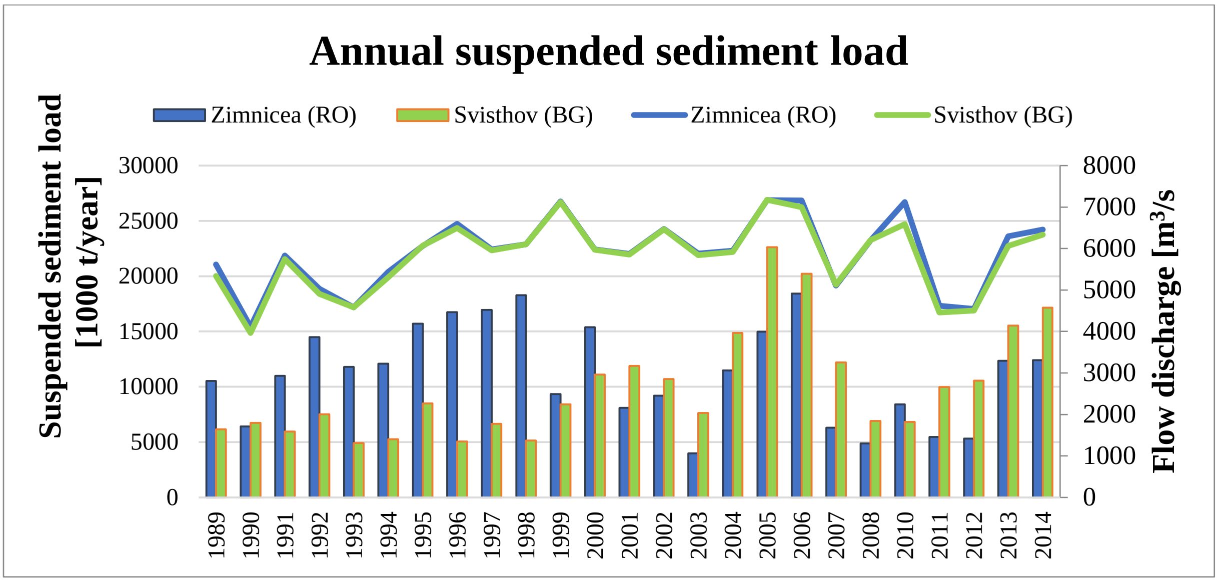


Figure 18 Annual suspended sediment yield and water discharge in 1989-2014 (Romania-Bulgaria)

3.3 Comparative analysis of results from joint measurement campaigns

Three joint field measurement campaigns were carried out within this project to enable the project partners to exchange knowledge and experiences of the different monitoring methods and to provide jointly collected sediment data for comparative analysis (Figure 20). It has to be noted that based on the results of single measurement campaigns no substantial conclusions can be drawn in terms of the capabilities and limitations of the different techniques, but at the same time a first impression can be gained, which might indicate possible drawbacks or advantages of the methods. The field campaigns were performed i) at the common Romanian-Bulgarian section at Giurgiu (rkm 493.05) on 30th August, 2017 (JM1); ii) at the common Serbian-Romania section at Kladovo (rkm 932.90) on 20th September, 2017 (JM2); iii) at the Austrian section at Bad-Deutsch Altenburg (rkm 1886.24) (JM3).

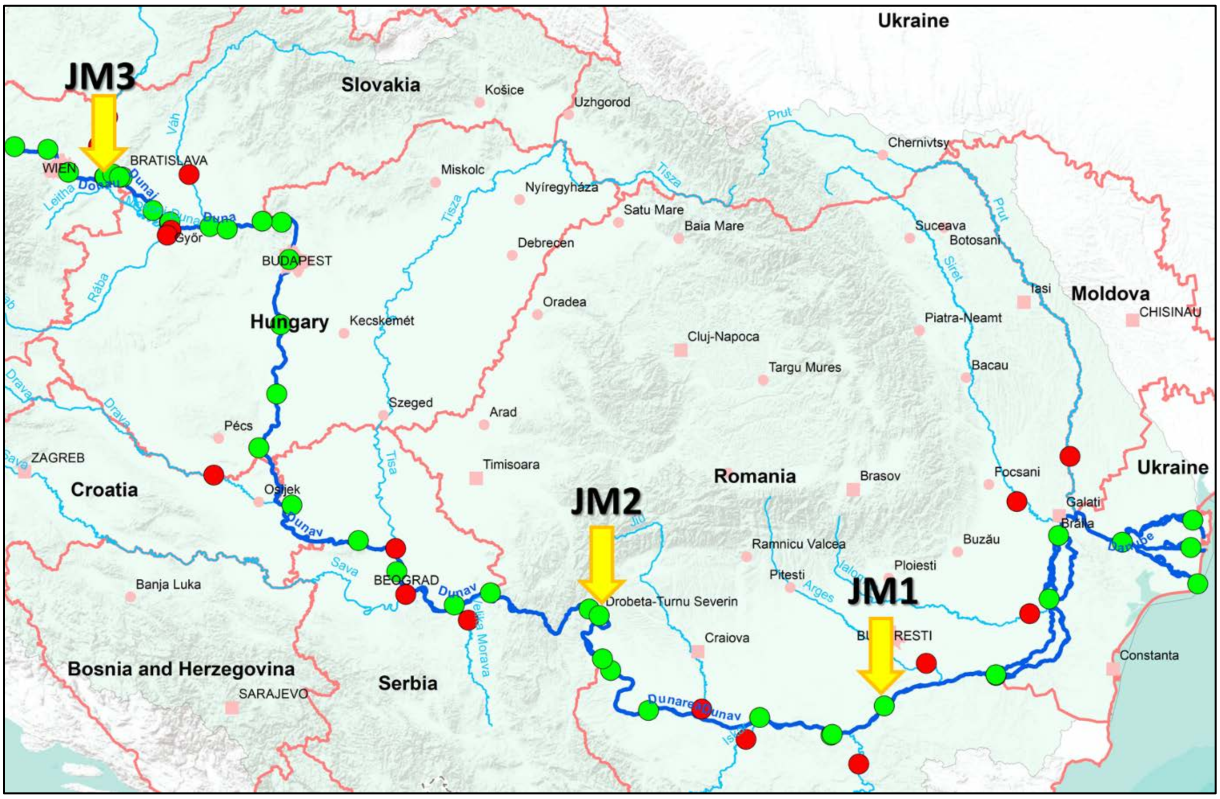


Figure 19 Locations of the joint measurement campaigns

3.3.1 Romanian-Bulgarian section (JM1)

The field campaign was organized by the National Institute of Hydrology and Water Management (NIHWM) team together with National Administration “Apele Romane” and with Bulgarian team from National Institute of Meteorology and Hydrology – Bulgarian Academy of Science. The campaign took place at the common Romanian-Bulgarian section at Giurgiu (rkm 493.05) on 30th August, 2017. The measurements were performed on the Sarmisegetuza vessel, of the Arges River Basin Administration. The following measurement methods were applied by the Romanian and Bulgarian partners, respectively (Figure 21):

- Romanian team:
    - Flow measurements with ADCP (Acoustic Doppler Current Profiler)
    - Suspended sediment sampling with bathometer
    - Suspended sediment concentration analysis with turbidity sensor
    - Bedload sampling with IMH bedload sampler
- Bulgarian team:
    - Suspended sediment sampling with isokinetic bottle sampler

The aim of the field campaign was to compare the different sediment monitoring methods used by the Romanian and Bulgarian partners. The NIHWM choose three verticals (left bank, middle, right bank) along the Giurgiu cross section and the Romanian and Bulgarian participants used their own equipment for sampling suspended matter at the same time, with different methods. NIHWM (RO) collected samples at three different depths, using bathometer for suspended matter, while the Bulgarian team sampled at the water surface, using specific glass bottle attached to the metal rod and performing point integrated measurements with a depth integrating sampler (Figure 21). The water samples at the Romanian partner were immediately analysed with a portable turbidity sensor, which provided concentration values. The water samples of the Bulgarian partner were analysed in laboratory, using the filtering method. No sediment load estimation was done due to the limited number of samples, rather a direct comparison of the measured point concentration of the samples collected at the water surface could be done. No significant differences could be found among the three data pairs (Table 24). Overall, the sediment concentration during the field campaign was reasonably low and so the highest disagreement of 16 mg/l still acceptable. At the same time, it is important to note that the turbidity sensor applied by the Romanian partners lacks calibration against concurrent laboratory data, which can bias the results and can influence the long-term sediment load calculations.

Table 24 Comparison of measured SSC values by the two participating teams

Depth of the river in the vertical (m)	11.10	8.4	3.5
Verticals/depth of sampling	90 m from RO bank / 2.2 m	362 m from RO bank – 1.7 m	660 m from RO bank – 0.7 m
SSC (mg/l) – RO team	26	10	22
Turbidity (mg/l)– BG team	22.4	6.3	6.1

Figure 20 Suspended sediment samplers by the Romanian (left) and Bulgarian measurement teams

3.3.2 Serbian-Romanian cross-border section (JM2)

The joint field measurement was performed on 20th September 2017 in the Serbian-Romanian cross-border river section (Figure 22). Two teams performed measurements: the Serbian team (JCI) used a pump sampler and the local flow velocity was measured with a propeller wing, whereas the Hungarian team (from BME) performed isokinetic sampling together with ADCP measurements (Figure 23). The samplings were performed along a cross-section of the Danube River at Kladovo (rkm 932.90) at five verticals, having five points in each vertical. The water samples taken by JCI were analysed according to the standard method in Serbia (evaporation method). The water samples taken by BME were analysed with a laser diffraction instrument (LISST-Portable). Vertical distributions of the flow velocity, SSC and specific suspended sediment load were calculated and integrated along the cross-section to provide sediment load. An example for the vertical parameter distributions can be seen in Figure 24.

Figure 21 Location of the joint field measurement in the Serbian-Romanian cross-border river section

Figure 22 Measurement infrastructure of JCI (left) and BME

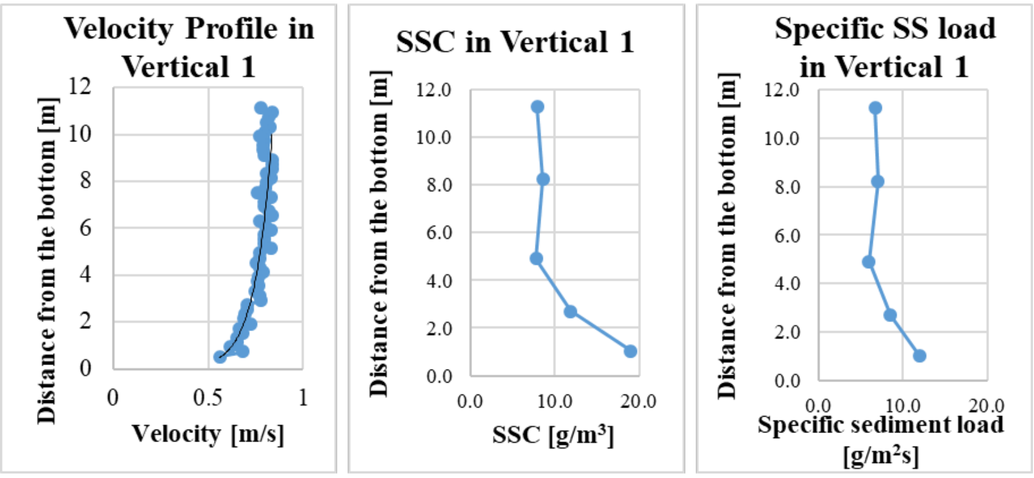


Figure 23 Measured (BME) flow velocity, SSC and specific SS load in a vertical

Based on the measurements, the cross-sectional distribution of the specific SS load could be quantified and compared (Figure 25). There can be higher differences found in the region of the left bank, which calls for further analysis. One possible explanation for the differences is that vertical 1 and 2 were measured at the end of the day by BME, in difficult weather conditions. It is, however, important to note that the laser diffraction based instrument needs further comparatives tests with conventional laboratory analysis methods to gain a better picture about the measurement limits of the SSC, how it depends on the grain size and also, how the different composition of the suspended sediment, even with organic material, influences the results. The resulted suspended sediment load for this measurement was 48 kg/s and 22 kg/s from the samplings of BME and JCI, respectively. In fact, the measured load values fit well on sediment load rating curve, which was set up based on the data provided by the Serbian partner in the project (Figure 26).

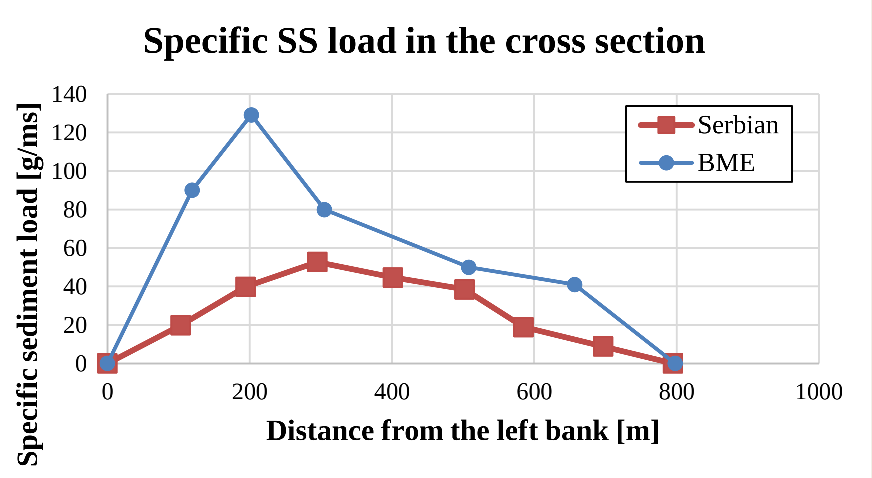


Figure 24 Comparison of specific SS load values at JM2

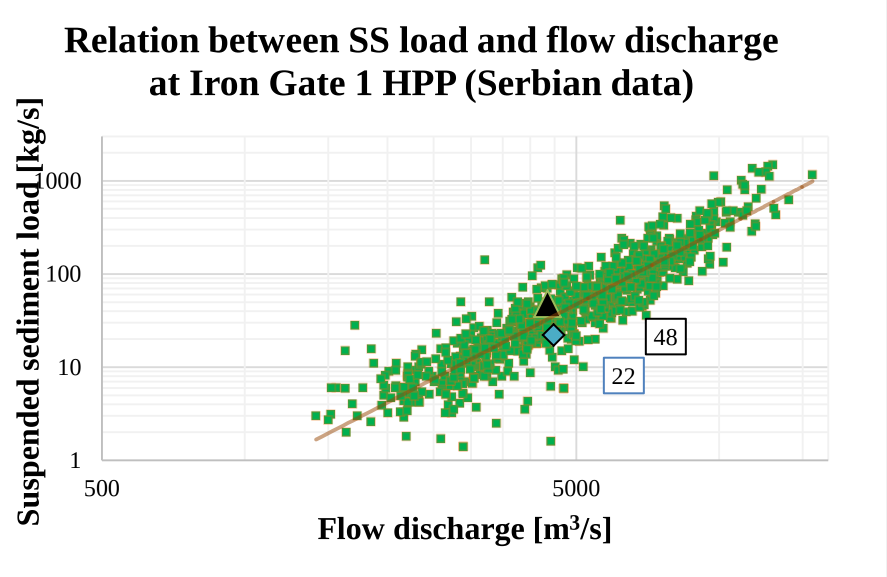


Figure 25 Measured SS load values (48 kg/s-BME, 22 kg/s-JCI) indicated on the sediment load rating curve provided by JCI

3.3.3 Austrian section (JM3)

The 3rd joint field campaign was performed on 8th November 2017 at the Austrian Danube (rkm 1886.24) close to the Austrian-Slovakian border section. The place of the joint measurement was the Hainburg road-bridge, located close to the municipalities of Hainburg an der Donau and Bad Deutsch-Altenburg (Figure 27).

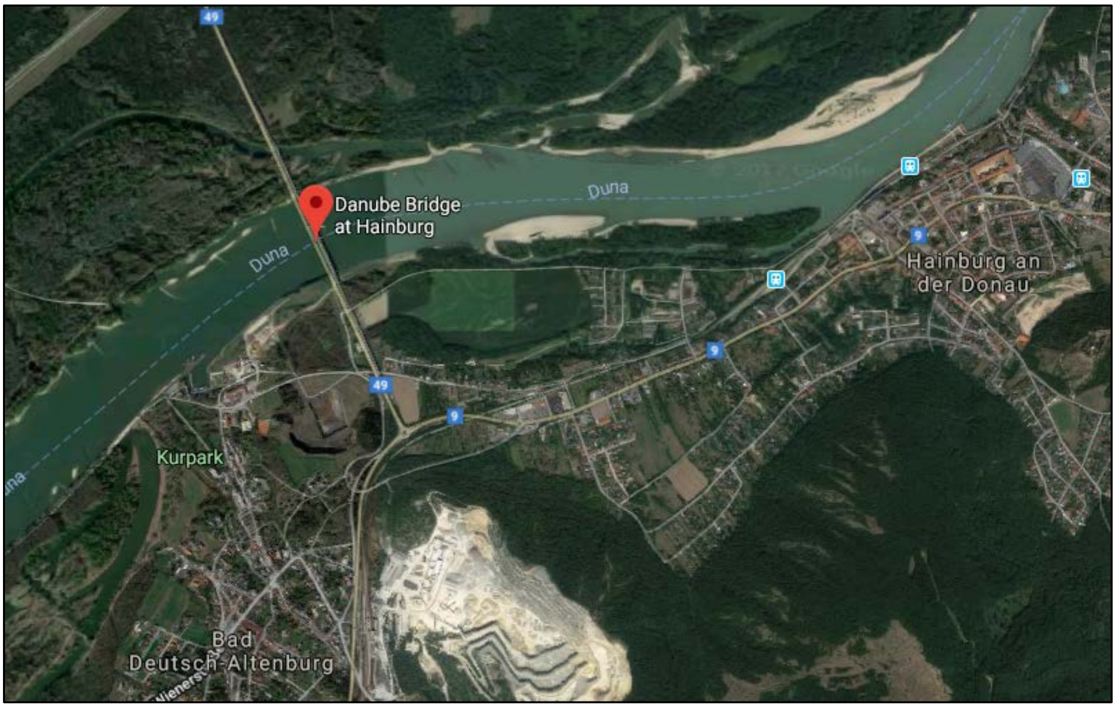


Figure 26 Location of the joint field measurement in the Austrian river section

The following measurement teams participated in the field campaign with the indicated instruments:

- BOKU (Austria)
    - US-P61-A isokinetic point-integrating sampler
    - Acoustic Doppler Velocimeter (ADV)
    - Laboratory analysis of samples (filtering method)
- VUVH (Slovakia)
    - VUVH depth-integrating sampler
    - Laboratory analysis of samples (filtering method)
- BME (Hungary)
    - US-P61-A isokinetic point-integrating sampler
    - Acoustic Doppler Current Profiler (ADCP)
    - Laser diffraction based SSC analysis

- OVF (Hungary)
    - pump sampling (10 litre/vertical)
    - Acoustic Doppler Current Profiler (ADCP)
    - Laboratory analysis of samples (evaporation method) at two different laboratories
    - Laser diffraction based SSC analysis

The measurements were performed in the same cross-section, however, with somewhat different distribution of the sampling points both along the cross-section and along the vertical. For the latter, BOKU and BME applied five points per vertical, OVF sampled 10 points (and poured together to have a depth-averaged sample), whereas VUVH used a depth-integrating sampler. The number of vertical changed from 5-8 (BME, OVF: 5, BOKU-VUVH: 8).

