Joint Danube Survey 4

Recording and assessment of hydromorphological changes 2013 - 2019

Ulrich Schwarz

Alexander Höbart (Data collection tool)

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Introduction

According to the decisions made in the HYMO Task Group the assessment prepared for the Joint Danube Survey 3 (JDS3) in 2013 (Schwarz, Holubova, et.al. 2015) should be updated by 2019 for JDS4. This concerns the update of the continuous survey of 241 sections of 10 km length, according to the agreed methodology (CEN Standards from 2004 and 2010) and comprises the overall and WFD 3-digit assessment of the hydromorphological features for the navigable Danube from Kelheim (rkm 2,415) to the delta (rkm 0 at Sulina branch).

Under the changed JDS4 framework conditions, with a more active role for national authorities and individual countries, the continuous assessment focused on the update of the HYMO assessment of the predefined 10-rkm-segments with regard to changes (deteriorations[1], improvements) of channel, banks and floodplain. The data collection and assessment was performed by national experts doing investigations (deskwork) supported by a consultant and the ICPDR Secretariat. For this task, an online data collection tool for the changes and projects was integral part of the JDS4 data collection portal.

The data collection started in early 2019 and comprises the full monitoring period from summer 2013 until summer 2019.

[1] The term "deterioration" reflects only the hydromorphological conditions within the 10-rkm river segments and is not to be used according to WFD, which refers to ecological status/potential assessed on water body scale.

1. Methods

For the JDS HYMO assessment 2013 the Danube was divided into 10-rkm-segments assessing channel, banks and floodplains individually before generating the overall assessment for each segment (compare figure 1 and chapter 1.2). The usage of the segmentation of JDS3 was mainly a technical step to precisely locate changes – deteriorations and improvements – and does not interfere with the definition of river section types as required to define the reference conditions for the assessment according to CEN standard. For JDS4 it was decided to update the HYMO parameters based on the same segments and to shift the assessment only to those segments with significant changes.

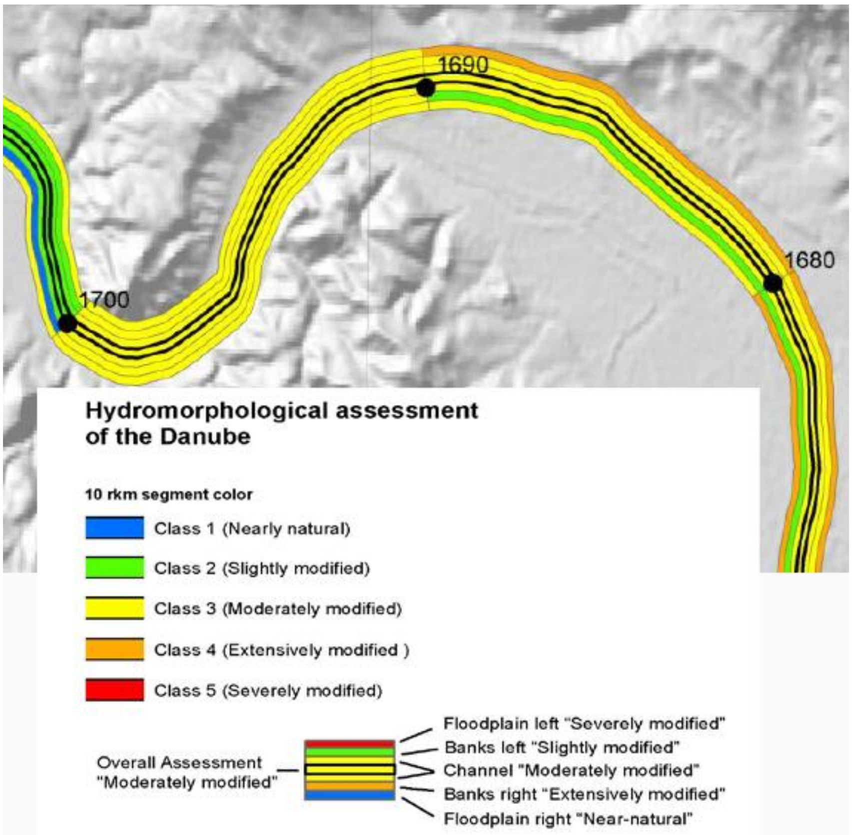

Figure 1: 10-rkm assessment segments of the JDS3 as base for JDS4 (Schwarz 2014).

The JDS4 data collection and assessment covered all relevant HYMO changes compared to JDS3 for the period from summer 2013 to summer 2019. The task included the following steps:

- Setup of an online HYMO "change" database under the roof of the JDS4 data collection portal by ICPDR Secretariat, considering the agreed HYMO parameters and significance criteria as based on the previous JDS3 assessment which need to be updated for the 10-rkm-segments.
- Collection of hydromorphological alterations for the 10-rkm-segments by the Danube countries (coordinated by the national expert of the ICPDR HYMO Task Group).

- Collection of information on relevant Danube river restoration projects and infrastructure projects within the period 2013-2019 by the countries, as integral inventories of the changes database.

- Analysis and assessment of the data and visualisation of individual changes of segments and finally of changed assessment, performed by consultant in co-operation with the countries.

The changed parameters for overall and WFD 3-digit assessment (morphology, hydrology and river continuity) have been collected in the data collection tool. For the detailed description of the 10 parameters, please compare detailed tables 1 and 2 in chapter 1.2:

- **Channel, hydrology, river continuity:** Planform (1), substrate (2), erosion/deposition character (3), artificial in-channel features (4) (dams with impoundments and changes in discharge, groynes), continuity (5) (biota/sediment)

- **Banks and riparian zone:** Extent of reach affected by artificial bank material (6), land cover in riparian zone (7)

- **Floodplain:** Land cover beyond the riparian zone (8), degree of lateral connectivity of river and floodplain (9), Degree of lateral movement of river channel (10)

Significant new alterations (occurring for the first time between summer 2013 and summer 2019), as well as restoration activities listed below had to be considered if the level of significance exceeded within one of the 241 10-rkm-segments, namely 0,5 km changes in lengths or 5% change of floodplain areas, compare chapter 1.2 for more details):

- **Channel, including hydrology and continuity:** Closure of side-channels, groyne construction/removal, specific, intensive dredging, ongoing, raising or decreasing channel incision, flow regime changes (impoundment length, hydropeaking, water abstraction, particular exposure to ship waves (no thresholds defined), restoration/widening/reconnection of Danube main and side-channels, construction of fish passes or measures to improve sediment transport (gravel feeding, sediment management).

- **Banks:** New riprap, bank reinforcements, change of land use in riparian zone, restoration of riverbanks (removal of rip-rap).

- **Floodplain:** Further reduction of floodplain areas by cut-off, change in land use or reconnection of floodplains/retention areas.

Pressure data generated under the DanubeSediment Project (Habersack et al. 2019 and 2020) have been considered as reference by the countries as far as available during the project phase.

Finally, the inventory table for infrastructure and restoration projects is based on the data entries made by the national experts of Danube countries for the JDS4.

1.1 The data collection tool

As part of the JDS4 online data collection portal developed by ICPDR, the module for HYMO allows the seamless data entry by all countries.

The web-based tool was built using Drupal 7 and based on the infrastructure of the Danubis information system of the ICPDR.

The online data entry tool was created for several reasons:

- Data collection via Excel (as for other JDS4 data) seemed to be inappropriate as the HYMO data has a more qualitative than quantitative nature and it was also expected to collect accompanying photos and documents.
- The online forms were built to make data entry for national experts as easy as possible and thus attracted a stronger involvement of experts in the countries.
- The more interactive data creation on a live system with easy-to-use data review and update options enabled more direct support and thus better harmonisation of reported data.
- The tool can serve as a reference or even be used as it is for the next update. As part of the JDS4 data collection portal, the ICPDR Secretariat will further maintain it.

As part of the JDS4 data collection portal, Danubis is used as the login server via the Central Authentication Service (CAS) protocol. This way, nominated HYMO TG expert users could use their existing account to authenticate and gain access to the tool. Additionally, the country affiliation of each user was synchronised from the user database of Danubis.

The database and data entry forms are based on the three entities segments, changes and projects:

- **Segments**: the spatial data (lines) and base attributes (rkm from – to, country, overall assessment result 2013) of the 10-rkm sections were imported from JDS3 data and served as a reference for the other entities.
- **Changes**: this data was entered by users into web forms with following fields (all fields are mandatory except where indicated, some fields are only relevant dependent on other entered values):
    - **Segment(s)**: reference to one or multiple segments
    - **Change**: no change, improvement, deterioration (selection list). If "no change" was selected, no further data was requested.
    - **Assessment Group**: selection based on parameters 1-10 of table 1; grouped in to Channel incl. hydrology and Continuity, Banks and Floodplain. Parameters 6-10 split into left and right side.
    - **Change type**: selection with following options:
        - Infrastructure project
            - Navigation
            - Hydropower
            - Flood protection
            - Water supply
            - Others

    - Maintenance (particular campaigns or programs)
    - Restoration project
        - CB1. Removal or structural modification of weirs/check dams and sills
        - CB2. Reconnection of side channels
        - CB3. Reactivation of channel dynamics through removal of bank protection
        - CB4. Channel widening
        - CB5. Addition of sediments in the river channel
        - CB6. Definition of an erodible corridor
        - CB7. Restoration of channel sinuosity
        - CB8. Restoration of continuity
        - F1. Removal/slicing/setting-back flood dikes for floodplain reconnection
        - F2. Recovery of floodplain by lowering terraces
        - F3. Afforestation to decrease flow velocity and increase of retention capacity and ecological habitats values
    - Natural process (accelerated incision or sedimentation, lateral erosion)
    - (Hydropower, Navigation - only for hydropeaking and wave pressure)

