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Danube Transnational Programme
DanubeSediment

Interactions of Key Drivers and Pressures on the Morphodynamics of the Danube

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with contributions by the project partners

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Project Introduction

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.

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

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.
A detailed list of all project activities and deliverables is available on our project website: www.interreg-danube.eu/approved-projects/danubesediment/outputs.

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

Interactions of Key Drivers and Pressures on the Morphodynamics of the Danube

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1.1 General overview on key drivers issue

1.1.1 Setting the scene: alteration of the sediment regime in the Danube River Basin

In the Danube Basin we observe an increasing discrepancy between surplus of sediment, e. g. reservoir sedimentation and deficit of sediment, e. g. river bed erosion and coastal erosion in the Danube Delta. This imbalance contributes to flood risk, reduces navigation possibilities, reduces hydropower production, deteriorates the ecological conditions of the Danube River and alters the ground water level.

The DanubeSediment project seeks to address the need for a transnational Danube Sediment Management Guidance that contains concrete recommendations for the different stakeholders' groups, explaining WHAT sort of measures can be implemented to improve sediment management in WHICH situations. These recommendations will be fed into the next Danube River Basin Management Plan as well as into the Danube Flood Risk Management Plan. In this way, the sustainability of the project results will be ensured.

Understanding alterations of the sediment regime – Overview of current reports on the Danube River Basin

When analysing reports on the Danube Basin, one receives a first picture about the source of the problem, about pressures leading to the alteration of the sediment regime, their respective impacts and about potential measures. For example, The Danube Basin Analysis (WFD Roof Report 2004[1] and 2013[2]), the Danube River Basin Management Plan (DRBMP 2009[3] and 2015[4]) as well as the Joint Programs of Measures defined in both DRBMPs.

The DBA 2004 briefly presents information about the main drivers, which influence the sediment regime. Hence, three main hydromorphological driving forces have been determined as most relevant on the basin scale: hydropower generation, flood defence and navigation. Gravel and water abstraction as well as outdoor recreation activities and fisheries have been identified as being of minor or local importance.

[1] ICPDR, 2005
[2] ICPDR, 2013
[3] ICPDR, 2009a
[4] ICPDR, 2015a

According to the Danube Basin Analysis 2013, the key driving forces causing continuity interruption are hydropower generation (50%), flood protection (18%) and water supply (10%). In many cases barriers are not linked to a single purpose due to their multifunctional characteristics (e. g. hydropower use and navigation; hydropower use and flood protection).

Information on sediment regime slightly linked to the main drivers are presented in the frame of the results of expeditions/surveys that took place on the Danube, namely, the Joint Danube Survey (JDS) 2[5] and 3[6], the results being similar. Thus, according to the "Joint Danube Survey 3 - A Comprehensive Analysis of Danube Water Quality" the most significant changes were defined by interruptions of longitudinal continuity (dams, thresholds), lateral connectivity disruptions (floodplain loss) and hydromorphological changes especially due to navigation, hydropower and flood protection. Significant changes in the amount and composition of sediments as well as the accumulation of sediment and erosion upstream and downstream of Danube River dams constitutes a basin wide issue.

The actual status of the hydromorphology in the Danube River Basin and the sediment regime parameters show a heavily disturbed system at various scales. The identification of the combined effects of different drivers, such as hydropower, navigation and flood protection, which are presumed as being responsible for the alterations in the sediment regime, e. g. a lack of bed load and suspended load in the remaining free-flowing sections, is the scope of this report.

Human activities as key drivers for alterations of the sediment regime

Long reaches of the Danube River and its main tributaries have been narrowed, channelized, disconnected from floodplains, and morphologically altered, at least over the last 200 years. Channel realignment, straightening and deepening due to navigation and flood protection frequently were carried out in the past and have led to bed or bank erosion in the altered reach, as well as increased sediment load entering the downstream reach and thereby causing further problems downstream.

River channel and watercourse activities, such as channel deepening, channel widening, channel regrading, channel realignment, alter the physical characteristics of the water body and therefore change the velocity and variability of flows. This impacts the sediment regime, for example by flushing sediment through a straightened system and reducing diversity or increasing sedimentation in over-widened or deepened reaches.[7]

[5] ICPDR, 2008
[6] ICPDR, 2015
[7] EEA, 2010

Chains of **hydropower** plants in the Danube itself and along many tributaries (approximately 700 large dams) interrupt natural transport of sediments. However, nearly all Danube countries depend on hydropower. The upper part of the Danube is ideal for building hydropower plants due to the river's natural gradient. Nevertheless, the middle and lower Danube sections also offer a high hydro energetic potential due to the large volume of water which can be used for energy production. The chains of reservoirs for hydropower plants in Austria (AT) and Germany (DE) impound a major share of the upper Danube River, being approximately 269 river kilometres (rkm) or around 9% of its total length. Around 60% of the electricity generated in Austria yearly originates from hydropower – 20% produced along the Danube itself. In Slovakia, hydropower counts for about 16% of the energy mix, of which 11% derives from the hydropower plant Gabčikovo. The largest hydropower dam and reservoir system along the Danube is located at the 117-km-long Djerdap Gorge (Iron Gate Dam I and II). This peak operation system consists of two dams, jointly operated by Serbia and Romania, producing about 37% of the total energy used in Serbia and 27% in Romania[8].

Navigation is a traditional activity on the Danube River. Rivers had been the first "transport highways" and already at Roman times two fleets had been established, Classis Pannonica on the upper and Classis Moesica on the lower Danube[9]. Since 1856 navigation is regulated by an international commission, since 1948 by the Danube Commission. At present the Danube is navigable from Kelheim (rkm 2411) to the Delta, so the Danube serves as an international waterway. These 2411 km are equivalent to 87 % of the Danube's length. 78 harbours[10] are located on the Danube between Kelheim and the Black Sea. Therefore, navigation is of multilateral importance[11].

Since the beginning of the 90s Pan-European Corridor VII and the Trans-European Transport Network (TEN-T) for navigation connect the Black Sea with the North Sea through the Rhine-Main-Danube-Corridor. According to the Danube River Basin District Management Plan, Part A Basin overview, update 2015, inland navigation does currently not play a major role in every Danube country – it is relevant only for some Danube countries as there is no commercial inland navigation in the countries on the edges of the Danube River Basin and on the tributaries of the upper Danube River Basin. The total freight transport on the entire Danube is approx. 79.5 million tons yearly related to the Danube – Black Sea Canal). These figures include transit traffic and also bulk cargo, but there is no separate estimation of these categories. The countries with the highest tonnage transported on the Danube are Romania, followed by Austria and Serbia (all three countries move more than 10 million tons of cargo annually)[12].

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[8] ICPDR, 2010
[9] Webster, 1998
[10] Via Donau, 2004
[11] ICPDR, 2005
[12] ICPDR, 2015a

The Danube River Basin has been the site of many disastrous **floods** in the past. In the last two decades, severe floods have been registered in 2002, 2006, 2010, 2013 and 2014.

Contrary to the massive flood events on the Danube which occurred in 2002 or 2006 due to high precipitation volume in a short time, in 2010 the scattered character of the rainfall throughout the whole year and throughout the most of the Danube River Basin led to a high number of damaging flood events at the local level. Structural, traditional engineering measures like dams, dykes and draining systems play a significant role in flood protection but at the same time contribute to alteration of sediment regime on significant length of the Danube River and tributaries along the Danube River Basin.

Sediment transport interactions with flood control are briefly specified in the Danube Basin Analysis (DBA), in the context of reduction of the safety of the existing flood protection works due to sediment deposition (see 2.3).

At the European Union level, due to increasing pressures on water resources, **legislative and planning instruments** have been promoted for their sustainable protection and management. From these, the most important is the **Water Framework Directive** 2000/60/EC, which provides the necessary framework for a sustainable water management and implies a management of waters and healthy ecosystems with the aim of achieving good water status[13]. As long as suspended sediments and bed load are unaltered or slightly modified, essential and dynamic components of aquatic systems, which occur naturally, are transported in watercourses by the flow, it is obvious that in order to achieve the goals of the WFD it is necessary to pay attention to sediments, since they are habitats for biological elements.

1.1.2 Framework dealing with sediment-related aspects at the European level and Danube Basin scale

This section includes approaches regarding consequences of alteration of sediment regime on hydromorphology and biology in terms of Water Framework Directive related aspects (status, objectives) and several considerations related to flood risk and habitat fragmentation.

The hydromorphological quality elements provided in the WFD in relation to ecological status classification are represented by hydrological regime, river continuity and morphological conditions.

[13] In this context water status refers to ecological status (natural water bodies), ecological potential (heavily modified and artificial water bodies) and chemical status.

In the frame of the river continuity quality element, sediment transport is specifically mentioned in the normative definitions of hydromorphological quality elements according to Annex V, respectively for high status normative definition. Also, sediments have relevance in relation to the shaping of habitats and biological quality elements, concerning the ecological status of biological quality elements (BQEs).

Through decades, human activities have impacted the water status, altering or changing the hydromorphology of water courses, implicitly the sediment regime.

As a result of the alterations of hydromorphological characteristics, a surface water body may be designated as a heavily modified or artificial water body according to the provisions of Art. 4.3 of the WFD. When these alterations are not significant / do not lead to the substantial changes in the character of a water body[14], those water bodies are classified as natural water bodies or non-heavily modified water bodies.

The main environmental objectives of surface water bodies are represented in a summarized way by achieving the good status (ecological status and good chemical status for natural water bodies), the good potential (good ecological potential and good chemical status for heavily modified water bodies or artificial water bodies) and by preventing their further deterioration.

An Alteration of the sediment regime could impede the achievement of the good status or good potential of water bodies as well as their further deterioration. In terms of the previously indicated ecological status, sediment transport is specifically mentioned only for the normative definition of "high status" for hydromorphological quality elements (Annex V of WFD): Alteration of sediment (regime) should be reflected in the assessment status of the hydromorphological quality elements (QEs) for high status and in relevant BQEs ecological status. As outlined in Common Implementation Strategy (CIS) Guidance Document No. 13[15], the values of the hydromorphological quality elements must be considered when assigning water bodies to the high ecological status class (and the maximum ecological potential class), i.e. when downgrading from high ecological status (or maximum ecological potential) to good ecological status (or potential). For the other status/potential classes, the hydromorphological elements are required to have conditions consistent with the values specified for the biological quality elements. For the assignment of water bodies to the classes "good", "moderate", "poor" or "bad" ecological status or potential, the hydromorphological elements have to confirm the adequate conditions for the biological quality elements. Therefore, the alteration of sediments should be reflected in the respective BQEs ecological status.

[14] The water body can meet the "good ecological status" (GES).
[15] European Commission, 2005

Sediment regimes are crucial to aquatic and riparian ecosystems in many ways, some species having preferences for a particular type of substrate along developmental stages[16]. For example, the fine sediments and organic matter create a very unstable and easily erodible habitat for aquatic invertebrates[17]. Pan et al. (2012) showed that the gravel substrate creates more stable microhabitats that allow the development of a greater number of species of invertebrates. Therefore, the large particles substrate is a high-quality habitat for benthic invertebrates in contrast to substrates composed of small sand particles[18]. In case of fish fauna, salmonids can be sensitive to excess of fine sediment and they require gravels substrate for spawning[19]. The predators are strongly dependent on suspended sediment and turbidity which can alter the visibility necessary for the food activity[20]. The linkages between riparian plans and sediments in terms of sediment retention have been widely described in the scientific literature[21].

A reduction in flow changes alters the depth, width, velocity, and reduces solid flow rates[22]. This can interrupt the migration routes of species, which may lead to habitat fragmentation, loss or conversion and to altered population composition, decline of species biodiversity and abundance and to a decrease in the capacity for self-recovery. Certain species are more sensitive to changes of their habitat condition and can decrease or, in some cases, disappear. The modified habitat can also provide an opportunity for invasive species to expand their range of distribution and to increase the fragility of native species[23].

A Decrease in sediment supply reduces the river braids, opens the river roosting habitat and reduces the sediment deposition on floodplain and the riparian heterogeneity. On the other hand, elevated levels of sediment, which are not within the natural seasonal fluctuations, may be harmful to aquatic species and habitats.

In order to improve flood protection and to reduce/minimize flood risks, flood protection measures have been built within the Danube River Basin. In some cases, the flood defence measures could lead or trigger alterations of the ecological status and of the sediment regime or transport by interrupting the longitudinal continuity.

Also, activities that change fluxes of sediment or lead to the resuspension of contaminated particulates can impact the chemical and/or ecological status through river basin-specific pollutants (RBSP).

[16] Angradi, 1999, Miyake and Nakano, 2002; Gilmore, 2002; Buss et al., 2004; Gonçalves and Menezes, 2011
[17] Allan and Castillo, 2007; Jones et al. 2011
[18] Duan et al., 2009
[19] Riebe et al. 2014
[20] Newcombe and MacDonald 1991
[21] Daniels and Gilliam, 1996; Dosskey et al., 2010; McKergow et al., 2003; Yuan et al., 2009
[22] Statzner and Higler, 1986; Armitage and Petts, 1992
[23] Baltz and Moyle, 1993; Brown and Moyle, 1997; Brown and Ford, 2002; Old and Acreman 2006

Changes in sediment regime or sediment transport could lead to the prevention of achieving a good status or potential could lead to exemptions to environmental objectives:

- extension of the deadline (phased achievement of good status/potential by 2021 or 2027, or beyond for natural conditions) – article 4.4.;
- achievement of less stringent objectives under certain conditions – article 4.5.;
- temporary deterioration of the status in case of natural causes or "major forces" (e.g. severe floods) – article 4.6.

In case of a new modification to the physical characteristics of a surface water body that lead to the failure of good ecological status or potential or the failure to prevent further deterioration in the status or potential of a surface water body, exemptions under Art. 4.7. of Water Framework Directive could be applied.

The hydromorphological quality elements are – within the meaning of the Water Framework Directive – "supporting elements" for communities of aquatic organisms. At values, which are defined for a good ecological status, these elements must be able to sustain the biological quality elements. In this respect, the assessment of hydromorphological elements in the frame of monitoring programs will support the interpretation, assessment and classification of ecological status.

On October 30th 2014, the Water Framework Directive was amended by Directive 2014/101/EC (Annex V, section 1.3.6 *Standards for monitoring of quality elements*), published by the European Committee for Standardization (CEN), some of them jointly with the International Standards Organization. Some old standards have been removed, a number of new standards introduced, addressing the biological sampling of phytoplankton, macrophytes and phytobenthos, benthic invertebrates, fish and hydromorphological characteristics. Referring to the monitoring of hydromorphological elements, the Standard EN 14614/2004 "Water quality – Guidance standard for assessing the hydromorphological features of rivers" has become mandatory.

The Standard EN 14614: 2004[24] aims to describe a standard protocol for recording the physical characteristics of river beds, banks, riparian areas and floodplains. This document considers the hydromorphological parameters. The methods used for the assessment may vary depending on the nature of the river and the objectives of the study. The standard is based on developed, tested and compared methods across Europe. Its main purpose is to improve the comparability of hydromorphological measurement methods, data processing, interpretation and presentation of results. This standard provides a common framework for the harmonization of these different methods as well as guidelines on the hydromorphological characteristics that should be used to characterise certain types of rivers and to assess the morphological characteristics comparing to the reference conditions.

[24] European Standardization Database, 2004

Although hydromorphology is dependent on hydrology and basic geology, this standard focuses on the structural characteristics and continuity of the river.

The river characteristics, that are recommended to be monitored during field campaigns, are grouped into 10 categories. The features characterize three river areas: the minor bed, the river bank or riparian area and the floodplain[25].

Regarding the sediments, Table 1 presents the mandatory list of assessment categories, generic features and attributes assessed, necessary to be considered in the frame of the monitoring program.

Table 1: Categories, features and attributes for standard assessment of geomorphological characteristics in relation with sediments (extract from SR EN 14614/2004)

No.	Assessment categories	Generic features	Attributes assessed
1	Substrate	Natural and artificial substrate types; Management/catchment impacts	Bedrock, large, coarse, fine, cohesive, organic substrates, concrete/bed-fixing; Degree of siltation, compaction
2	Erosion/deposition character	Features in channel and at base of bank	Point bars, side bars, mid-channel bars and islands (vegetated or bare), stable or eroding cliffs, slumped or terraced banks
3	Longitudinal continuity as affected by artificial structures	Artificial barriers affecting continuity of flow, *sediment transport* and migration for biota	Dams, weirs, sluices across beds, culverts

The standard does not refer explicitly to the specific drivers which cause a certain pressure with a certain impact on different hydro morphological features. But, at the same time, the standard mentions that these features can be selected based on the aim pursued. The right selection of the monitoring sections will be a key factor in capturing the influence of a certain driver in the frame of alteration of sediment regime.

In addition, although the important influence of hydromorphology on aquatic ecology is recognized by the continuum interruption by transversal structures (and the other way around aquatic ecology's influence on hydromorphology), no attempt is made in the standard to provide guidelines in this regard. Only the rules of vegetation in channel development (macrophytes, riparian zone and floodplain as well as large woody debris) are considered, linking somehow to biological parameters.

[25] From SR EN 14614/2004

1.2 DPSIR-Model: Driver, Pressure, Status, Impact, Response

1.2.1 Concept, definition and linking of the DPSIR elements

As mentioned above, first reports on the European level have taken a first look at the drivers and pressures on the sediment regime. However, a detailed and comprehensive analysis combining all relevant aspects of the DPSIR framework, Drivers and Pressures, Pressures and Impacts, Impacts and adequate Responses is needed.

The DPSIR concept has been adopted by the European Environment Agency, based on the pressure-state-response (PSR) model that was developed in the 1970s by the Canadian statistician Anthony Field. The PSR approach was adopted and enhanced by researchers of the Organisation for Economic Co-operation and Development (OECD) in the 1980s. *Pressures* are direct results of the drivers in form of environmental stress, leading to altered *states* of the environmental compartments like air, water and soil. The effects are *impacts* on ecosystems or human health and functions, eventually leading to *responses*, which are defined as human measures like research and information, regulations and adjustments (Figure 1).

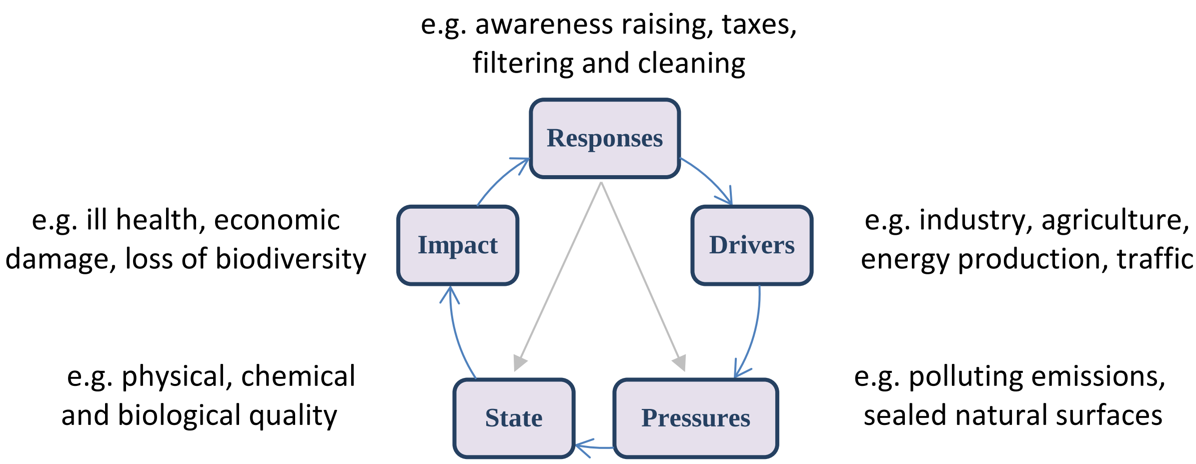

Figure 1: DPSIR approach according to the European Environment Agency (source: EEA, 1998)[26]

[26] EEA, 1998

Linking DanubeSediment to DPSIR

Within Work Package 5 of the DanubeSediment, the model is applied step by step along the Deliverables, as shown in Figure 2.