For the analysis of the samples collected by OVF, three methods were applied. First (indicated as OVF1 in the following), laser diffraction was used to analyse SSC. Second and third (OVF2 and OVF3) two different laboratories analysed the samples, however, in the same way, i.e. performing the evaporation method. The specific suspended sediment load values derived from the field data show similar behaviour along the cross-section, but a deviation of ±30% can be observed (Figure 28).

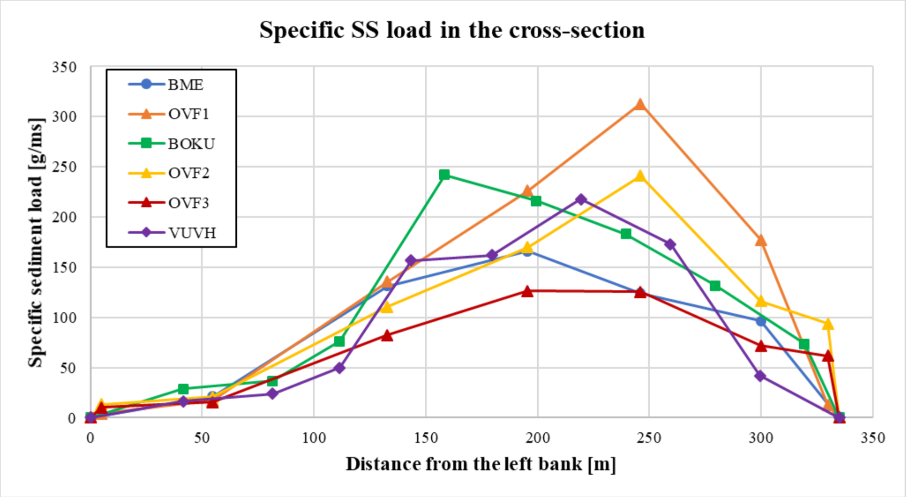


Figure 27 Measured specific suspended sediment load values at the JM3 campaign

The calculated suspended sediment load values fall in the range of 26-49 kg/s, which fits in the suspended sediment load rating curve of this monitoring station (note that the flow discharge was 1800 m^3/s) (Figure 29). However, it can be seen that for the results of OVF, where the evaporation method was used (OVF2 and OVF3), there is a significant difference between the two values, 40 kg/s vs. 26 kg/s, which, in fact, indicates only the difference in the laboratory analysis method, as the same water samples were used. Also, it can be seen that the highest and lowest sediment load values of 49 kg/s and 26 kg/s, measured by OVF (OVF1 and OVF3), was based on pump sampling, in contrast with the results from other teams, where isokinetic sampling was performed. Extracting the measured suspended sediment load values, where isokinetic sampling was performed, the values of 32 kg/s, 39 kg/s and 33 kg/s were resulted by BME (HU), BOKU (AT) and VUVH (SK), respectively, indicating much lower deviation.

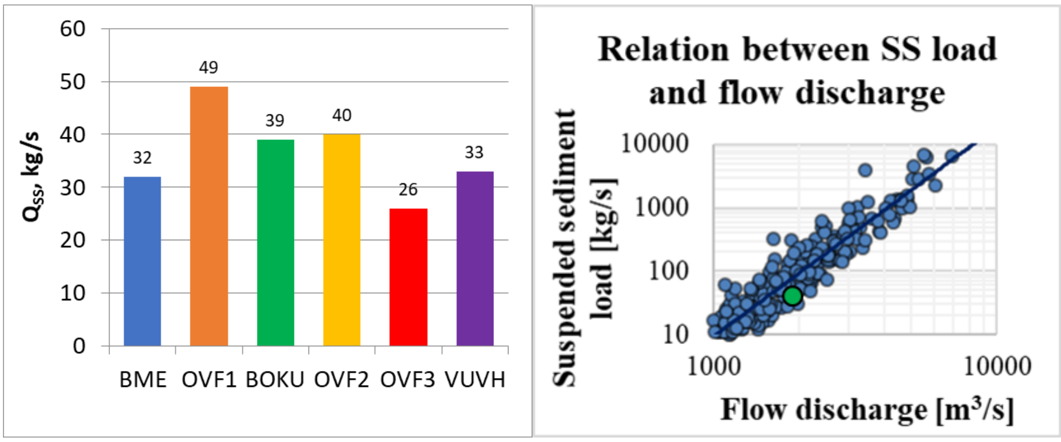


Figure 28 Calculated SS load values (left) at the JM3 campaign and SS load rating curve with the measured sediment load by BOKU (data source right figure: viadonau)

3.4 Conclusions from the comparative analysis

Based on both the long-term, historical suspended sediment data based comparative analysis and the ones based on the joint measurement campaigns, we conclude the followings, as relevant findings for the data analysis and for future improvements of the sediment monitoring network:

- Data from German and Austrian stations indicate good quality
- The applied monitoring methods of continuous turbidity measurements, completed with sensor and cross-sectional calibration can be considered as good practices.
- The comparative assessment of Austrian and Slovakian data also showed good agreement, both for the long-term datasets and for the results of the joint measurement.
- The currently applied monitoring methodology, 4-6 cross-sectional measurement per year, in Hungary is not adequate for the temporal analysis of the sediment transport. Also, the measurement technique lacks isokineticity, which leads to higher uncertainty. Furthermore, the laboratory analysis method, i.e. the evaporation method, can cause significant uncertainty, even though relatively large sampling volumes of 10 litres are used.
- The sediment monitoring method applied by Serbia provides good quality information, but it has to be noted that the applied evaporation method for the laboratory analysis is not practical in terms of the necessary large volumes of the water samples and can show high uncertainty in low flow regimes, where the concentration and the analysed amount of the solid matter is low.
- The suspended sediment load values provided by the Romanian partner showed unrealistic temporal behaviour at the Iron Gate 1 HPP from 2003, which might be the effect of the change in the monitoring methodology in the same year, when instead of the laboratory analysis of the water samples, in-situ turbidity measurements have been implemented. The turbidity sensors are not calibrated against laboratory data and therefore can be biased. This unrealistic character could only be found for the stations close to the Iron Gate 1 HPP, and not for the downstream stations.
- The monitoring methodology applied by the Bulgarian institutes provide high temporal resolution, however, no cross-sectional calibration of the nearbank data is performed. Due to the fact that the Bulgarian stations are located close or between operating Romanian stations, the data from the latter is used in the follow-up analysis.

4 Sediment data analyis

4.1 Introduction

The goal of this chapter is to establish a quality checked sediment database both for suspended sediment and bedload transport, using the collected information from the project partners. In the project report entitled “Sediment monitoring in the Danube River” a thorough overview was given about the past and currently applied sediment monitoring methods, which could be used to perform a quality assessment of the collected data, which was introduced in Chapter 2, together with the quantity of the available data. The comparative analysis of historical and newly collected sediment data (see Chapter 3) enabled the clarification of some further data discrepancy issues and led to the correction or omission of some data.

As presented in Chapter 2, monthly suspended sediment load values were collected for the period 1986-2016, whereas yearly load for the antecedent period. For the bedload, yearly load values were collected for all available stations and years. In the followings, we introduce how the raw data was processed towards a harmonized database, how the data gaps were handled, how the annual sediment load values and long-term mean annual values vary along the Danube River. Furthermore, the influence of floods on the sediment regime will be assessed as well as longitudinal variation of the characteristic grain sizes both for suspended sediment and bedload. The main result of the data analysis is the sediment database with mean annual load values, which is further analysed and involved in the sediment budget assessment for the whole Danube River.

4.2 Analysis of suspended sediment data

4.2.1 Sediment load analysis for the period 1986-2016

Based on the monthly sediment load values provided by the project partners mean annual sediment load values were calculated summing up the monthly mean values. The data series were manually corrected at locations, where data gaps were found. In those cases, the values were either interpolated or simply excluded. Missing values were replaced based on the sediment load rating curves for those time series, where less than four-month data were missing in a year. If more than four months were missing, the given year was not considered in the long-term mean load processing. Such corrections were made only at two German stations (Vilshofen and Kachlet).

As introduced in Chapter 3, significant data discrepancies were found at three Romanian monitoring stations (Bazias, Drobeta Turnu Severin and Gruia) possibly due to the changes in the monitoring method, which took place in 2003. The provided dataset was therefore had to be neglected for the data analysis. For details, see Chapter 3.

Using the corrected annual sediment load values, the longitudinal variation of the 30-years mean annual load was calculated. When preparing the graph of the long-term mean sediment load, the tributaries were considered as point sources in the sediment regime. Accordingly, their contribution is indicated as local increases at the inflow sections. For the calculation of the longitudinal variation of the SS load between two monitoring stations, where a tributary inflow is located, a mathematical method was applied. At such locations, we assumed that the longitudinal variation of the load in the Danube is linear and shows the same tendency before and after the inflow, i.e. the same slope is indicated.

The influence of hydropower plants, i.e. the sediment trapping effect of the upstream reservoirs had also to be taken into account when preparing the graph. In fact, the two most significant effects can be captured at the Slovakian reservoirs and the Iron Gate reservoirs. For both, the provided data adequately covers the affected section of the Danube. In order to assess the temporal variation of the sediment load along the Danube River, a statistical analysis was performed on the provided monthly sediment load values. We assumed that the monthly sediment load values follow lognormal distribution (see an example for an Austrian station in Figure 29). A theoretical lognormal function was fitted on the monthly load values at each monitoring station, expressed in the following form:

$$P(x) = \frac{1}{(x-\gamma)\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\ln(x-\gamma)-\mu}{2\sigma^2}\right)^2}$$

where x is the monthly load and γ is the continuous location parameter (here $\gamma = 0$), μ and σ are the mean and standard deviation of the natural logarithm of x.

It has 68.3% probability that the monthly sediment load values fall within the range of the expected (or mean) value with a deviation of σ and so we assumed that the annual values will have a deviation of 12σ. These low and high threshold values ($P_{16\%}$ and $P_{84\%}$) were derived for all stations to provide the expected temporal behaviour of the annual load values.

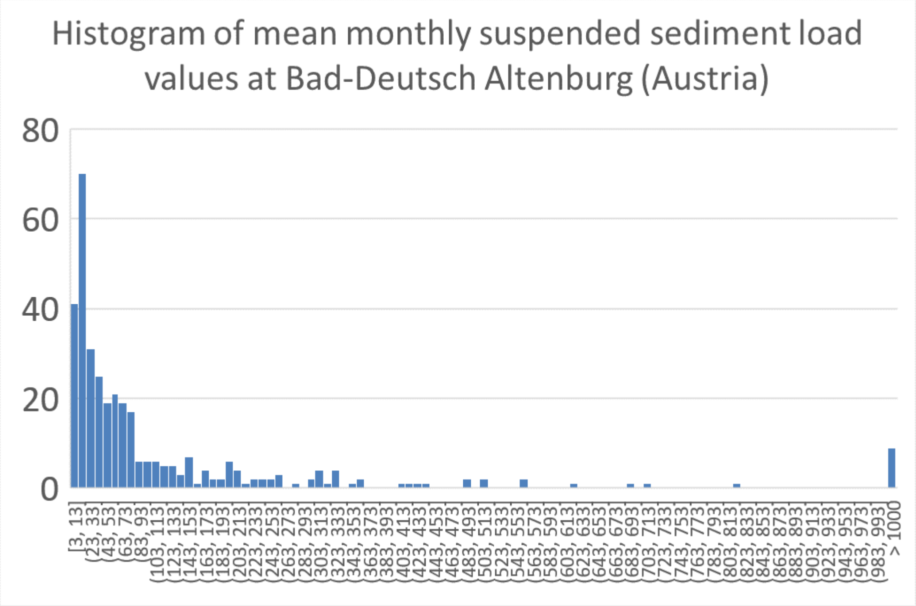


Figure 29 – Histrogram of mean monthly suspended sediment load values at Bad-Deutsch Altenburg (Austria) (data source: viadonau)

Figure 32 illustrates the long-term, 30 years mean annual suspended sediment load values along the whole Danube River (period 1986-2016). In the graph, the quality of the information, based on the qualitative classification introduced in Chapter 2, is also shown. The deviations from the mean values based on the previously described statistical calculations are also plotted. The suspended sediment load remains below 1 Mt/year along the larger part of the German section, and the inflow of the Isar River has no significant influence. On the contrary, the Inn River brings an order of magnitude higher amount of sediment, which results in a local increase up to almost 5 Mt/year. Along the Austrian reach, local smaller scale variation can be observed within 1 Mt/year, which is the influence of the fine sediment remobilization from the HPP Aschach during the floods in 2002 and 2013, the tributary Enns and some scatter in the suspended sediment load values. No clearly visible longitudinal changes take place though. The reservoirs at the Slovakian hydropower plants, on the other hand, seem to have significant trapping effect, where a local drop of the sediment load from 3.5 Mt/year to 1.3 Mt/year is shown. There is a slight increase along the Hungarian section at the Rába (through Mosoni-Duna) inflow of 0.5 Mt/year, however, due to the rather small tributaries along this section, the sediment load is quite constant. From the Hungarian-Croatian border (rkm 1431) a continuous increase of the load is observed until the upstream end of the Iron Gate 1 reservoir (from 1.6 Mt/year to 13.7 Mt/year). This is due to large tributaries entering the Danube River, i.e. Drava (rkm 1382.5), Tisza (rkm 1214.5), Sava (rkm 1170.0) and Great Morava (rkm 1103.0), indicating a sediment inflow of 0.3 Mt/year, 2.6 Mt/year, 2.9 Mt/year and 2.1 Mt/year, respectively. Further it might be the result of the clear sand bed conditions, in contrast with the upstream reaches of sand-gravel and clear gravel bed. There is a significant drop in the sediment load that can be seen at the

Iron Gate 1 hydropower plant (rkm 943.0), where the mean annual load is 2.5 Mt, showing a ~80% trapping efficiency. Downstream of the hydropower plants, there is a significant increase of the load from 2.5 Mt/year to 13.5 Mt/year at the Iantra River inflow (rkm 536.7). This growth can be explained partly with the contribution of the tributaries, e.g. the Jiu River brings 3 Mt/year, and partly with the fact that compared to the sediment transport capacity of the river, the available sediment source is limited due to the sediment blocking effect of the hydropower plants. Consequently, this section is exposed to bed erosion processes, which could indeed be found at the assessment of long-term morphological changes, at least along some parts of this section, to be analysed in another work package of this project. A quite stable section with slight increase in the sediment load characterizes the river between Zimnicea (rkm 553.23) and Chiciu Calarasi (rkm 379.58), with mean annual values of 13 Mt/year to 14.6 Mt/year. Despite the fact that a high sediment input arrives from the Ialomita River of 3.2 Mt/year, there is an extreme reduction of the sediment load between Chiciu Calarasi and Vadu Oii (rkm 238.0) from 14.6 Mt/year to 10.7 Mt/year. In this section of the Danube River, a bifurcation characterises the river morphology, which can act as a sink in the fine sediment transport (Figure 30). This assumption is in accordance with the local morphological changes, which indicate sedimentation between the two mentioned monitoring stations.

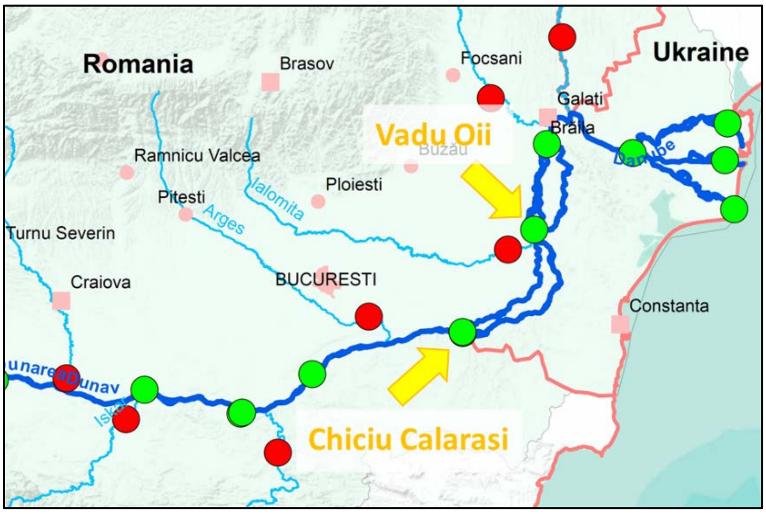


Figure 30 Suspended sediment monitoring stations along the Romanian reach of the Lower Danube River

From Vadu Oii until the inlet section of the Danube Delta region (Isaccea, rkm 100.2) again continuous increase of the load can be observed raising from 10.7 Mt/year to 21.4 Mt/year. The Siret River (at rkm 155.05) and the Prut River (at rkm 134.14) contribute with 4 Mt/year, and the remaining amount is likely to be resuspended from the river bed, yielding local erosion along this reach. The Danube Delta region indicates lowering transport towards the Black Sea, which might be explained with the natural sedimentation of such locations. However, it is important to note that sediment load data is available only from the three main branches (Chilia, Saint Geroge, Sulina) but not from the other branches of the system and therefore, the total load is obviously underestimated.

The apparently significant variations of the suspended sediment load along the Romanian section of the river required some further double check of the dataset. A simple approach was applied here for this purpose, calculating theoretical bed elevation changes along the Lower Danube River, based on the longitudinal changes in the SS transport. Collecting the characteristic widths of the river section between the monitoring stations, a simple volume continuity was set up and mean annual bed change values were estimated to see order of magnitude values. As shown in Figure 31 the theoretical bed changes range between ± 3 cm/year for the Danube reach downstream from the Iron Gate HPPs. These magnitudes of local erosion and sedimentation processes are realistic, which supported that the mean SS load values can show such variations.