  - **Length in km**
  - **Area in %**: only requested for floodplain (based on selection of assessment group)
  - **Project**: optional reference to a project (see below), only requested if change type indicates a project
  - **Description**: text with formatting options
  - **Photos**: optional photos for documentation
  - **Documentation**: optional files for documentation
  - **Report**: defaulted to "JDS4" – intended for future use of further updates
  - **Country**: set automatically from data entry user's country

- **Projects**: each project can be related to one or more changes (see Project field in Changes).
  - **Project type and purpose**: Infrastructure project or restoration project, followed by the same sub types (purpose) as in the list for Change type of Changes.
  - **Project code**: optional reference to an external project identifier
  - **Title**: title of the project
  - **Implementation year:** single year or year range
  - **Description**: optional text with formatting options
  - **Report**: defaulted to "JDS4" – intended for future use of further updates
  - **Country**: set automatically from data entry user's country

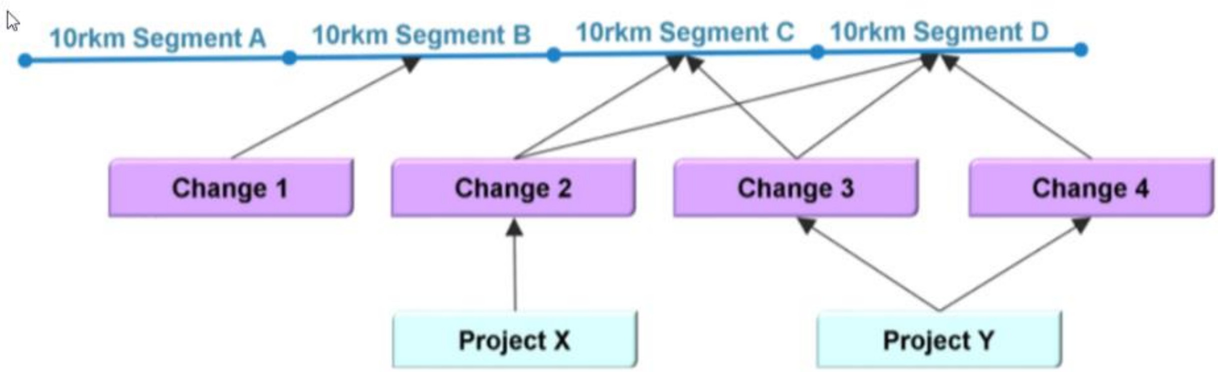

Figure 2: Possible relations (segments, changes, projects): A segment can be affected by 0, 1 or multiple changes. A change can affect 1 or multiple segments. A change can be caused by 0 or 1 project. A project can cause 0 or multiple changes. The below graph illustrates this by example.

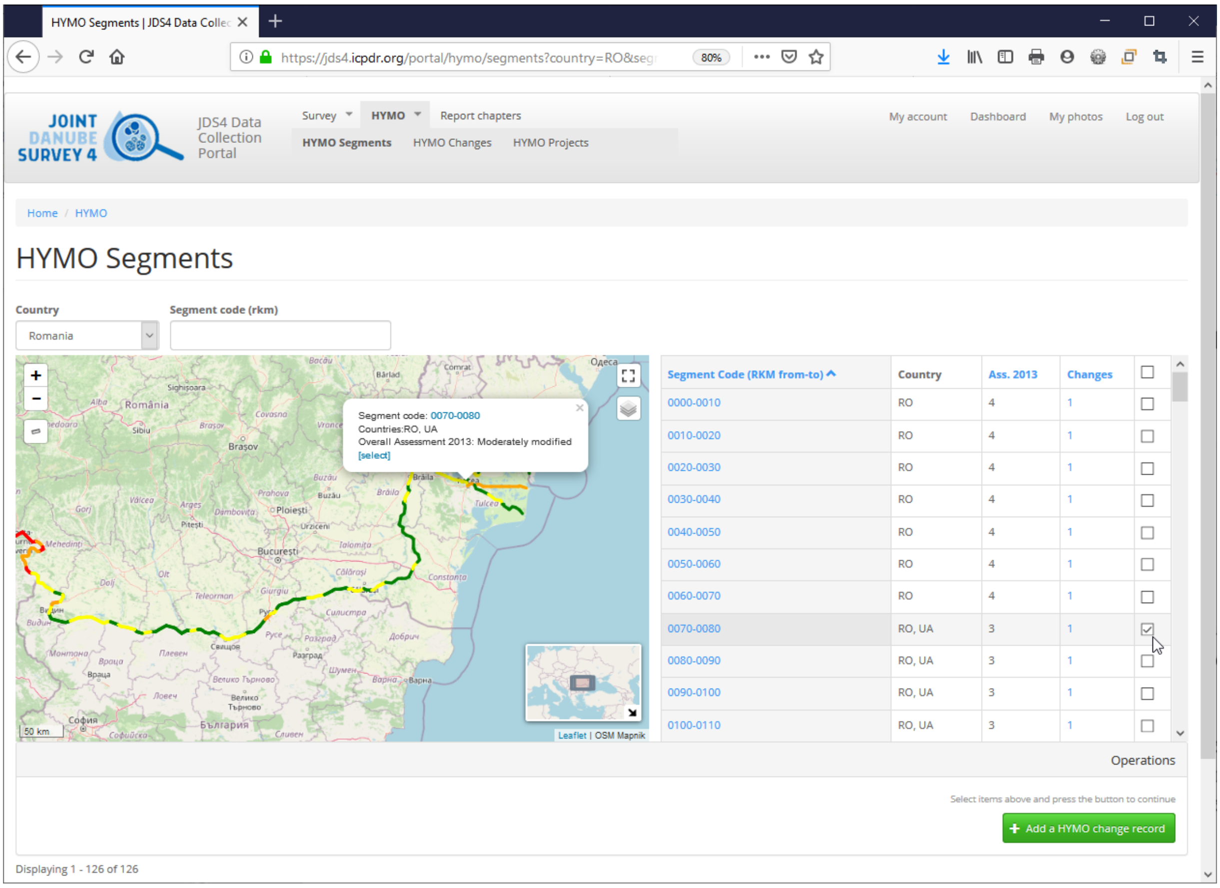

Figure 3: The online tool provides a map and list of segments as an entry point to search and select segments for viewing and entry of change records.

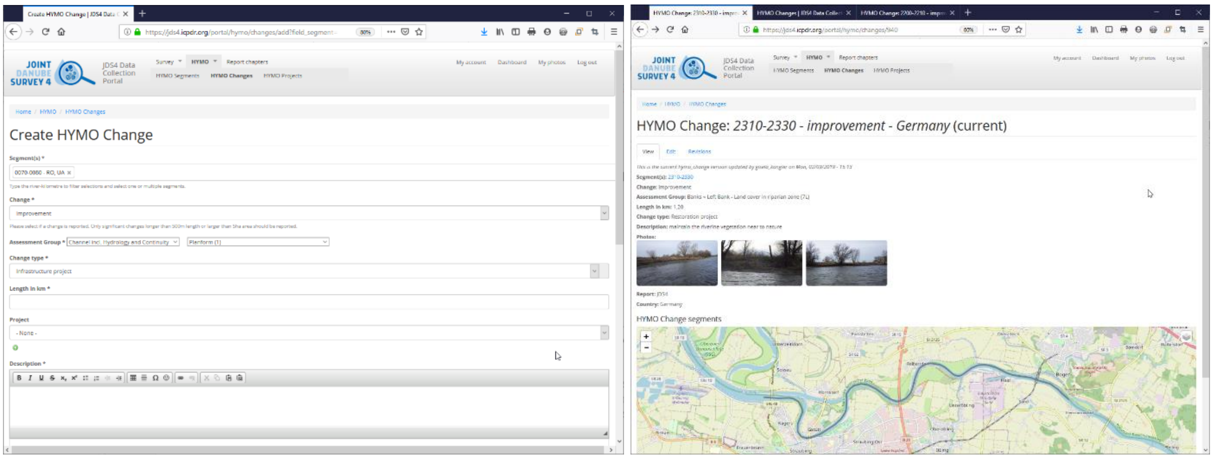

Figure 4: Each different change had to be recorded using below online form. However, as each change record could be related to multiple segments and projects could be referenced to multiple changes, the overall data entry work was minimised.