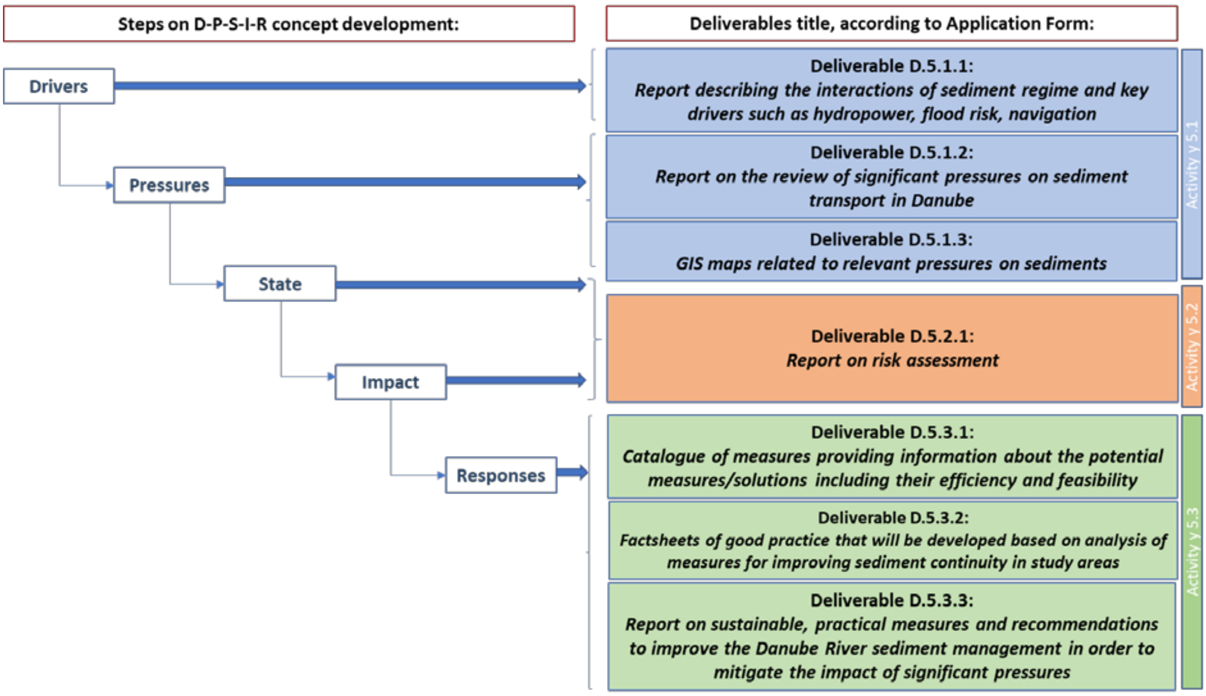

Figure 2: Links between DPSIR concept and deliverables from WP5 in the DanubeSediment project

The Elements of DPSIR represent in fact the key elements of the Pressure and Impact analysis, which finally will underpin the risk assessment (Figure 3).

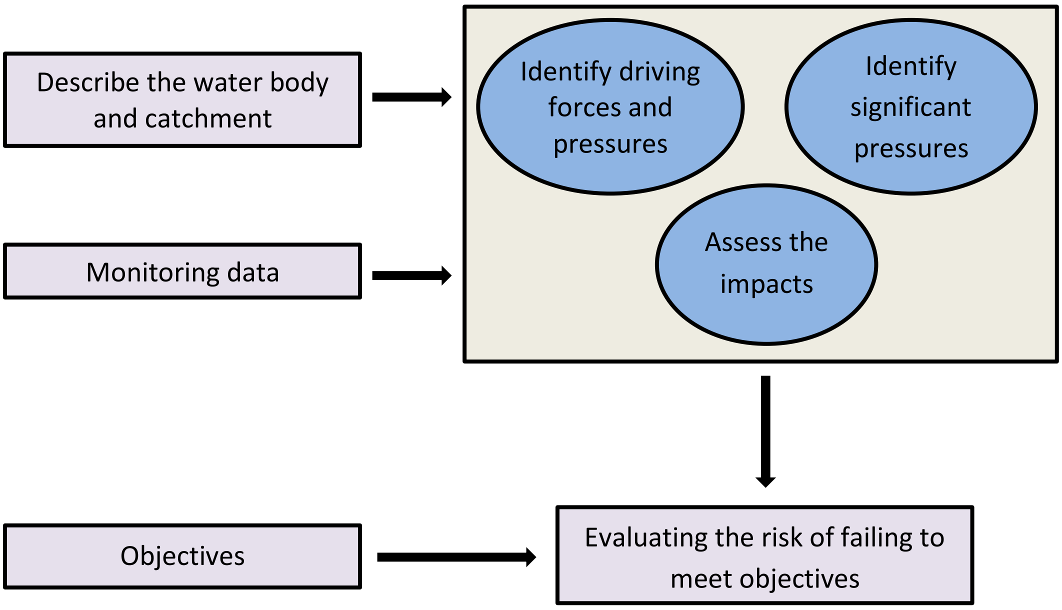

Figure 3: Key elements in the analysis of pressures and impacts (source: CIS Guidance Document no 3, Analysis of Pressures and Impacts, processed)

Therefore, in addition to a general description of the river, it is important to identify the **driving forces** that may cause pressures on the water body. Driving forces represent a basic element in DPSIR concept, because ultimately the response (measure) will have consequences on it.

The inventory of **pressures** is likely to contain several pressures which cannot generate an impact on water bodies, are of temporary kind/of reduced intensity. According to the Water Framework Directive requirements, only significant pressures are considered in terms of impact assessment, in fact those pressures which contribute to an impact on the water body and that may result in failing of the environmental objective.

Assessing the **impacts** on a water body requires quantitative information to describe the state of the water body itself and the pressures acting on it. The type of analysis will be dependent on what data are available.

The assessment requires a conceptual understanding of what causes impacts and what the elements affected in relation with a specific issue, e. g. sediment regime, are. Therefore, it can be necessary to identify river sections where monitoring is required to better understand if the water body is at risk of failing to achieve good status due to the above specific issue.

Once the impact has been identified and sufficiently quantified, a **response** to mitigate the impact or even to eliminate it has to be elaborated. The response may be of structural or non-structural nature, for example a change in the policy of a certain driving force in relation with a specific issue.

To understand the dynamics of relationships between the reference conditions and the consequences of environmental issues, it is also necessary that we focus on the links between the DPSIR elements (Figure 4). For instance, the relationship between anthropogenic activities and the pressures caused by these activities reflects the alteration of sediment regime and could lead to the preventing of achievement of good status or potential of water bodies and to their further deterioration.

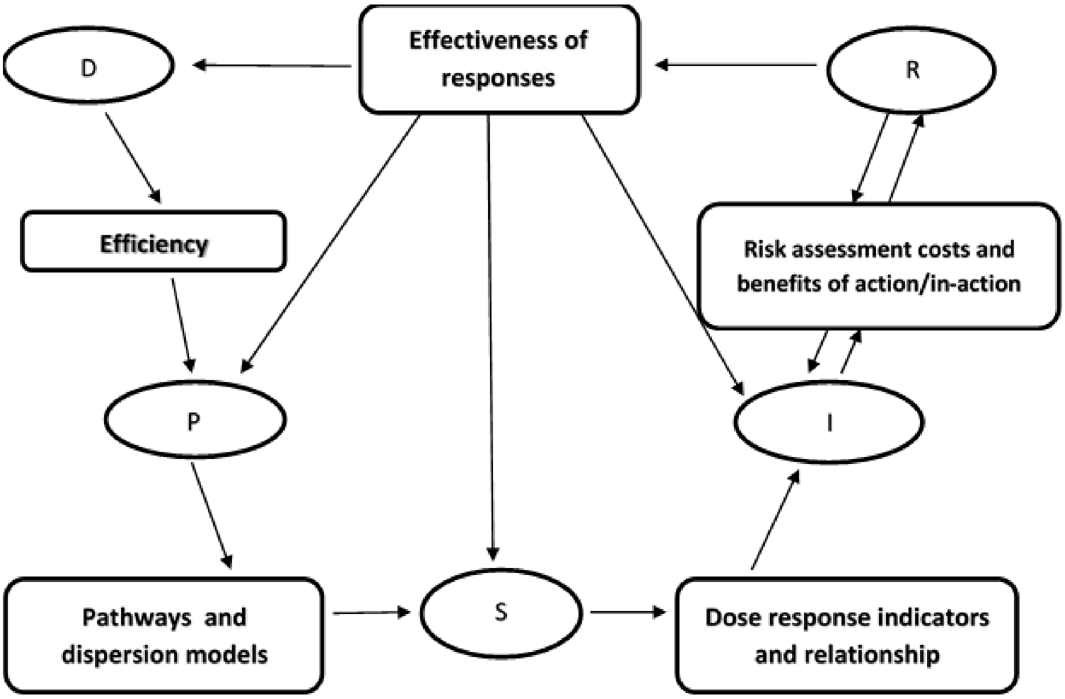

Figure 4: Linking DPSIR elements (source: EEA 1999, processed)

The DPSIR model allows a comprehensive assessment of water and sediment issues through examination of the significant pressures on water bodies, their consequential state, its impacts, the measures undertaken, and of the interlinkages between each of these elements. Furthermore, the DPSIR framework is not just a model to elaborate the cause-effect relationships that lead to environmental challenges; rather, its original goal is to identify appropriate indicators for the measurement and evaluation of those water and sediment issues for developing an improved water quality monitoring system.

As it was previously mentioned, it is essential to identify the driving forces that may be exerting pressures on the water body. Instead of assessing if there is an impact on the water body, according to the WFD there is a need to consider if the pressure is significant. One approach is to compare the magnitude of the pressure with a threshold value or criteria, relevant to the water body type.

The Assessment of pressures and significant pressures will be a subject of the *Report on the review of significant pressures on sediment transport in the Danube*, but in this subchapter, it is intended to present a link between drivers and pressures which practically acts on sediment regime, by considering the DPSIR concept.

Different drivers act on different paths on the sediment regime and implicitly on the water body status. Based on already identified key drivers in relation with sediment regime, a short overview of the link with pressure is presented below.

Navigation, through dredging for channel deepening, ship locks, groynes, river regulation (modification of the river bank), alters the physical characteristics of the water body and therefore has the potential to change the sediment regime. For example, changes in flow velocity can increase sediment transport in a straightened area of the river or increase sedimentation in over-widened to deepened reaches.

Degradation of the river bed by changes in composition of the substrate can significantly lead to severe ecological problems. When limitation of lateral erosion occurs by stabilizing the navigation channel-, the natural sediment exchange with the floodplain is no longer balanced. Dredging the channel bed usually destroys, or at least disrupts, the environmental features, creating a more uniform, less stable and less diverse environment.

Hydropower acts on the natural hydrological regime, especially due to the river dams, weirs, and water storage. These pressures are affecting the flow regime through change in seasonal flow, daily flow (hydro-peaking) and water level fluctuations. In addition, river stretches may dry up and water levels of lakes and reservoirs may be heavily regulated. Alterations of the flow regime act in a direct way on aquatic ecosystems through modification of physical habitat, erosion and sediment supply rates and transport. Barriers, such as dams and weirs, have an effect on the natural sediment transportation, resulting in retention of sediment upstream of dams and loss of sediment downstream of dams, which changes the suspended sediment balance. River dams also cause an effect of deepening of the river bed downstream – the river is only able to compensate the deficit of sediments downstream by gathering material from the bottom, causing it to “dig into” the landscape more extensively along certain stretches.

Land use, like agriculture and afforestation, is a driver of sediment input into rivers, especially concerning synergistic interactions with sediment load[27]. Alongside land use change and accompanying intensification of human uses, together with climate change act as ‘big player’ as a driver of habitat change in rivers[28]. While land use types with crop cultivation (cropland, fallow, tree crops and vineyards) have higher mean soil loss rates than land use types under (semi-) natural vegetation (grassland, rangeland, shrubland, forest and post-fire), there are still large variations within each of these land use types differences[29]. Annual runoff rates follow the same pattern as annual soil loss rates, but differences between land uses are less clear. The generally good relations between annual runoff and annual soil loss illustrate the key importance of the relation between runoff and soil loss for a good assessment of soil loss rates[30].

[27] Townsend et al., 2008; Molinos and Donohue, 2010; Wagenhoff et al., 2011
[28] Palmer et al., 2009; Kingsford, 2011
[29] W. Maetens, M. Vanmaercke, I. Ionita et al., 2012
[30] Maetens et al., 2012

The above information illustrates some examples concerning the relation between key drivers and pressures in the context of the sediment issue. Certainly, several other drivers like water supply, gravel extraction for other purposes than navigation or climate change, also play a role in the process of the sediment regime alteration, through their specific pressures, but the importance has been assigned to the identified main key drivers.

1.2.2 DPSIR framework in relation to water and sediments issues

As an indicator-based environmental reporting approach, the DPSIR framework in relation to water and sediments aims to describe environmental - problems by identifying the cause-effect relationships between the environment and various anthropogenic activities in a wider socio-economic context.

The implementation of the WFD sets the scope to the integrated approach of water and sediments, from the water body level to the river basin scale, as sediments are an essential part of the aquatic environment. In the frame of River Basin Management, the DPSIR framework is applied and up-dated every six-year updating-cycle of the River Basin Management Plan which is the basic instrument to implement the WFD.

The DPSIR framework, in relation to water and sediments issues, includes the following four key stages of the general approach as laid down in the WFD:

- identifying driving forces and pressures
- identifying the significant pressures
- assessing the impacts
- evaluating the likelihood of failing to meet the WFD environmental objectives

To undertake the four key stages, three elements must be considered:

- describe the water body and catchment
- monitoring data
- environmental objectives

Even though there will be many instances in which these key stages need not be undertaken as a linear sequence because it is more appropriate to adopt a different sequence for the analysis, anyway all key stages need to be addressed.

The DPSIR concept and its four stages are applied at water body level for both components: water and sediment. Even if WFD does not specifically deal with sediment, it is clear that there is a link between sediment issues and achieving WFD objectives, as long as pressures that act on water body also affect sediment regime.

As a first key stage within the DPSIR water-sediment framework, socio-economic and cultural developments function as drivers of human activities that increase or mitigate pressures on the water and sediments. Therefore, it is necessary to collect information on anthropogenic activities and changes that influence the water status and sediment regime.

Concerning the pressures stage, the principle outline is the following: if the water body fails to meet its environmental objective or is at risk of failing to meet its environmental objective, then the occurrence- of a cause of this failure, respectively the significant pressure, which could be a single or combination of pressures, must be investigated. Under this stage, the assessment of pressures will provide useful elements for the next sequences.

1.2.3 Outlook on the identification of key drivers for sediment imbalance in the Danube Basin

The WFD could contribute to mitigating existing sediment problems, as it contains comprehensive approaches to an analysis on all drivers which caused different pressures and impacts in relation with sediment regime.

The Danube Basin Analysis (WFD Report 2004, 2013), the Danube River Basin Management Plans (2009, 2015) and the Programs of Measures in the last Danube River Basin District Management Plan (2015) [31] offer a picture about the source of the problem, about pressures leading to the alteration of sediment regime that cause an impact and about potential measures.

On the Danube River Basin scale, WFD is also implemented by the Danube River Basin Management Plan. ICPDR developed the Danube River Basin District Management Plan (DRBMP) in 2009 and updated the plan in 2015. Both Danube River Basins Management Plans maintain and strengthen the idea that among climate change and flood control, sediment transport represents a relevant issue on a Danube Basin wide scale, whereas navigation, hydropower and flood control, represent the most important drivers which act on the sediment regime. Hence, "*the retained sediment has often to be extracted in order to maintain the river depth for navigation and reservoir operation and in order to limit the height of the water level in the case of floods*"[32].

As of 2009, the DRBMP stated that "*sediment balance of most large rivers within the Danube River Basin can be characterised as disturbed or severely altered. Morphological changes during the last 150 years due to river engineering works, torrent control, hydropower development and dredging, as well as the reduction of adjacent floodplains by nearly 90%, are the most significant causes of impacts*."

[31] Mentioned in *sub-chapter 8.1.4.1 - Interruption of river continuity and morphological alterations, page 125*
[32] ICPDR, 2009a

Therefore, the DRBMP proposes:

- to establish a sediment balance for the Danube River Basin and to provide sufficient data for this approach;
- to ensure the sediment continuum by improving existing barriers and avoiding additional interruptions, and;
- to provide additional investigations to identify the significance of sediment transport on Danube basin scale.

The plan was updated in 2015[33] and reiterates the fact that the combined factors of navigation, hydropower and flood protection in particular are responsible for longitudinal and lateral disturbances of sediment regime. At the same time all the previous documents conclude that the sediments represent an essential, integral and dynamic part of water ecosystems with a significant contribution to the good status of water bodies.

In the context of flood control, the Danube Flood Risk Management Plan (DFRMP), which was also coordinated by the ICPDR, sees sediment as vital for flood protection measures for reducing erosion and torrents. From the sediment perspective, the flood risk maps show the potential adverse consequences for sediment associated with flood scenarios[34]. These are expressed in terms of areas where floods with a high content of transported sediments and debris floods can occur.

1.3 Results of key driver analysis

1.3.1 The questionnaire as a tool for DPSIR

Input from the DPSIR model is needed within the **DanubeSediment** project in order to review the main key drivers and the impacts of significant pressures on sediment quantity for the Danube River, which is the scope of this report.

Project specific requirements

First off, the Danube River was divided into different sections according to their morphology (Upper, Middle and Lower Danube). This undertaking was thoroughly discussed with the ICPDR Expert Group on Hydromorphology and agreed by the Flood Protection Expert Group and all PPs involved.

[33] ICPDR, 2015a
[34] ICPDR, 2015b

The Danube River sections are as follows:

- Upper Section: From spring to the Gonyu village (river km 1790), situated downstream from the Moson Danube mouth (river km 1794), as well as downstream from the Gabčikovo hydropower plant, the general longitudinal slope of the river channel ranges between 0,95 ‰ and 0,32 ‰[35].
- Middle Section: From Gonyu village to Iron Gate I dam (river km 943) at the border of Serbia and Romania, the riverbed widens and the average general longitudinal slope in this section drops to 0,07 ‰[36].
- Lower Section: From Iron Gate I dam to Sulina at the Black Sea at river km 0, the average general longitudinal slope of the Danube river channel further decreases to 0,06 ‰[37].