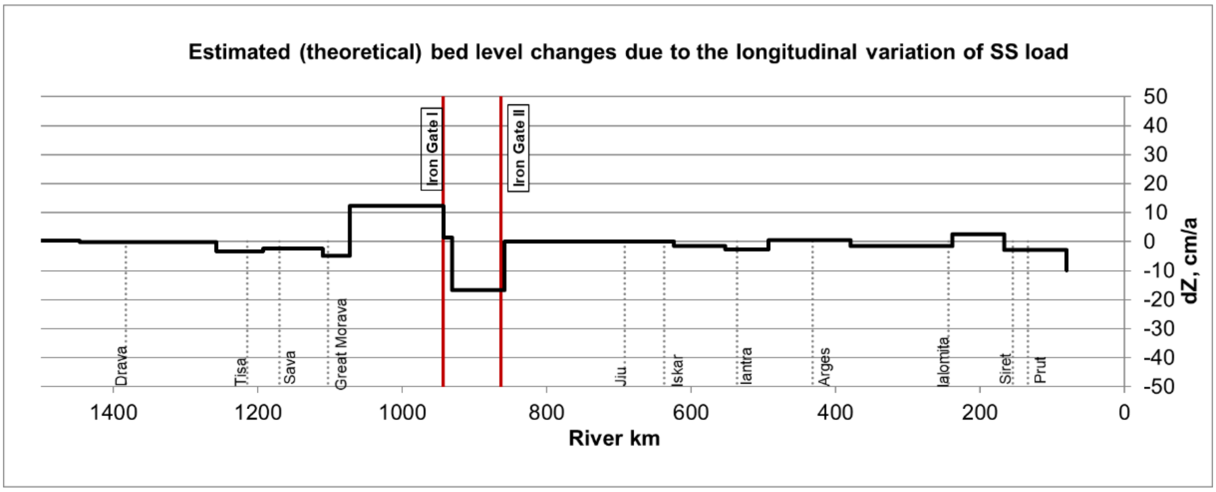


Figure 31 Conversion of the longitudinal variation of the mean annual suspended sediment load to bed elevation changes

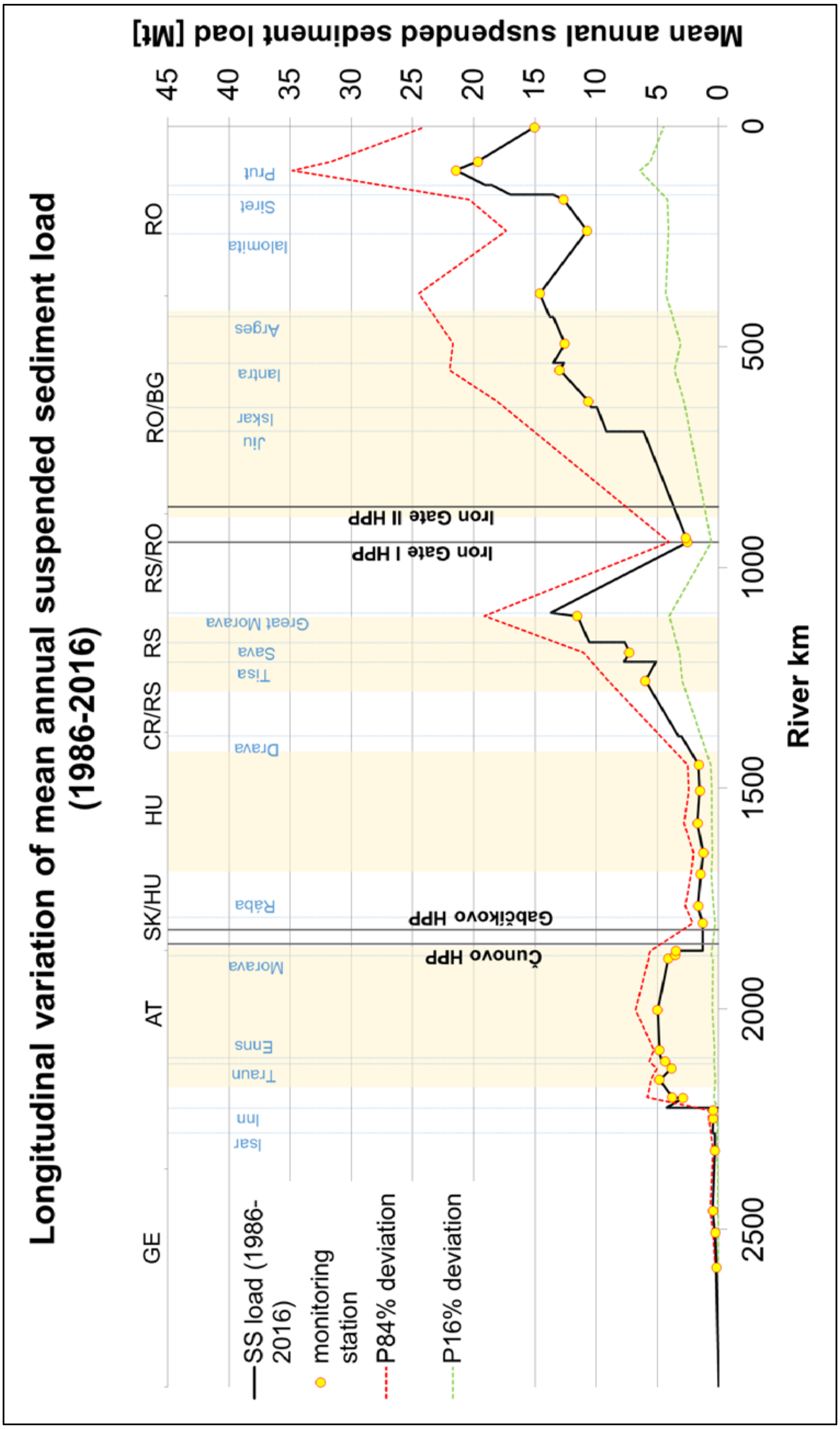


Figure 32 Longitudinal variation of long-term (1986-2016) mean annual suspended sediment load along the Danube RIver (data source AT: viadonau and Verbund)

In order to have a better insight in the temporal variation of the suspended sediment load, not only the one sigma deviation from the mean values was calculated, but the actual annual load values were assessed for a few wet and dry years. *Figure 33* shows the longitudinal variation of SSL in years, where significant floods occurred during the year. Significant floods happened in 2002 and 2013 along the Upper and Middle Danube River, whereas in 1988 and 2005 rather in the Lower Danube River, furthermore a relatively high flood wave took place along the whole Danube in 2006. The amount of the transported sediment during the extreme flood event of 2013 exceeded 20 Mt between Aschach Strombauleitung (rkm 2161.27) and Stein-Krems (rkm 2002.69). From Bad Deutsch-Altenburg (rkm 1886.86) a significant decrease can be observed, indicating the combined sediment trapping effect of the floodplains, the Slovakian reservoir and the large, ~30 km long, secondary branch system of the Danube along the common Hungarian-Slovakian section of the Danube River. The floodplain sedimentation could be well seen on photos taken after the flood event (see Figure 39 in Chapter 4.2.3). From the Hungarian section, the detected suspended sediment load can be characterized with values close to the long-term mean values. The 2002 flood shows similar behaviour with somewhat lower annual loads along the Austrian section compared to 2013, reaching 12-17 Mt. Similarly to 2013, no significant influence of the flood could be seen along the Middle and Lower Danube. The floods on the Lower Danube in 1988, 2005 and 2006 indicated extreme amount of sediment load close to the Danube Delta region. Here, the annual load exceeded 30 Mt (2006), 45 Mt (2005), and 60 Mt (1988), respectively, showing two-three times higher values than the mean ones. In all the mentioned years, the local decrease of the loads in the vicinity of the largest reservoirs is apparent. The contribution of the Romanian tributaries to the sediment load is notable with extreme SSL values of 9.5 Mt and 4.6 Mt from the Jiu River in 2005 and 2006, respectively, and 15.7 and 8.5 Mt from the Siret River in 1988 and 2005, respectively.

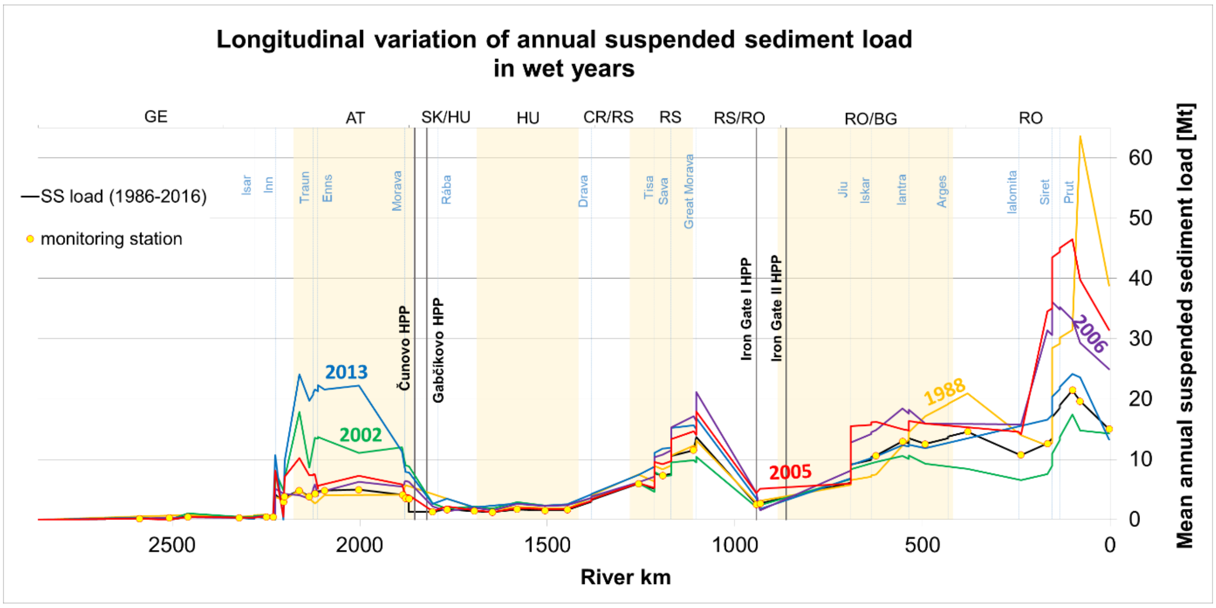


Figure 33 Longitudinal variation of annual suspended sediment load along the Danube River in wet years (data source AT: viadonau and Verbund)

As for the dry years, we considered 1994, 2003 and 2011, when the annual sediment load remained below the long-term mean values along the whole Danube River (Figure 34). The difference along the whole river compared to the mean values is around 50-80%, except for 1994, when the Sava brought higher sediment load (4.2 Mt) compared to the mean load (2.9 Mt), and therefore a local increase upstream of the Iron Gate reservoir can be seen. A similar local surplus of the sediment load can be seen, also in 1994, between the confluence of the Iskar and Iantra Rivers, which is the likely influence of the Olt River.

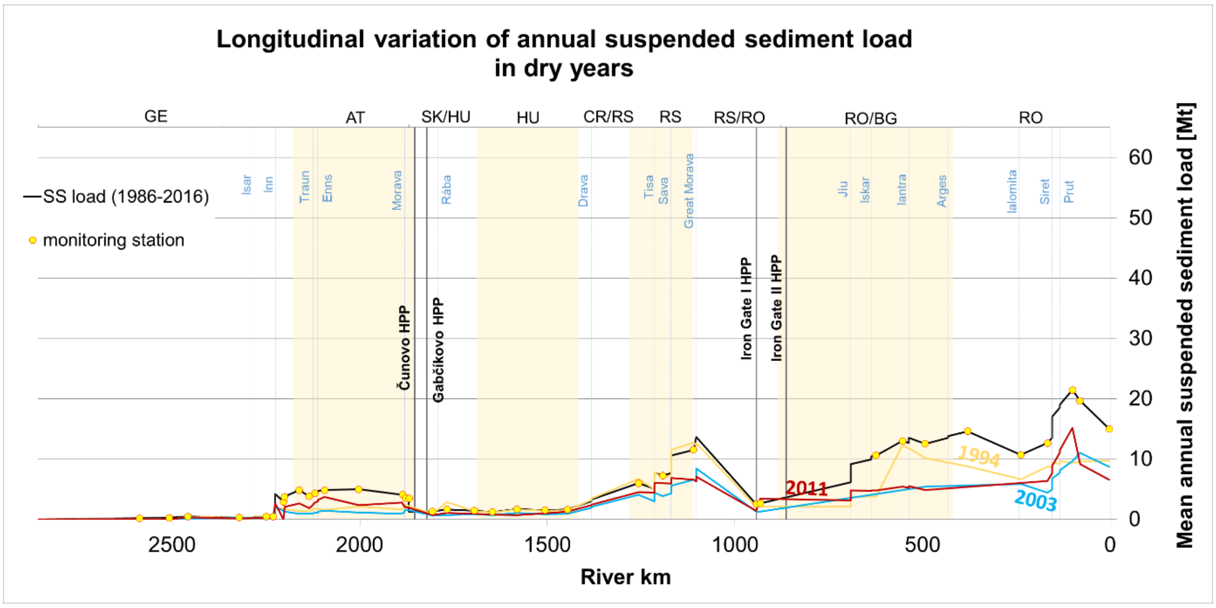


Figure 34 Longitudinal variation of annual suspended sediment load along the Danube River in dry years (data source AT: viadonau and Verbund)

4.2.2 Sediment load analysis for the period before 1986

Historical data, from the period before 1986, was also collected within the project. Mean annual sediment load values were provided by the partners for all the monitoring stations, where data was available. Furthermore, the sediment data introduced in the study of Rákóczi (1994) was also used at stations, where data was not provided. See Annex II for the collected annual suspended sediment load data from the indicated period. An attempt was made to estimate the mean annual suspended sediment load values for the periods before the construction of the hydropower plants. For this purpose, different time periods were chosen at the given sections of the Danube River, considering the construction year of the nearby hydropower plants, which can indeed affect the suspended sediment transport, locally (

Figure 35).

Along the German section, until the inflow of the Inn River (rkm 2225.2), the times series was split at in 1956. For instance, at Vilshofen (rkm 2249.5), the mean annual SS load decreased from 1.5 Mt/year to 0.5 Mt/year after 1956, indicating a decrease of 66% here. At the monitoring station Linz (rkm 2135.17) a first decrease in the suspended sediment transport can already be seen around the late 1930ies, before the construction of the Austrian HPPs at the Danube River. Thus, it is more likely, that this drop results from the chain of HPPs built along the Inn River, as the Inn River at the confluence contributes far more to the suspended sediment load as the Danube itself and thus is more important for the suspended sediment load transported in the Austrian Danube. Thus, the construction of the hydropower plants at the end of the 1930ies was considered and the period before and after 1938 was taken into account for the data analysis. Here, the mean annual SS load decreased from 6.7 Mt/year to 3.8 Mt/year (~43%). The effect of the Slovakian HPPs (at Cunovo, rkm 1853 and Gabcikovo, rkm 1821) could be captured at the closest Hungarian monitoring stations downstream of the reservoirs. For instance, at Budapest (rkm 1646.50), the long-term mean annual SSL before the construction of the Gabcikovo HPP (in 1992) was 4.5 Mt/year, whereas for the subsequent period it lowered to 1.23 Mt/year, indicating a decrease of ~70%. The same difference characterises the Danube River until the Iron Gate 1 reservoir. At the section of Drobeta Turnu Severin (rkm 931), right downstream of Iron Gate 1, the mean annual SSL of 30 Mt/year (estimated for the period ending in 1972, when the operation of the HPP started) dropped to 3.4 Mt. From the Iron Gate HPPs until the Danube Delta region the mean annual SSL decreased with ~70%, considering again the period before and after 1972. It is important to note that it is most probably not only the hydropower plants built in the Danube River, which are responsible for the decreasing of sediment load. Significant anthropogenic influences took place along the river basins of the Romanian tributaries as well, among which several hydropower plants were built in the tributaries, too.

A clear separation between the effects from the tributaries and the measures in the Danube River, however, cannot be made, since no historical data was available for the tributaries.

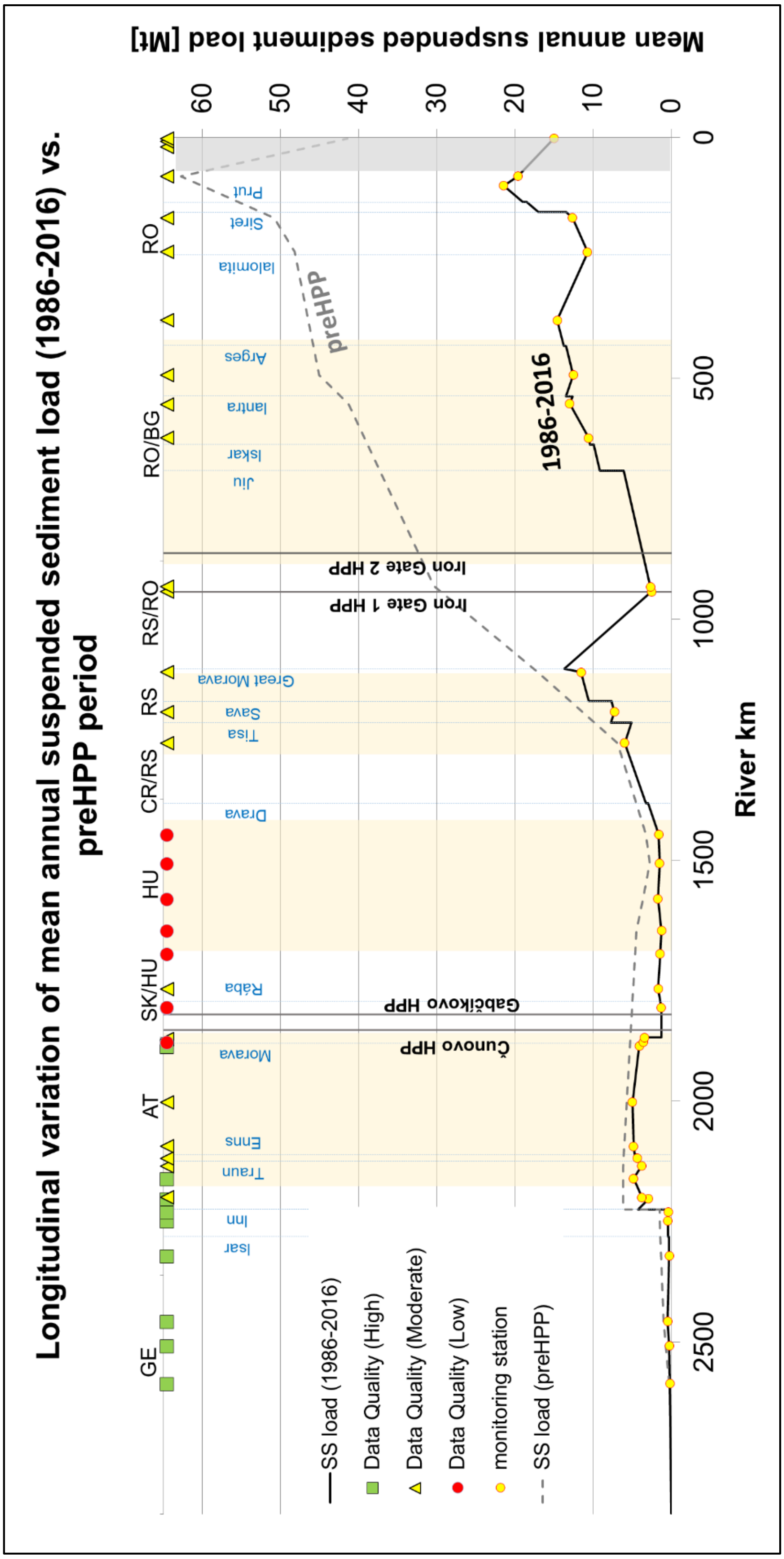


Figure 35 Longitudinal variation of long-term (1986-2016) mean annual suspended sediment load along the Danube River compared to the time period before the operation of hydropower plants (data source AT: viadonau and Verbund)

4.2.3 Influence of floods on the suspended sediment regime

In order to get a deeper insight to sediment transport processes during floods, higher frequency sediment data is required compared to monthly dataset used in the previous points. This is due to the fact, that during floods, the hydrodynamic conditions, determining sediment transport (e.g. bed shear stress, turbulent kinetic energy, etc.), also change rapidly over time. During flood events, the flow is generally released without retention with higher flow velocities in the reservoirs compared to normal conditions, which leads to more intensive sediment remobilization and transport towards downstream. Moreover, the deposited sediment in the upstream reservoirs of the hydropower plants can get remobilized during short periods, i.e. days or weeks. For the assessment of these short-term events, daily or even finer sediment load datasets were collected from the partners, where such information was available. In fact, the flood in 2013 was an extreme event in the Upper Danube River. During this flood event, quite detailed datasets were provided for the analysis, therefore this flood event is analysed in more details here. The goal of this analysis is to gain a better understanding on the contribution of extreme floods to both the short and long-term sediment regime.