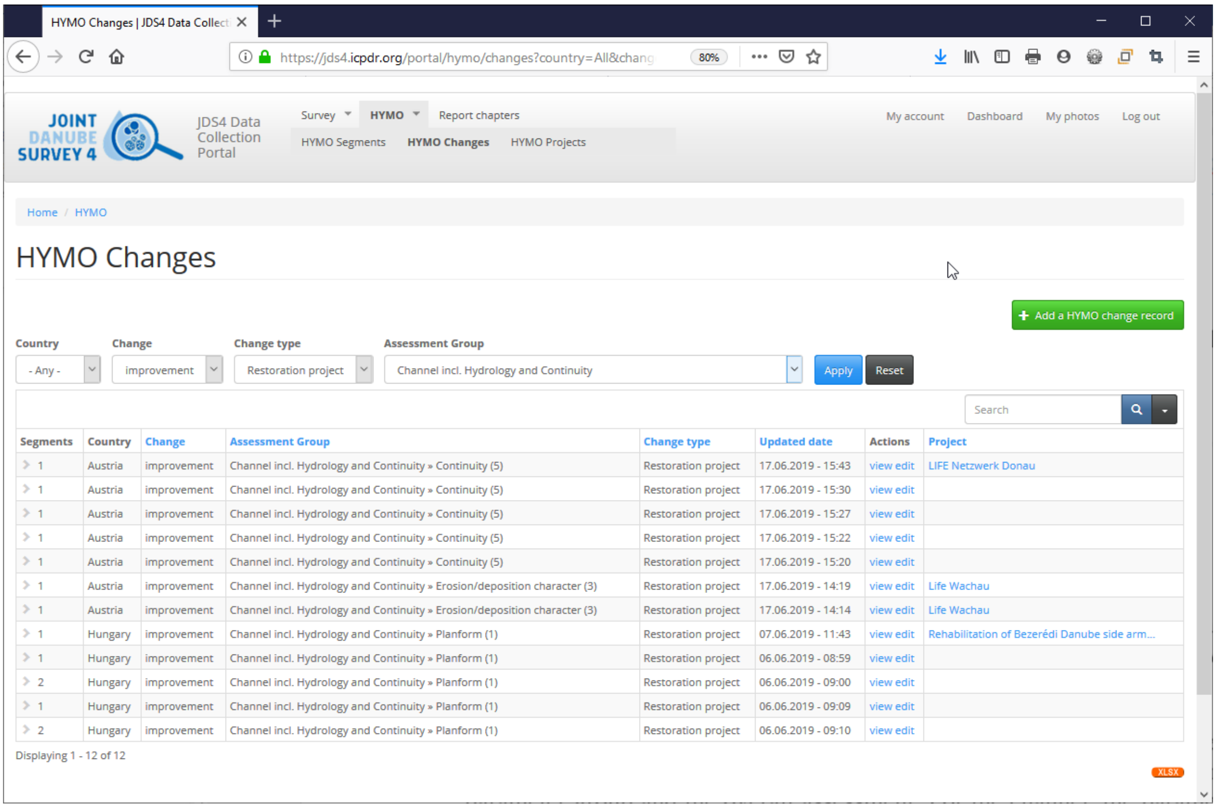

Figure 5: The entered changes can be listed and filtered by various criteria (see below). The consultant could review the full data and data providers could update their data during the data entry period. This possibility helped to collect data in a more harmonised way.

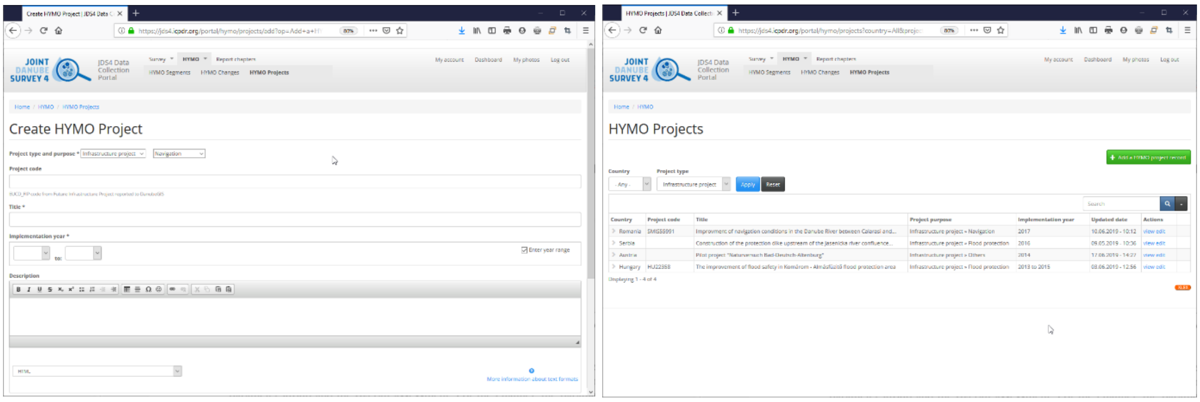

Figure 6: Project data was entered and can be retrieved in a similar way.

All data can be exported as Excel (XLSX) files. The further analysis of data was done externally by the consultant.

1.2 Assessment based on JDS3

After the collection and analysis of changes (improvements and deteriorations) the two assessments of 10-rkm-segments as of JDS3, the overall continuous assessment and the WFD 3-digit assessment had to be revised for the reported 10-rkm-segments with changes.

The overall CEN assessment (table 1 on next page) is based on individual parameters for channel, banks and floodplain and allows an assessment into five classes based on arithmetic mean values for each parameter group and the overall assessment. For channel, the parameters 2-5 are assessed only in three classes (1, 3 or 5).

According to the assessment methods used for the JDS3, the threshold for changes in the assessment for the individual parameters was set for most of the parameters to >5% of affected assessment segment or with other words, if 500 m out of the 10-km assessment segment was altered within the monitoring period, it must be recorded for the update (for areas to be assessed 5% of floodplain area respectively). The “significance” of changes was approved by entire “class changes”, but all sub-classes were considered for cumulative effects (e.g. if the sum of changes in the sub-parameters 1-5 for “Channel” exceeded together the 500 m, the assessment for the “Channel“ might be changed). Not in all cases did changes necessarily lead to a shift in the assessment class.

Table 1: Assessment scheme for the CEN overall continuous survey

	Parameter	**Descriptions**
Channel		
Parameter No 1	Planform (based on deviation from near to natural conditions for section types)	>500m length **change** of reach length with changed planform (changes between assessment classes 1,2,3,4,5); *Class 1 = 0 % to 5 % of reach length with changed planform.* *Class 2 = > 5 % to 15 % of reach length with changed planform.* *Class 3 = > 15 % to 35 % of reach length with changed planform.* *Class 4 = > 35 % to 75 % of reach length with changed planform.* *Class 5 = > 75 % of reach length with changed planform.*

	Parameter	Descriptions
2	Substrates (Natural substrate mix or character altered), (based on deviation from near to natural conditions for section types)	>500m length **change** from “Near-natural mix” to “character slightly to moderately altered” or “character greatly altered” (changes between assessment classes 1,3,5). *1 = Near-natural mix* *3 = Natural mix/character slightly to moderately altered* *5 = Natural mix/character greatly altered*
3	Erosion/deposition character (based on deviation from near to natural conditions for section types)	>500m length **change** from “Erosion/deposition features reflect near-natural conditions” to “Erosion/deposition features reflect moderate departure from near-natural conditions (10 % to 50 % of the features expected are absent)” or “Erosion/deposition features reflect great departure from near-natural conditions (≥ 50 % of the features expected are absent)” (changes between assessment classes 1,3,5). *1 = Erosion/deposition features reflect near-natural conditions.* *3 = Erosion/deposition features reflect moderate departure from near-natural conditions (10 % to 50 % of the features expected are absent).* *5 = Erosion/deposition features reflect great departure from near-natural conditions (≥ 50 % of the features expected are absent).*
4	Impacts of artificial in-channel structures within the reach (impoundments, groynes, incl. flow character)	>500m length **change “**Flow character not, or only slightly, affected by structures within the reach” to “Flow character moderately altered” or “Flow character extensively altered” (changes between assessment classes 1,3,5). *1 = Flow character not, or only slightly, affected by structures within the reach.* *3 = Flow character moderately altered.* *5 = Flow character extensively altered.*
5	Reach-based and local impacts of sluices and weirs on ability of biota (e.g. migratory fish) to travel through reach, and sediment to be transported naturally	**Changes** in continuum from “No structures, or if present they have no effect (or very minor effect) on migration or on sediment transport” to “Structures present, but having only minor or moderate effects on migratory biota and sediment transport” or “Structures that in general are barriers to all species and to sediment” (changes between assessment classes 1,3,5). *1 = No structures, or if present they have no effect (or very minor effect) on migration or on sediment transport.* *3 = Structures present, but having only minor or moderate effects on migratory biota and sediment transport.* *5 = Structures that in general are barriers to all species and to sediment.*
Banks		
6	Extent of reach affected by artificial bank material (% of bank length)	>500m length **change** to **“**Banks affected by hard artificial materials” (changes between assessment classes 1,2,3,4,5); *1 = Banks affected by 0 % to 5 % hard, artificial materials.* *2 = Banks affected by > 5 % to 15 % hard, artificial materials.* *3 = Banks affected by > 15 % to 35 % hard, artificial materials.* *4 = Banks affected by > 35 % to 75 % hard artificial materials.* *5 = Banks affected by > 75 % hard artificial materials.*
7	Land cover in riparian zone (% of bank length)	>500m length **change** to non-natural land cover in riparian zone (changes between assessment classes 1,2,3,4,5); *1 = 0 % to 5 % non-natural land cover in riparian zone.* *2 = > 5 % to 15 % non-natural land cover in riparian zone.* *3 = > 15 % to 35 % non-natural land cover in riparian zone.* *4 = > 35 % to 75 % non-natural land cover in riparian zone.* *5 = > 75 % non-natural land cover in riparian zone.*
Floodplain		
8	Land cover beyond the riparian zone	>5% area **change** to non-natural land cover beyond the riparian zone (changes between assessment classes 1,2,3,4,5); *1 = 0 % to 5 % non-natural land cover beyond the riparian zone.* *2 = > 5 % to 15 % non-natural land cover beyond the riparian zone.* *3 = > 15 % to 35 % non-natural land cover beyond the riparian zone.* *4 = > 35 % to 75 % non-natural land cover beyond the riparian zone.* *5 = > 75 % non-natural land cover beyond the riparian zone.*
9	Degree of lateral connectivity of river and floodplain (Extent of	>500m length **change** of affected reaches by flood dikes or other measures impeding flooding of floodplain (changes between assessment classes 1,2,3,4,5);