The main justifications for this sectioning are changes in relation to the sediment regime, such as slope and river bed morphology. Furthermore, the construction of the Danube dams caused severe changes in the river hydrology, the flow velocity was reduced, the water level rose, and the sedimentation was increased. These elements are analysed in the project context within WP4 activities (assessment of the sediment balance and long-term morphological development).

Second, the project partners agreed upon a list of “main tributaries”: Isar, Inn, Traun, Enns, Morava, Lajta, Raba, Vah, Drava, Tisza, Sava, Velika Morava, Jiu, Iskar, Yantra, Arges, Ialomita, Siret, Prut. They were selected due to the relevance of their input to the sediment balance, for their sediment monitoring profiles and as sites for measuring suspended and bed load data as well as the availability of long-term data resolution on the sediment regime. The tributaries were elaborated according to morphometry, location and characterization. In addition, GIS templates were used to collect spatial data on the pressures as GIS shapefiles.

The content of the questionnaire

The questionnaire *“Templates for identification of key drivers on national level”* was developed and made available to project partners online[38]. Together with a *Completion guidance* (Annex no. 1 on this Report), project partners were initially asked for feedback and then for detailed completion. Therefore, all information needed about activities and pressures that may impact the sediment regime was collected via the partners through the questionnaires.

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[35] According to results from morphological analysis provided by WP4 in the DanubeSediment project.
[36] According to results from morphological analysis provided by WP4 in the DanubeSediment project.
[37] According to results from morphological analysis provided by WP4 in the DanubeSediment project.
[38] During Activity 5.1. in the project, the questionnaire was hosted on: https://goo.gl/forms/eahjauda6CyMv39v1

The comprehensive questionnaire was based on the DPSIR (Driver-Pressure-State-Impact-Response) concept, see sub-chapter 1.2. It aimed to identify key drivers on the level of national Danube sections and selected tributaries and to collect data for describing the interactions of the sediment regime and the key drivers as well as reviewing significant pressures and their impact on sediment transport and quantity, which are the first three stages of the DPSIR framework.

The questionnaire had six main sections (making up 21 questions):

- basic information (data provider)
- identification (tributary, Danube section)
- key drivers (selection in relation with sediment balance/transport continuity)
- identification of pressures
- selection of significant pressures (affecting sediments and assessed criteria)
- effect of the pressures (referring to hydromorphological pressures on sediment quantity/continuity and on relevant biological elements) and
- observations (descriptions).

A total of 33 questionnaires were completed by all PPs: nine for national Danube sections (DE, AT, SK, HU, HR, RS, BG, RO) and 24 for the above-mentioned selected tributaries (see also Figure 5 for spatial distribution of major selected tributaries). Some tributaries, like Inn, Morava, Sava, Drava cross more countries, so a separate questionnaire was provided for each national section. For common sections of the Danube River and cross-border tributaries, each partner filled in the questionnaires only with data referring to the respective national side. Only for the tributaries, this information has been aggregated for the entire river again concerning the evaluation of the questionnaires. However, the detailed situation of identified key drivers for each national section can be seen in Annex 2b *(Map of the key drivers in relation with sediment regime on major selected tributaries).*

Figure 5: General view on spatial distribution of major selected tributaries in project area

Regarding the data collection process, from the total number of questionnaires completed for all major selected tributaries and the national sections of the Danube River, ten are from the Upper Danube, 15 are from the Middle Danube and nine are from the Lower Danube, according to spatial distribution of Danube national sections and major selected tributaries in the project.

The distribution of the questionnaires from the Project Partners participating in the Activity 5.1 from *WP5 – Impact and measures*, related to the major selected tributaries and the national sections of the Danube River is presented in Table 2. It also gives an outlook on the length of the different river stretches that have been analysed.

Table 2: Questionnaires filled out by Project Partners

Stretch per questionnaire	Confluence of tributary with Danube (in river kilometer)	Project Partner	Absolute length of stretch (km)	Adapted length of stretch to avoid double-counting (km)	% total adapted length	% section
Danube DE	-	TUM	655 incl. 22 common with AT	644,0	6,3%	25,71%
Isar DE	2,282 rkm (near Deggendorf, DE)	TUM	2,282 rkm (near Deggendorf, DE)	270,0	2,6%	10,78%
Inn DE	2,225 rkm (Passau, DE)	TUM	219 incl. 79 common with AT	179,5	1,8%	7,17%
Danube AT	-	BOKU	351 incl. 22 common with DE and 7 km common with SK	336,5	3,3%	13,43%
Inn AT	-	BOKU	281 incl. 79 common with DE	241,5	2,4%	9,64%
Traun AT	2,125 rkm (near Linz, AT)	BOKU	153	153,0	1,5%	6,11%
Enns AT	2,112 rkm (Mauthausen, AT)	BOKU	254	254,0	2,5%	10,14%
Morava AT	-	BOKU	91 incl. 91 common with SK	45,5	0,4%	1,82%
Morava SK	1,880 rkm (Devín, SK)	VUVH	329 incl. 91 common with AT (and 50 common with CZ)	283,5	2,8%	11,32%
Danube SK	-	VUVH	173 incl. 7 common with AT and 144 km common with HU	97,5	1,0%	3,89%
Upper DRB	**-**	**-**	**-**	**2505,0**	**24,5%**	100%
Vah	1,766 rkm (Komárno, SK)	BME	398	398,0	3,89%	11,33%
Danube HU	-	BME	417 incl. 144 common with SK	345,0	3,38%	9,82%
Lajta/ Leitha HU	1,792.5 rkm (near Mosonmagyaróvár, HU)	BME	182 incl. 60 in AT	182,0	1,78%	5,18%
Rába	1793 rkm (Györ, HU)	BME	311 excl. section in AT	311,0	3,04%	8,85%

Stretch per questionnaire	**Confluence of tributary with Danube (in river kilometer)**	**Project Partner**	**Absolute length of stretch (km)**	**Adapted length of stretch to avoid double-counting (km)**	**% total adapted length**	**% section**
Mosoni Danube	-	IzVRS	121	121,0	1,18%	3,44%
Drava SI	-	IzVRS	140 incl. 23 common with HR	128,5	1,26%	3,66%
Drava HR	1,382 rkm (near Osijek, HR)	HRVODE	322 incl. 133 common with HU and 23 common with SI	244,0	2,39%	6,95%
Sava SI	-	IzVRS	202	202,0	1,98%	5,75%
Sava HR	-	HRVODE	446	446,0	4,36%	12,70%
Danube HR	-	HRVODE	137 (mainly shared with RS)	68,5	0,67%	1,95%
Tisza RS	1,214 rkm (near Titel, RS)	JCI	168 (from total of 966)	168,0	1,64%	4,78%
Sava RS	1,170 rkm (Belgrade, RS)	JCI	206	206,0	2,02%	5,86%
Danube RS	-	JCI	449 incl. 137 mainly shared with HR and 235 common with RO	263,0	2,57%	7,49%
Velika Morava	1,103 rkm (near Smederevo, RS)	JCI	430	430,0	4,21%	12,24%
Middle DRB	**-**	**-**	**-**	**3513,0**	**34,38%**	**100%**
Danube RO	-	NARW	1.050 incl. 235 common with RS and 471 common with BG	697,0	6,82%	16,59%
Danube BG	-	NIMH-BAS	471 incl. 471 common with RO	235,5	2,30%	5,61%
Jiu	694 rkm (near Gighera, RO)	NARW	339	339,0	3,32%	8,07%
Iskar	636 rkm (Gigen, Pleven Province, BG)	NIMH-BAS	368	368	3,60%	8,76%
Iantra	537 rkm (Svishtov, BG)	NIMH-BAS	285	285	2,79%	6,78%
Arges	432 rkm (Oltenita, RO)	NARW	350	350	3,43%	8,33%

Stretch per questionnaire	Confluence of tributary with Danube (in river kilometer)	Project Partner	Absolute length of stretch (km)	Adapted length of stretch to avoid double-counting (km)	% total adapted length	% section
Ialomiţa	244 rkm (near Hârsova, RO)	NARW	417	417	4,08%	9,93%
Siret	155 rkm (Galati, RO)	NARW	559	559	5,47%	13,31%
Prut	132 rkm (near Reni, UA)	NARW	950	950	9,30%	22,62%
Lower DRB	**-**	**-**	**-**	**4200,5**	**41,1%**	**100%**
Total river	-	-	-	**10218,5**	**100%**	-

1.3.2 Results and interpretation of the key drivers

In the DanubeSediment project, Work Package 4 calculates the sediment balance. The types of reaches and scale of data analyses strongly differs according to the Danube sections and tributaries. Therefore, information on key drivers has been assessed both on the entire Danube river scale and on the Danube sections scale.

Regarding the interpretation of the key drivers, the figures below refer to the answers provided by the Project Partners in the frame of the questionnaire, respectively to Question 6 related to key drivers. The topic of pressures is analysed in the chapter 2 - *Report on the review of significant pressures on sediment transport in Danube.* It will provide an assessment and interpretation of the results in relation with the Questions 7-23 from the Questionnaire.

In order to visualize the impact of “key drivers” in the Danube and its tributaries, we chose to compare the length of river stretch impacted. This means we added the lengths of those stretches where the questionnaire states that a key driver occurs.
However, each questionnaire was limited to a respective national stretch of the Danube or a tributary. Since some of these borders share the same stretch of the Danube or a tributary, we received two questionnaires for these stretches. If we added the length, this would cause a double counting. To avoid this, the length of river stretch covered by two questionnaires (with shared borders) was “adapted” as follows: divide the length of the shared stretch by two. Subtract this halved length from the absolute stretch (per questionnaire), since this includes the shared river stretch. We recalculated the “adapted length” for every questionnaire with shared borders (see Table 2). For example, the Romanian Danube stretch (1050 KM) borders Serbia for 235 KM and Bulgaria for 471 KM. The “adapted length of the

Romanian stretch" is determined as follows: Length of Romanian section (1050 KM) minus 50% of shared stretch with Serbia (0.5 x 235 KM = 118 KM) minus 50% of shared stretch with Bulgaria (0.5 x 471 KM = 236 KM) equals 698 Km.

In Table 3, you can find the "key drivers" named for each stretch of questionnaire. The table also calculates the percentage of total river length for each questionnaire. Figure 6 visualizes the total river length impacted by a key driver (i.e. "adapted length of stretch") for each Danube River Basin section and for the total length of all river stretches.

*Table 3: Overview of key drivers occurring in the **Upper, Middle and Lower Danube River Basin** (see also map presented in Annex no. 2a and 2b)*

Stretch per questionnaire	**Flood protection = 99%**	**Hydropower = 89%**	**Water supply = 53%**	**Dredging (not for navigation) = 49%**	**Navigation = 40%**	**Agriculture = 39%**
Danube DE	x	x	x	x	x	x
Isar, DE	x	x	x	x		x
Inn DE	x	x	x	x		x
Danube AT	x	x			x	
Inn AT	x	x				
Traun AT	x	x				
Enns AT	x	x				
Morava AT	x					
Morava SK	x			x		
Danube SK	x	x	x	x	x	x
Upper DRB	**100%**	**87%**	**48%**	**59%**	**43%**	**48%**
Vah	x	x	x		x	x
Danube HU	x				x	
Lajta/ Leitha HU	x	x				
Rába	x	x				
Mosoni Danube	x					
Drava SI	x	x				x
Drava HR	x	x			x	
Sava SI	x	x		x		x
Sava HR	x	x			x	
Danube HR					x	
Tisza RS	x	x			x	
Sava RS	x	x	x	x		
Danube RS	x	x		x	x	
Velika Morava	x	x		x		
Middle DRB	**98%**	**85%**	**17%**	**31%**	**55%**	**21%**

Stretch per questionnaire	Flood protection = 99%	Hydropower = 89%	Water supply = 53%	Dredging (not for navigation) = 49%	Navigation = 40%	Agriculture = 39%
Danube RO	x	x	x	x	x	x
Danube BG	x				x	
Jiu	x	x	x	x		x
Iskar	x	x	x			
Iantra	x	x	x			
Arges	x	x	x	x		
Ialomiţa	x	x	x	x		
Siret	x	x	x	x		
Prut	x	x	x			x
Lower DRB	**100%**	**94%**	**94%**	**56%**	**22%**	**47%**
Total river	**99%**	**89%**	**53%**	**49%**	**40%**	**39%**

This presentation is complemented by the Annexes 2a and 2b of this Report presenting maps of the key drivers in relation with sediment regime in the Danube River and its selected main tributaries.

It must be mentioned that the activity ”dredging (not for navigation)” includes different key drivers, such as industrial use, ecological restoration, etc. Also, we mention that navigation includes dredging to ensure the proper and efficient depth and width of waterway.

Furthermore, gravel is extracted, e.g. in Romania, in order to allow an optimal flow section and maintenance the natural thalweg, which contributes to flood risk reduction or for ecological purposes such as wetland restoration, ecological reconstruction of degraded ecosystems to restore the self-regulation, filtration, purification and regeneration of water ecosystems. Even if undertaken as a “response”[39] in the DPSIR logic, these kinds of projects entail dredging, movement and placement of sediment in order to construct or create sandbars or chutes, or to make structural adjustments.

Other potential key drivers in relation with an alteration of the regime, like river regulation, have been indicated, but only qualified as being of secondary importance.

With respect to the data analysis, it has to be mentioned, that the results do not indicate the intensity of the identified key drivers on sediment regime in the national sections. Analysing the data provided by the Project Partners for all examined river stretches, it is clearly shown that navigation, flood protection and hydropower are the main drivers which act on the

[39] As described in the DPSIR concept, “response” refers to measures. Ecological reconstruction is a common measure used by different countries in their own RBMPs in order to improve ecological status (mainly addressed to biological quality elements).

sediment regime at the Danube Basin wide level. Agriculture and water supply for drinking water and industrial purposes play also a role in this regard but with a lower importance than the main drivers. Concerning agriculture, it has to be clarified, that it was not the main focus of DanubeSediment and consequently the scope of the analysis had to be limited to the key-drivers in a very restricted corridor of the examined river stretches.

Looking only at the stretches of the Danube River itself, navigation and flood protection, followed by hydropower were most frequently identified as main key drivers (see Table 3).

The results are more complex at the level of the Danube River Basin sections (see Figure 6). The highest importance for the alteration of sediment regime is allocated to:

- flood protection followed by hydropower and dredging in the upper section;
- flood protection followed by hydropower and navigation in the middle section;
- flood protection followed by hydropower and water supply in the lower section.

It can be noticed that for all analysed tributaries, hydropower and flood protection have been identified as main key drivers in relation with alteration of sediment regime. This could be due to high runoff rates and steep elevation gradients that require many barriers in the Upper part of the tributaries throughout the river basin. Due to their limited suitability for navigation, this key driver only impacts the Upper and Middle Danube, but is not an important key driver on the scale of the examined tributaries.

The identification of water supply for population and industry as a major key driver for the alteration of sediment regime for the tributaries of the Lower Danube Basin could be an indication for the relative strong importance of the tributaries for a large-scale water balance. It is also remarkable that water supply was only named once in the middle section.

When looking at the entire Danube River and all major selected tributaries impacted by key drivers, the strongest key driver (in terms of river stretch impacted) is found to be “flood protection” (99%) and “hydropower” (89%).

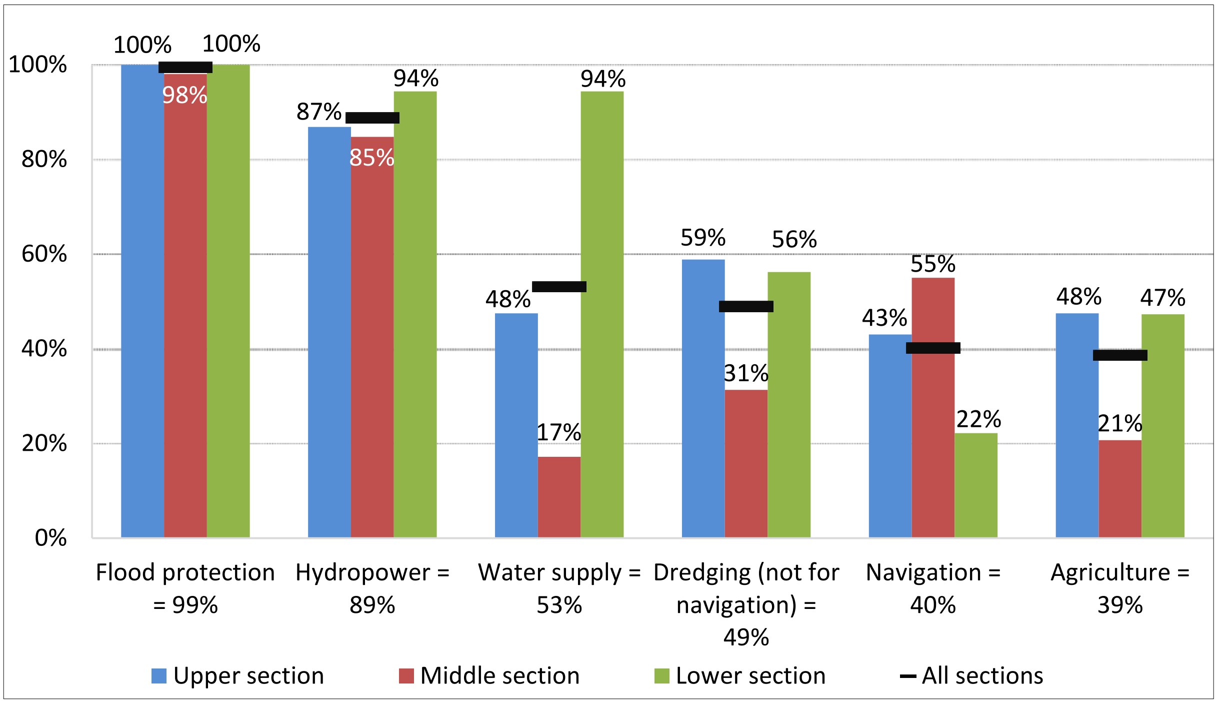

Figure 6: Percentage of river stretches to absolute length affected by key drivers on the ***Upper, Middle and Lower Danube River section and on all sections*** *(see also Annexes 2a and 2b)*

1.4 Projecting trends for identified key drivers in relation with sediment regime and climate change

This chapter presents a short overview on the trends in relation with the identified main key drivers on sediment regime. So far, a direct interlinkage between economic development and sediment regime could not be confirmed in the Danube River Basin. If the EU and the Danube countries are continuously concerned about sustainable development, giving equal priorities to ecologic, economic and social development, mitigation measures must be a substantial part for the development of economy sections with influence on the sediment regime like hydropower and navigation.

According to the European Commission, the Euro area economy grew in 2017 at its fastest pace in this decade, with real GDP growth of 2,2%[40]. Growth rates for the Euro area and the EU exceeded expectations last year as the transition from economic recovery to expansion continues. The Euro zone and EU economies are both estimated to grow more than 2% yearly in the near future.