One of the ways to utilize the fine time resolution sediment load time series is to estimate the amount of mobilized sediment along the river. In the 2013 flood the Inn River had a very significant contribution to the total sediment load of the Danube, therefore, the section assessed within the following analysis starts downstream of the confluence at rkm 2225.2. Along the Austrian reach of the Danube 10 HPPs are located and there are two more at the Slovakian section. Measured suspended sediment loads are plotted as a function of time in Figure 36 for eight monitoring stations along the Upper Danube River. The flood was outstanding not only of the flow discharges but in terms of the transported amount of sediment, too, as the peak values of the sediment load exceeded 60 t/s in the reach downstream of the HPP Aschach. However, in contrast with the flow discharges, the short-term sediment transport is strongly determined by the significant sediment sources from the reservoirs, accumulated for years, or even from the upstream reservoirs. The remobilization of the trapped sediment from one reservoir can be well seen in the temporal variation of the volume of the Aschach reservoir (Figure 37), where an erosion of 5.5 Mm^3 (approx. 7.5 Mt – Habersack et al., 2015) took place during the investigated flood event.

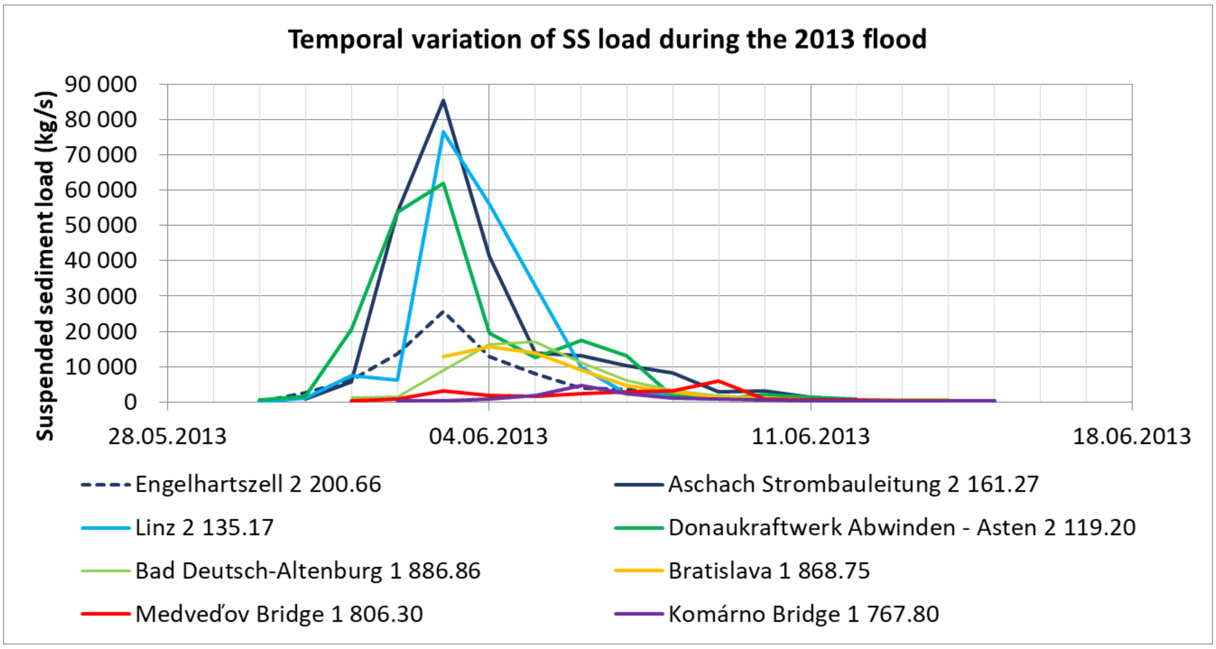


Figure 36 Time series of daily suspended sediment load values during the 2013 flood along the Upper Danube River (data source AT: viadonau and Verbund)

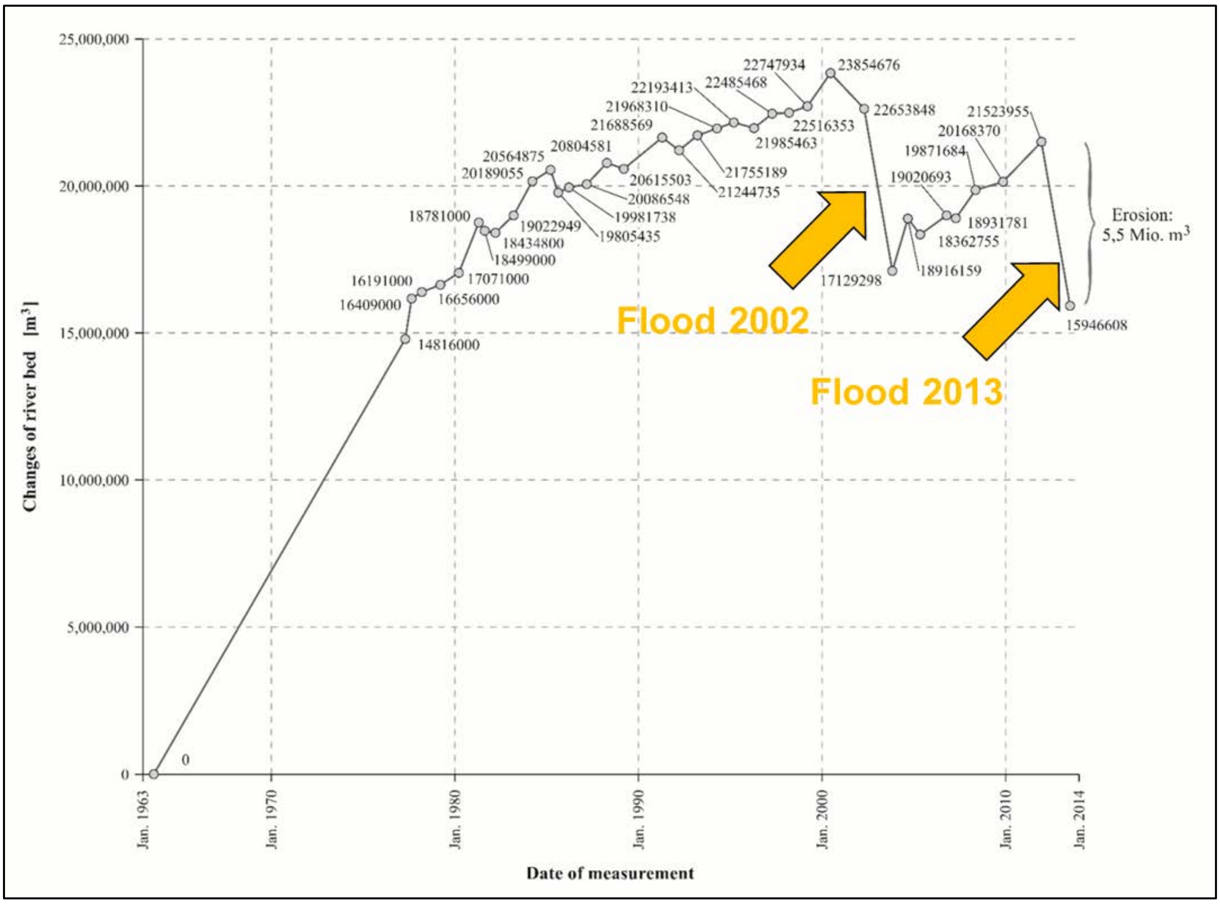


Figure 37 Temporal variation of the volume of deposited sediment in the Aschach reservoir (source: Habersack et al, 2016)

For a better understanding, a quantification of the mobilized mass of the sediment was calculated together with the longitudinal variation. In order to evaluate the influence of the flood wave on the sediment transport, a separation of the daily sediment load values was performed based on the mean monthly load and only the part above the mean was used for the mass calculation. Performing a numerical integration of daily loads for the period of the flood event a total mobilized mass was estimated for the monitoring stations, shown in Figure 38, together with the peak sediment load values. The transported sediment mass of ~20 Mt can be seen at Aschach, which can be partly explained with the eroded material from the reservoir and partly with the already high arriving load from the Inn River. Both the peak load values and the sediment mass decrease towards downstream, reaching Bratislava, Slovakia (rkm 1868.75) with a value of 6.7 Mt. As can be seen in the photos in Figure 39, a considerable amount of the transported sediment has been deposited in the floodplains. The contribution of the mobilized sediments during the floods to the annual load can reach 85% at some sections of the Danube, which shows for the significance of the sediment measurements during flood events, especially considering the fact that the disagreement between measured and estimated (based on rating curves) sediment loads can be higher in such extreme events (Haimann et al., 2014).

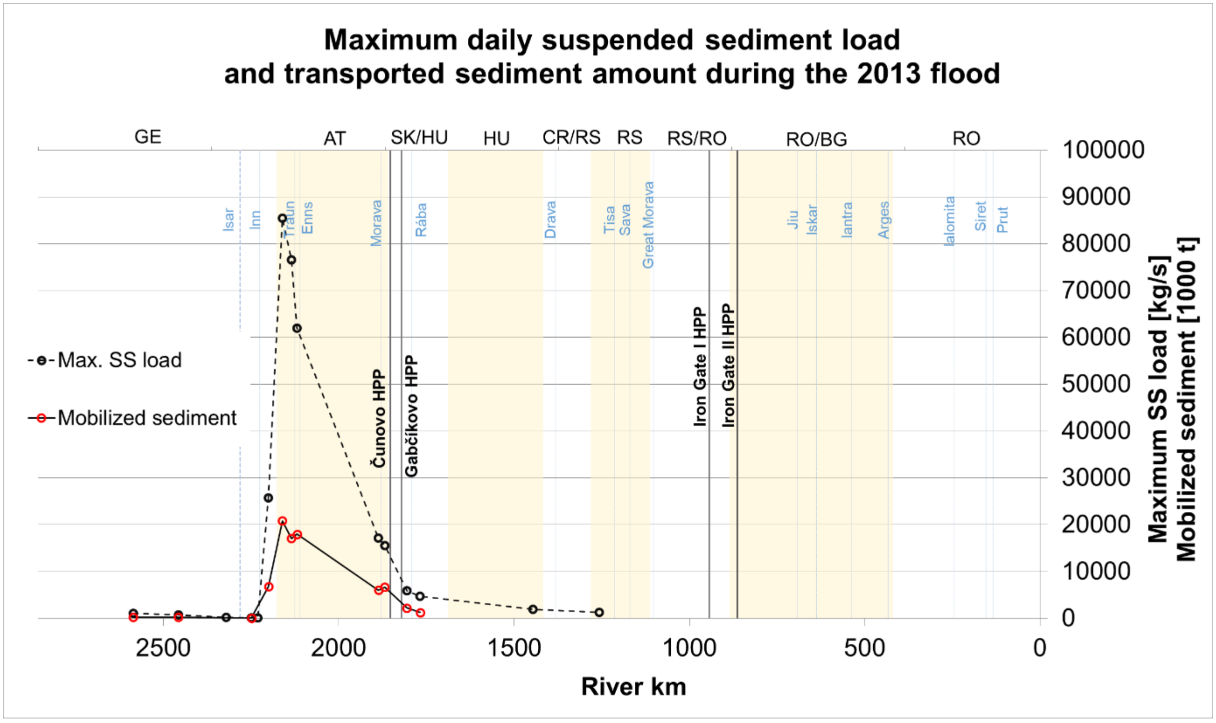
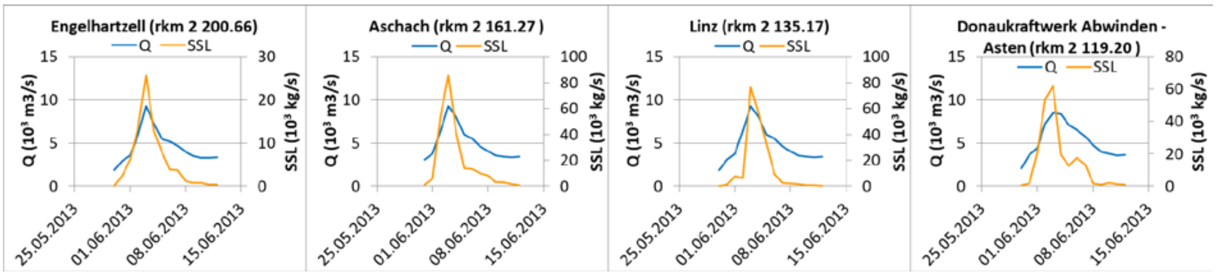


Figure 38 The influence of the 2013 flood in the sediment regime in the Upper Danube River (data source AT: viadonau and Verbund)

Figure 39 Floodplain sediment depositions in Upper Danube River during the 2013 flood in Upper-Austria (left) and in Hungary (source: left: Verbund, Schmalfuß, 2013, right: ÉDUVIZIG)

From sediment monitoring aspects it is important to see the dynamics of the sediment transport compared to the flow dynamics, i.e. the temporal behaviour of the sediment load waves. In this case the peaks of the sediment load arrive at the same time or earlier than the peak of the flow discharges (Figure 40). Until Linz in Austria (rkm 2135.17), the sediment load and flow discharge peaks occur on the same day. Further downstream, however, there is a time lag of one day between the two peaks and the highest sediment load arrives earlier. The reason of this phenomenon can be physically based, such as the peak of the local bed shear stress, together with the slope, arrives earlier, and so the resuspension of fine sediments can take place before the flow peak arrives. Another explanation could be the operation of hydropower plants during floods, where the remobilization of the fine sediment in the reservoir takes place before the flood peaks. When performing sediment measurements in the river, it is crucial to know that the highest load might not coincide with the flood peaks and for the most accurate sediment load assessment the field samplings might have to be carried out one or two days before or after the expected peaking. This is also a reason why a continuous monitoring with an OBS or ABS is recommended.



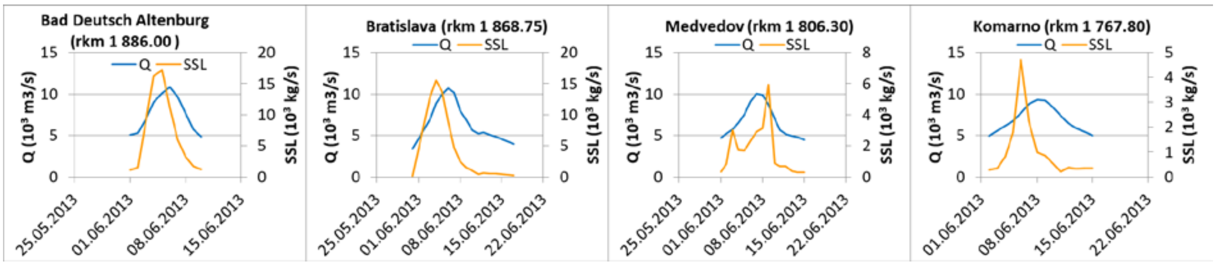


Figure 40 Time series of daily mean flow discharge and suspended sediment load values during the 2013 flood at stations along the Upper and Middle Danube River (data source AT: viadonau and Verbund)

4.3 Analyis of bedload transport

For the analysis of the bedload transport in the Danube River, only very limited data was available from the partners due to the low number of bedload monitoring stations. As summarized in Chapter 2, continuous bedload monitoring is performed only at one location in Austria, one in Hungary, however due to the unreliable dataset we excluded those from the analysis, and there are eleven more stations along the Romanian section. There are a few locations in Germany (9) and in Slovakia (2), where bedload measurement campaigns where carried out in the Danube in the past, based on which an estimation on the bedload transport could be done.

When preparing the assessment of the longitudinal variation of the long-term bedload transport, three time periods were considered. The period before 1931 was considered as the condition before the construction of the hydropower plants, but does not represent the natural regime, as the Danube was already regulated by that time. An interim period was also defined for the years between 1940-1960 for the Middle Danube River as the period before the construction of the Slovakian power plants. On the Lower Danube a few data were available for the 1970-1972 period, which was considered as the time before the operation of the Iron Gate HPPs. Furthermore, the timeframes of the years after 1992 in the Upper and Middle Danube and after 1972 in the Lower Danube were chosen to assess the bedload transport after the construction of the HPPs.

For the German section, data was available for the after HPP period in forms of bedload rating curves (see two examples in Figure 41). Based on the rating curves and the mean annual flow discharges, yearly bedload transport was estimated and averaged over the years to provide mean annual bedload transport.

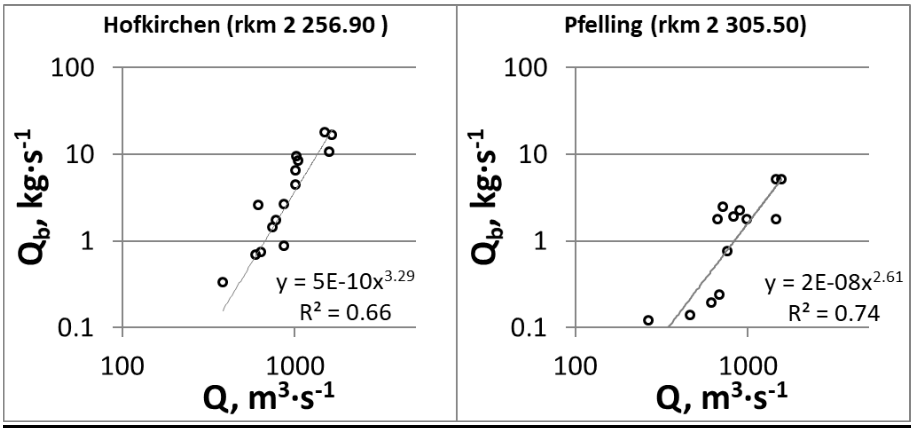


Figure 41 Bedload rating curves at Hofkirchen and Pfelling (both in Germany)

For the Austrian station at Vienna (rkm 1930.8), historical data is available for the years 1910, 1921 and 1925-1931. At the Austrian station at Bad-Deutsch Altenburg data was provided in form of yearly mean loads for the following periods: 1951-1957 (rkm 1885.9) and 2005-2015 (rkm 1886.24).