	Parameter	Descriptions
	floodplain not allowed to flood regularly due to engineering-based on hydromorphological surveys.) (based on deviation from near to natural conditions for section types)	*Is over-bank flooding likely to occur (or likely to have occurred historically) naturally in the reach?* *Yes/No.* *If No – N/A.* *If Yes, score:* *1 = 0 % to 5 % reach affected by flood dikes or other measures impeding flooding of floodplain* *2 = > 5 % to 15 % as above.* *3 = > 15 % to 35 % as above.* *4 = > 35 % to 75 % as above.* *5 = > 75 % as above.*
10	Degree of lateral movement of river channel (% of length where lateral movement is artificially constraint)	>500m length **change** of constrained reaches (changes between assessment classes 1,2,3,4,5); *Is the river likely to move laterally within its floodplain in the absence of any man-made constraints?* *Yes/No.* *If No – N/A.* *If Yes, score:* *1 = 0 % to 5 % reach constrained.* *2 = > 5 % to 15 % reach constrained.* *3 = > 15 % to 35 % reach constrained.* *4 = > 35 % to 75 % reach constrained.* *5 = > 75 % reach constrained.*

Assessment class boundaries:

1,0 to 1,4= Class 1 Reference conditions (blue) “Near-natural”

1,5 to 2,4= Class 2 (green) “Slightly modified”

2,5 to 3,4= Class 3 (yellow) “Moderately modified”

3,5 to 4,4= Class 4 (orange) “Extensively modified”

4,5 to 5,0= Class 5 (red) “Severely modified”

Table 2: Assessment scheme for the CEN WFD 3-digit survey

	Parameter	Descriptions
Morphology		
Parameter No 1	Planform (based on deviation from near to natural conditions for section types)	s. above
2	Substrates (Natural substrate mix or character altered) (based on deviation from near to natural conditions for section types)	s. above
3	Erosion/deposition character (based on deviation from near to natural conditions for section types)	s. above
6	Extent of reach affected by artificial bank material (% of bank length)	s. above
7	Land cover in riparian zone (top of banks and adjacent narrow strip) (% of bank length)	s. above
8	Land cover beyond the riparian zone (based on deviation from near to natural conditions for section types)	s. above
9	Degree of lateral connectivity of river and floodplain (Extent of floodplain not allowed to flood regularly due to engineering-based on hydromorphological surveys.) (based on deviation from near to natural conditions for section types)	s. above
10	Degree of lateral movement of river channel (% of length where lateral movement is artificially constraint)	s. above

	Parameter	Descriptions
Hydrology		
4	Changes of flow conditions due to artificial in-channel structures within the reach (impoundments, density of groynes and reflectors)	s. above
River continuity		
5	Reach-based and local impacts of sluices and weirs on river continuity with regard to biological and sediment continuity	s. above

The following description taken from the manual for JDS4 illustrates potential changes of the individual parameters, which had to be reported using the data collection tool.

Parameter 1 "Planform"
The planform of the major rivers was changed systematically since at least 150 years by the rectification and regulation of main channels, the cut-off of side channels and floodplains for navigation and flood protection and later for the hydropower construction (impoundments, residual water stretches).
No major changes were expected over large extent within the project period; however, planform changes should be recorded in case that major side channels were cut (or reconnected) and the cross section significantly changed in those reaches. Another case are significant planform changes due to particular dredging (Figure 7) within the last six years period. Regarding long-term trends of incision or aggradation of the riverbed (e.g. by sediment deficit) only reaches should be recorded where significant changes were observed compared to the period before 2013, e.g. when the channel incision is accelerated or stopped (it was recommended to use the parallel data analysis of the Danube sediment project).

The planform gives the framework condition for all major habitats in the river, such as pools, riffles, side channels, steep banks and point bars as well of all kind of sediment bars and islands. Changes in planform significantly reduce and impact those habitats, mainly for fish and benthic invertebrates.

Potential changes of planform	**Description of changes, affecting > 500 m river reaches**
Disconnection or reconnection of major side-channels	The changes affect at least the length of entire side-channel/island
Widening or narrowing of river reaches	When reaches significantly change in width-depth (infrastructure or restoration projects)
Significant changes of river bed/cross-sections	Particular dredging activities, but also strong deposition (compare parameter erosion/deposition character below)

Parameter 2 "Substrates"
Danube bottom sediments vary over the entire reach from gravel to sandy and finally silty substrates and are subject to permanent movement, with the exception of deeper impoundments.

As sediments in large rivers cannot be assessed systematically with the descriptive general approach only three assessment classes are used for the JDS. The Danube sediment project delivered new figures about the grain size distribution, dredging, the sediment balance and even sorting of sediment in the Danube.

Figure 7: Particular dredging activities exceeding regular maintenance dredging affecting > 500 m reaches should be recorded (photo credit: Wolfgang Kraier).

Changes on a minimum of 500 m length can be recorded only based on precise dredging data. It should be possible to identify those > 500 m reaches in a respective 10-km segment with the highest dredging intensity, in the six years period (permanent long-lasting maintenance dredging operation is not part of the update as already considered for the overall assessment in previous surveys).
Other changes can be observed maybe for impoundments (e.g. due to sedimentation/remobilisation processes or changed hydropower regime or the construction of ground sills, even with artificial material in the bottom.

The sediment composition and distribution at the bottom and the shoreline of rivers are essential for all aquatic but also interstitial life in the river. Changes in the composition (the substitution of gravel by fine sediments in impoundments totally change all bottom habitats and trophic conditions, but also the clogging or sorting/armouring of the gravel bottom can considerably alter the habitat conditions)

Potential changes of substrates	**Description of changes, affecting > 500 m river reaches**
Grain size changes due to dredging	Particular dredging activities exceeding regular maintenance dredging
Grain size/type changes upstream/downstream of dams, ground sills/chevrons	Significant changes of substrate composition, up and downstream of dams (coarsing, sorting), local introduction of (artificial) material (stones, gabions)

Potential changes of substrates	Description of changes, affecting > 500 m river reaches
Newly established or intensified sediment feeding (introduction)	To reduce channel incision material of various grain sizes (natural substrate, coarser material) can be added

Parameter 3 “Erosion/deposition character”
For the large rivers, at least the deposition character is well visible during low water conditions. Gravel and sand bars are subject of dynamic processes and can be suddenly appear and after a short while disappear (strong linkage to more general planform). For the JDS only major changes of the erosion/deposition character can be recorded. The appearance or disappearance of unvegetated bars can be but might not be always an indicator for impacts within a 10-km segment or even wider extent. Therefore, only changes which are considerable within the 6 years monitoring period should be recorded. For the exact localisation, the regularly reported bottlenecks for navigation[2] can be used as information sources or specific projects such as the Danube wild island project[3]. As both processes can have natural as well as anthropogenic reasons, the final assessment will consider and revise the recorded changes (in most cases the accelerated incision in free flowing reaches can be seen as a “deterioration” of the system, while deposition process in reaches which have been heavily regulated in the past might be seen as “improvement”).

The erosion/deposition character is a natural behaviour generating river reaches with stronger erosion followed by reaches with prevailing deposition. Both are extremely important for the major habitats in the channel building deep pools and shallow ripples and of course all kind of bars offering a wide spectrum of flow, temperature and trophic conditions for fish and macrophytes. By uniforming the erosion/deposition character or e.g. by strong channel incision downstream of dams due to interrupted bedload transport or by dredging, habitats will decrease or even disappear.

Potential changes of erosion/deposition character	Description of changes, affecting > 500 m river reaches
Significant erosion change	Acceleration or significant reduction of river bed incision
Significant deposition change	Appearing or disappearing of sand and gravel bars, island development

Parameter 4 “Artificial in-channel structures and flow conditions”
The parameter group 4 is one of the most relevant including all major hydraulic structures in the channel and allows assessing hydrology (flow conditions) as well as river continuity (dams).

2 https://www.unece.org/fileadmin/DAM/trans/doc/2013/sc3wp3/ECE-TRANS-SC3-159-Rev1e.pdf

3 http://wildisland.danubeparks.org/

Figure 8: New established or enlarged groynes influencing flow conditions > 500 m reaches (also groin fields, guiding walls or new chevrons should be recorded (photo credit: Wolfgang Kraier).

Transversal regulation works should serve for the river regulation and the low water concentration for navigation, but also as dams for hydropower generation and navigation. In most cases, those structures are groynes (Figure 8), ground sills, ramps and even dams. Aside of the drastically changes of flow conditions in impoundments (down to stagnant conditions) also groynes or ground sills can significantly change the general and local flow conditions. The disturbance within groin fields impact the shallow water reaches influencing young fish populations.

Only three descriptive assessment classes for the pressure on the flow conditions are subject to the JDS assessment. Therefore, the flow conditions will change only in case that several groynes over a length of in total 500 m length of rivers were constructed or removed. If new water abstraction/diversion of water was established which could influence the flow conditions the change have to be recorded. There is no threshold for the change.

Potential changes for artificial in-channel structures and flow conditions	**Description of changes, affecting > 500 m river reaches or dams**
Construction or removal of hydraulic structures	Groynes, ground sills, chevrons
Change of length of impoundments, hydropeaking (daily or even hourly water level fluctuation for peak power production downstream of dams)	Changes in dam operation
New water abstraction/diversion	Changes by water abstraction for any purpose

Parameter 5 “Continuum interruptions for biota and sediment”
There are no new dams built in Danube between 2013 and 2019. Therefore, only the restoration of fish passability is important (Figure 9). The continuum interruption for sediments was part of the DanubeSediment project. Significant changes of dam operation to improve sediment continuity or by feeding material downstream of dams should be recorded for the project period.

Figure 9: The hydropower dam at Melk in Austria is already equipped with a fish bypass (photo credit: Wolfgang Kraier).