[40] European Commission, 2017

Economy in the Non-EU countries is also expected to have an ascendant trend. According to the World Bank[41], the economy in the western Balkans for example is expected to grow with approximately 3% until 2020 and this trend is expected to continue.

The Danube Region is one of currently four macro-regional strategies of the European Union. As a unique integrated framework, it is supposed to address common challenges faced by a defined geographical area covering Member States and third countries which thereby benefit from strengthened cooperation contributing to the achievement of economic, social and territorial cohesion[42]. EUSDR was endorsed in June 2011 by the European Council. Sediment management is concerned by five of its current 11 priority areas:

Priority Area 1A "To improve mobility and intermodality of inland waterways"

Priority Area 2 "To encourage more sustainable energy"

Priority Area 4 of the EUSDR "To restore and maintain the quality of waters"

Priority Area 5 of the EUSDR "To manage environmental risks"

Priority Area 6 "To preserve biodiversity, landscapes and the quality of air and soils"[43]

From an economic perspective, the Danube River has a large developing potential in terms of **navigation.** Hence, the Danube River is recognized as a major transport corridor, it is still used far below its full capacity. As inland waterway with important environmental, social and economic benefits, its potential must be developed in a sustainable way and can only be improved by international cooperation, joint planning and coordinated activities.

The European transport policy has reached a major milestone in 2013, with the adoption of the TEN-T and CEF Regulations that will lead to a more efficient transport policy. The approach of the core network linking among others navigable ways and harbours is considered to be the backbone of a European transport area that guarantees an effective link within all European regions. The Rhine-Danube Corridor[44] covers all modes of transport and connects eight Member States - six of which benefit from Cohesion Fund support - one candidate country and one potential candidate country. It intends to strengthen and improve transport interconnections in France, Germany, Austria, the Czech Republic, Slovakia, Hungary, Croatia, Romania and Bulgaria, Serbia and Bosnia and Herzegovina along the main rivers and the Danube to the Black Sea. Regarding navigation, this Corridor comprises 3656 km, 18 interior harbours and one marine harbour.

Interaction of inland navigation and environment represent a significant concern for the Danube Countries.

[41] World Bank, 2018
[42] Council of the European Union, 2017
[43] EUSDR, 2018
[44] European Commission, 2018

A Joint Statement was developed in 2007 by the ICPDR[45] through a process of intensive, cross-sectional consensus building between stakeholders with responsibility and interest in navigation, river ecological integrity and water management in the Danube river basin. Stakeholders generated a common understanding on the protection of the riverine environment and the necessary processes and conditions for conducting and developing sustainable inland navigation, including the maintenance of existing infrastructure and the development of new navigation projects.

A non-exhaustive overview of inland navigation projects and actions to fulfil the Joint Statement principles developed has been integrated in the Danube River Basin Management Plan – Update 2015[46].

The stakeholders involved in developing this Joint Statement underline that the full respect of the existing legal framework, including all relevant transport and environment legislation (national legislation, EU directives and international requirements), is a pre-condition for any activity in the Danube Region. To implement an integrated planning approach for all plans and projects, all involved stakeholders need to agree on common planning principles leading to acceptable solutions for ecological integrity as well as navigation[47].

Energy is a central political and economic issue in the Danube Region. With its important supranational dimension, it has an impact on a range of sections, thereby making it critical for the overall successful implementation of the Danube Strategy. A further goal is the integration of the energy markets in those Danube countries that are not in the EU[48].

Through its projects in the Danube Region, the EU supports also the implementation of the EU-Energy-strategy[49] with the aim of increasing energy efficiency and promoting the use of renewable energy sources. Hence by 2020, a fifth of all energy consumption in European Union member countries must come from renewable sources – e.g. hydro, wave, solar, wind, and biomass. For hydropower, this mandate is transposed through significant growth in development of new capacity and in upgrading of existing facilities throughout Europe.

Following a request by the Danube Ministerial Conference 2010, the ICPDR has become active in initiating a dialogue with representatives from the hydropower section. As an initial step the „Assessment Report on Hydropower Generation in the Danube Basin“ has been elaborated, followed by the "Guiding Principles on Sustainable Hydropower Development in the Danube Basin"[50]. The guiding principles, which represent an essential step in this process, have been developed and were finalized and adopted in June 2013. Danube

[45] ICPDR, 2007
[46] ICPDR, 2015a
[47] ICPDR, 2007
[48] European Commission, 2016
[49] European Commission, 2010
[50] ICPDR, 2013a

countries are committed to the implementation of water, climate, nature and other environmental legislation. Specifically, the EU Water Framework Directive (WFD, see chapter 1) plays a leading role and is the key tool for water policy. Here undisturbed sediment transport is mentioned as a normative definition for the high status of river continuity as one of the hydromorphological quality elements[51].

Based on the findings of the „Assessment Report on Hydropower Generation in the Danube Basin - 2013“, the amount of electricity production from hydropower will increase in most of the Danubian countries until 2020 in order to achieve the renewable energy targets (Figure 7).

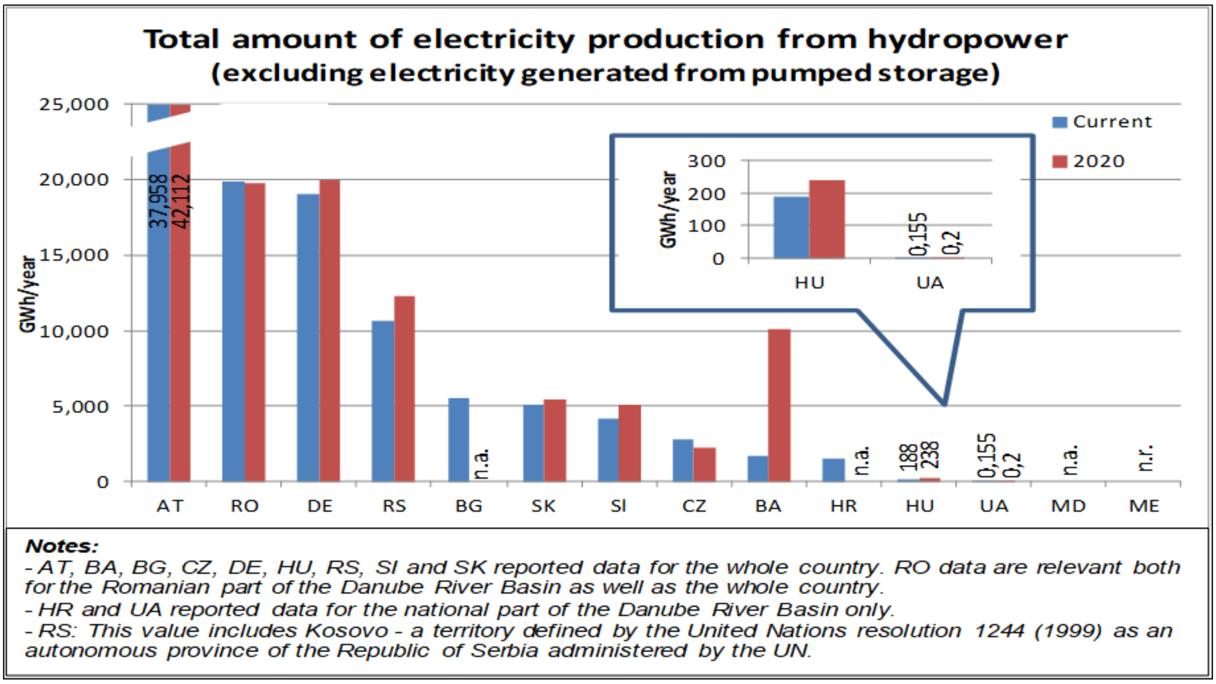

Figure 7: Total amount of electricity production from hydropower (excluding electricity generated from pumped storage) (source: „Assessment Report on Hydropower Generation in the Danube Basin“, 2013)

According to the projection trends in key economic indicators and drivers up to 2021, delivered by Danube countries in the frame of DRBMP update 2015, it is expected to register a significant growth till 2020 (*Table 29, DRBMP – Update 2015*). It was also mentioned that this expected growth *“can have significant impacts on water bodies (…) through hydro morphological impacts”[52].*

Flood protection is one crucial concern on the Danube Basin level. The impacts of major floods in the Danube River Basin may increase considerably in the future, since society is becoming more vulnerable to the damage and disruption caused by floods, and because

[51] Directive 2000/60/EC, Annex V
[52] ICPDR, 2013b

floods may become more serious and more frequent due to climatic changes. In this respect, the measures for flood protection will be proportionally implemented. It is expected that the countries will do their best to identify and implement natural retention measures as much as possible and do not entail disproportioned costs. At the same time, it must be recognised that the structural measures could not be avoided. Nevertheless, under the umbrella of the International Commission for the Protection of the Danube River (ICPDR) the countries are multilaterally cooperating towards a harmonized flood protection in the Danube River Basin.

In response to the danger of flooding the ICPDR adopted already at the ICPDR Ministerial Meeting on 13 December 2004 the Action Programme for Sustainable Flood Prevention in the Danube River Basin. The adoption of the EU Floods Directive had its impact also on the implementation of the ICPDR Action Programme incorporating the future developments of the EU flood policy.

Directive 2007/60/EC on the assessment and management of flood risks (EU Floods Directive, FD) entered into force on 26 November 2007. This Directive requires Member States to assess if all water courses and coast lines are at risk from flooding, to map the flood extent and assets and humans at risk in these areas and to take adequate and coordinated measures to reduce this flood risk.

Article 7 of the Floods Directive requires Member States to prepare flood risk management plans for all areas identified as being at potentially significant flood risk (APSFR) under article 5 or article 13.1(a), as well as older areas from before 2010 covered by article 13.1(b), based on the maps prepared under the article 6.

The first Flood Risk Management Plan of the Danube River Basin District (DRBD)[53] sets out appropriate objectives for the management of flood risk on the level of the international river basin district covering the whole Danube catchment. It highlights issues relevant for the basin wide perspective and as such it is complementary to the national flood risk management plans. These plans provide all necessary information on measures, flood maps and other national activities in the section of flood protection, prevention and mitigation in a more detailed way.

The Earth's **climate system has changed** over the past century. An increasing body of observations gives a collective picture of a warming world and other climate system changes. There is now new and stronger evidence that most of the warming observed over the past 50 years is attributable to human activities[54]. The global warming phenomenon has led to an increasing frequency of extreme events, the rapid alternation between severe heat / severe drought and abundant rainfall / floods being increasingly evident.

[53] ICPDR, 2015b
[54] IPCC, 2013

Climate change is having and will have an important effect on agricultural lands, forestry and waters, next to the direct impact from agriculture (among other sectors) through modifying land-use, habitat loss, degradation and indirect impacts including the accumulation of sediment in rivers. Having in view the research results[55,56,57] and following the Project Partners' discussions, it could be concluded that climate change represents an important driver in the water management and consequently on sediment management.

According to the IPCC, the Climate Change scenarios for the Danube River Basin[58] were analysed and for 2021-2050. For 2071-2100 the changes in precipitation and temperature values were predicted. There is a general agreement that extreme weather events are increasing in the most parts of the Danube basin. Generally, however, extreme events, especially heavy rainfall, are very difficult to model and therefore the results are linked with related uncertainties.

Naturally there are regionally opposing trends. For the Middle Danube Basin, a reversal of seasonal precipitation distribution is often indicated in research results. This means that currently, most precipitation falls during summer and least during winter. The projected changes anticipate that this pattern will significantly change in the future with a more uniform precipitation distribution over the Upper and Middle Danube Basin sections. In the same context, in the Lower section of the Danube, no significant changes are expected on precipitation for 2021-2050, but the temperatures will increase by a maximum of 5°C[59] according to the Special Report on Emissions Scenarios - IPCC SRES, 2007 A1B. The A1B scenario was developed by describing a future world of very rapid economic growth, a global population that peaks in the middle of the current century, and the rapid introduction of new and more efficient technologies.

An increase in air and water temperature, combined with changes in precipitation, water availability, water quality and increasing extreme events, such as floods, low flows and droughts, may lead to changes to ecosystems, life cycles, and biodiversity in the DRB in the long-term. Changes in precipitation patterns and an increase in torrential rain and flash flood events can lead to more intense soil erosion. Sediment input in the river system is likely to increase due to more extreme events and permafrost thawing. Being of primal importance for the close future, this subject needs to be dealt with in future projects and adaptation strategies, as it is out of scope of the current DanubeSediment project.

[55] Glowa-Danube project, 2010
[56] Nichersu, I., 2009
[57] Barret, S., Starnberger, R., Tjallingii, R, Brauer, A. & Spatl, C., 2017
[58] ICPDR, 2012
[59] IPCC SRES, 2007

1.5 Conclusion and outlook regarding interactions between key drivers and morphodynamics

The assessment of interactions of sediment regime and key drivers in the frame of the "*Activity 5.1 Review of key drivers and the impacts of significant pressures on sediment quantity for the Danube River"* shows, that at the moment, alterations of the sediment regime represent a relevant issue at the Danube Basin wide level. The key drivers "responsible" for this issue are navigation, flood protection and hydropower.

According to the presence of drivers in the Danube, navigation is the strongest key driver but flood protection and hydropower need be considered as a priority as well.

Regarding the major selected tributaries of the Danube, flood protection, hydropower, and navigation (relevant only in the Upper and Middle Danube sections) and water supply have a significant influence on sediment regime. This is mainly due to river dams, which disrupt the sediment transport.

Besides these key drivers, agriculture may also play a role in altering the sediment regime through land use and climate change. However, their detailed analysis lies outside the scope of this report.

Finding out "*who does what*" to the sediment regime might be possible after a comprehensive analysis of the sediment balance. The idea is to identify critical spots and corroborate them through an adequate assessment of drivers and significant pressures that act on the sediment regime. Therefore, a detailed comprehensive assessment of pressures and identification of significant pressures will be performed in the frame of DanubeSediment project in *The Report on the review of significant pressures on sediment transport in Danube* (chapter 2).

2 Review of significant pressures on sediment transport

2.1 General overview on significant pressures issue

2.1.1 Water Framework Directive and hydromorphological pressures

Rivers shape landscapes, transport water and sediment, help to maintain the natural balance of ecosystems and are used for many purposes. However, their capacity to fulfil these functions might be impaired by man-made structures (e.g. for hydropower generation, flood protection, navigation) high-intensity industrial or agricultural use. Hydromorphological alterations represent changes to the natural flow regime and structure of surface waters such as modification of bank structures, sediment continuity, gradient and slope etc. Consequently, these alterations can impact the aquatic fauna and flora and can henceforth significantly impact the water status.

Having in view the objectives of Water Framework Directive (WFD), there are four important steps to be followed in order to assess the pressures and their impacts in relation with the sediment regime: identification of activities that generate pressures, identification of significant hydromorphological pressures, assessment of impacts of those significant pressures and establishment of water bodies at risk of failing to achieve environmental objectives of the WFD (Figure 8).

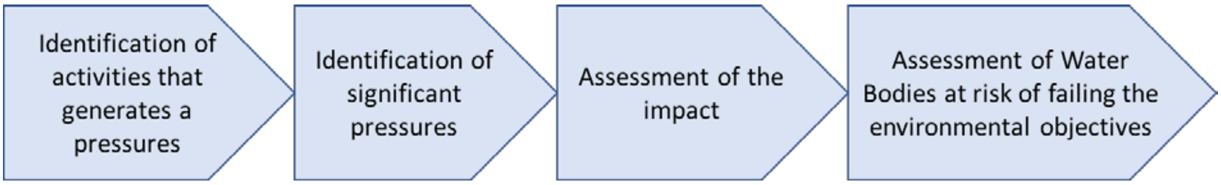

Figure 8: Steps for analysis of pressures and impacts on the water bodies (source: CIS Guidance Document no 3, Analysis of Pressures and Impacts, processed)

Nevertheless, the above schematical way for assessment of the pressure and impact refers to the approach in relation with Water Framework Directive, with the risk of failing to achieve the environmental objectives, as they are defined in the Article 4.1 of WFD[60]. The risk assessment in relation with sediment regime as a result of project *Activity 5.2 - Risk assessment related to sediment regime (continuity and quantity)* from *WP5 – Impact and*

[60] European Commission, 2000

measures, will approach and integrate not only WFD related aspects but also aspects regarding impact on main key drivers (e.g. navigation, flood protection).

The inventory of hydromorphological pressures is likely to contain all the pressures, including ones that have no impact or have a reduced impact on the water body status.

As it is defined in the frame of Common Implementation Strategy (CIS) *Guidance Document no. 3 Analysis of pressures and impacts*, a pressure represents "*the direct effect of the driver (for example, a direct effect of a barrier that causes a flow regime modification or regulation)*"[61].

"Significant" is interpreted as pressure or combination of pressures which contribute to an impact that may result in failing of environmental objectives defined in the Art. 4.1 WFD[62]. The identification of significant pressures could involve different approaches like field surveys, inventories, modelling, expert judgement or a combination of tools. Another option is to compare the magnitude of the pressure with a certain criterion or limit value (e.g. suspended load or bed load in case of sediment). Having in view the sediment issue, the assessment of whether a pressure is significant or not it should be based on knowledge of the pressures within the catchment area, with a conceptual understanding of flow regime, sediment dynamics and biological functioning of the water body within the catchment system.

This approach involves a scale dependence analysis in the way that different kinds of pressures have different impact in terms of space and time scale. It is obvious that in case of the sediment regime combined/multiple pressures (e.g. dams and dredging on the Danube River) may act over a relatively long temporal and spatial scale. The higher the number and retention capacity of the dams on a river or a sub-basin are, the more significant the retained and deficit volume of the sediment is.

An easier assessment of the relevant space and time scales is performed when it is considered that a pressure generates a modification in suspended load or bedload, exerted during a certain time over a certain size.

[61] European Commission, 2003
[62] European Commission, 2003

2.1.2 Addressing significant hydromorphological pressures in Danube River Basin Management Plans - sediment aspects

In the DRBMP 2009 and the DRBMP Update 2015 it is mentioned that "*investigations have also been and will be undertaken to identify relevant issues and their significance on the basin-wide scale. These include climate change, flood/drought events, and **sediment transport**"*[63].

Significant Water Management Issues (SWMI) addressed in the DRBMP on the basin-wide scale, based on WFD requirements, clearly indicate that hydromorphological alterations and their effects gained vital significance in water management due to their impacts on the abiotic sphere as well as on the ecology and ecological status of the river system[64].

The significant hydromorphological pressures include the following categories:

- disruption of longitudinal continuity for aquatic organisms and sediment transport, the alteration of river morphology and habitats,
- the disconnection of adjacent wetlands, floodplains,
- impoundments, water abstractions or diversions and hydropeaking.

Thereby significant hydromorphological pressures can induce a high degree of changes in flow dynamics, sediment continuity and river morphology. Hence, the alteration of sediment transport is a direct effect of the hydromorphological pressures.

The DRBMP Update 2015 highlights that "*transversal structures in the rivers like dams*[65] *and weirs*[66] *are interrupting the longitudinal continuity and therefore hinder fish from migration. Further effects can include changes of the natural river dynamics, river morphology as well as river bed incision due to the interruption of sediment transport*"[67].