At the Slovakian stations, Devin (rkm 1878.15) and Klizska Nema (rkm 1795.58) again, bedload rating curves were provided (Figure 42). Daily discharge values were used to estimate daily bedload transport, based on which the long-term mean annual value were determined.

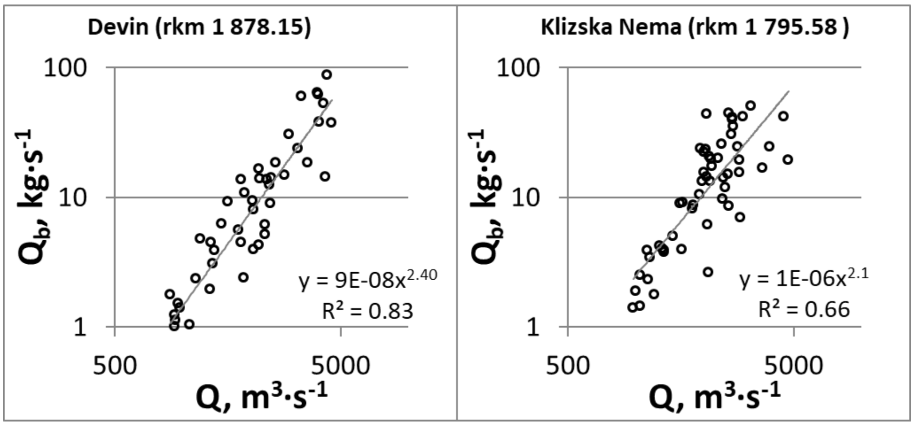


Figure 42 Bedload rating curves at Devin and Klizska Nema (both in Slovakia)

Along the Hungarian section of the Danube River, the mean annual values for the period between 1940-1960 were taken from Bogárdi (1964) for six stations. There is one bedload monitoring station in Hungary in the Danube at Vámosszabadi (rkm 1805.60), where significant data discrepancies were found compared to the values provided by the Slovakian partner for the nearby station at Klizska Nema (rkm 1795.58), moreover, field tests indicated the underestimation of the bedload transport by the applied methodology, and therefore that dataset was excluded from this analysis.

Along the common Serbian-Romanian, Bulgarian-Romanian and Romanian section of the Danube River, there is continuous monitoring of the bedload transport from 1970 at some sections. Using the bedload rating curves (see examples in Figure 43) setup for those stations, the mean annual values of bedload transport could be estimated for the pre and after HPP periods, considering the construction of the Iron Gate HPP (1972).

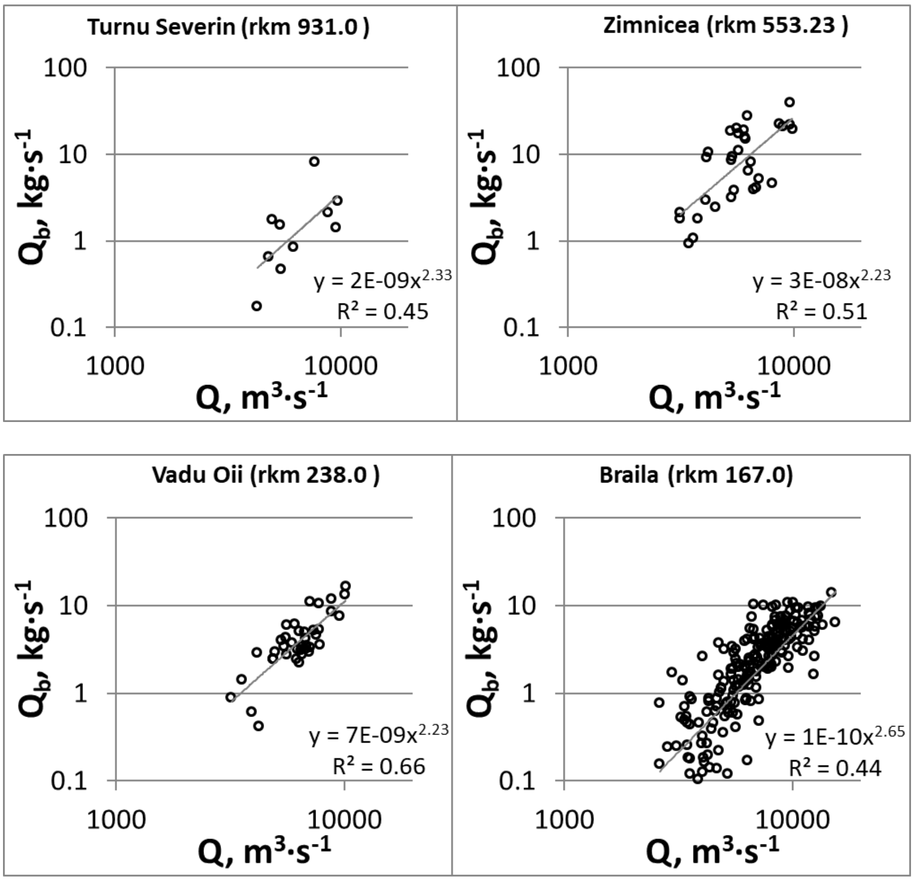


Figure 43 Bedload rating curves at four Romanian monitoring stations.

The methods described above provided quantitative information on the temporal and longitudinal variation of the bedload transport (Figure 44). At the German section the mean annual bedload ranges between 0.001-0.03 Mt/year for the period after the construction of the chain of hydropower plants. For the period, before 1931, the mean annual bedload transport for the years 1925 to 1931 in Vienna (AT) at rkm 1930.80 was around 1.01 Mt/year. For the years from 1951-1957 (period 1940-1960 in Figure 44) a mean annual value of 0.94 Mt/year was calculated for Bad Deutsch-Altenburg (AT) rkm 1885.90. Both periods represent the transport in the downstream part of the Austrian Danube after the regulation, but before the construction of the relevant hydropower plants in the Austrian Danube (Jochenstein commissioned in late 1955 is approx. 320 km upstream). For the period after the construction of the last hydropower plant in the Austrian Danube, (HPP Freudenau at rkm 1921.05 in 1997/1998) the mean annual value for the years 2005-2015 is

0.44 Mt/year at rkm 1886.24 in Austria. This means a local bedload transport decrease of ~53%. This values agrees well with the mean annual bedload value of 0.40 Mt/year found at rkm 1878.15 (Devín). On the other hand, from the downstream sections of the Slovakian HPPs a significant increase was found from the preHPP period. For instance, the mean annual bedload transport at rkm 1825.6 was around 0.19 Mt/year in the period 1940-1960, increasing to ~0.55 Mt/year (at Klizska Nema, rkm 1795.58). This temporal variation suggests a locally increasing transport capacity of the river downstream of the HPPs. Indeed, significant bed erosion in the years after the starting of the operation of the Gabcikovo HPP was found along the Upper-Hungarian section of the Danube River (see e.g. Török and Baranya, 2017). Unfortunately, no recent bedload data is available for the Middle-Danube River throughout the Hungarian, Croatian and Serbian reaches. Based on the mean annual bedload transport values estimated for the Romanian stations the locally low values at the Iron Gate reservoir, ranging between 0.02-0.1 Mt/year, indicate the likely sediment blocking influence of the reservoir, whereas an increase up to ~0.5 Mt/year can be observed right downstream of the Iron Gate hydropower plants, where the natural sediment transport capacity is determining the sediment load.

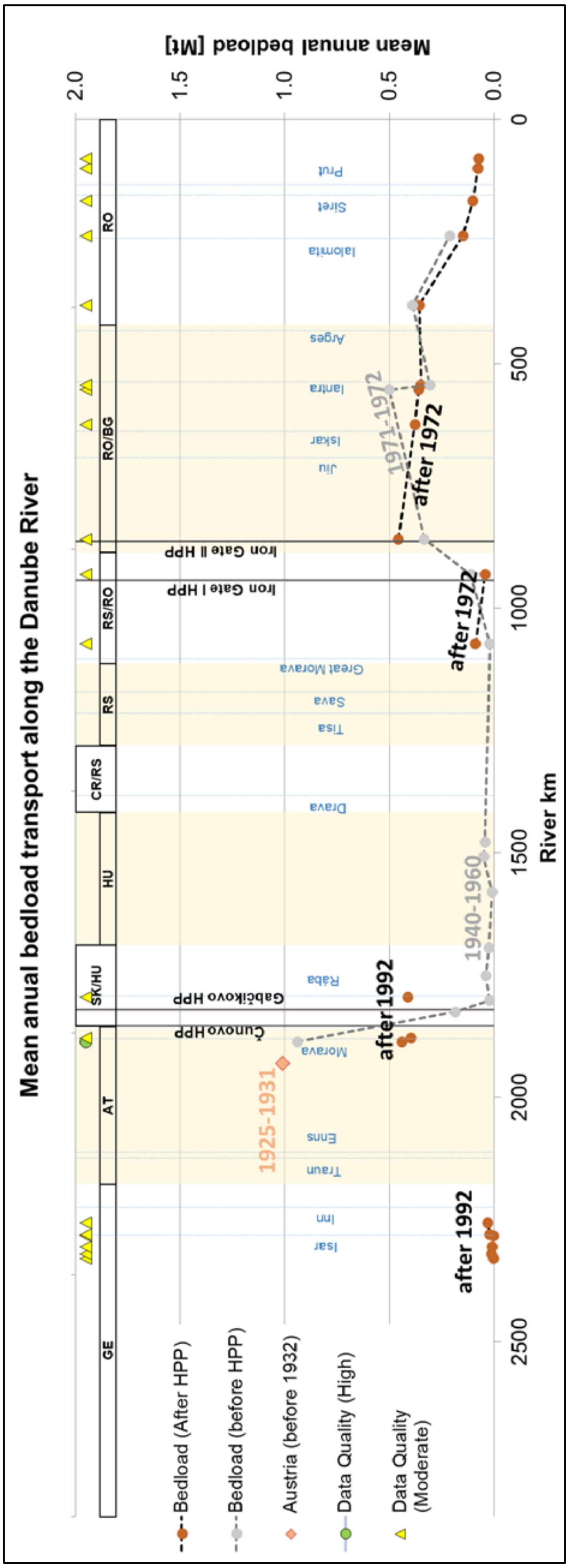


Figure 44 Longitudinal variation of mean annual bedload transport along the Danube River

The contribution of the bedload transport to the total sediment transport indicates a clear domination of the suspended sediment all along the Danube River (Figure 45). Comparing the values estimated from the dataset for the recent period with the ones found by Kresser and Lászlóffy (1964) the actual conditions for the Austrian part at Bad Deutsch-Altenburg shows values below 10% compared to the 18 - 19% reported by Kresser and Lászlóffy (1964). But it has to be mentioned that Kresser and Lászlóffy (1964) used a mean annual suspended sediment-load of 4.7 Mt/year, which is already influenced by hydropower constructions, as the mean annual load of 6.7 Mt/year for Linz for the years 1928-1937 is higher. Therefore, the value of 18 - 19% seems to be an overestimation in favour of the bedload. As to the Romanian reach, a typically sand bed section of the Danube River, a contribution of ~5% can be observed, with a decreasing tendency towards the Delta region. At this point it is important to refer to the difficulties in the bedload monitoring and the consequent uncertainty in the bedload transport data. This issue was thoroughly described in the report entitled “Sediment Monitoring in the Danube River” of this project. Also, recommendations were made towards the good practices in bedload measurements, moreover, novel, surrogate techniques have also been introduced, which can contribute to a cost-efficient and more accurate way to quantify bedload transport.

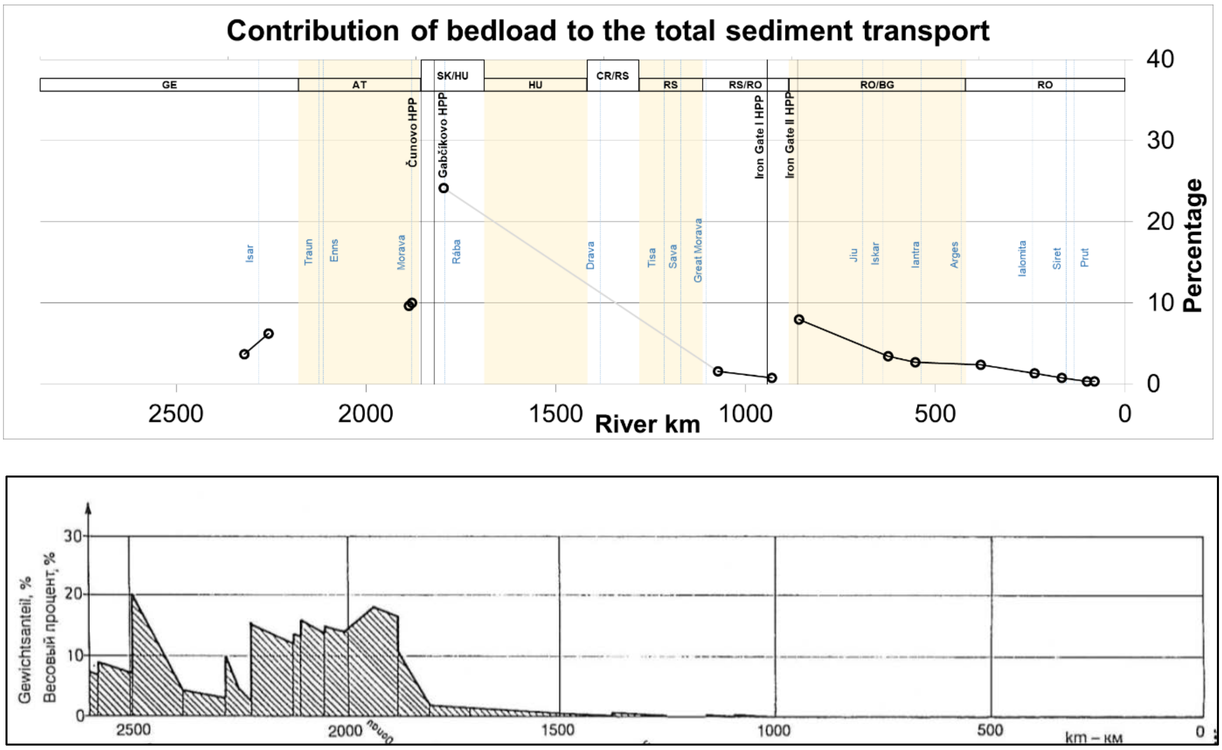


Figure 45 Contribution of the bedload transport to the total sediment load (top: after 1992, bottom: before 1960, source: Kresser and Lászlóffy, 1964)

4.4 Variation of sediment grain size along the Danube River

Based on the sediment data collected from the project partners, it was feasible to assess the longitudinal variation of the characteristic grain size in both the suspended sediment load and bedload transport. Grain size distribution (GSD) curves were provided for several monitoring stations along the Danube River, even for different flow regimes for a few locations both for SS and BL. A few characteristic GSD curves for the bedload are shown in Figure 46. In the Upper Danube, the dominating fraction is gravel ranging from 2-63 mm, with D_{50} values around 4-18 mm. As a comparison, Schmutterer (1961) reported a D_m (arithmetic average after Meyer-Peter) in Austria from 37 mm (rkm 2092-2093), 29 mm (2088-2089), 22 mm (rkm 2084) and 13 mm at Bad Deutsch-Altenburg (rkm 1885.9) for the year 1957, where the first three values stem from dredged gravel in the upstream part of the HPP Ybbs-Persenbeug and the last one from bedload measurements. An additional value of the transported bedload can be found in Gruber (1969) for the years 1962/1965 at Bad Deutsch-Altenburg with a D_m of 26 mm. Today the D_m in Bad Deutsch-Altenburg of the transported gravel has a size of around 22 mm. On the upper part of the Hungarian Danube reach, Bogárdi (1971) found the mean diameter varying between 10 and 15 mm, however, on the middle part around 0.4-0.5 mm and at the lowest part 0.3 mm only. The present situation in Hungary indicates well the transition from gravel to sand within the country. The Upper reach (at Vámosszabadi, rkm 1805.6) has a D_{50} around 15 mm, whereas at Dunaföldvár (rkm 1555.3) the sand fractions dominate with a D_{50} around 0.4 mm, still with a ~20% of gravel, and reaching the border the D_{50} at Béda (rkm 1434.5) is around 0.2 mm and the gravel fraction disappears. In the Serbian section, upstream of the confluence of the Great Morava River, the bedload consists of medium sand with a D_{50} of 0.3 mm and the same characteristics were found for the Romanian section, both representing the present situation.

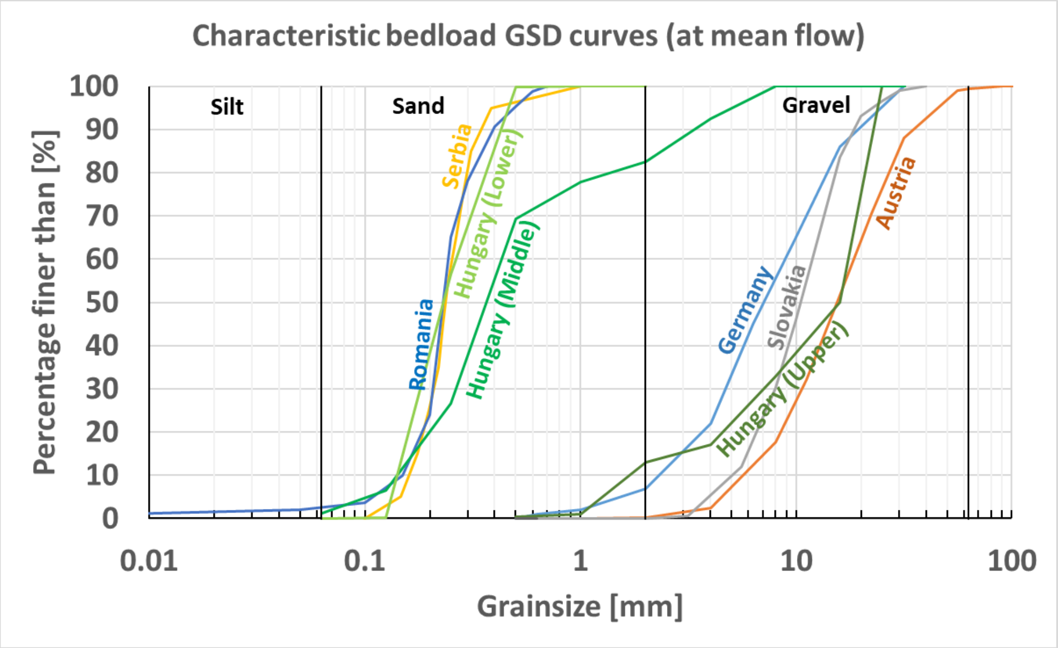


Figure 46 Typical grain size distribution curves of bedload along the Danubian countries

The same assessment of particle size distribution (PSD) curves was performed for the suspended sediment (Figure 47). Here, a slight refinement of the sediment composition can be observed towards downstream, indicating a D_{50} of 0.07 mm in Germany and 0.02 mm in Romania. The composition of the SS in the Austrian section of the river apparently differs from all the others. In fact, much finer particles are found in the water samples, showing a range of 0.0001-0.1 mm, mainly clay and silt fraction and no sand at all. The reason for the absence of sand is that this is a surface near sample taken directly upstream of a hydropower plant. The higher amount of the silt and clay fractions (with clay being more or less absent in the PSD of the other countries) might be due to different grain size analysis methods of the suspended sediment samples.