Ensuring river continuity is crucial for biota (in particular fish) to be able to access the appropriate spawning and feeding habitats and to fulfil their life cycles. Sediment continuity has a strong impact on entire riverine systems, as deficits in sediment balance will alter type-specific habitat conditions also in the long run.

Potential changes of river continuity	**Description of changes for dam location**
River continuum changes for biota	Fish passes and type
River continuum changes for sediment	Sediment management and dam operation (feeding of gravel, flushing)

Parameter 6 “Extent of reach affected by artificial bank material”
The river regulation is based mostly on the protection of erodible banks, mainly by rip-rap (Figure 10) but also by concrete. The artificial bank material totally changes the type-specific physical characteristic of banks (strong inclination of fixed banks, no shift of banks). The natural habitats of the sensitive semi aquatic contact zone are modified and substituted by stone and rock, which often became favoured habitats for alien species (e.g. mussels).

For banks and floodplain changes for both sides (right and left bank) have to be recorded in general. The balance of construction and removal of bank reinforcements was on focus for the HYMO update for JDS4.

Figure 10: New or reinforced bank reaches > 500 m length should be reported (photo credit: Wolfgang Kraier).

Potential changes of bank material	**Description of changes, affecting > 500 m river reaches, both for left and right bank**
Change of bank material, new or reconstructed/renovated bank reinforcements or restored river banks	Bank revetments or stabilisation by rip-rap, concrete or other material also for the case of renovation of old rip-rap, restoration by removal of artificial material

Parameter 7 "Land cover in the riparian zone"

The removal or change of bank vegetation is frequent where roads, infrastructure or harbours (Figure 11) have been built. The "riparian zone" in the JDS assessment comprises only the narrow strip of land on top of the river banks and is not covering the floodplain, which is a separate parameter. The changes must be long-lasting, e.g. if vegetation is cleared only temporarily to construct a new groin, the change is not to be recorded. In particular, macrophytes and helophytes living on the edge of young shallow bars and banks are affected, but also pioneer and young softwood stands, which are not assessed in respect of the WFD (EC 2000). In smaller side-channels the shadow of the bank vegetation can influence the water temperature, tree roots and woody debris origin from riparian zone influencing the aquatic life.

Figure 11: Completely modified riparian zone > 500 m (photo credit: Wolfgang Kraier).

Potential changes of land cover in the riparian zone	Description of changes, affecting > 500 m river reaches, both for left and right bank
Change of bank vegetation, such as removal or substitution of natural vegetation	Construction of harbours, infrastructure, bank reinforcements, but also removal of vegetation for flood management, riparian zone restoration (natural succession, replanting)

Parameter 8 "Land cover beyond the riparian zone" (Floodplain)
The floodplain is integral part of the river ecosystem and influences aquatic habitats, as by woody debris, trophy, water temperature and temporal water bodies importing for fish spawning. As larger the river and its floodplain as more important the floodplain becomes for the riparian ecosystems and finally also the aquatic system. The assessment of floodplains support the general hydromorphological assessment and allow conclusions regarding the occurrence of permanent and temporal floodplain waters to serve as fish spawning habitats or as refuge area in case of pollution accidents (resilience of ecosystem). Many species have stations in their life cycle in the main channel as well as in in floodplain waters.
About 78% of the Danube floodplain is today disconnected from the river. The floodplain area (active and former) is still subject of land use changes. To allow a pragmatic way for the JDS it had to be estimated first how far the general landcover was changing (within active and former floodplain, compare Danube Flood Risk Atlas[4] for estimating the area, the flood risk map sheets can be

[4] http://www.icpdr.org/main/activities-projects/danube-floodrisk-project

downloaded). At the Danube, the floodplain can easily reach up to 10 km in total width. Therefore, it was proposed to take into account a maximum buffer of 5 km on the left and right side of the river including active and former floodplain (changes in areas adjacent to the flood dikes had to be considered as well as potential restoration/retention areas). No detailed land cover analysis was expected, but major changes such as the construction of large infrastructure, commercial areas or even settlements, but also major changes in floodplain land cover also induced by restoration projects (e.g. significant change of agricultural land into grasslands or afforestation) have been recorded. The Danube floodplain project[5] starting in 2019 had to be used as reference (best practise and case examples), even the project exceed JDS4.

Potential changes of land cover	**Description of changes, affecting > 5% of adjacent floodplain (max. 5 km each on left and right river bank)**
New infrastructure, commercial areas, settlements	New embankments and earth work, sealed areas, removal of vegetation
Large scale, and significant land cover and usage changes including	Changes of land uses e.g. by restoration or flood projects, switch from agriculture to grassland or afforestation (but also vice versa, deforestation and intensification of land uses such as conversion of grassland (incl. land drainage or removal of drainage)

Parameter 9 "Degree of lateral connectivity"
Lateral connectivity between the main channel and side-channels, but also directly into the floodplain during raising water levels is a remarkable characteristic of the river-floodplain system. Closing side channels, reinforcing of banks and particular cutting of active floodplain by dikes limit or even prevent the lateral connectivity and lead to changed habitat and sedimentation conditions, modifying the aquatic species composition., in particularly also already during lower water levels. For the JDS newly constructed or increased flood dikes, in particular side-channel closures on mean water level influencing a > 500 m reach or affecting 5% of floodplain had to be recorded.

Potential changes in lateral connectivity	**Description of changes, affecting > 500 m river reaches or 5% of floodplain area**
Construction or removal of dikes, side channel closures / opening	Disconnection or reconnection of major side-channels and floodplain areas

Parameter 10 "Degree of lateral movement of river channel"
The last parameter supplement the floodplain assessment, is the capability of river to shift laterally. This is only possible in river reaches without bank protection or groynes/guiding walls and sufficient active floodplain space. As for planform, the lateral shift of the channel creates new steep and shallow banks and in-channel features such as bars and islands can be seen as "motor" for habitat creation in the channels. If the lateral movement is reduced or impossible, the width and depth variability of the channel significantly decrease and affect all in-channel habitats. The strong rejuvenation and habitat development cycles (duration), a typical feature of riverine landscapes, strongly decrease with missing lateral shift of the main channel.

[5] http://www.interreg-danube.eu/approved-projects/danube-floodplain/partners

Potential changes of lateral movement of river channel	Description of changes, affecting > 500 m river reaches or 5% of floodplain area
Prevention of movement by bank and channel fixation	Bank and channel fixation
Increase of movement by removal of bank and channel fixation, widening	By widening, removal of bank reinforcement having impact on lateral shift/floodplain

Additional parameters (without precise thresholds, not covered during JDS3 in 2013, should be recorded as amendment)

Hydropeaking
Hydropeaking usually occurs downstream of storage plants. Producing electricity on demand leads to unnatural rapid flow fluctuations. The rapidly increasing flows phase ("Schwaller (pulse)") has a "flushing effect" leading to a drift of aquatic organisms. When the electricity production is stopped the abrupt reduction of flow ("Sunk") leads to a "stranding effect" in the shallow shore line as the wetted area is reduced within short time. This is in particular relevant for early life stages of fish.
Water level fluctuations also occur if a run-of-river hydropower plant is also operated to produce electricity on demand (managing ponding). This might lead to changes in water levels up to several decimetres (as for large rivers as the Danube). So far it is not considered to be a significant pressure on the Middle and Lower Danube (only in Germany on the Upper Danube, downstream of Lech tributary it is recorded with unknown amplitude and was recorded within DRBMP Update 2015). Hydropeaking should be measured in decimetres per day for the respective 10-km segments. Basically hydropeaking would fall under parameter 4 (incl. flow conditions), but there are no common metrics or assessment schema right now (please describe the local situation).

Importance for general riverine habitats and ecology:
Hydraulic stress (drift) and of the abrupt change of the extent of wetted area are threatening the survival of aquatic species. In addition, interstitial species (in addition to water fluctuations clogging in case of fine sediment supply with the hydropeaking waves) and semi-aquatic life groups living on the bars are affected.

Wave effects
So far, wave effects were not considered to be a significant pressure of basin wide importance. Nevertheless, wave effects should be recorded in case that impact on aquatic species or life stages (e.g. fish) are already observed on national level or highly expected. Density of waterway traffic[6] (number of ship passages/day or week as based on traffic recording of the navigation authorities) might help to identify likelihood of negative effects. In addition, the distance to banks and the shape/depth of cross-section is important. Basically wave effects would fall under parameter 4 (incl. flow conditions), but there are no metrics or assessment schema right now (please describe the local situation).

Importance for general riverine habitats and ecology:
Wave activity can strongly disturb early fish life stages in particular at shallow banks (as recorded for gravel/sand bars e.g. in Ipoly national park in the Danube bend in HU or as indicated by current studies from Austria[7]). The density of traffic can be only a general indicator and not all ships cause significant waves. Further sport boat and recreational activities could be considered. In Lower Danube, wave

[6] http://www.danubecommission.org/dc/en/danube-navigation/danube-navigation-statistics/

[7] http://www.interreg-danube.eu/uploads/media/approved_project_public/0001/05/dd84ff31a62eb40d73117978c615a42674288243.pdf

activity may also occur naturally on shallow banks in case of strong winds, which have to be separated from artificial causes.

Finally, to illustrate and refer the changes the countries provided data on restoration and infrastructure projects using the data collection tool.

Restoration projects

All kind of restoration projects within the period 2013-2019 affecting > 500 m length of river and or bank reaches or 5% floodplain area within the 10-km-segment which were implemented for example to improve continuity, lateral connectivity (side-channels and floodplain extension), removal of bank reinforcements/rip-rap and groynes/cross or spur dikes or guiding walls).