The above-mentioned (both) DRBMPs indicate that when addressing pressures on basin-wide scale, it is clear that cumulative effects on alteration of the sediment regime may occur. This is one reason why the basin-wide perspective is needed, including in the frame of sediment issues.

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[63] ICPDR, 2015a
[64] ICPDR, 2015a
[65] According to International Glossary of Hydrology, UNESCO-OMM - 1992, Pierre Hubert, the term "dam" is defined as follows "*Barrier constructed across a valley to store water or to raise the water level*", very similar to the term "barrage" which is defined as follows: "*Structure across a stream, equipped with a series of gates or other mechanisms which control the water-surface level upstream to regulate the flow or to divert water supplies into another watercourse*".
[66] According to International Glossary of Hydrology, UNESCO-OMM - 1992, Pierre Hubert, the term "weir" is defined as follows: "*Overflow structure which may be used for controlling upstream water level or for measuring discharge or for both*".
[67] ICPDR, 2015a

In terms of longitudinal river continuity, the DRBMP Update 2015 highlights that *for the Danube River itself, 83 barriers were identified, most of them located in the Upper Danube, out of which 32 barriers are passable for fish by 2015. Although progress on addressing this issue is made, the Austrian/German chain of hydropower dams, the Gabčíkovo Dam (SK) and the Iron Gate Dams I and II (RO/RS) remain significant river and habitat continuity interruptions for the Danube River, posing problems for long and medium distance migratory fish*[68].

Effects of large dams like Gabčikovo (in the Upper Danube), Iron Gate I and II (in the Lower Danube) are associated with long impoundments and implicitly with sedimentation on upstream and sediment deficits downstream of the dams.

2.1.3 Gaps and uncertainties

Despite the detailed picture on hydromorphological pressures that the DRBM Plan – update 2015 conveys, there are some data gaps and uncertainties regarding sediment-related pressures. For example, a harmonization of the different sediment monitoring methods throughout the Danube river basin is needed, hotspots and boundaries for significant pressures must be defined, and the interactions among pressures, sediment-specific issues as amount, type and dynamics and ecological aspects need further analysis. Within the updated pressure assessment, key drivers, significant pressures and their influence on the water status on the basin-wide scale are identified.

By adding comprehensive information regarding the sediment's relationship between sediment retention and transport due to different pressures and downstream sediment quantity, the identification of sediment behaviour will be improved. More information will complete the risk assessment related to sediment regime (subject of Activity 5.2 in the project) and a more coherent framework for decision factors will be available to decide on adequate and sustainable measures.

[68] ICPDR, 2015a

An illustration of the sediment related topics which need to be improved to take appropriate actions on Danube basin-wide level is presented below in Figure 9.

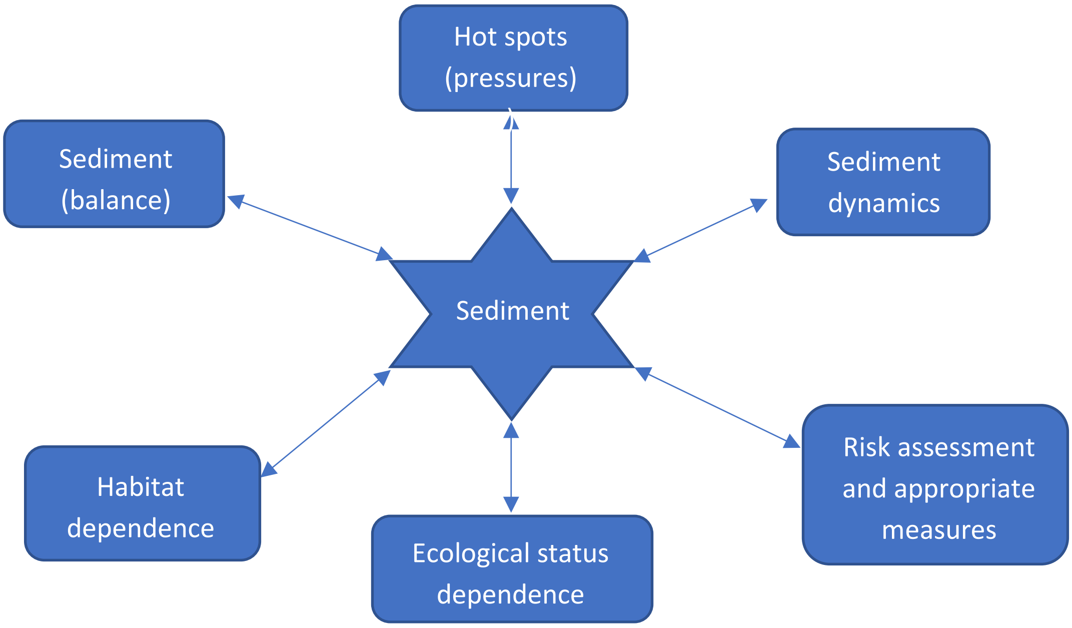

Figure 9: Gaps and uncertainties knowledge in relation to sediment regime

The hydromorphological assessment represents an important aspect which must be considered. Hydromorphology is a basic support for biotic communities in streams and rivers. Rivers are characterised by a dynamic environment, constantly changing due to variations in flow and sediment transport. These variations and the resulting physical alterations of the river bed, banks and riparian zones are important boundary conditions for riverine ecosystems.

2.2 Using the DPSIR concept for sediments

2.2.1 Short overview of DPSIR

The concept of DPSIR (Driver, Pressure, State, Impact, Response) introduced in sub-chapter 1.2 from present Report, is the basis of analysis type proposed to tackle the sediment related pressure and impact.

According to the DPSIR framework there is a chain of causal links starting with '*driving forces*' through '*pressures*' to '*states*' and '*impacts*' leading to several types of '*responses*'. The DPSIR approach is a cyclic, iterative and complex process, considering the (continuous) changes of significant pressures generated by different driving forces, the (continuous) changing of water status, corresponding impact and related measures (Figure 10).

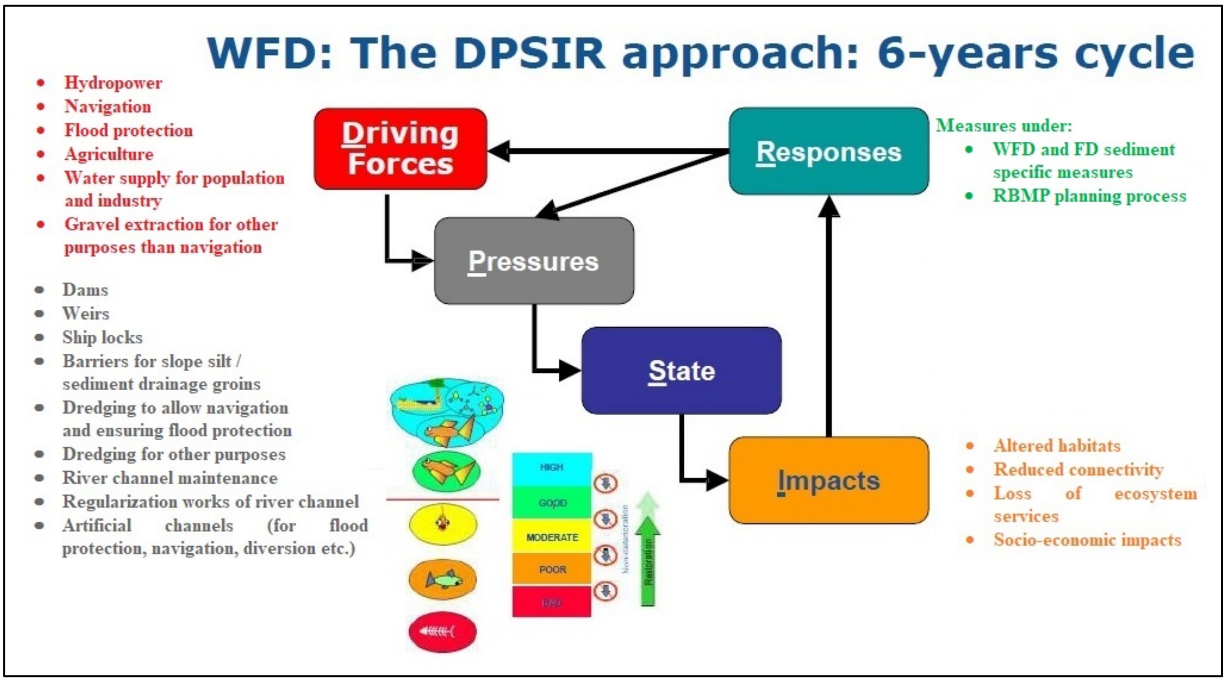

Figure 10: WFD: DPSIR approach (adapted from Peter Pollard, Scottish Environment Protection Agency)

The DPSIR concept together with methodologies for the assessment of significant pressures and significant impacts have been demonstrated to be an essential approach in assessing the risk of failing to achieve the objectives of the WFD.

2.2.2 DPSIR conceptual framework and sediment

When assessing the risk of failing to achieve the WFD objectives, the sediment issues must be considered in a more comprehensive manner and not only in terms of quality, but also quantity. Using the DPSIR conceptual framework, by considering significant pressures which act on sediment regime, the risk assessment process will definitely be improved.

Following the DPSIR concept, the main significant pressures that affect the sediment balance and transport continuity have been identified as follows: dams, weirs, ship locks, sediment drainage groynes, dredging to allow navigation and ensuring flood protection, dredging for other purposes (i.e. industrial use, ecological restoration), river channel maintenance, regularisation works of river channel, and artificial channels (for flood protection, navigation, diversion etc.). The above-mentioned hydromorphological pressures can mainly have a direct impact on hydromorphological and biological status of surface waters (e.g. dredging and sediment disposal can produce smothering of bed, alteration of invertebrate communities).

Each pressure acts in a different way and on different scales and pathways. River dams, for example, cause a loss of sediment downstream of the barrier, but at the same time cause a sedimentation in the impounded area upstream of the barrier. Disconnection of floodplains will increase transport capacity and, thus, shear stress on river bed. Groynes influence the sediment supply of the river bank.

When we talk about impact, erosion and sedimentation represent a direct effect of the sediment related pressures. Hence, downstream of dammed rivers, it is obviously a decrease of riparian zones and wetlands due to the loss of transported sediment. Erosion downstream of a river dam or weir is common. The discharge downstream of a dam will entail new sediment from the bottom and river banks, in order to reach a balance of energy that is needed to maintain the flow and transport the sediment. Maybe the most sensitive key element in DPSIR framework is the response to mitigate the impact of different pressures. It is obvious that pressure assessment should be accomplished in a very comprehensive manner by integrating the historical and present sediment monitored data.

An effective sediment basin-wide management supposes a site-specific response. The processes controlling sediment transport and sedimentation are dynamic and highly variable. Therefore, an effective sediment management must be site specific, by acting on the level of each significant pressure and understands the dominant spatial and temporal processes operating by the pressures at the basin-wide level.

2.3 Assessment of the sediment related pressures

2.3.1 Questionnaire results on pressures assessment

Inventory of the hydromorphological pressures in relation with the alteration of the sediment regime was based on the data and information collected through the questionnaires (see Annex no. 1) provided by the following countries: Germany, Austria, Slovakia, Hungary, Slovenia, Croatia, Republic of Serbia, Romania and Bulgaria. The questionnaire refers also to an inventory of significant pressures and criteria for defining the significant character of those pressures.

Analysis of the pressures related to alteration of the sediment transport has been performed according to geomorphological characteristics of the Danube. Therefore, the Danube basin was divided into three sections (Upper, Middle and Lower Danube), as it was detailed in the sub-chapter 1.3.1.

Pressures have been grouped in categories based on associated main types of works and indicators which might lead to alteration of the sediment regime and was not assessed from significance point of view (Table 4):

Table 4: Pressure categories

Pressures Categories		Indicators describing the pressure category
Interruption of longitudinal continuity	dams, weirs, sluices, groynes	Density of barriers (no./km) or height of obstacle (cm)
	Reservoirs (impoundments) with hydropeaking effect	Gradient of decreasing/increasing water level (cm/h)
Morphological alteration due to dredging	Dredging / extraction	Dredged / extracted volume (Mio m^3)
Interruption of lateral connectivity	dykes agricultural and fish ponds	Length of dykes/length of water body (%)
		Affected area/floodplain area
	regulation works in the river channel, cutting meanders, artificial channels, river channel maintenance	Length of regulation works/length of water body (%)

Referring to the interruption of longitudinal continuity, the flow dynamics is influenced by the operation of chains of hydroelectric power plants (more representative in the Upper Danube basin). These dams create a cascade of impounded river sectors that act as a barrier for sediment transport. Subsequently slowly flowing sections upstream of dams are impounded and a more dynamic flow occurs in short section downstream of dams. *Gabčíkovo dam in Upper Danube and the Iron Gate at lower end acts also on flow conditions of Danube River. The flow dynamics in the river section which is out of the major effect of above both HPPs are mostly influenced longitudinally by in-stream structures (e.g. groynes) and laterally by side arms closure. Effects of these interventions can be substantial but mostly local. Slowly flowing sections alternate more dynamic sections*[69].

[69] Schwarz, U.; Holubova, K.; Cuban, R.; Matok, P.; Busovsky. J., 2014

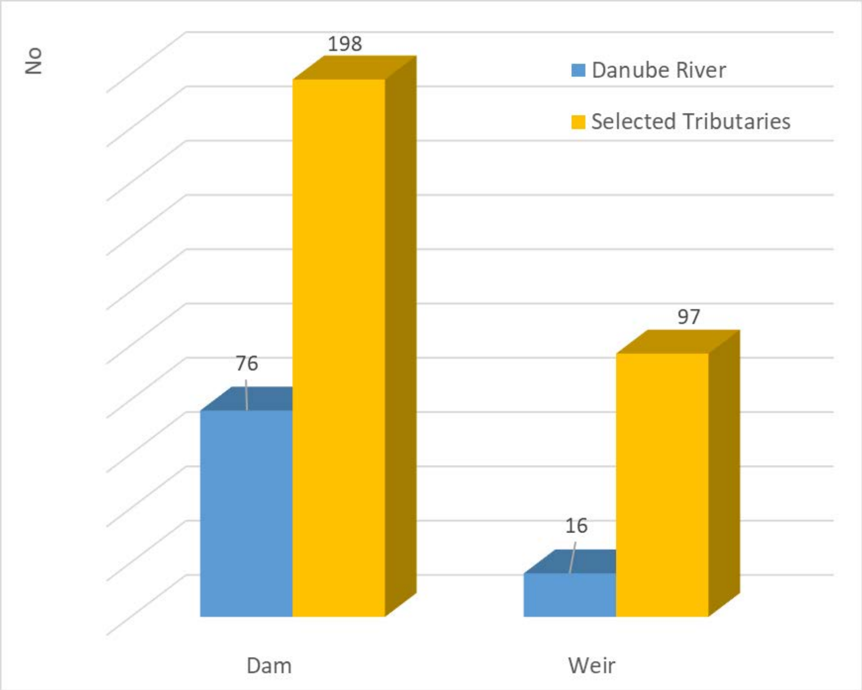

Figure 11: Pressures related to interruption of the longitudinal continuity of the sediment transport (Danube River and selected tributaries)

Concerning the longitudinal river continuity, out of a total of 1262 pressures, 747 were identified on the Danube River and 515 on its major selected tributaries. The number of transversal structures (dams, weirs) is also indicated (Figure 11).

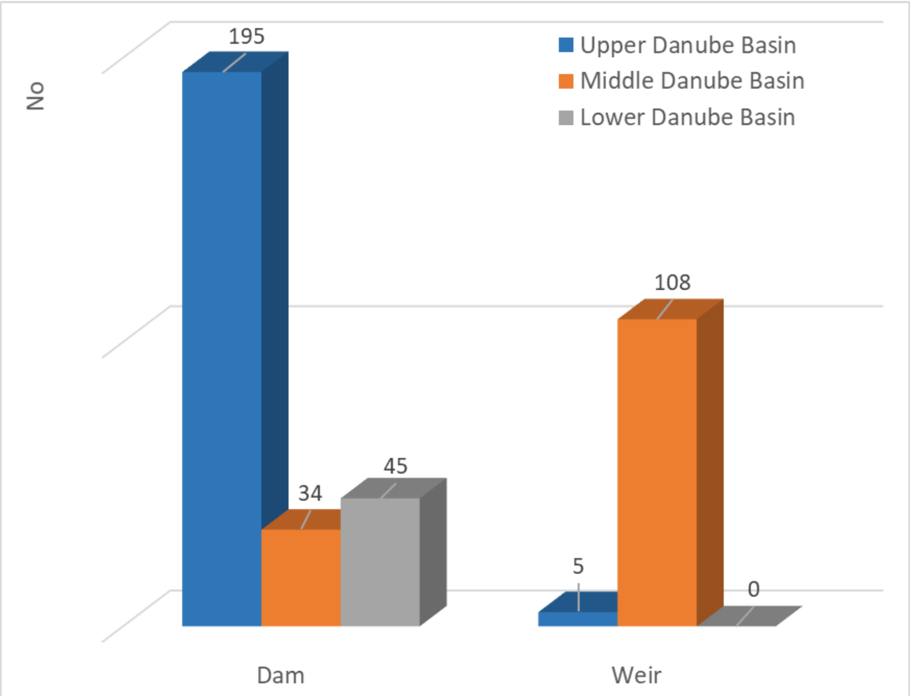

Figure 12: Pressures related to interruption of the longitudinal continuity of the sediment transport (Upper, Middle, Lower Danube Basin)

These 1262 pressures mentioned above, were analysed on the level of the three sections of the Danube river basin: 705 pressures in the upper section, 512 pressures in the middle section and 45 pressures in the lower section. A number of 274 dams, 113 weirs has been identified (Figure 12). Also, additional to the figure mentioned above, a number of 815 groynes and 60 sluices (accompanying a dam, a HPP or any other transversal structures) has been indicated.

Impoundments are an important part of this category of pressures that interrupt continuity. At the Danube river level, the impoundments identified stretch on 480 km^2 and on the major selected tributaries level, the impoundments cover a total area of 633 km^2 (based on GIS data provided by PPs).

Groynes are usually constructed for the stabilization of the projected river line. They concentrate and consequently increase the river flows and generate an effect on flow dynamics and even on sediment erosion. The groynes might lead to a longitudinal interruption when they are filled with fine material (e.g. in Serbia - one of the design criteria of the groynes is that they fill up with fine sediments – a sediment sink); in Austria for instance the aim is the lateral constriction of the river width to get the necessary depth in the fairway and they are acting more as a lateral interruption (no bank erosion/lateral movement) than a sediment sink; in Hungary it can be mentioned the “T-type groynes” and the parallel training walls, creating a lateral interruption, also.