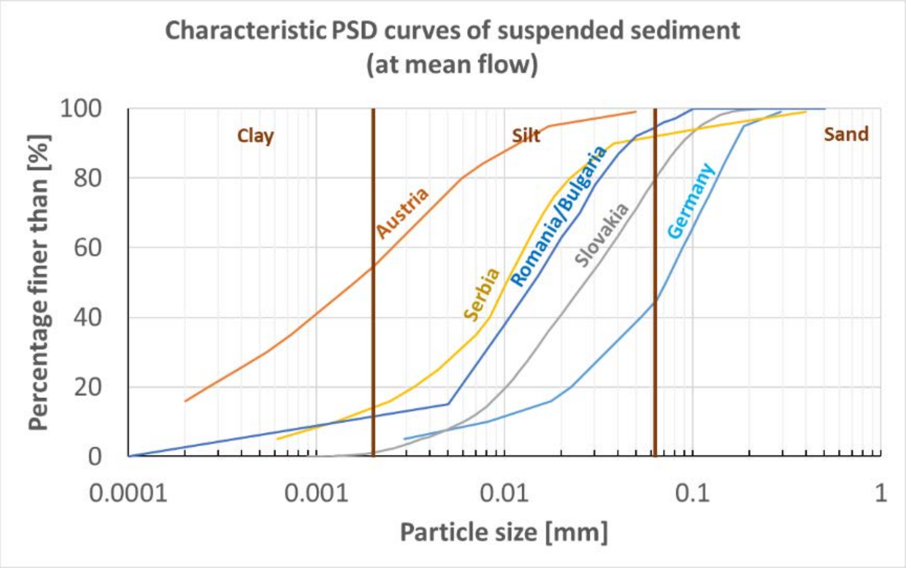


Figure 47 Typical particle size distribution curves of suspended sediment along the Danubian countries

An attempt was made to assess the longitudinal variation of the sediment composition in terms of characteristic grain sizes of D_{10}, D_{50} and D_{90} both for SS and BL for mean flow conditions (as most of the available data represented mean flow) (Figure 48). As already introduced, the typical grain sizes in the bedload transport along the Upper Danube are fine, medium and coarse gravel between 2-63 mm. Gravel fractions in the bedload transport can also be found in the Middle Danube at Dunaföldvár in Hungary (rkm 1555.3), which is actually a transition zone between the gravel and sand bed sections as well as between the confluences of the Sava and the Great Morava River, where the tributaries bring coarse material in the Danube. However, toward downstream there is a decrease of the composition, suddenly lowering to sand at the Iron Gate 1 reservoir, and from the Iron Gate 1 it continuously decreases towards the Delta region to fine sand. On the contrary, the composition of the suspended sediment is rather constant along the whole Danube River, ranging in the silt-fine sand fractions, with slight decrease of the particle sizes towards downstream. Local influences of the tributaries, coarsening of the suspended sediment, can be captured at the Morava River in the Upper Danube and at the Sava River in the Middle Danube. Also, as mentioned before, the suspended sediment in the Austrian section of the Danube seems to be finer, which might be due to the particle analyses method and the sampling location near the water surface.

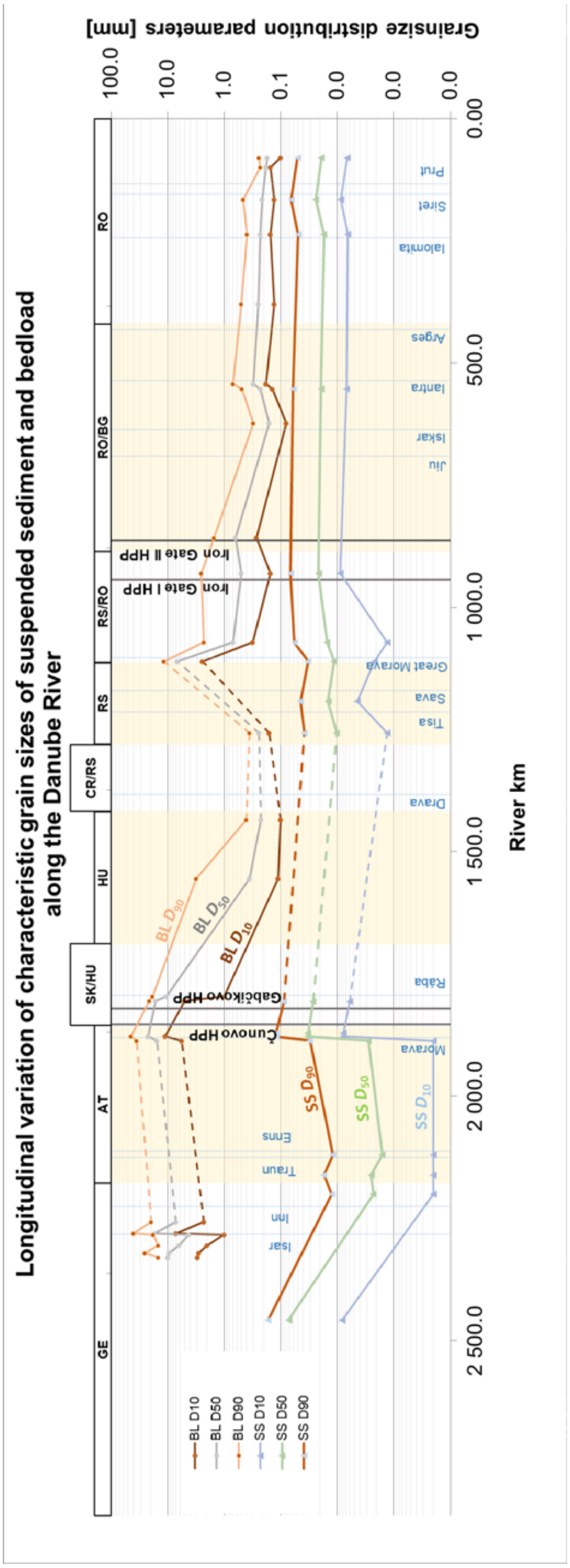


Figure 48 Longitudinal variation of characteristic grain sizes of bedload and suspended sediment

4.5 Conclusions of data analysis

A thorough dataset of the suspended sediment load and bedload transport could be established based on the information provided by the project partners. As to the suspended sediment, a reasonably large dataset covering a time period of 1956-2016 for most of the stations, in some cases even longer time series were given, moreover, for the significant flood events, daily or even finer datasets were provided. As to the bedload, on the other hand, much less information was available in form of bedload rating curves of mean yearly load values. For both sediment transport modes, information on the characteristic grain composition was also provided. The main conclusions of the data analysis are the followings:

- The long-term suspended sediment load along the German section down to the Inn River inflow is around 0.5 Mt/year, which, compared to the time period before 1956, means a decrease of ~50-70%.
- With a mean annual load of ~4.1 Mt/year (period 1986-2016) the Inn River brings a significant amount of sediment to the Danube River.
- In the Upper Danube, downstream of the Inn River inflow, historical sediment load data (starting in 1928) was available only for the station at Linz, where a decrease of ~43% was found from 1928-1937 compared to the actual conditions (1986-2016).
- Due to the construction of the HPPs, especially the HPP Aschach, the timing of the suspended sediment transport has changed due to sedimentation in dry periods and remobilisation during wet years. Furthermore, more sediment is transported in a much shorter time period during flood events.
- The Slovakian hydropower plants can be characterized with a sediment trapping efficiency of ~65% (mean annual SS load decreases from 3.5 Mt/year to 1.3 Mt/year between Bratislava and Medvedov).
- No significant longitudinal variation of the mean annual suspended sediment load along the Hungarian reach of the river can be observed in the present situation, however, compared to the historical data (before 1956) a decrease of ~70% took place. Furthermore, it has to be noted that at this section the measurement and the consequent estimation method of the long-term SS load shows high uncertainty.
- Along the Serbian reach, the tributaries Tisa, Sava and Great Morava have a significant contribution of 2-3 Mt/year for each river.
- The Iron Gate 1 reservoir has a sediment trapping efficiency of ~80%.
- Along the whole Romanian-Bulgarian and Romanian reaches, until the Danube Delta region, a significant decrease of the long-term suspended sediment load of ~70% can be observed compared to the historical conditions before the construction of the hydropower plants.

- The most significant tributaries along the Lower Danube River in terms of sediment inflow are Jiu River (3 Mt/year), Ialomita River (3.2 Mt/year) and Siret River (3.5 Mt/year).
- The transported suspended sediment during extreme flood events can have a contribution to the annual sediment load as high as ~85%.
- The mean annual bedload transport in both the reaches affected by the backwater of hydropower plants and the free flowing sections is low, below 0.1 Mt/year in the German section a well as upstream of the Iron Gate 1. No data is available from such Austrian sections of the Danube River.
- The mean annual bedload transport in free flowing sections ranges between 0.3-0.5 Mt/year, such as the reach east of Vienna, downstream of the Gabcikovo HPP, or downstream of the Iron Gate HPPs. For the Romanian section a continuous decrease towards the Delta region can be seen lowering from 0.5 Mt/year to 0.1 Mt/year.
- The composition of the bedload is gravel dominated along the Upper Danube and sand dominated at the Lower Danube. The transition zone in terms of bedload and bed material composition is in the Hungarian section of the river, however, a local coarsening of the bedload composition, indicating gravel fractions was found at the inlet of the Great Morava River in Serbia.
- The typical fractions in the suspended sediment are silt and fine sand, except along the Austrian section, where rather clay and silt dominate.

List of Abbreviations

ADCP	Acoustic Doppler Current Profiler
ADUVIZIG	Lower-Danube-Valley Water Directorate (Hungary)
ADV	Acoustic Doppler Velocimeter
AT	Austria
BAW	Federal Waterways Engineering and Research Institute (Germany)
BfG	Federal Institute of Hydrology (Germany)
BG	Bulgaria
BL	Bedload
BME	Budapest University of Technology and Economics
BOKU	University of Natural Resources and Life Sciences (Austria)
DE	Germany
DFRMP	Danube Flood Risk Management Plan
DHMZ	Hydrological and Meteorological Service (Croatia)
DRBMP	Danube River Basin Management Plan
DSMG	Danube Sediment Management Guidance
DTP	Danube Transnational Programme
ÉDUVIZIG	North-Transdanubian Water Directorate (Hungary)
ERDF	European Regional Development Fund
GKD	Bavarian Hydrological Service (Germany)
GSD	Grain Size Distribution
HD OOE	Hydrographic Service of Upper Austria (Austria)
HPP	Hydropower Plant
HR	Croatia
HU	Hungary
ICPDR	Internal Commission for the Protection of the Danube River
IMH	Institute of Meteorology and Hydrology (Romania)
IPA	Instrument for Pre-Accession Assistance
IWHW	Institute of Water Management, Hydrology and Hydraulic Engineering
JCI	Jaroslav Černi Water Institute
KDVVIZIG	Middle-Danube-Valley Water Directorate (Hungary)
LfU	Bavarian Environment Agency (Germany)
LISST	Laser In Situ Scattering and Transmissometry
NIHWM	National Institute of Hydrology and Water Management
NIMH-BAS	National Institute of Meteorology and Hydrology – Bulgarian Academy of Sciences (Bulgaria)
OBS	Optical Backscattering

OVF	General Water Directorate (Hungary)
PE	Public Enterprise (Serbia)
PSD	Particle Size Distribution
RO	Romania
RS	Serbia
SHMU	Slovak Hydrometeorological Institute (Slovakia)
SK	Slovakia
SS	Suspended Sediment
SSC	Suspended Sediment Concentration
VHP	Verbund Hydro Power GmbH (Austria)
VUVH	Water Research Institute (Slovakia)
WP3	Work Package 3
WSV	Federal Waterways and Shipping Administration (Germany)

List of Symbols

c_{MPM}	the Meyer-Peter and Müller Prefactor
d_i	Mean Diameter of the Sediment Fraction
d_{ref}	Reference Diameter
D_{xx}	Characteristic Grain Size (with xx denoting an integer between 1 and 99; d10 for instance denotes the grain size in mm at a percentage finer than 10%)
g	Gravitational Constant
P(x)	Probability (x denotes the monthly load)
p_i	Mass Fraction of Grain Size i
Q	Water Discharge
q_{si}	Fractional Bedload Transport (of the sediment fraction i)
R^2	Coefficient of Determination
S	Mean Slope
u*	Grain Related Shear Velocity
x	Monthly Load
y	Continuous Location Parameter
α	Hiding-exposure Exponent
$\Theta_{c,MPM}$	Critical Shields Parameter
μ, σ	Parameters of the Log-normal Distribution
ρ	Density of Water
ρ_s	Density of Sediment
τ	Bed Shear Stress

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Annexes

Annex 1: Summary tables

Summary table of suspended sediment data quantity provided for the monitoring stations in the Danube River

Country	River	Name of mon. site	Location (rkm)	Monthly data	Mean annual data	Flood data	Rating curve	PSD
Germany	Danube	Neu-Ulm Bad Held	2586.70	1986-2016	1931-1985	2002, 2006, 2013	SSC	NO
Germany	Danube	Donauwörth	2508.13	2015-2016	NO	NO	SSC	NO
Germany	Danube	Ingolstadt Luitpoldstrasse	2457.85	1986-2016	1931-1985	2002, 2006, 2013	SSC	PSD for different flow regimes
Germany	Danube	Straubing gauging station	2321.30	1986-2005, 2009-2016	1983-1985	2002, 2010, 2013	SSC	NO
Germany	Danube	Vilshofen	2249.50	1986-2016	1930-1985	2002, 2006, 2010, 2013	SSC	NO
Germany	Danube	Kachlet	2230.70	1986-2016	1975-1985	2002, 2006, 2010, 2013	SSC	NO
Germany	Danube	Jochenstein	2203.10	1986-2016	1975-1985	2002, 2006, 2010	SSC	NO
Austria	Danube	Engelhartszell	2200.66	1986-2016	1956-1985	2002, 2006, 2010, 2013	NO	PSD for different flow regimes
Austria	Danube	Aschach Strombauleitung	2161.27	1986-2016	1960-1985	2002, 2006, 2010, 2013	NO	PSD for different flow regimes
Austria	Danube	Linz	2135.17	1986-2016	1956-1985	2002, 2006, 2010, 2013	NO	NO
Austria	Danube	Donaukraftwerk Abwinden - Asten	2119.20	1986-2016	1970-1985	2002, 2006, 2010, 2013	NO	PSD for different flow regimes
Austria	Danube	Donaukraftwerk Wallsee - Mitterkirchen	2094.21	1986-2004, 2009-2016	1958-1967, 1970-1985	2002, 2010, 2013	NO	PSD for different flow regimes
Austria	Danube	Stein-Krems	2002.69	1991-2016	NO	2002, 2006, 2010, 2013	NO	PSD for different flow regimes
Austria	Danube	Bad Deutsch-Altenburg (Bauleitung) + Hainburg Straßenbrücke	1886.86	1986-2014	1956-1985	2002, 2006, 2010, 2013	NO	PSD for different flow regimes
Slovakia	Danube	Devín	1878.15	1986-2016	NO	NO	SSC	YES
Slovakia	Danube	Bratislava, Lafranconi Bridge	1871.30	1986-2016	1956-1985	2009, 2010, 2011, 2013	SSC	YES
Slovakia	Danube	Medveďov	1806.30	1993-2016	1979-1985	2002	SSC	YES
Hungary	Danube	Vamosszabadi	1805.60	1996-2016	NO	NO	NO	NO
Slovakia	Danube	Komárno Bridge	1767.80	1993-2016	NO	2006, 2009, 2010, 2011,	NO	NO

Country	River	Name of mon. site	Location (rkm)	Monthly data	Mean annual data	Flood data	Rating curve	PSD
						2013		
Hungary	Danube	Budapest	1646.50	1986-2013	1976-1985	2002	SSC	NO
Hungary	Danube	Dunaújváros	1580.60	1986-2015	1960-1985	2010	SSC	NO
Hungary	Danube	Dombori	1506.80	1986-2015	1968-1985	2010	SSC	NO
Hungary	Danube	Mohács	1446.90	1986-2015	1949-1985	1966, 2013	SSC	NO
Serbia	Danube	Novi Sad	1257.10	1986-2015	1974-1985	2006, 2013	SSL	PSD for different flow regimes
Serbia	Danube	Stari Banovci	1192.75	1987-2015	NO	2006	SSL	PSD for different flow regimes
Serbia	Danube	Smederevo	1110.40	1986-2015	1974-1985	2006	SSL	PSD for different flow regimes
Romania	Danube	Bazias	1072.50	1986-2014	1976-1985	2001, 2006, 2010, 2013	SSC	YES
Serbia	Danube	HPP Đerdap 1 dam	943.00	1986-2015	1974-1985	2006	SSL	NO
Serbia	Danube	Kladovo	932.90	1986-2015				NO
Romania	Danube	Drobeta Turnu Severin	931.00	1986-2014	1971-1985	2001, 2006, 2010, 2013	SSC	YES
Bulgaria	Danube	Lom	743.30	1989-2015	NO	2000, 2006, 2010, 2013	SSC	NO
Romania	Danube	Corabia	624.20	1986-2002, 2004-2014	1973-1985	2001, 2006, 2010, 2013	SSC	NO
Bulgaria	Danube	Svishtov	554.30	1989-207, 2011-2015	NO	2001, 2006, 2010, 2013	SSC	NO
Romania	Danube	Zimnicea	553.23	1986-2002, 2004-2014	1972-1985	2001, 2006, 2010, 2013	SSC	YES
Romania	Danube	Giurgiu	493.05	1986-2014	1966-1985	2001, 2006, 2010, 2013	SSC	NO
Romania	Danube	Chiciu Calarasi	379.58	1986-2002, 2004	1973-1985	2001	SSC	NO
Bulgaria	Danube	Silistra	375.50	1989-2015	NO	2002, 2006, 2010, 2013	SSC	NO
Romania	Danube	Vadu Oii	238.00	1986-2003, 2005-2010	1957-1985	2001, 2006, 2010	SSC	YES
Romania	Danube	Braila	167.00	1986-2013	1956-1985	2001, 2006, 2010, 2013	SSC	YES
Romania	Danube	Ceatal Izmail	80.50	1986-2014	1968-1985	2001, 2006, 2010, 2013	SSC	YES
Romania	Danube/ Branch Chilia	Periprava	20.00	1986-2015	1961-1985	2001, 2006, 2010, 2013	SSC	NO
Romania	Danube/ Sfantu Gheorghe	Sfantu Gheorghe Harbour	8.00	1986-1997, 1999-2015	1979-1985	2001, 2006, 2010, 2013	SSC	NO
Romania	Danube	Sulina	2.50	1986-2014	1979-1985	2001, 2006, 2010, 2013	SSC	NO