Infrastructure projects

As based on previous investigations and templates all infrastructure projects directly affecting the river within the period 2013 - 2019 had to be recorded. Those are river regulation projects or water abstraction/diversion projects with significant effects on > 500 m reaches (channel/bank) or 5% of floodplain area for various purposes (waterway transport incl. harbour construction/extension, flood protection, infrastructure, urbanisation, erosion control or hydropower). Furthermore, major dredging campaigns as part of infrastructure projects should be recorded (not the long-lasting maintenance dredging).

2. Results

Based on the 241 10-rkm JDS3 segments (navigable Danube downstream of Kelheim, including only the Sulina branch in the Delta), countries recorded changes of the three main assessment groups (channel, banks and floodplains) for the period 2013-2019.

All riparian countries participated using the data collection tool provided by ICPDR to record all relevant changes. While for the Upper Danube and SK-HU reach of the Middle Danube reported changes are frequent, long reaches on the Lower and Middle Danube segments have no change. Transboundary reaches were collected independently for each country, but analysed jointly for the whole segment. Reference projects and documentation were not available in all cases.

2.1 Analysis of recorded changes

In total, the recorded changes comprise 54 improvements and 19 deteriorations (73). However, several changes occurred in the same 10-rkm-segments for individual parameters, transboundary changes were reported twice (as planned), changes were recorded for two neighbouring segments at once or being recorded for one and the same segment as deterioration and improvement, which is possible. Therefore, only 56 main segments (entire 10-km-segment including all sub segments for channel, banks right/left and floodplain right/left, compare Figure 1) have been subject to individual changes. Nine further changes below the threshold of 0.5 km in length have to be allocated with other changes in the same segment (possible aggregation to 0.5 km) or to be excluded from the segment assessment, which are five segments (three improvements and two deteriorations). Finally, changes as required by the methodology can be assumed for only 55 main segments or 23% of all segments.

Aside of many segments with no changes (186 or 77%), most records are improvements falling into 43 main segments or 18% covering mostly the Upper and Middle Danube in DE, AT, SK and HU, while the 12 segments with deteriorations (5%) can be find in HU, RS, BG, RO and UA (Figure 12). The further assessment of the 10-rkm-segments follows in chapter 2.2.1.

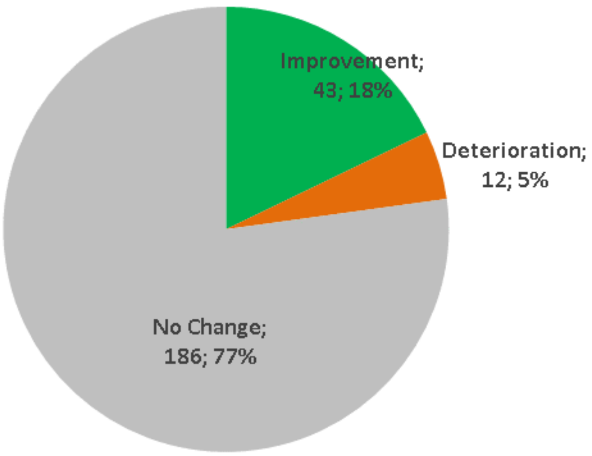

Figure 12: Distribution of changes by number of continuous 10-rkm-segments

The analysis of changes (Figures 13-15 and maps in chapter 2.2.3) is based on the total number of recorded changes (73) to keep transparently all records sent by the countries (from data collection tool).

River bank changes (restoration or construction) prevail with 46% followed by changes of the floodplain (29%) including the reconnection of side-channels and 25% for the channel (Figure 13).

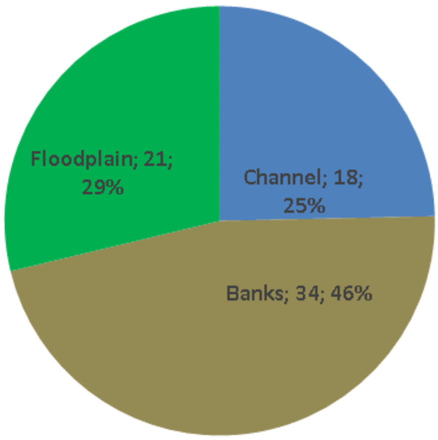

Figure 13: Distribution of prevailing changes for the main categories

The total lengths of all changes (73) cumulatively sums up to 159.69 km. Regarding the length of the changes, rather "short and small" projects predominate. The exception are fish passes opening entire 10-rkm-segments for migration of biota. Short measures < 2 km comprise 64% of all changes, but only 37.99 km or 24% of all changes by total length (Figure 5). The average length of changes is about 2.2 km, but excluding the full length of 10-km-sections for continuum restoration by fish passes, the average length dropped to 1.7 km.

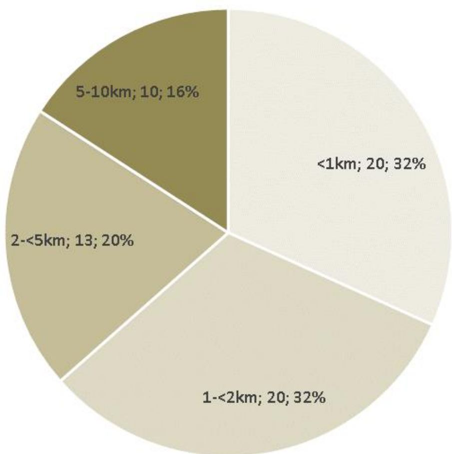

Figure 14: Length classes distribution in km for changes

Most of the changes are related to river bank development [parameters 6 & 7] with in total 34 changes (Figure 15). The removal of rip-rap clearly prevails with 23 cases. Side channel connections [9] as mainly improvements are rather frequent (8 times) followed by channel changes [1], which are recorded in junction to side-channel connections on the Middle Danube (five times), but also as deterioration (four times due to infrastructure and dredging activities on the Lower Danube). As already mentioned, parameter [5] for continuum improvements are realised entirely in the Upper Danube. Merely the parameter [4] on changed flow conditions and regime by structures (groynes, dams with impoundments) was not reported at all.

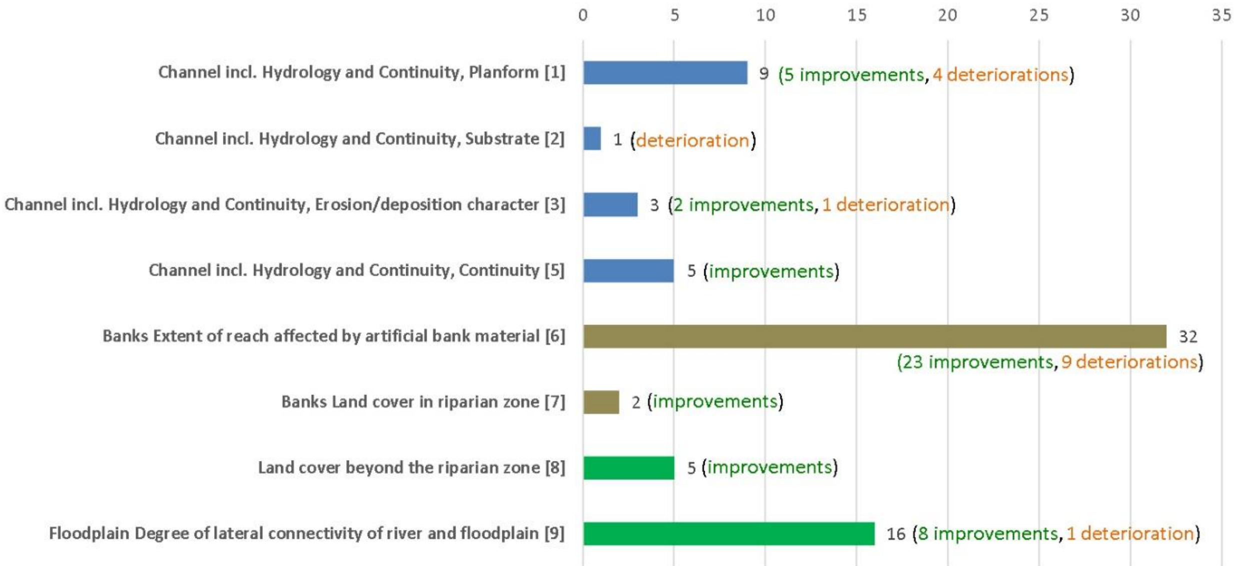

Figure 15: Types of restoration/alteration per all individual changes (blue for "Channel", brown for "banks" and green for "floodplains") and number of improvements/deteriorations per type.

2.2 Reassessment of 10-rkm-segments with observed changes

2.2.1 Overall assessment

Most of the observed changes cover bank and floodplain segments and show the ambitions of many countries to improve the hydromorphological conditions. However, the length and extent of changes (for structural measures the mean length is 1.7 km) did not lead in all cases to a shift of assessment classes. This has two reasons, firstly the "small size" of changes in relation to the 10-rkm-segment and secondly the previous nearest assessment class boundary.
This lead in total to the class shift of individual assessments for channel, banks and floodplain of 22 out of 55 segments with changes (compare also the maps in chapter 2.2.4 for precise location).