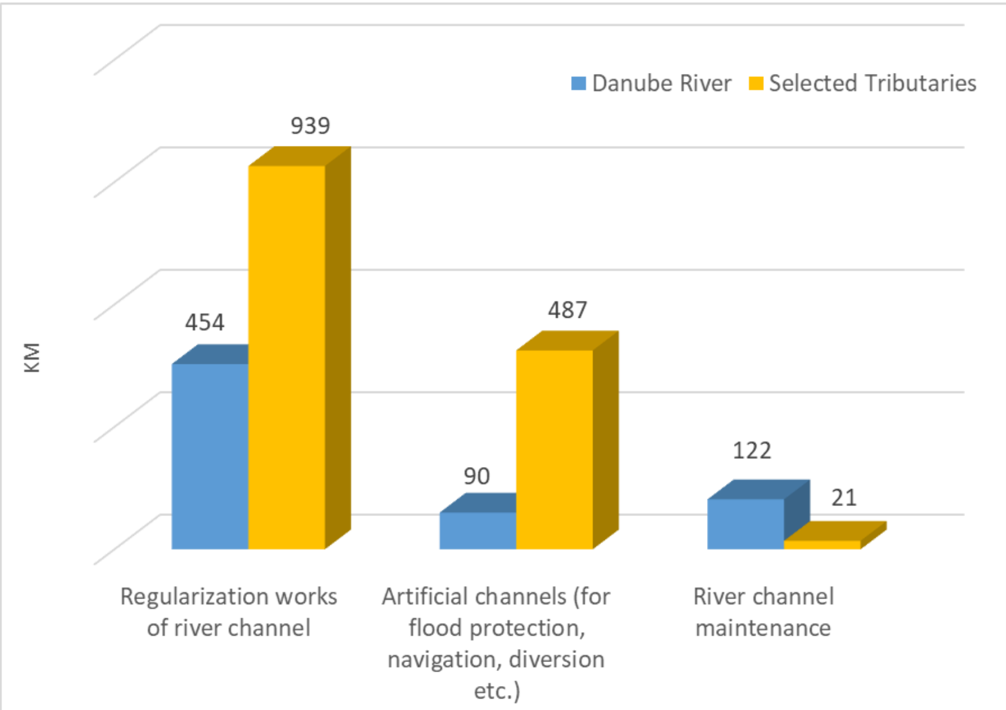

Figure 13: Pressures related to interruption of the lateral connectivity of the sediment transport (Danube River and tributaries)

Concerning the lateral river connectivity, the Figures 13 and 14 give an outlook of the absolute length of the Danube stretches which are influenced by infrastructure that has an impact on the river bed. Thus, 454 km of the Danube River and 939 km of the major selected tributaries consist of regulation works, artificial channels and river bed maintenance works.

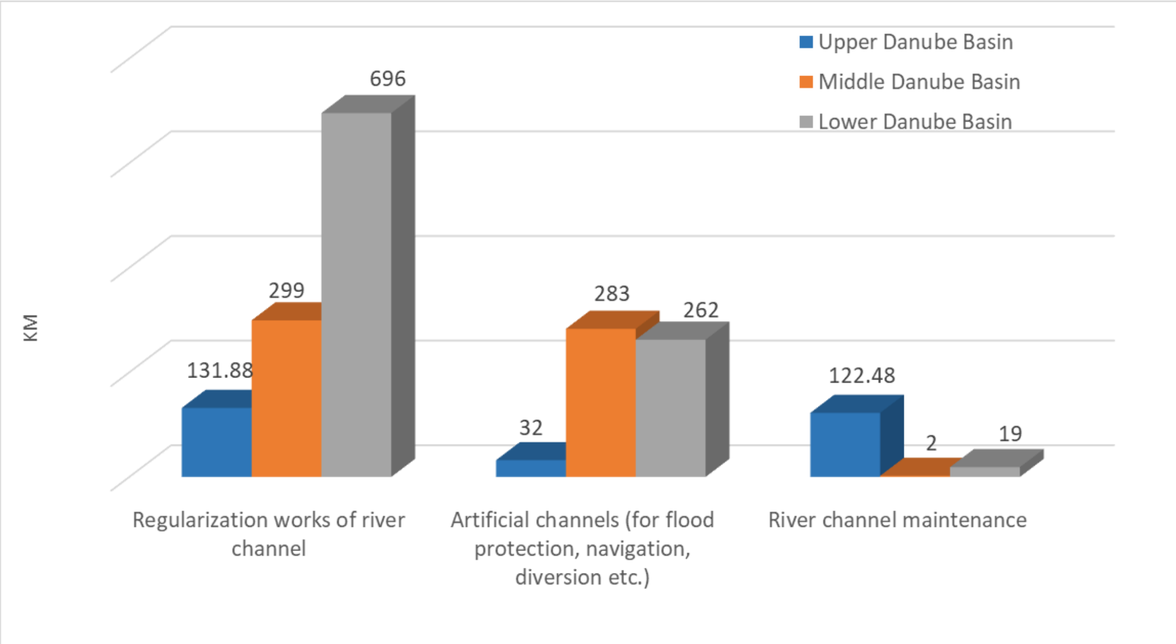

Figure 14: Pressures related to interruption of the lateral connectivity of the sediment transport (Upper, Middle, Lower Danube Basin)

Regarding their distribution on the Danube Basin sections, they sum up to 132 km in the Upper section, 299 km in the Middle section and 696 km in the Lower section (Figure 14).

By looking at the different categories of pressures impacting river connectivity in the Danube and its main tributaries (Figure 13), regulation works of the river channel represent the most relevant pressure according to the length of stretch (1126 km). Further pressures are artificial channels that cover 577 km and river channel maintenance (over 143 km).

At the Danube river basin level, 7807 km of dykes were identified on the Danube River and 2254 km on the tributaries. Related to the high number of kilometres of river dykes, this is due to two particular situations:

- In some cases, the length of dykes counted includes both river banks,
- In other cases, the dykes are doubled in order to strengthen flood protection.

The figures presented above represent the total number of dykes' length.

The distribution of this pressure (dykes) on the level of the sections of the Danube River basin is as follows:

- All major selected tributaries and national sectors of the upper section of the Danube River Basin (4757 km);
- In the middle section on the selected tributaries in Hungary (Laitha, Raba, Mosoni-Danube), the Slovakian tributary Vah, also on part of the national Slovakian, Hungarian and Serbian national sector of Danube River (2193 km);
- In the lower Danube in all selected tributaries and national sectors of the Danube river (3112 km).

Dredging for navigation and flood protection has been also identified as pressure which acts on sediment regime. Dredging occurs along the national sectors of the whole Danube (in Germany, Austria, Croatia, Slovakia, Hungary, Serbia, Romania and Bulgaria) and in some major selected tributaries (e.g. Vah/Slovakia, Drava/Croatia sector and Sava/Croatia and Slovenia sector). Dredging activities are performed to allow/ensure an optimal capacity/depth of the river channel and maintenance of the natural thalweg, which contributes to the flood risk reduction as well.

The detailed situation of identified significant pressures for each national sector of the Danube river and all major selected tributaries can be seen in *Annexes 3 a-c. Maps of spatial distribution of significant pressures related to sediment regime on major selected tributaries and national sectors of the Danube River, as points (Map A), lines (Map B) and polygons geometry (Map C)*. The data were provided by all PPs involved in a shapefile data collection.

2.3.2 Inventory of the significant pressures and criteria

As it was previously mentioned, the WFD states that ''significant pressures must be identified'', being defined as any pressure that, on its own or in combination with other pressures, may lead to a failure to achieve the specified environmental objective (European Commission, 2003).

The answers provided in the frame of the questionnaire indicate that the significant character of the pressure is given by a set of rules and abiotic criteria (thresholds) mainly addressing the modifications of hydromorphological parameters (hydromorphological quality elements) included in the hydromorphological status (e.g. river continuity; quantity and dynamics of the water flow, structure and substrate of the river bed). Neither of the mentioned rules or criteria envisage a certain limit or thresholds directly address the sediments in terms of amount or suspended sediment concentrations or bedload.

Assessment of the criteria provided by the PPs indicates that such an approach cannot be valid using one set of thresholds across the Danube river basin.

This is mainly due to different scales of assessment (river water bodies, river stretches), different characteristics of the pressures (e.g. magnitude, combination of pressures or a single pressure), different relationship between pressures and river hydromorphology parameters (alignments of the rivers, width of river bed, riparian zone, vegetation of the river banks, connection with the floodplains).

Criteria for establishing the “significant hydromorphological pressures” were defined by each country in their national methodologies and the criteria mainly address the WFD requirements in the meaning that the significant pressure contributes to an impact that may result in the failing of achieving the environmental objective and do not specifically address sediment issues. Morphological and hydrological features of the rivers are generally assessed on a national level as key parts in the process of evaluation and classification of the hydromorphological status.

In the dedicated section of the questionnaire, the questions refer to the specification of criteria for assessment of significant pressures in relation with sediment regime and ecological status/potential and to their description.

Annex 4 presents a synthesis of answers from the questionnaire which summarizes the criteria of assessment of different river hydromorphological features provided in the context of significant pressures and used by each project partner.

2.3.3 Inventory of sediment management policies

In the questionnaires, the project partners indicate policies (e.g. guidelines for implementing measures, management policies or operational guidelines) that target and ensure sediment transport and continuity. The synthesis of the contributions is presented below.

For the lower sections of the Danube river, operational rules for Iron Gate I and II on the Danube river address the sediment regime (according to Romanian-Serbian Law no. 14/1999). No measures have been mentioned for the BG national sector of the Danube River. In the Middle section of the Danube River, sediment specific policies and measures are not specified for large national sector, e.g. in Hungary and Serbia. On a few sectors from Upper Danube River there are operational rules and policy measures in place ensuring sediment transport and continuity. Feeding of sediments downstream of the last dam in some cases are also in place (AT).

Details about sediment management policies given in the questionnaire are presented in Annexes 5a and 5b.

In general, concerning the selected main tributaries of the Lower section of the Danube River basin, the sediment is discharged, usually through the bottom outlet of river dams but the operational rules do not include specific provisions related to the issue of sediments.

For example, the Drava and Sava (HR) in the Middle section of the Danube River Basin, sediment specific measures are in place.

With one exception - the Morava River - the Upper section of the Danube River Basin offers an overall picture where policies and measures to improve the continuity of sediment transport are in place.

2.3.4 Gaps and uncertainties

A key step in the process of assessing hydromorphology of a river is the hydromorphological characterization which means to look at rivers from a perspective that discloses the relevant processes and forms. Hydromorphology is a matter of water and sediment, but also of habitat consisting of water and sediment. This makes both geomorphological and ecological processes relevant.

In general, the project partner countries in the Danube River Basin apply a large variety of hydromorphological assessment methods with notable differences in terms of aims, spatial scales and approaches and consequently with specific strengths and shortcomings[70]. Links between hydromorphology and biology still represent a challenge.

The Danube River Basin Management Plan Update 2015 mentioned that at a Danube Basin-wide, the hydromorphological alterations and their effects gained important significance in water management field. This is due to their relevant impacts on the abiotic sphere as well as on the ecology and ecological status of the river system. The significant character of a hydromorphological alteration is based on the intensity and magnitude of the pressure described by a parameter/ indicator/ threshold. The criteria/parameters/ indicators which reflect the significant character of the pressures are generally of abiotic nature (i.e. density of barriers in no./km or height of the obstacle). In general, if the longitudinal continuity was interrupted by the artificial structures, the sediment transport is one of the assessment categories in the hydromorphological assessment process that needs to be surveyed and assessed. Also, biota is an important element in the defining of the significant pressures.

However, within the Danube River Basin Management Plan Update 2015 the direct link between sediment and the criteria defining the significance of pressures is missing. Sediment should therefore be included in a holistic approach aiming to determine the significant character of the pressures on the waterbody level/ stretch/ section.

[70] REFORM, 2015

To propose measures for water managers related to an impact caused by a river longitudinal continuity interruption (transversal structure), it is necessary to know the interlinkage between the necessary amount of sediment and a healthy aquatic ecosystem. Only then the rehabilitation methods which restore the sediment regime in a proper and efficient way could be identified.

The need for hydromorphological assessments to consider a more comprehensive, process-based approach has also been seen by the European project REFORM, which clearly indicates: "In most EU Member States, the consideration of physical processes remains the main gap in hydromorphological assessment methods". The integrated use of different components of the assessment is limited but is recently increasing. There is a need for more comprehensive process-based hydromorphological assessments that consider the character and dynamics of river reaches and how these are affected by present and past natural and human-induced changes within the catchment as well as the reach level".

2.4 Proposed criteria for defining the significance of pressure in relation to sediment transport continuity

The process of identifying and assessing criteria to define the significant character of a certain pressure in relation with the sediment regime should be clearly integrated in the process of risk assessment (i.e. analysing pressures and their impacts).

Within the DanubeSediment project, it is difficult to perform an outlook for sediment issues on a broader scale due to the large variety of location-specific pressures and their respective impacts on sediment.

The results of WP4 clearly indicate a decrease in bedload discharges and suspended sediments from upstream to downstream locations on the Danube River when comparing the actual data with the data for the period 1960-1970.

In the context of sediment, anthropogenic pressures along different Danube sectors could be important for one sector but less important for another. This is mainly due to differences at spatial scale such as the physical degradation of the river bed by erosion, widening by bank erosion, a decrease of the river bed depth due to sedimentation processes, an increase in the number of islands and secondary branches or an increase in the number of navigation bottlenecks. Therefore, the criteria to determine the significance of a pressure on a wider scale is very important to be harmonized on the Danube-wide scale.

In the frame of the *Activity 5.2* from *WP5 – Impact and measures*, the risk assessment approach proposes to combine the significant pressure identification with the sediment data and the hydromorphological assessment by trying to identify a set of criteria that if are exceeded, they could pose a risk on biota and on achieving the environmental objectives.

Sediment data (hydrology, bathymetry, river bed dredging and sediment disposals) in relation to sediment budget such as sediment sources, sinks and redistribution of sediments and longitudinal profile, represent the basis in the risk assessment process. Hydromorphological assessment and biological response estimation should be further considered within the frame of the *Activity 5.2* from *WP5 – Impact and measures*.

2.5 Conclusions and outlook regarding the review of significant pressures on sediment transport

As this report has shown, hydromorphological alterations, which act on the sediment regime on the Danube Basin-wide scale, are evident and are generated by the following anthropogenic pressures: longitudinal continuity interruption (dams, weirs, sluices, groynes, dredging), lateral continuity interruption (dykes, regularization works in river), navigation.

Establishing the significant character of the pressure in relation with the sediment regime by making correlation with sediment related features like suspended sediment and/or bed load or changes in river bed profiles is a complex and challenging issue. As was mentioned, the current approaches of the Danubian countries do not refer directly to sediment but rather to hydromorphological features.

The river morphological and hydrological features are generally assessed by the countries as the key parts in the evaluation and classification of hydromorphological status and ecological status process in the frame of the WFD.

Sediment data assessment in different sectors of the Danube River and selected project tributaries indicates a sediment regime that features a disturbed system at various scales as a direct effect of the significant pressures in relation with the sediment regime.

Combined impacts of dams and weirs with hydropower, flood protection or water supply purposes and dredging to ensure/optimize the navigation fairway and regulation of the river channel have been identified as being responsible for specific alterations of sediment regime (lack of bed load and suspended load in the remaining free-flowing sectors).

Comparing to the middle and lower Danube, dams and weirs are present in a much larger number in the Upper part, both on Danube River and tributaries. Dredging, which is performed to maintain and improve the navigation conditions on the Danube River but also for commercial purposes and flood protection, is significantly present along the Danube River.

Moreover, long sectors of the Danube River have been narrowed, channelized, disconnected from floodplains, and morphologically altered through regulation works and maintenance works. These have caused increased bottom shear stresses, increased sediment transport capacities and in addition a lack of lateral self-forming processes and corresponding reduced morphodynamics in the non-impounded sectors.

To reach a Danube-wide comparison, proposals of criteria to determine the significant character of a pressure in relation to the sediment regime are needed. This task must be interlinked with a risk assessment analysis, which identifies possible qualitative or quantitative criteria concerning the risk of the sediment regime having an impact on the natural and human environment, e. g. on ecology, flood protection or navigation.

List of Abbreviations

Art. - article
APSFR - Areas with Potential Significant Flood Risk
AT - Austria
BG - Bulgaria
BME - Budapest University of Technology and Economics
BOKU - University of Natural Resources and Life Science
BQEs - Biological Quality Elements
CEN - European Committee for Standardization
CIS - Common Implementation Strategy
DBA - Danube Basin Analysis
DE - Germany
DPSIR - Drivers-Pressures-State-Impact-Response
DRB - Danube River Basin
DRBD - Danube River Basin District
DRBMP - Danube River Basin District Management Plan
DRPC - Danube River Protection Convention
EAEMDR - Executive Agency "Exploration and Maintenance of the Danube River"
EEA - European Environment Agency
ERDF - European Regional Development Fund
EQS - Environmental Quality Standard
EU - European Union
EUSDR - EU Strategy for the Danube Region
FD - EU Floods Directive 2007/60/EC
FP EG - Flood Protection Experts Group
FRMP - Flood Risk Management Plan
GES - Good Ecological Status
GDP - Gross Domestic Product
GLC - Global Land Cover
HPP - Hydroelectric power plant
HR - Croatia
HRVODE - Hrvatske vode (Croatian Waters)
HU - Hungary
HYMO EG - Hydromorphology Experts Group
IAD - International Association for Danube Research
ICPDR - International Commission for the Protection of the Danube River
IPA - Instrument for Pre-Accession Assistance

IPCC SRES - Intergovernmental Panel on Climate Change - Special Report on Emissions Scenarios
IzVRS - Institute for water of the Republic of Slovenia
JCI - Jaroslav Černi Institute for the Development of Water Resources
JDS - Joint Danube Survey
JRC - Joint Research Centre
NARW - National Administration "Romanian Waters"
NIHWM - National Institute of Hydrology and Water Management
NIMH-BAS - National Institute of Meteorology and Hydrology – Bulgarian Academy of Sciences
Non-EU - non-European Union Member State
NUV 2 – RBMP - 2nd River Basin Management Plan in Slovenia
OECD - Organisation for Economic Co-operation and Development
PA - Priority Area
PPs - Project Partners
PSR - Pressure-State-Response
QEs - Quality Elements
REFORM - Restoring rivers for effective catchment Management project
RBM - River Basin Management
RBMP - River Basin Management Plan
RBSP - River Basin-Specific Pollutants
Rkm - River kilometre
RO - Romania
RS - Republic of Serbia
SAMS - Sustainable Asset Management System
SK - Slovak Republic
SI - Slovenia
SWMIs - Significant Water Management Issues
TEN-T - Trans-European Network – Transport
TUM - Technical University of Munich, Hydraulic Research and Water Resources Management
VUVH - Water Research Institute
WFD - EU Water Framework Directive 2000/60/EC
WP - Work Package
WPLs - Work Package Leaders

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Annexes

Annex 1: Completion guidance for Questionnaire: “Templates for identification of key drivers on national level” (for Danube River national sector and major selected tributaries)

The **DPSIR** (**Driver-Pressure-State-Impact-Response**) concept is used for the pressure and impact analysis, so it is necessary to include information on anthropogenic activities and changes induced in the sediment regime and the response (measures taken to improve the current situation). Figure 1 illustrates the DPSIR analytical scheme.