Summary table of suspended sediment data quantity provided for the most important tributaries

Country	River	Name of mon. site	Location (rkm)	Monthly data	Mean annual data	Flood data	Rating curve	PSD
Germany	Isar	Plattling	9.12	1986-2016	1965-1985	2002, 2006, 2013	SSC	NO
Germany	Inn	Passau Ingling	3.10	1986-2015	1969-1985	2002, 2006, 2013	SSC	NO
Austria	Inn	Schärding (Schreibpegel)	16.25	2008-2014	NO	2010, 2013	NO	PSD for different flow regimes
Austria	Traun	Wels-Lichtenegg	33.25	1986-1997, 1999, 2004-2014	1960-1961, 1965-1979, 1984-1985	2010, 2013	NO	PSD for different flow regimes
Austria	Enns	Steyr (Ortskai)	30.88	1986-2014	1984-1985	2002, 2006, 2010, 2013	NO	YES
Austria	Morava	Angern	31.89	1988-2016	1957-1961	NO	NO	NO
Slovakia	Morava	Záhorská Ves	32.52	1986-2016	1977-1985	1997, 2006, 2010	SSC	NO
Slovakia	Morava	Moravský Ján	67.15	1986-2016	NO	1997	SSC	NO
Hungary	Rába	Győr	14.50	1986-2015	NO	NO	SSC	NO
Croatia	Drava	Donji Miholjac	80.50	1986-2016	1968-1985	(1991, 1992, 1994, 1996 profil meas.)	SSC	NO
Serbia	Tisza	Titel	4.90	1986-2015	1974-1985	2006	SSL	PSD for different flow regimes
Serbia	Sava	Belgrade	5.20	1986-2015	1974-1985	2014	SSL	PSD for different flow regimes
Serbia	Velika Morava	Ljubičevski Bridge	21.83	1986-2015	1974-1985	2006	SSL	PSD for different flow regimes
Romania	Jiu	Zaval	8.00	1986-1992, 1994-2014	NO	NO	NO	YES
Bulgaria	Iskar	Oriahovitza	340.50	1961-2015	1961-2015	2002, 2006, 2010, 2013	SSC	YES
Bulgaria	Iantra	Karantzi	208.00	1964-2015	1964-2015	2002, 2006, 2010, 2013	SSC	YES
Romania	Arges	Budesti	2.00	1986-1988, 2006-2014	NO	NO	NO	NO
Romania	Ialomita	Tandarei	29.00	2005-2014	NO	NO	NO	NO
Romania	Siret	Lungoci	77.00	1986-2014	NO	NO	NO	NO
Romania	Prut	Oancea	79.20	1986-2014	NO	NO	NO	NO

Summary table of suspended sediment data quality provided for the monitoring stations in the Danube River

Country	River	Name of mon. site	Location (rkm)	Monitoring performed by	Time period	Applied method	Frequency	SSC analysis method
Germany	Danube	Neu-Ulm Bad Held	2586.70	Wasserwirtschaftsamt Donauwörth	1966-	Optical backscatter point sensor (2011-), calibrated by acoustic devices and physical sampling (bottle)	4 times per hour (1 time per year, 1 time per week)	Filtration
Germany	Danube	Donauwörth	2508.13	Wasserwirtschaftsamt Donauwörth	2014-	Optical backscatter point sensor (2011-), calibrated by acoustic devices and physical sampling (bottle)	4 times per hour (1 time per year, 1 time per week)	Filtration
Germany	Danube	Ingolstadt Luitpoldstrasse	2457.85	Wasserwirtschaftsamt Ingolstadt	1966-	Optical backscatter point sensor, calibrated by acoustic devices and physical sampling (bottle)	4 times per hour (1 time per year, 1 time per week)	Filtration
Germany	Danube	Straubing gauging station	2321.30	Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG), BAW	1982-	Physical sampling (bottle)	1 time per day	Filtration
Germany	Danube	Vilshofen	2249.50	Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG), BAW	1966-	Physical sampling (bottle)	1 time per day	Filtration
Germany	Danube	Kachlet	2230.70	Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG), BAW	1975-	Physical sampling (bottle)	1 time per day	Filtration
Germany	Danube	Jochenstein	2203.10	Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG), BAW	1974-	Physical sampling (bottle)	1 time per day	Filtration
Austria	Danube	Engelhartszell	2200.66	via donau - Österreichische Wasserstraßen-Gesellschaft mbH	1968-	Physical sampling (bottle)	Flow-dependent, from 3/w to 4/d	Filtration

Country	River	Name of mon. site	Location (rkm)	Monitoring performed by	Time period	Applied method	Frequency	SSC analysis method
Austria	Danube	Aschach Strombauleitung	2161.27	via donau - Österreichische Wasserstraßen-Gesellschaft mbH	1960-	Physical sampling (bottle), isokinetic sampling (point-integrating), optical backscatter point sensor (2011-), acoustic devices	OBS: 4 times per hour Physical sampling: Flow-dependent, from 1/2 weeks to 1+/d	Filtration
Austria	Danube	Linz	2135.17	via donau - Österreichische Wasserstraßen-Gesellschaft mbH	1961-	Physical sampling (bottle)	Flow-dependent, from 3/w to 4/d	Filtration
Austria	Danube	Donaukraftwerk Abwinden - Asten	2119.20	Verbund Hydro Power GmbH (VHP)	2000-	Pump sampling, automatized bottle sampling	Flow-dependent, from 3/w to 4/d	Filtration
Austria	Danube	Donaukraftwerk Wallsee - Mitterkirchen	2094.21	Verbund Hydro Power GmbH (VHP)	2000-	Pump sampling, automatized bottle sampling	Flow-dependent, from 3/w to 4/d	Filtration
Austria	Danube	Stein-Krems	2002.69	via donau - Österreichische Wasserstraßen-Gesellschaft mbH	1991-	Physical sampling (bottle)	Flow-dependent, from 1/every 3 days to 4/d	Filtration
Austria	Danube	Bad Deutsch-Altenburg (Bauleitung)	1886.86	via donau - Österreichische Wasserstraßen-Gesellschaft mbH	1956-	Physical sampling (bottle)	Flow-dependent, from 1/every 3 days to 4/d	Filtration
Austria	Danube	Hainburg Straßenbrücke	1886.24	via donau - Österreichische Wasserstraßen-Gesellschaft mbH; BOKU	2008-	Physical sampling (bottle), isokinetic sampling (point-integrating), optical backscatter point sensor, acoustic devices	OBS: 4 times per hour Physical sampling: Flow-dependent, from ½ weeks to 1+/d	Filtration
Slovakia	Danube	Devín	1878.15	Water Research Institute (VUVH Bratislava)	1986-2016	Isokinetic sampling (depth-integrating, point-integrating)	19 whole profile measurements	Filtration
Slovakia	Danube	Bratislava, Lafranconi Bridge	1871.30	Water Research Institute (VUVH Bratislava)	1986-2016	Isokinetic sampling (depth-integrating)	Flow-dependent, from 3/w to 1+/d	Filtration
Slovakia	Danube	Medveďov (VUVH)	1806.30	Water Research Institute (VUVH Bratislava)	2000-2002	Isokinetic sampling (depth-integrating)	n/a	Filtration
Hungary	Danube	Vámosszabadi	1805.60	North-Transdanubian Water Directorate (ÉDUVIZIG)	1988-	Physical sampling (bottle), pump sampling	5 times per year	Evaporation
Slovakia	Danube	Komárno Bridge	1767.80	Slovak Hydrometeorological Institute (SHMU)	1992-2016	Physical sampling (bottle)	Flow-dependent, from 1/d to 1+/d	Filtration

Country	River	Name of mon. site	Location (rkm)	Monitoring performed by	Time period	Applied method	Frequency	SSC analysis method
Hungary	Danube	Nagymaros	1694.60	Middle-Danube-Valley Water Directorate (KDVVIZIG)	1951-	Pump sampling	5 times per year	Evaporation
Hungary	Danube	Budapest	1646.50	Middle-Danube-Valley Water Directorate (KDVVIZIG)	1969-	Pump sampling	5 times per year	Evaporation
Hungary	Danube	Dunaújváros	1580.60	Lower-Danube-Valley Water Directorate (ADUVIZIG)	1950-	Pump sampling	5 times per year	Evaporation
Hungary	Danube	Dombori	1506.80	Lower-Danube-Valley Water Directorate (ADUVIZIG)	1968-	Pump sampling	5 times per year	Evaporation
Hungary	Danube	Mohács	1446.90	Lower-Danube-Valley Water Directorate (ADUVIZIG)	1949-	Pump sampling	5 times per year	Evaporation
Serbia	Danube	Novi Sad	1257.10	Jaroslav Černi Institute for the Development of Water Resources (JCI)	1986-	Physical sampling (bottle)	1 time per day	Evaporation
Serbia	Danube	Stari Banovci	1192.75	Jaroslav Černi Institute for the Development of Water Resources (JCI)	1986-	Physical sampling (bottle)	1 time per day	Evaporation
Serbia	Danube	Smederevo	1110.40	Jaroslav Černi Institute for the Development of Water Resources (JCI)	1986-	Physical sampling (bottle)	1 time per day	Evaporation
Romania	Danube	Bazias	1072.50	National Administration "Apele Romane"/Jiu River Basin Administration	1971-	Physical sampling (bottle)	2 times per day, expeditionary measurements 4-6 times per year	Turbidity meter
Serbia	Danube	HPP Đerdap 1 dam	943.00	Jaroslav Černi Institute for the Development of Water Resources (JCI)	1974-	Physical sampling (bottle)	1 time per day	Evaporation
Serbia	Danube	Kladovo	932.90	Jaroslav Černi Institute for the Development of Water Resources (JCI)	1974-	Physical sampling (bottle)	1 time per day	Evaporation
Romania	Danube	Drobeta Turnu Severin	931.00	National Administration "Apele Romane"/Jiu River Basin Administration	1980-	Physical sampling (bottle)	2 times per day, expeditionary measure-ments 4-6 times per y.	Turbidity meter
Bulgaria	Danube	Lom	743.30	National Institute of Meteorology and Hydrology - Bulgarian Academy of Sciences (NIMH-BAS)	2017	Physical sampling (bottle)	1 time per day	Filtration
Romania	Danube	Corabia	624.20	National Administration "Apele Romane"/Arges River Basin Administration	1979-	Physical sampling (bottle)	2 times per day, expeditionary measurements 4-6 times per year	Turbidity meter

Country	River	Name of mon. site	Location (rkm)	Monitoring performed by	Time period	Applied method	Frequency	SSC analysis method
Bulgaria	Danube	Svishtov	554.30	National Institute of Meteorology and Hydrology - Bulgarian Academy of Sciences (NIMH-BAS)	1989-	Physical sampling (bottle)	1 time per day	Filtration
Romania	Danube	Zimnicea	553.23	National Administration "Apele Romane"/Arges River Basin Administration	1931-	Physical sampling (bottle)	2 times per day, expeditionary measurements 4-6 times per year	Turbidity meter
Romania	Danube	Giurgiu	493.05	National Administration "Apele Romane"/Arges River Basin Administration	1931-	Physical sampling (bottle)	2 times per day, expeditionary measurements 4-6 times per year	Turbidity meter
Romania	Danube	Chiciu Calarasi	379.58	National Administration "Apele Romane"/Dobrogea-Litoral River Basin Administration	1931-	Physical sampling (bottle)	2 times per day, expeditionary measurements 4-6 times per year	
Bulgaria	Danube	Silistra	375.50	National Institute of Meteorology and Hydrology - Bulgarian Academy of Sciences (NIMH-BAS)	1989-	Physical sampling (bottle)	1 time per day	Filtration
Romania	Danube	Vadu Oii	238.00	National Administration "Apele Romane"/Dobrogea-Litoral River Basin Administration	1931-	Physical sampling (bottle)	2 times per day, expeditionary measurements 4-6 times per year	
Romania	Danube	Braila	167.00	National Administration "Apele Romane"/Dobrogea-Litoral River Basin Administration	1931-	Physical sampling (bottle)	2 times per day, expeditionary measurements 4-6 times per year	Turbidity meter
Romania	Danube	Ceatal Izmail	80.50	National Administration "Apele Romane"/Dobrogea-Litoral River Basin Administration	1931-	Physical sampling (bottle)	2 times per day, expeditionary measurements 4-6 times per year	
Romania	Danube/ Branch Chilia	Periprava	20.00		1961-			
Romania	Danube/ Sfantu Gheorghe	Sfantu Gheorghe Harbour	8.00		1979-			
Romania	Danube	Sulina	2.50		1979-			

Summary table of bedload data quantity provided for the monitoring stations in the most important tributaries

Country	River	Name of mon. site	Location (rkm)	Annual BL data 1986-2016	Historical annual data 1956-1985	Flood data	Rating curve	GSD
Germany	Danube	Straubing 1	2 329.30	NO	NO	NO	YES	2
Germany	Danube	Straubing 2	2 321.0	NO	NO	NO	YES	2
Germany	Danube	Pfelling	2 305.50	NO	NO	NO	YES	several
Germany	Danube	Deggendorf	2 283.20	NO	NO	NO	YES	several
Germany	Danube	Halbmeile	2 280.0	NO	NO	NO	YES	several
Germany	Danube	Hofkirchen	2 256.90	NO	NO	NO	YES	several
Austria	Danube	Vienna	1 930.80	NO	1910-1932	NO	YES	YES
Austria	Danube	Bad Deutsch-Altenburg	1 885.90	NO	1951-1957	NO	YES	YES
Austria	Danube	Hainburg Straßenbrücke	1 886.24	2005-	1951-1957	NO	YES	GSD
Slovakia	Danube	Devín	1 878.15	1991-2016	NO	NO	YES	YES
Slovakia	Danube	Klizska Nema	1 795.58	1992-2016	NO	NO	YES	YES
Slovakia	Morava	Moravský Ján	67.15	1990-2016	NO	NO	YES	YES
Hungary	Danube	Vámosszabadi	1 805.60	NO	NO	NO	YES	YES
Romania	Danube	Bazias	1 072.50	NO	1971-1984	NO	YES	NO
Romania	Danube	Corabia	624.20	1992-	NO	NO	YES	NO
Romania	Danube	Zimnicea	553.23	1985-1996, 2007-2008, 2010-2012, 2014-	1972-1985	NO	YES	NO
Romania	Danube	Giurgiu	493.05	1986-	1970-1985	NO	YES	NO
Romania	Danube	Chiciu Calarasi	379.58	1986-	1980-1985	NO	YES	NO
Romania	Danube	Vadu Oii	238.0	1986-	1970-1985	NO	YES	NO
Romania	Danube	Braila	167.0	1986-	1971-1985	NO	YES	NO
Romania	Danube	Ceatal Izmail	80.50	1986-	1969-1985	NO	YES	NO

Summary table of suspended sediment data quality provided for the monitoring stations in the most important tributaries

Country	River	Name of mon. site	Location (rkm)	Monitoring performed by	Time period	Applied method	Frequency	SSC analysis method
Germany	Isar	Plattling	9.12	Wasserwirtschaftsamt Deggendorf	1966-	Optical backscatter point sensor (2011-), calibrated by acoustic devices and physical sampling (bottle)	4 times per hour (1 time per year, 1 time per week)	Filtration
Germany	Inn	Passau Ingling	3.10	Wasserwirtschaftsamt Deggendorf	1970-	Optical backscatter point sensor (2011-), calibrated by acoustic devices and physical sampling (bottle)	4 times per hour (1 time per year, 1 time per week)	Filtration
Austria	Inn	Schärding (Schreibpegel)	16.25	Hydrographic service of Upper Austria	2008-	Physical sampling (bottle), isokinetic sampling (point-integrating), optical backscatter point sensor, acoustic devices	OBS: 4 times per hours Physical sampling: Flow-dependent, from 1/w to 1+/d	Filtration
Austria	Traun	Wels-Lichtenegg	33.25	Hydrographic service of Upper Austria	1950-	Physical sampling (bottle), isokinetic sampling (point-integrating), optical backscatter point sensor (2008-), acoustic devices	OBS: 4 times per hours Physical sampling: Flow-dependent, from 1/w to 1+/d	Filtration
Austria	Enns	Steyr (Ortskai)	30.88	Hydrographic service of Upper Austria	1984-	Physical sampling (bottle), isokinetic sampling (point-integrating), optical backscatter point sensor (2008-), acoustic devices	OBS: 4 times per hours Physical sampling: Flow-dependent, from 1/w to 1+/d	Filtration
Austria	Morava	Angern	31.89	via donau - Österreichische Wasserstraßen-Gesellschaft mbH	1998-	Physical sampling (bottle)	Flow-dependent, from 1/every 3 days to 4/d	Filtration
Slovakia	Morava	Záhorská Ves	32.52	Water Research Institute (VUVH)	1993-1997	Physical sampling (bottle), isokinetic sampling (depth-integrating)	Flow-dependent, cca. 2 times per week	Filtration
Slovakia	Morava	Moravský Ján	67.15	Water Research Institute (VUVH)	1993-1997	Physical sampling (bottle), isokinetic sampling (depth-integrating)	n/a	Filtration
Hungary	Rába	Győr	14.50	North-Transdanubian Water Directorate (ÉDUVIZIG)	1988-	Physical sampling (bottle), isokinetic sampling (depth-integrating)	n/a	Filtration
Croatia	Drava	Donji Miholjac	80.50	Meteorological and Hydrological Institute of Croatia (DHMZ)	1993-	Physical sampling (bottle), pump sampling, acoustic devices	1 time per day, plus cross-sectional measurements 6 times per year	Filtration