After screening and comparing the changes in detail (starting with major changes > 1 km length and by overlaying changes within one and the same segment, e.g. for the transboundary reach of Danube downstream of Gabčikovo improvements and deterioration reported by both countries neutralize each other), only two segments changed in overall assessment, two in the worse direction, but already having been close to poor assessments before. Those are the segments just downstream of Iron Gate II in Serbia (the bank assessment was reduced from three to class four leading to an overall shift from 3 to 4, however the bank and flood dike construction for Radujevac affect only a small new stretch, in total 2.8 km) and

the Danube near Reni in Ukraine (due to recorded dredging in and close to the harbour affecting planform and substrates of channel from 3 to 4 leading to a shift in overall assessment, however the reach of 1.2 km and the amount of dredged material is limited and the dredging start in early 2019, at the end of the monitoring period).
Further several overall assessments for segments (arithmetic mean of classes for channel, banks and floodplain) fail to shift in a better class due to close boundaries, but being strong candidates for the next cycle of restoration measures (e.g. two segments in the AT reach east of Vienna).
Regarding the fish bypasses in the Austrian Danube the four related segments didn't shift in assessment as for the 3-digit assessment (compare chapter 2.2.2) due to the numbers of sub-parameters for the channel group remaining in the worst class: If planform, flow character, sediment grain size, sedimentation/deposition character are untouched from the measure the segment remains in the worst class 5, even the barrier is assessed with as "3" for "partial passable" (for fish but not for sediment).

Considering the reported changes only a few 10-rkm-segments changed for overall class: In two cases the assessment drop from class three to four in already strongly altered reaches (Figure 16).

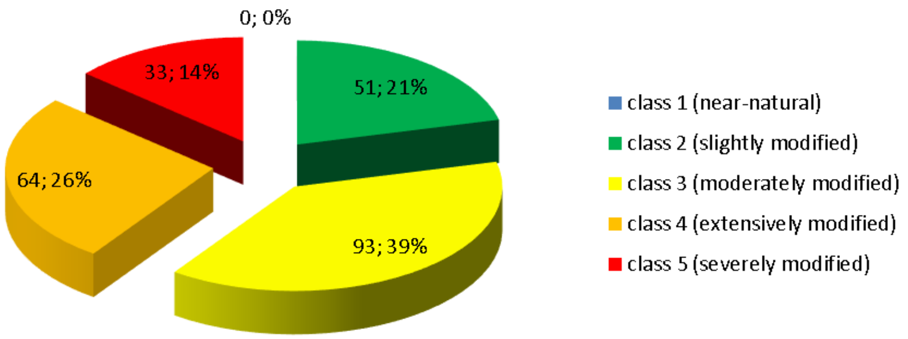

Figure 16: Overall assessment of JDS4 as based on JDS3 with only slight changes (shift of two segments from class 3 to 4, no change in percentage)

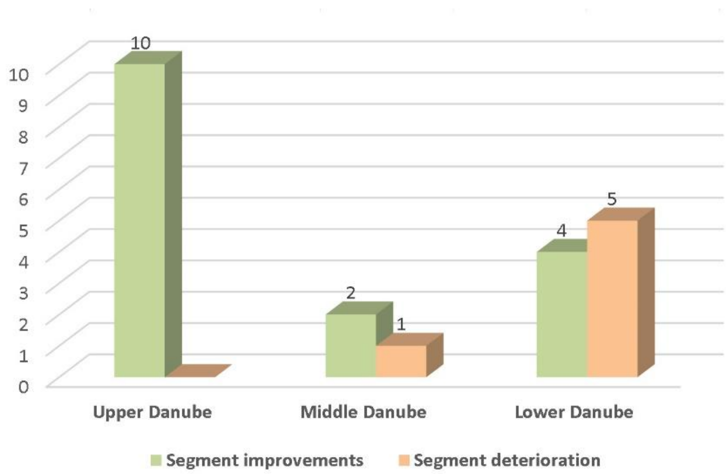

Figure 17: Overview of segments with changes for at least one parameter group (channel, banks, and floodplain) along the three main section of Danube

In general, the recorded changes imply many improvements in the strongly altered Upper and partial the Middle Danube while on the Lower Danube a few deteriorations prevail (Figure 17), however, based on the much better original JDS3 assessment for the Lower Danube in comparison with the Middle and Upper Danube and the deteriorations are spatially limited. In the total perspective, the positive aspects predominate, regarding the fish continuum the construction of bypass solutions for Austrian dams is an important step. Several side-channel connections including SK and HU are good examples for the proceeding restoration. The reason why more segments on the Upper Danube improved in comparison to the Middle Danube, can be explained with the worse situation before in DE and AT, while the free-flowing SK and HU reach assessment in the third moderate class was closer to class four instead two.

2.2.2 WFD 3-digit assessment

The WFD 3-digit analysis for the entire Danube (Figure 9) indicates the general alteration similar to the overall assessment (prevailing classes 3-5 for the 241 10-km-segement), in particular for the best documented parameter group "Morphology", but also the "Hydrology". The longitudinal continuity is interrupted by 18 dams (segments). In 2013 for two dams with functionning fish passes and partial sediment feeding (Wien-Freudenau and Melk) the value was "3" according to CEN standard.

The biggest difference now is the restoration of partial continuum (for fish) in the Austrain Danube reach. Four additional hydropower dams are in the meantime equipped with fish bypasses, the ecologically most efficient way to restore fish passability. For the Austrian reach therefore only the dams in Altenwörth and Ybbs-Persenbeug remain, but will be equipped until 2021, which will expand the passability towards Wachau and even up to Aschach. For bedload sediment (gravel) the dams are still a considerable obstacle (compare outcomes of the Danube Sediment Project, Habersack et al. 2019 & 2020).

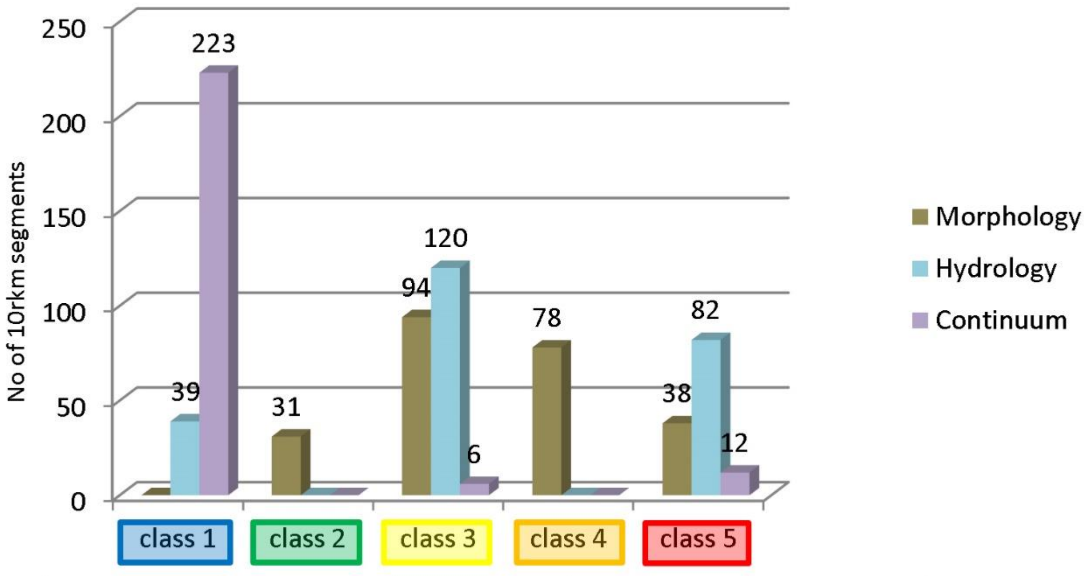

Figure 18: WFD 3-digit assessment as based on JDS3, mainly changed for the continuity for fish by the construction of fish passes in AT (hydrology and continuum were assessed only in classes 1, 3 or 5).

For most of the other changes, mainly improvments like the removal of rip-rap for short stretches only on the left or rigth side respectively, the 3-digit evaluation is not as sensitive as the overall assessment, due to the integration of assessment values for both banks and floodplains. For example, if the bank was improved from class 5 to 4 only on rigth side, the integrative "Bank" indicator (arithmetic mean) remains class 5. Only in case of improvments on both side the assessment value shift. Regarding this major changes within two of the three assessment groups "Morphology" and "Continuum" in total seven segments shift to a better class, including 4 fish bypasses all on Upper Danube, while two deteriorations on Lower Danube have been recorded.