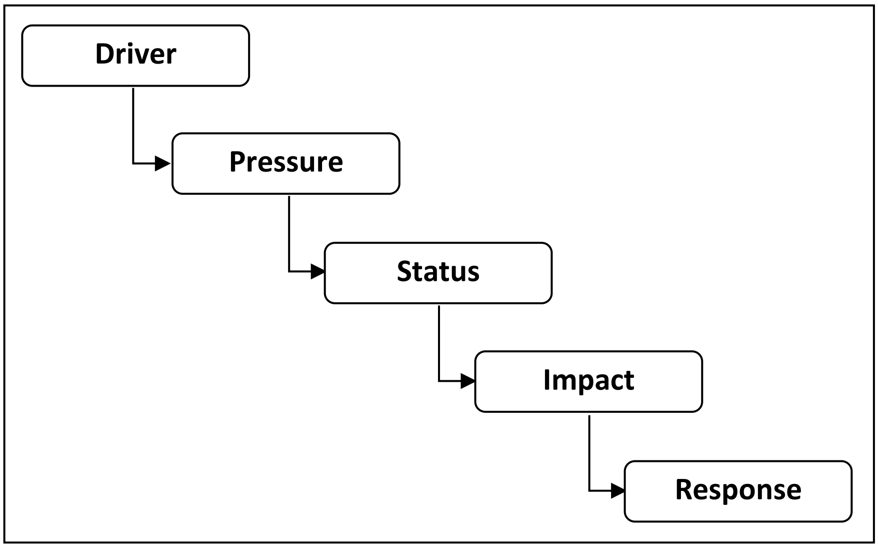


Figure: Illustration of the DPSIR concept

In the Activity 5.1 of the project, information needed about activities and pressures that may impact the sediment regime are collected through the Questionnaire. The questionnaire should be filled for each national sector of Danube River and for each major selected tributary where the identified pressures affected the sediments are located.

For common sectors of Danube River, each Partner will complete the data regarding only national side, and NARW – PP3 will make the harmonization of information.

Table: Questionnaire

#	Question	Completion guidance
	Section: BASIC INFORMATION	
1.	**Country:**	Complete name of your country
2.	**Project Partner:**	Complete fully name of your institution /organization
3.	**Name of person filling the questionnaire:**	Complete the name of the person indicated as contact for this questionnaire issues
4.	**E-mail address:**	Indicate valid e-mail address for contact
	Section: IDENTIFICATION	
5.	**Name of river**	Complete ***Danube River national sector*** or ***the name of the major selected tributary***
	Section: KEY DRIVERS	
6.	**Key drivers for pressure in relation with sediment balance / transport continuity**	According to *Guidance Common Implementation Strategy - CIS 3 Pressure and impact*: an anthropogenic activity that may have an environmental effect (i.e. hydropower, agriculture, navigation etc.). Please, select one or several options • *Hydropower* • *Navigation (including gravel extraction for navigation purposes)* • *Flood protection* • *Agriculture* • *Water supply for population and industry* • *Gravel extraction for other purposes than navigation (i.e. infrastructure development)* • *If **other**, please specify: ……………….* There are cases where one driver is related to more than one pressures.
	Section: SIGNIFICANT PRESSURES	
7.	**Pressures affecting the sediment balance / transport continuity**	Please, select one or several options • *Dam*[1)] • *Weir*[2)] • *Ship locks* • *Barriers for slope silt/sediment drainage* • *Groins* • *Dredging to allow navigation and ensuring flood protection* • *Dredging for other purposes (i.e. infrastructure works)* • *River channel maintenance* • *Regularization works of river channel*[3)]

#	Question	Completion guidance
		• *Artificial channels (for flood protection, navigation, diversion etc.)* • *If **other**, please specify: …………………*
8.	**Indicator describing the pressure category**	i.e.: • for dams, weir, ship locks, groins – number; • for dykes, river channel, regularization works, artificial channels – km; • for dredging – 1000 m^3/year etc.
9.	**Is there any pressure selected in the point 7 assessed as significant pressure based on predefined criteria in relation with sediment regime and /or ecological status/potential?**	• *Dam* • *Weir* • *Ship locks* • *Barriers for slope silt/sediment drainage* • *Groins* • *Dredging to allow navigation and ensuring flood protection* • *Dredging for other purposes (i.e. infrastructure works)* • *River channel maintenance* • *Regularization works of river channel)* • *Artificial channels (for flood protection, navigation, diversion etc.)* Please select one or several options (by marking with YES) or don't in case of no pressure has been identified as significant one.
10.	**In case of YES, please specify the criteria, if more than one pressures has been assessed as significant pressure this has to be detailed in the point 10. Specify the criteria:**	Specify the criteria By 'significant pressure' is meant that it is any pressure which may lead to a failure to achieve one of the Water Framework Directive objectives (CIS Guidance 3 Pressure and Impact https://circabc.europa.eu/sd/a/7e01a7e0-9ccb-4f3d-8cec-aeef1335c2f7/Guidance%20No%203%20-%20pressures%20and%20impacts%20-%20IMPRESS%20(WG%202.1).pdf). The criteria for defining if a pressure is significant or not could take into consideration the type of pressure, the magnitude or the effect of the pressure on ecological status /potential Criteria could be for example abiotic ones, like: exceeding a certain quantity of dredging, or embankment a river for more than a certain % from entire length, etc. Any other qualitative and quantitative criteria.

#	Question	Completion guidance
		Also, please specify if the pressure has been assessed as significant pressure based on **expert judgment.**
11.	**Description of the criteria, the methodology/guidance used:**	Comparing to the point 10 where the criteria should be listed, in the point 10 a shortly and comprehensive description of these criteria/methodological base should be fulfilled. Please provide descriptive text or link or send by E-mail
12.	**Which characteristics / parameters of the sediments quantity are affected?**	The point 12 envisages parameters collected and analysed in WP3 and WP4 activities, and refers to those sediment related parameters which are affected by the pressures identified in the frame of point 7. The analysed parameters should be correlated with the information from WP3 and WP4 results. Please, select one or several options • *suspended sediment load* • *granulometric composition of the river bed* • *bed load* • *particle size fraction of suspended load/bedload* • *If **other**, please specify: (Ex.* Timing: in the past small floods transported already a significant amount of sediments, today only very large floods (when the gates are opened) transport these) This data/information are needed for quantitative assessment of impact.
13.	**Is there in place facilities / measures / management policies in order to ensure sediment transport and continuity?**	Mark “yes” or “no”.
14.	**In case of YES, please shortly describe:**	Note that “transport facilities” meaning the works/measures to facilitate the transport of sediments (i.e. reservoir operation rules for sediment release/automatic transport). The facilities/measures could envisage either bad load but also suspended loads
15.	**There are any studies, projects etc. available regarding identified**	Please, provide information about relevant studies or insert link/URL to official project

#	Question	Completion guidance
	pressures affecting sediments regime? Please insert link, title, reference on pressure that is the subject of the study, projects, etc.	website.
	Section: EFFECT OF THE PRESSURES	
16.	**Have been assessed the impact of hydro-morphological pressures on the sediment quantity, continuity and balance (including results from research studies, projects etc.)?**	Mark "yes" or "no".
17.	**Have been assessed the effect of the changes in sediment quantity, continuity and balance (according to point 16) on the relevant biological elements?**	Mark "yes" or "no".
18.	**In case of YES, please shortly describe the impact and the effect (referring to the points 16, 17):**	Describe the results of assessments of the link/effects between the sediments regime and biological elements. Insert link to relevant documents, if available or send by Email
19.	**Considering the whole Danube catchment or sector have been assessed the relation of sediment transport changes (yield, transport and deposition) to land use and climate changes?**	Mark "yes" or "no".
20.	**In case of YES, please shortly describe the impact:**	Describe the results of assessment of the impact of land use and climate changes to sediment transport changes.
	Section: OBSERVATIONS / COMMENTS	
21.	**Any helpful comments or observations:**	i.e. any other important data and information to describe/characterize the pressures.

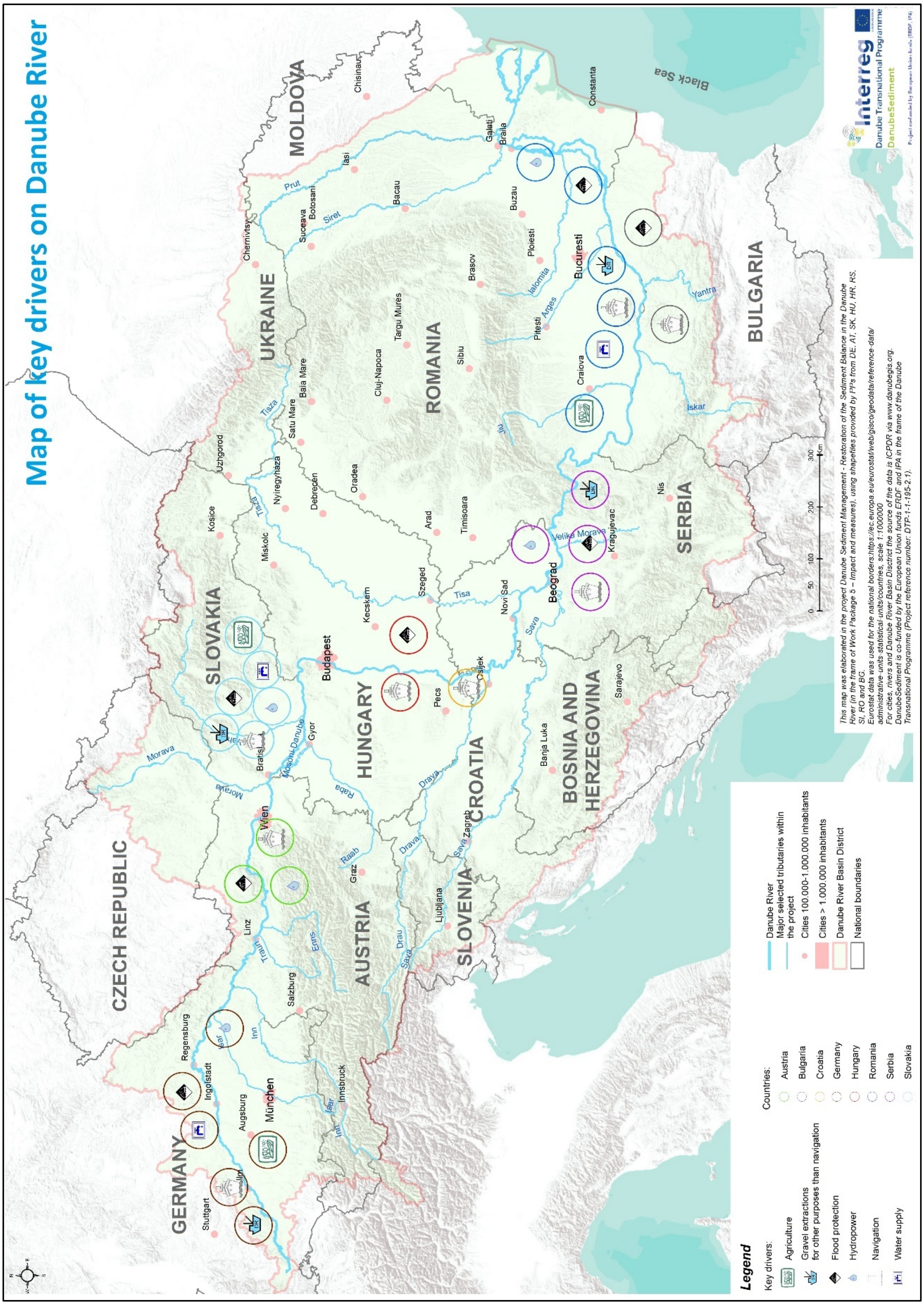
ADDITIONAL EXPLANATIONS:

1) River dam refers at a hydraulic work (concrete, rock fill, clay) which creates a significant storage lake and which purpose is mostly hydropower, water supply, flood protection, etc.

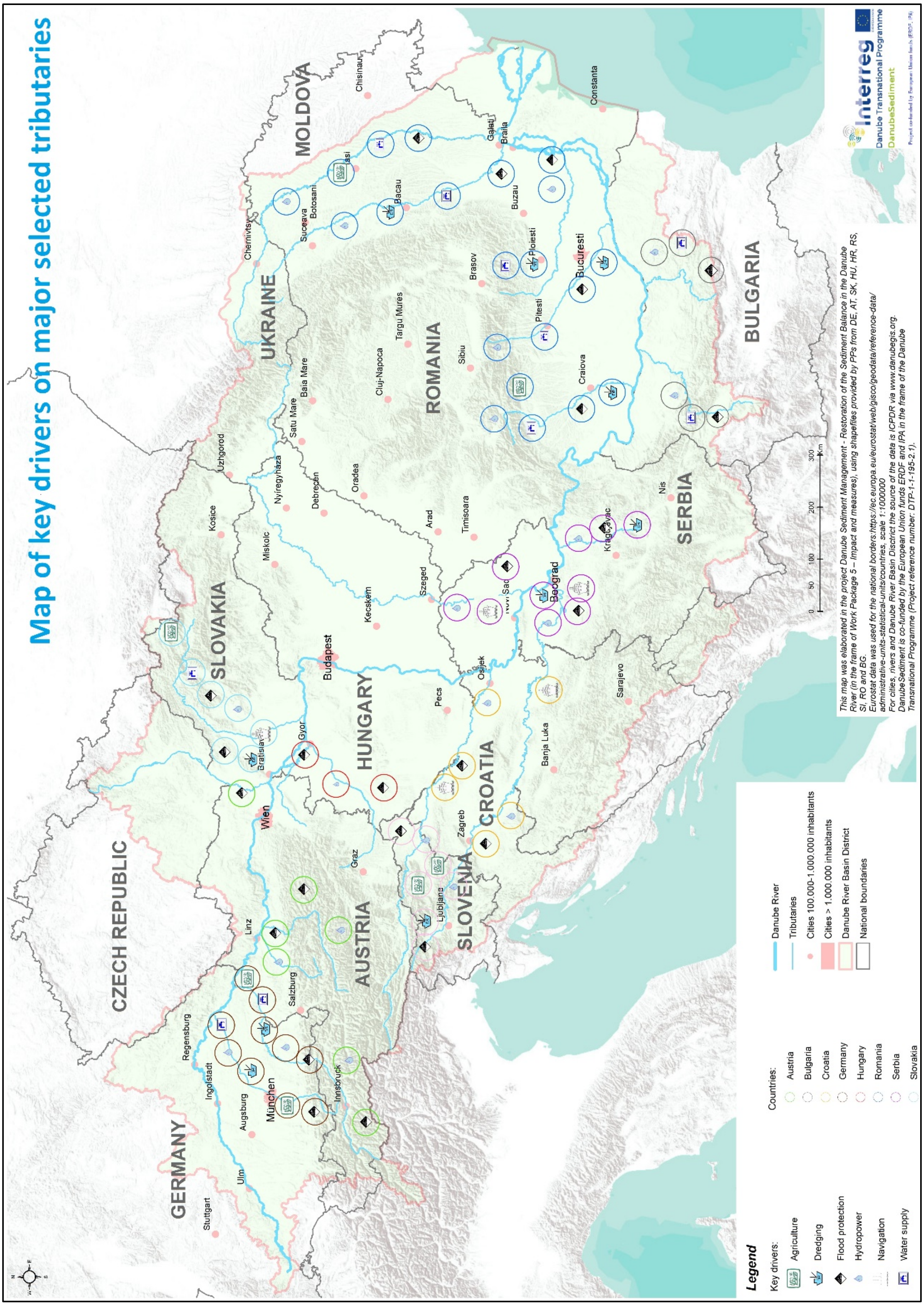
2) *Weirs* refer at a hydraulic work usually made from iron, concrete, wood, used for adjusting the flow rate in the upstream.

3) *Regularization work* referes at hydraulic works for artificial modification, adjustment, consolidation of river bed in order to achive a stable river bed, to protect certain objectives, to reduce the erosion process, to ensure certain runnoff, or for an efficient water use for economy.

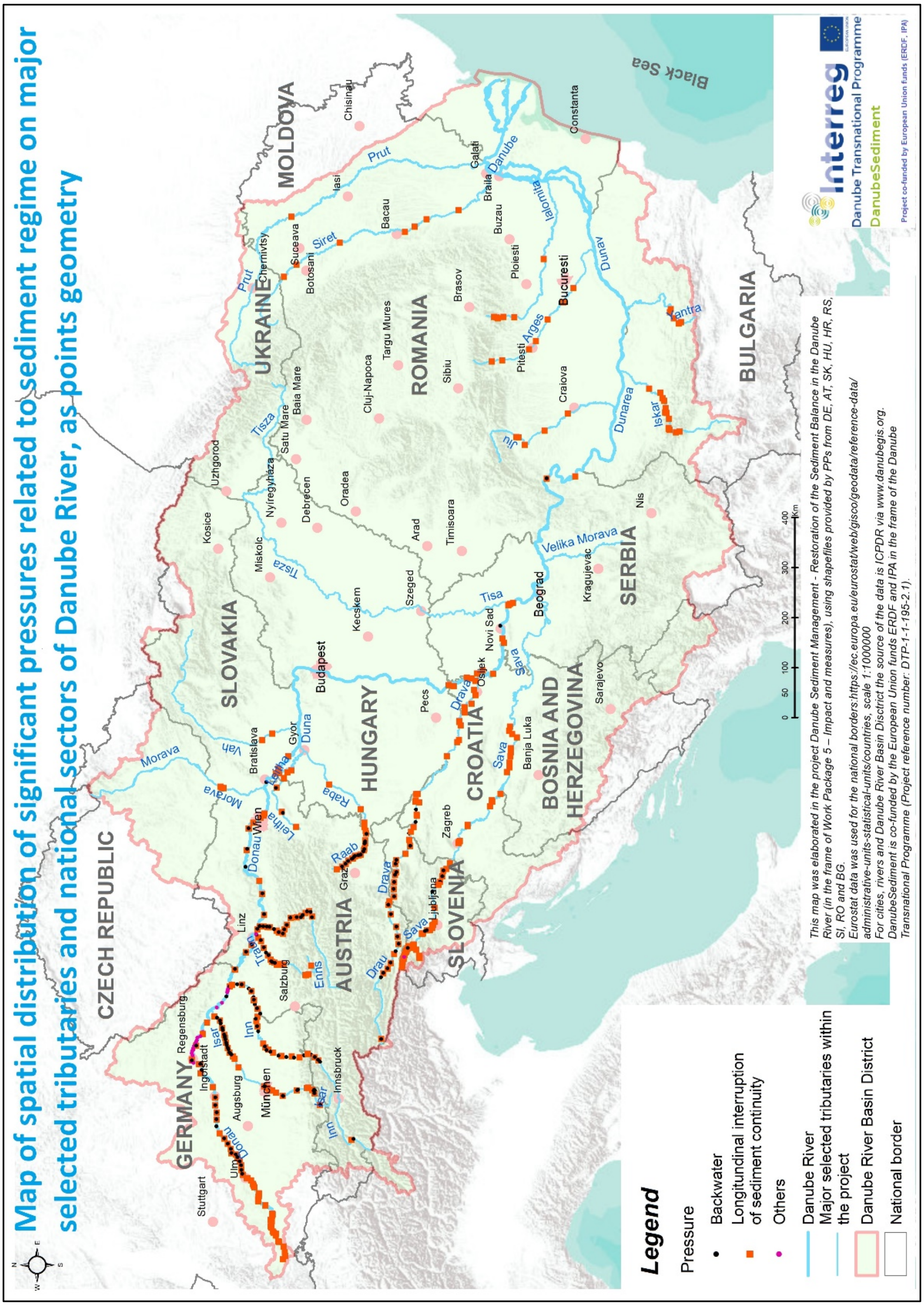
Annex 2a: Map of key drivers on Danube River