Serbia	Tisza	Titel	4.90	Jaroslav Černi Institute for the Development of Water Resources (JCI)	1986-	Physical sampling (bottle)	1 time per day	Evaporation
Serbia	Sava	Belgrade	5.20	Jaroslav Černi Institute for the Development of Water Resources (JCI)	1986-	Physical sampling (bottle)	1 time per day	Evaporation
Serbia	Velika Morava	Ljubičevski Bridge	21.83	Jaroslav Černi Institute for the Development of Water Resources (JCI)	1986-	Physical sampling (bottle)	1 time per day	Evaporation
Romania	Jiu	Zaval	8.00	National Administration "Apele Romane"/Jiu River Basin Administration	1963-	Physical sampling (bottle)	2 times per day, expeditionary measurements 4-6 times per year	Filtration
Bulgaria	Iskar	Oriahovitza	340.50	National Institute of Meteorology and Hydrology - Bulgarian Academy of Sciences (NIMH-BAS)	1961-	Physical sampling (bottle)	Flow-dependent, average: 14/y	Filtration
Bulgaria	Iantra	Karantzi	208.00	National Institute of Meteorology and Hydrology - Bulgarian Academy of Sciences (NIMH-BAS)	1964-	Physical sampling (bottle)	Flow-dependent, average: 60/y	Filtration
Romania	Arges	Budesti	2.00	National Administration "Apele Romane"/Arges River Basin Administration	1955-	Physical sampling (bottle)	2 times per day, expeditionary measurements 4-6 times per year	Filtration
Romania	Ialomita	Tandarei	29.00	National Administration "Apele Romane"/Ialomita-Buzau River Basin Administration	1977-	Physical sampling (bottle)	2 times per day, expeditionary measurements 4-6 times per year	Filtration
Romania	Siret	Lungoci	77.00	National Administration "Apele Romane"/Siret River Basin Administration	1956-	Physical sampling (bottle)	2 times per day, expeditionary measurements 4-6 times per year	Filtration
Romania	Prut	Oancea	79.20	National Administration "Apele Romane"/Prut River Basin Administration	1958-	Physical sampling (bottle)	2 times per day, expeditionary measurements 4-6 times per year	Filtration

Summary table of bedload data quality provided for the monitoring stations in the most important tributaries

Country	River	Name of mon. site	Location (rkm)	Data owner	Monitoring performed by	Time period	Applied method	Frequency	GSD analysis method
Germany	Danube	Straubing 1	2329.30	Federal Waterways and Shipping Administration (WSV)	Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG), BAW	2010-2012	BfG-sampler	3 sampling campaigns	Dry sieving
Germany	Danube	Straubing 2	2321.00	Federal Waterways and Shipping Administration (WSV)	Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG), BAW	2010-2012	BfG-sampler	3 sampling campaigns	Dry sieving
Germany	Danube	Pfelling	2305.50	Federal Waterways and Shipping Administration (WSV)	Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG), BAW	1970-2012	BfG-sampler	16 sampling campaigns	Dry sieving
Germany	Danube	Deggendorf	2283.20	Federal Waterways and Shipping Administration (WSV)	Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG), BAW	2008-2012	BfG-sampler	9 sampling campaigns	Dry sieving
Germany	Danube	Halbmeile	2280.00	Federal Waterways and Shipping Administration (WSV)	Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG), BAW	2008-2012	BfG-sampler	9 sampling campaigns	Dry sieving
Germany	Danube	Hofkirchen	2256.90	Federal Waterways and Shipping Administration (WSV)	Federal Waterways and Shipping Administration (WSV), Federal Institute of Hydrology (BfG), BAW	1970-2012	BfG-sampler	1 time per day, 17 sampling campaigns	Dry sieving
Austria	Danube	Vienna	1930.80	Staatliche Versuchsanstalt für Wasserbau	Staatliche Versuchsanstalt für Wasserbau	1910, 1921, 1925-1931	Ehernberger sampler	4 measurements 1930/1931	Dry sieving

Country	**River**	**Name of mon. site**	**Location (rkm)**	**Data owner**	**Monitoring performed by**	**Time period**	**Applied method**	**Frequency**	**GSD analysis method**
Austria	Danbue	Bad Deutsch-Altenburg	1885.90	Via donau - Östereichische Wasserstraßen-Gesellschaft mbH	Bundesstrombauamt (predecessor of the viadonau)	1951-1957	Ehrenberger sampler	1 campaign with several measurements 1956/1957	Dry sieving
Austria	Danube	Hainburg Straßen-brücke	1886.24	via donau - Österreichische Wasserstraßen-Gesellschaft mbH; BOKU	via donau - Österreichische Wasserstraßen-Gesellschaft mbH; BOKU	2005-2015	BfG-sampler	ca. 3 times per year	Dry sieving
Slovakia	Morava	Moravský Ján	67.15	Water Research Institute (VUVH)	Water Research Institute (VUVH)	1990-2016	Helley-Smith sampler	campaigns	Dry sieving
Slovakia	Danube	Devín	1878.15	Water Research Institute (VUVH Bratislava)	Water Research Institute (VUVH Bratislava)	1991-2016	Helley-Smith, Novak sampler, Swiss type sampler	46 full-profile measurement campaigns	Dry sieving
Hungary	Danube	Vámosszabadi	1805.60	North-Transdanubian Water Directorate (ÉDUVIZIG)	North-Transdanubian Water Directorate (ÉDUVIZIG)	1998-2014	Károlyi-sampler	5 times per year	Dry sieving
Slovakia	Danube	Klizska Nema	1795.58	Water Research Institute (VUVH Bratislava)	Water Research Institute (VUVH Bratislava)	1992-2016	Swiss type sampler	54 full-profile measurement campaigns	Dry sieving
Romania	Danube	Bazias	1072.50	National Administration "Apele Romane"/National Institute of Hydrology and Water Management	National Administration "Apele Romane"/Jiu River Basin Administration	1971-1984	IMH bedload equipment	4 times per year	Dry sieving
Romania	Danube	Corabia	624.20	National Administration "Apele Romane"/National Institute of Hydrology and Water Management	National Administration "Apele Romane"/Arges River Basin Administration	1992-	IMH bedload equipment	Flow-dependent freq., ca. 4 times per year	Dry sieving
Romania	Danube	Zimnicea	553.23	National Administration "Apele Romane"/National Institute of Hydrology and Water Management	National Administration "Apele Romane"/Arges River Basin Administration	1985-1996, 2007-2008, 2010-2012, 2014-	IMH bedload equipment	Flow-dependent freq., ca. 4 times per year	Dry sieving

Country	River	Name of mon. site	Location (rkm)	Data owner	Monitoring performed by	Time period	Applied method	Frequency	GSD analysis method
Romania	Danube	Giurgiu	493.05	National Administration "Apele Romane"/National Institute of Hydrology and Water Management	National Administration "Apele Romane"/Arges River Basin Administration	1970-	IMH bedload equipment	Flow-dependent freq., ca. 4 times per year	Dry sieving
Romania	Danube	Chiciu Calarasi	379.58	National Administration "Apele Romane"/National Institute of Hydrology and Water Management	National Administration "Apele Romane"/Dobrogea-Litoral River Basin Administration	1980-	IMH bedload equipment	Flow-dependent freq., ca. 4 times per year	Dry sieving
Romania	Danube	Vadu Oii	238.00	National Administration "Apele Romane"/National Institute of Hydrology and Water Management	National Administration "Apele Romane"/Dobrogea-Litoral River Basin Administration	1970-	IMH bedload equipment	Flow-dependent freq., ca. 4 times per year	Dry sieving
Romania	Danube	Braila	167.00	National Administration "Apele Romane"/National Institute of Hydrology and Water Management	National Administration "Apele Romane"/Dobrogea-Litoral River Basin Administration	1971-	IMH bedload equipment	Flow-dependent freq., ca. 4 times per year	Dry sieving
Romania	Danube	Ceatal Izmail	80.50	National Administration "Apele Romane"/National Institute of Hydrology and Water Management	National Administration "Apele Romane"/Dobrogea-Litoral River Basin Administration	1969-	IMH bedload equipment	Flow-dependent freq., ca. 4 times per year	Dry sieving

Annex 2: Summary tables of sediment data

Mean annual suspended sediment load (1986-2016)

Country	River	Monitoring station	River km	River km [Danube]	mean annual suspended sediment load (Mt/a)	Covered time period
Germany	Danube	Neu-Ulm Bad Held	2 586.70	2 586.70	0.182	1986-2016
Germany	Danube	Donauwörth	2 508.13	2 508.13	0.278	2015-2016
Germany	Danube	Ingolstadt Luitpoldstrasse	2 457.85	2 457.85	0.472	1986-2016
Germany	Danube	Straubing gauging station	2 321.30	2 321.30	0.287	1986-2015
Germany	Isar	Plattling	9.12	2 281.71	0.186	1986-2016
Germany	Danube	Vilshofen	2 249.50	2 249.50	0.446	1986-2015
Germany	Danube	Kachlet	2 230.70	2 230.70	0.429	1986-2015
Germany	Inn	Passau Ingling	3.10	2 225.20	4.130	1986-2015
Austria	Inn	Schärding (Schreibpegel)	16.25	2 225.20	5.045	2008-2014
Germany	Danube	Jochenstein	2 203.10	2 203.10	2.928	1986-2010
Austria	Danube	Engelhartszell	2 200.66	2 200.66	3.783	1986-2016
Austria	Danube	Aschach Strombauleitung	2 161.27	2 161.27	4.831	1986-2016
Austria	Danube	Linz	2 135.17	2 135.17	3.811	1986-2016
Austria	Traun	Wels-Lichtenegg	33.25	2 124.73	0.083	1986-2014
Austria	Danube	Donaukraftwerk Abwinden - Asten	2 119.20	2 119.20	4.346	1986-2016
Austria	Enns	Steyr (Ortskai)	30.88	2 111.83	0.305	1986-2014
Austria	Danube	KW Wallsee-Mitterkirchen	2 094.21	2 094.21	4.835	1986-2016
Austria	Danube	Stein-Krems	2 002.69	2 002.69	4.974	1991-2016
Austria	Danube	Bad Deutsch Altenburg - Hainburg	1 886.00	1 886.00	4.100	1986-2014
Austria	Morava	Angern	31.89	1 880.26	0.180	1988-2016
Slovakia	Morava	Záhorská Ves	32.52	1 880.26	0.119	1986-2016
Slovakia	Morava	Moravský Ján	67.15	1 880.26	0.259	1986-2016
Slovakia	Danube	Devín	1 878.15	1 878.15	3.557	1986-2016
Slovakia	Danube	Bratislava	1 868.75	1 868.75	3.476	1986-2016
Slovakia	Danube	Medveďov Bridge	1 806.30	1 806.30	1.291	1993-2016
Hungary	Rába	Győr	14.0	1 793.00	0.050	1986-2016
Slovakia	Danube	Komárno Bridge	1 767.80	1 767.80	1.679	1993-2016

Country	River	Monitoring station	River km	River km [Danube]	mean annual suspended sediment load (Mt/a)	Covered time period
Hungary	Danube	Nagymaros	1 694.60	1 694.60	1.446	1986-2015
Hungary	Danube	Budapest	1 646.50	1 646.50	1.247	1986-2012
Hungary	Danube	Dunaújváros	1 580.60	1 580.60	1.712	1986-2015
Hungary	Danube	Dombori	1 506.80	1 506.80	1.528	1986-2015
Hungary	Danube	Mohács	1 446.90	1 446.90	1.630	1986-2015
Croatia	Drava	Donji Miholjac	80.50	1 382.50	0.272	1986-2016
Serbia	Danube	Novi Sad	1 257.10	1 257.10	5.985	1986-2015
Serbia	Tisa	Titel	4.90	1 214.50	2.637	1986-2015
Serbia	Danube	Stari Banovci	1 192.75	1 192.75	7.286	1987-2015
Serbia	Sava	Belgrade	5.20	1 170.00	2.911	1986-2015
Serbia	Danube	Smederevo	1 110.40	1 110.40	11.539	1986-2015
Serbia	Great Morava	Ljubičevski Bridge	21.83	1 103.00	2.163	1986-2015
Serbia	Danube	HPP Đerdap 1 dam	943.00	943.00	2.532	1986-2015
Serbia	Danube	Kladovo	932.90	932.90	2.672	1986-2015
Romania	Jiu	Zaval	323.0	691.55	3.020	1986-2014
Bulgaria	Iskar	Oriahovitza	340.50	637.00	0.484	1986-2015
Romania	Danube	Corabia	624.20	624.20	10.613	1986-2014
Romania	Danube	Zimnicea	553.23	553.23	12.994	1986-2014
Bulgaria	Yantra	Karantzi	208.0	536.70	0.879	1986-2015
Romania	Danube	Giurgiu	493.05	493.05	12.558	1986-2014
Romania	Arges	Budești	297.0	432.00	0.259	1986-88, 2006-2014
Romania	Danube	Chiciu Calarasi	379.58	379.58	14.608	1986-2004
Romania	Ialomita	Tandarei	417.0	244.00	3.200	2005-2014
Romania	Danube	Vadu Oii	238.00	238.00	10.722	1986-2009
Romania	Danube	Braila	167.00	167.00	12.641	1986-2013
Romania	Siret	Lungoci	610.0	155.05	3.528	1986-2014
Romania	Prut	Oancea	805.0	134.14	0.525	1986-2014
Romania	Danube	Isaccea	100.20	100.20	21.458	1986-2014
Romania	Danube	Ceatal Izmail	80.50	80.50	19.664	1986-2014
Romania	Danube/Branch Chilia	Periprava	20.00	20.00	8.997	1986-2015
Romania	Danube/Sfantu Gheorghe branch	Sfantul Gheorghe Harbour	8.00	8.00	3.517	1986-2015
Romania	Danube	Sulina	2.50	2.50	2.514	1986-2014

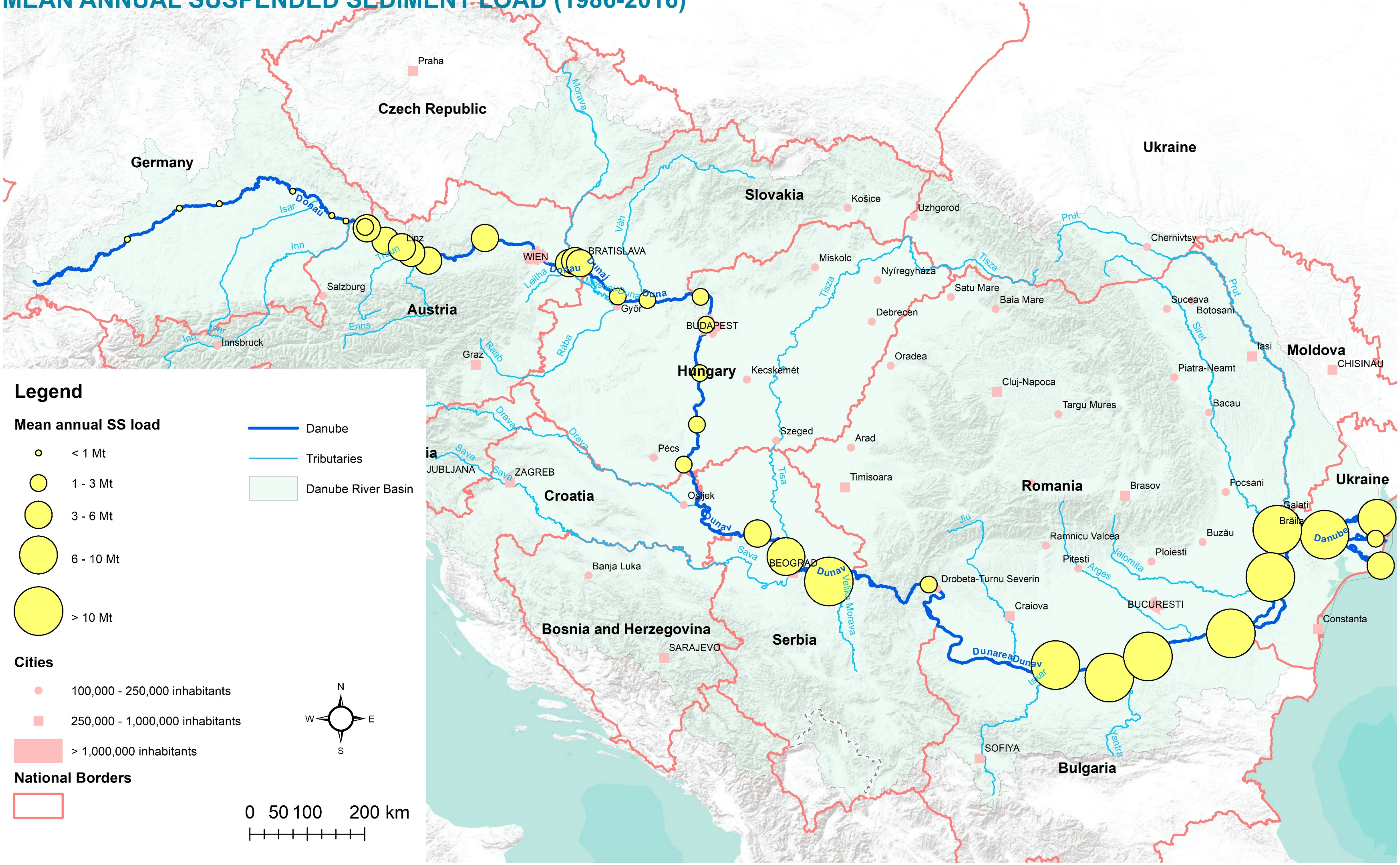
Mean annual suspended sediment load before 1986

Country	**River**	**Monitoring station**	**River km**	**mean annual suspended sediment load (Mt/a) in the past**	**comments to data before 1985**
Germany	Danube	Neu-Ulm Bad Held	2 586.70	0.25	1931-1956
Germany	Danube	Ingolstadt Luitpoldstrasse	2 457.85	0.99	1931-1956
Germany	Danube	Vilshofen	2 249.50	1.48	1931-1956
Austria	Danube	Linz	2135.17	6.7	1928-1937 as the operation of HPP in the Inn River started in the late 1930ies
Hungary	Danube	Budapest	1 646.50	*4.50*	data available from 1976
Hungary	Danube	Dunaújváros	1 580.60	*3.66*	data available from 1960
Hungary	Danube	Dombori	1 506.80	*2.77*	data available from 1968
Hungary	Danube	Mohács	1 446.90	*3.30*	1956-1985
Serbia	Danube	Novi Sad	1 257.10	*6.92*	data available from 1974
Serbia	Danube	Smederevo	1 110.40	*17.08*	data available from 1974
Romania	Danube	Drobeta Turnu Severin	931.00	*30.37*	1931-1972 as the operation of Iron Gate 1 HPP started in 1973
Romania	Danube	Zimnicea	553.23	*41.31*	1931-1972 as the operation of Iron Gate 1 HPP started in 1973
Romania	Danube	Giurgiu	493.05	*45.08*	1931-1972 as the operation of Iron Gate 1 HPP started in 1973
Romania	Danube	Vadu Oii	238.00	*48.17*	1931-1972 as the operation of Iron Gate 1 HPP started in 1973
Romania	Danube	Braila	167.00	*50.80*	1931-1972 as the operation of Iron Gate 1 HPP started in 1973
Romania	Danube	Ceatal Izmail	80.50	*62.76*	1931-1972 as the operation of Iron Gate 1 HPP started in 1973
Romania	Danube/Branch Chilia	Periprava	2.50	*41.474*	estimated based on Periprava data and current ratio between Periprava and SS_total in DanubeDelta
Romania	Danube/Branch Chilia	Periprava	20.00	*24.885*	1956-1972 as the operation of Iron Gate 1 HPP started in 1973 (see the comment in the cell above)

Annex 3: Map of mean annual suspended sediment load in the Danube

Suspended sediment monitoring stations along the Danube

MEAN ANNUAL SUSPENDED SEDIMENT LOAD (1986-2016)



http://www.interreg-danube.eu/approved-projects/danubesediment

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Danube Transnational Programme
DanubeSediment