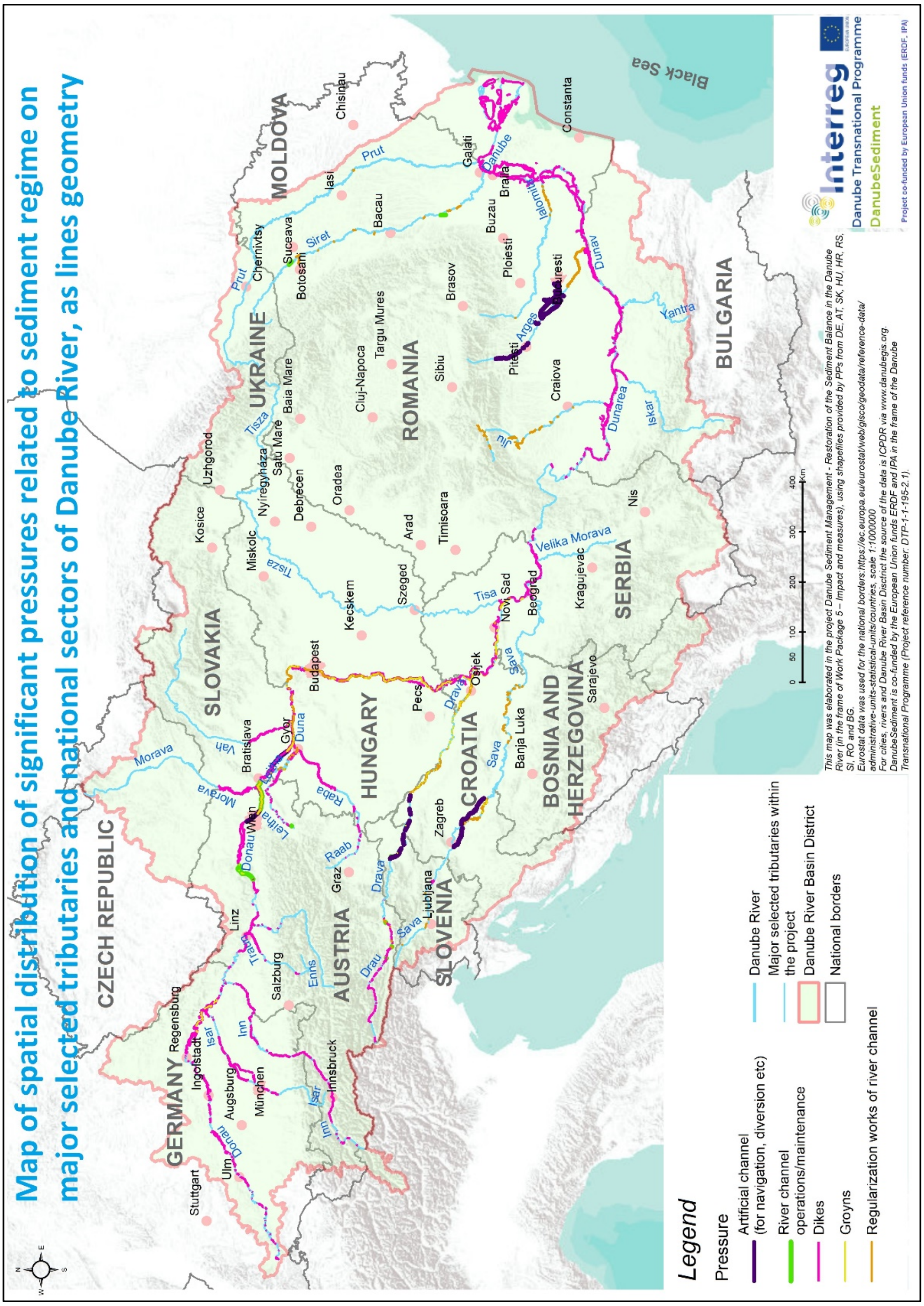
Annex 2b: Map of key drivers on major selected tributaries



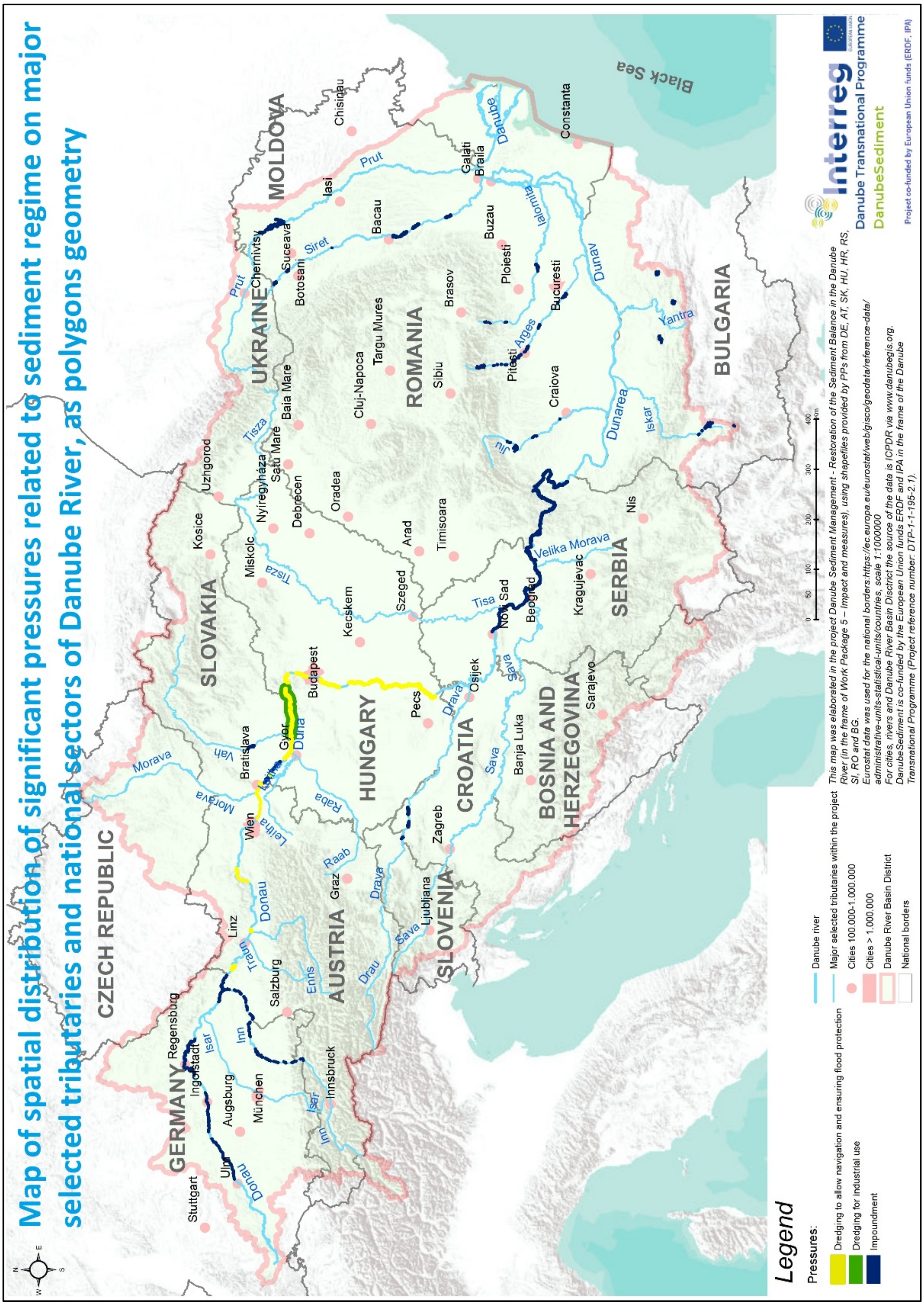
Annex 3a: Map of spatial distribution of significant pressures related to sediment regime on major selected tributaries and national sectors of Danube River, as points geometry



Annex 3b: Map of spatial distribution of significant pressures related to sediment regime on major selected tributaries and national sectors of Danube River, as lines geometry



Annex 3c: Map of spatial distribution of significant pressures related to sediment regime on major selected tributaries and national sectors of Danube River, as polygons geometry



Annex 4: Description of the criteria used by country to assess hydromorphological significant pressures

#	Country	Description of the criteria used by country to assess hydromorphological significant pressures
1.	**Germany**	Seven different classes assess the structural quality of rivers: 1) Unchanged: The river structure is close to the natural status 2) Slightly changed: The structure is affected by single, small-scale measures; 3) Moderately changed: The structure is changed by many small-scale measures; 4) Clearly changed: The structure is changed by different measures, e.g. river bed, embankments, damming, use of flood plains; 5) Heavily changed: The structure is changed by a combination of measures, e.g. river regulation, barriers, hydropeaking, flood protection; 6) Severely changed: The structure is drastically changed by a combination of measures, e.g. river regulation, barriers, hydropeaking, flood protection; 7) Completely changed: The structure is changed completely; In this approach, the river is split into sections of 1 km length, which are each assigned one of the seven classes. The classes 5, 6, and 7 are classified as significantly changed regarding morphology. This is done by using a parameter table, consisting of nine parameters. The parameters, which cover on the one hand the river bed, on the other hand the flood plain, are: - alignment of the river; - fixed (constructed) embankments; - transverse structures; - control of the flow; - vegetation at the river banks; - flood protection structures; - connection of flood plains; - land use in the flood plains; - riparian zone. Germany also has a second, more detailed approach for smaller rivers based on 100 m sections and a different evaluation table with 25 parameters. For the purpose of DanubeSediment, which looks at the Danube Basin scale on a large-scale, the first approach with 1 km sections is sufficient.

#	Country	Description of the criteria used by country to assess hydromorphological significant pressures
2.	**Austria**	The criteria selected for significant pressures were dam height /continuum interruption (availability of functioning fish passes), hydrological alterations, namely impoundments, water abstraction with residual water reaches (ecological minimum) and hydropeaking (daily fluctuation defined to be above 1 m) as well as significant and morphological alterations. Criteria for morphological alterations that have a significant impact on sediment movement are assessed in five classes and aggregated to 500m river sections (not available for Danube). Regarding waterbodies, the assessment score must represent > 60% of the length of the waterbody ("one out -all out" principle - which is WFD Status assessment principle). The Danube was only assessed based on the entire water bodies. According to the Austrian national WFD RBMP, the height of barriers was assessed in different regions in the context of fish migration, but not in relation to sediment continuity.
3.	**Slovenia**	It is specified that the only pressure stated as significant is „Dam". This is based on the 2nd River Basin Management Plan (NUV 2 - RBMP) 2016-2021 for the Danube River Basin District (Danube RBD). The pressure to the sediment balance and transport regime considered significant is a direct consequence of energy sector, ie. power plants with > 10 MW power output (as stated in River Basin Management Plan 2016-2021).
4.	**Slovakia**	Following main indicators of hydromorphological alteration are used to determine the hydromorphological status: - river planform (shortening, straightening compared to reference conditions); - habitat diversity (width/depth variability; heterogeneity of the river bed sediments; channel forms, e.g. islands, various channel bars etc.); - flow regime and flow dynamics (hydrological regime; impoundments; flow regulation; hydropeaking); - sediment continuity/instability: barriers to sediment transport - changes in sediment transport, dredging; - local structures in the river channel: groins, in channel lateral structures; - lateral continuity/connectivity: bank protection, side arms (meanders) closure; - riparian zone: type of land cover, vegetation; - floodplain: size against original, vegetation cover. Based on these indicators, the hydromorphological modifications of the Danube and its tributaries were defined and the hydromorphological status

#	Country	Description of the criteria used by country to assess hydromorphological significant pressures
		of the river section (water body) was classified (classes 1 to 5). The detailed procedure is summarized in the national methodology for hydromorphological assessment: River hydromorphology quality assessment for BQE (developed by VUVH).
5.	**Hungary**	The analysis is based on the national methodology applied in the RBMPs. A pressure is a "Significant pressure", when both of the following criteria are fulfilled: - 50% of the naturally floodplain is removed; Works (embankments) along certain river sections reduce lateral connectivity, have an impact on the inundation of natural floodplains and increase the sediment transport along the river section - dams having a significant effect on sediment transport and biota migration or the natural flow velocity. Dams have an effect on natural hydrological regime, sediment transport and biota migration. They generate significant morphological changes (riverbed degradation or accumulation). Criteria regarding the significant hydro morphological pressures are based on the principles of the Hungarian River Basin Management Plans. To identify significant pressures, it followed the methodology of "Identifying highly modified water bodies" and "Hydromorphological state evaluation system". These criteria relate to hydro morphological pressures in relation to the environmental objective.
6.	**Croatia**	All pressures listed in the questionnaire are considered significant (these criteria are included into the River Basin Management Plan)
7.	**Serbia**	All pressures listed in the questionnaire are considered based on expert judgement.
8.	**Romania**	The significant pressure has been assessed in relation to risk of failing to meet the environmental objective. Abiotic criteria regarding the significant hydro morphological pressures have been adopted from the "*Methodological elements for identifying significant pressures and assessing their impact on surface water status - Identification of water bodies that are at risk of not achieving the objectives of the WFD*"[71]. The potential significant hydromorphological pressures and possible changes induced by

[71] http://www.rowater.ro/TEST/Planul%20Na%C8%9B.%20de%20Manag%20actualizat%202016-2021-Sinteza%20Planurilor%20de%20Manag.%20la%20nivel%20de%20bazine-spa%C8%9Bii%20hidrografice%20actualizate/Planul%20National%20de%20Management%20actualizat.pdf

#	Country	Description of the criteria used by country to assess hydromorphological significant pressures
		those pressures on the status of the water body, as well as the response have been analyzed. The Impact Assessment[72] was carried out by assessing the status of water bodies, mainly based on monitoring data from 2013. In this way, significant pressures have been validated, having in view reaching environmental objectives for water bodies. Criteria for identifying hydromorphological pressures take into account the pressure intensity, based on abiotic parameters, as well as their effect on biota. Hence the hydromorphological alterations were structured in four main categories: ***longitudinal*** and ***lateral works***, like dams and dykes, ***navigation fairway*** and ***water intakes and derivations***. For each category the effect on different river hydromorphological features, like hydrologic regime, river bed stability, lateral connectivity, and longitudinal river profile has been indicated. The parameters reflecting these pressures include the density of longitudinal interruption, the height of the obstacle, the length of embankments, the area of affected floodplains, the ratio between abstracted flow and natural flow.
9.	**Bulgaria**	No criteria were specified. The only reference is a qualitative assessment of dredging for navigation. Dredging works are undertaken in the aquatorium at port rkm 491 to ensure navigation for the most critical section of the Bulgarian part of the Danube River.

[72] http://www.rowater.ro/TEST/Planul%20Na%C8%9B.%20de%20Manag%20actualizat%202016-2021-Sinteza%20Planurilor%20de%20Manag.%20la%20nivel%20de%20bazine-spa%C8%9Bii%20hidrografice%20actualizate/Planul%20National%20de%20Management%20actualizat.pdf

Annex 5a: Description of the facilities / measures / management policies in order to ensure sediment transport and continuity on the Danube River

#	Country	Description of the facilities / measures / management policies in order to ensure sediment transport and continuity on the Danube River
1.	**Germany**	• Artificial sediment supply (currently performed in Isar confluence zone) • Map of planned measures to improve the morphology of Bavarian rivers • Possible measures collected in the document "Measures for the Bavarian part of the Danube". The proposed measures cover (excerpt): o Introduce sediment o Connect side arms/relicts o Establish continuity of sediments o Unload full groyne fields o Optimize sediment feeding (temporally/spatially)
2.	**Austria**	Management of bedload and dredging. Feeding of sediments downstream of the last dam Wien-Freudenau at river-km 1921.05 (about 186,000 m^3/year on average between 1996-2017) to stabilize the river bed in a specified maintenance reach (river-km 1921 to 1910) downstream of the dam. In the future it is envisaged to raise the amount of material that is fed per year. East of Vienna the management of the dredged material for the fairway maintenance has undergone several stages over the last 20 years[73]. Between 1996 and 2005 approx. 50% were fed back into the main stream, 30% were extracted and 20% used for the construction of gravel structures. From 2006 on all the dredged material was fed back into the mainstream first downstream and from 2009 upstream of the dredging location. Finally, from 2015 on the upstream transfer distance was considerably increased, which lies on average around 11 km. At the moment, improvements are under research in the CD-Laboratory "Sediment Research and Management". Management of fine sediments from impoundments (regular releases, ecological assessment and improvements are under investigation).
3.	**Slovakia**	Gabčíkovo Operational manual - flushing during floods (Hrušov reservoir and Cunovo weir)
4.	**Romania**	In general, the bottom outlets of the dams are used for sediment release. There are no specific requirements in the operational rules of the dams but, usual, the sediment release is performed whether the bathymetric measurements indicate a certain level of sedimentation.

[73] Markus Simoner (viadonau), 2018., Sedimente und Wasserstraßenmanagement – Probleme und Lösungen. Presentation at the 1st National Stakeholder Workshop of the project DanubeSediment, Vienna.

Annex 5b: Description of the facilities / measures / management policies in order to ensure sediment transport and continuity on the selected Tributaries

#	Tributaries (Country)	Description of the facilities / measures / management policies in order to ensure sediment transport and continuity on the selected Tributaries
1.	**Isar (DE)**	Artificial sediment supply (currently performed in the Isar confluence zone)
2.	**Inn (DE)**	Flushing of sediment at certain dams in the Inn (no information about the effect on the Danube – mainly suspended loads/fine material enters the Danube)
3.	**Traun, Enns (AT)**	Management of hydropower dams/impoundments (flushing of sediments)
4.	**Morava (AT)**	Several transboundary river projects with Slovakia, including restoration and river management
5.	**Drava, Sava (HR)**	Several measures in River Basin Management Plan
6.	**Drava, Sava (SI)**	According to NUV 2 – RBMP of Slovenia no specific measures to enhance sediment transport/continuity are specified. The only measures that can relate to this are mostly defined to provide adequate hydromorphological state of the river. Resulting from this list of measures in RBMP are the following measures that directly affect sediment transport: maintaining the balance of downstream water table, providing transport of the bedload that is characteristic to the ecological type of the river section, woody debris management and suspended sediment dredging. Dam gates manipulation to flush the excess suspended sediment as an addition to the mechanical dredging is in this moment only a consideration yet to be put to the practice (Sava and Drava River)
7.	**Jiu, Arges, Ialomita, Siret, Prut (RO)**	In general bottom outlets are used for sediment release. There are no specific requirements in the operation rules of the dams but, usually, the sediment release is performed whether the bathymetric measurements indicate a certain level of sedimentation.