2.2.3 Maps of changes

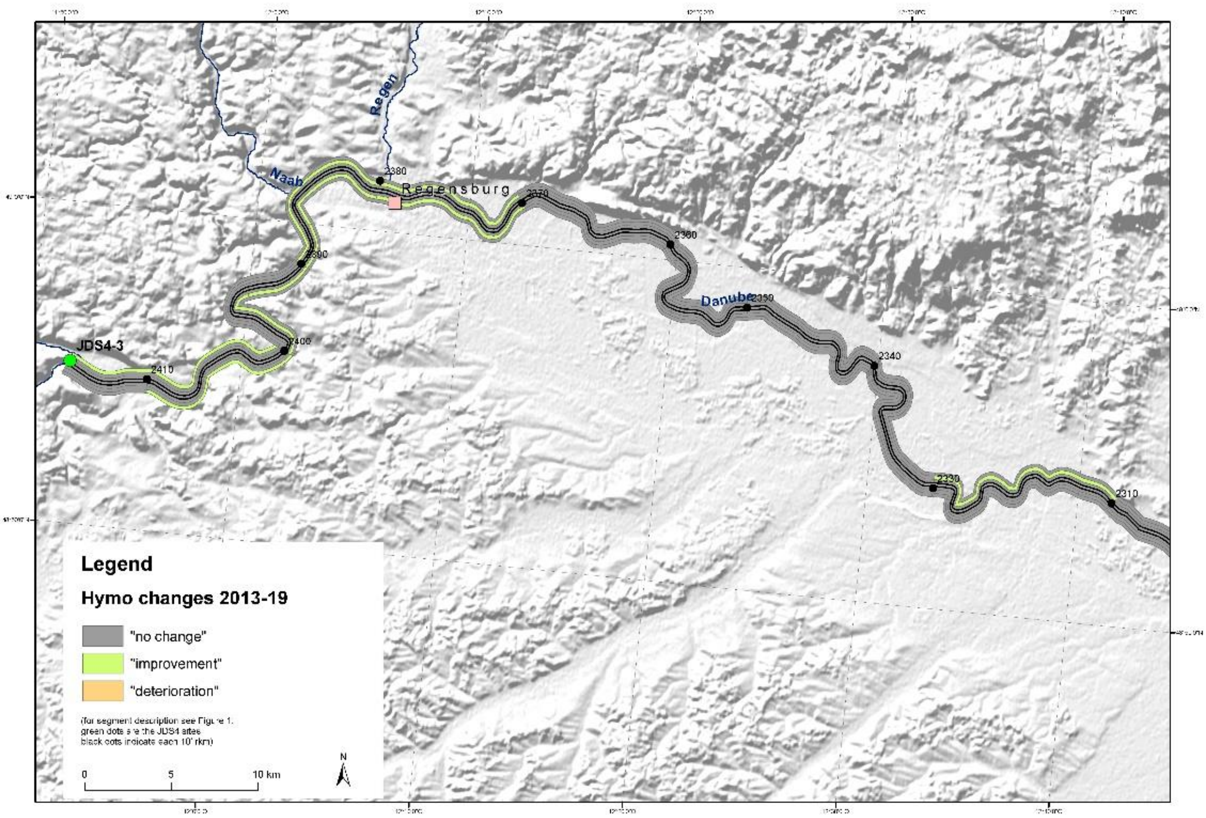

Figure 19: On the Upper Danube between Kelheim and Regensburg, many small-scale measures to improve banks and partially floodplain were implemented. However, the degree of alteration remains very high, the entire reach is impounded (green dots in the maps mark the JDS4 stations).

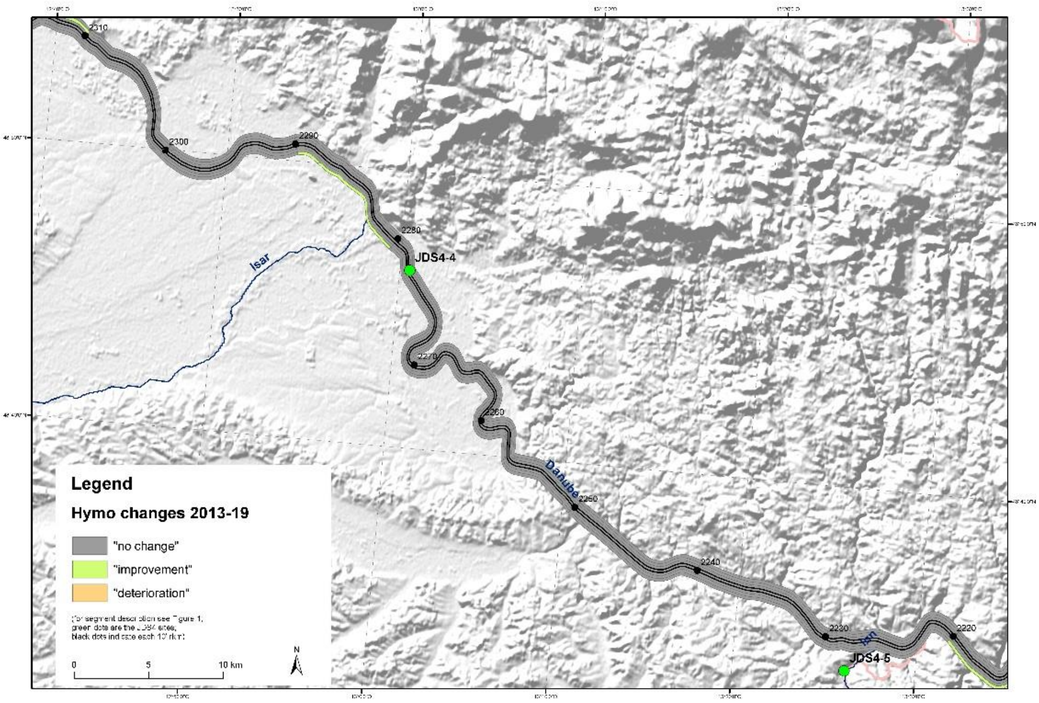

Figure 20: In the free-flowing section downstream of Straubing, but in particular opposite to Deggendorf, close to the Isar mouth banks and the floodplain have been partially restored. The floodplain restoration near Deggendorf is the only active flood dike repositioning (to increase retention volume) along the entire Danube in the reported period).

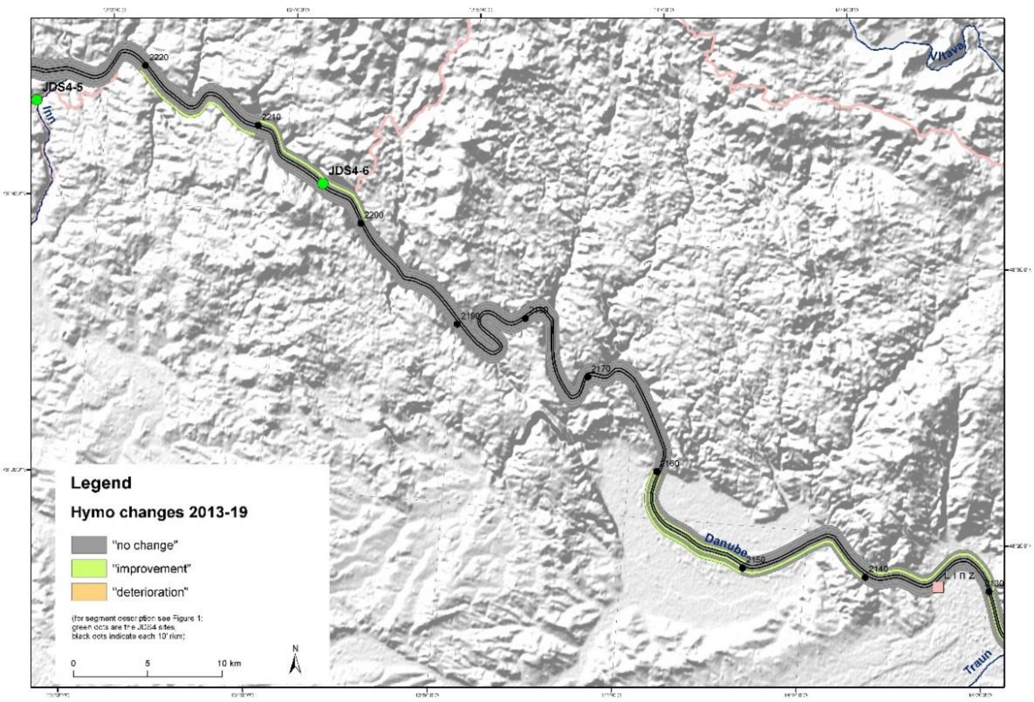

Figure 21: In the border reach DE-AT some improvements on right floodplain and left bank (backwater Engelhartzell) happened. Upstream of Linz local measures cover works in the right floodplain (connectivity, fine sediment removal) and shorter sections of bank improvements.

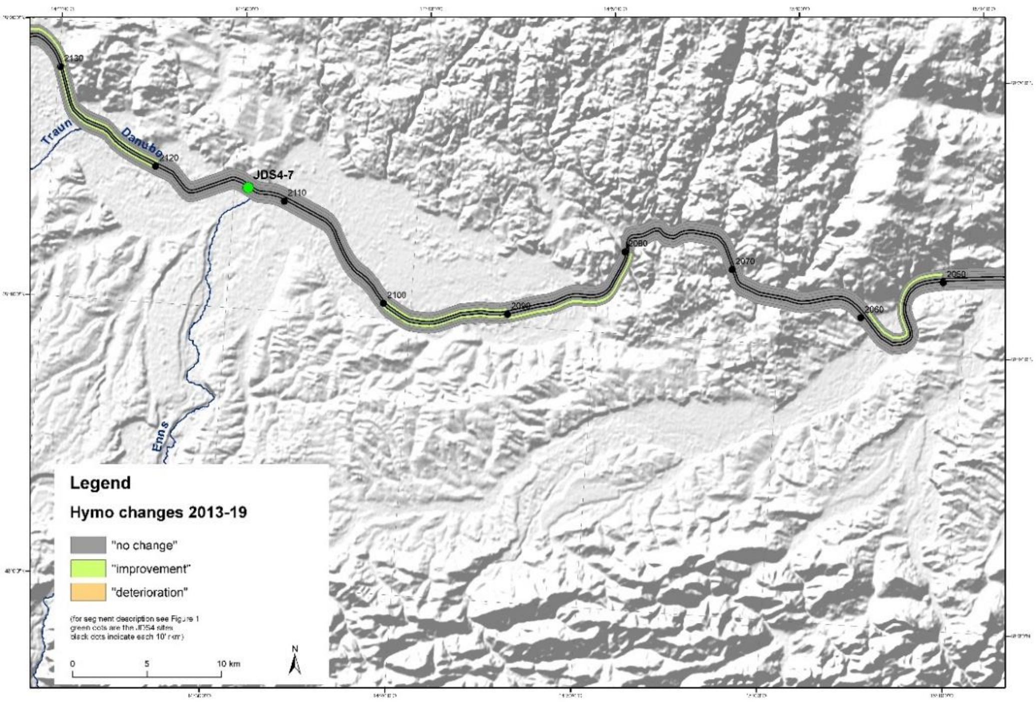

Figure 22: Downstream of Linz the new fish passes for the two hydropower plants, Abwinden Asten and Wallsee-Mitterkirchen must be highlighted. Further activities can be find in the upper backwater reaches by introducing gravel banks.

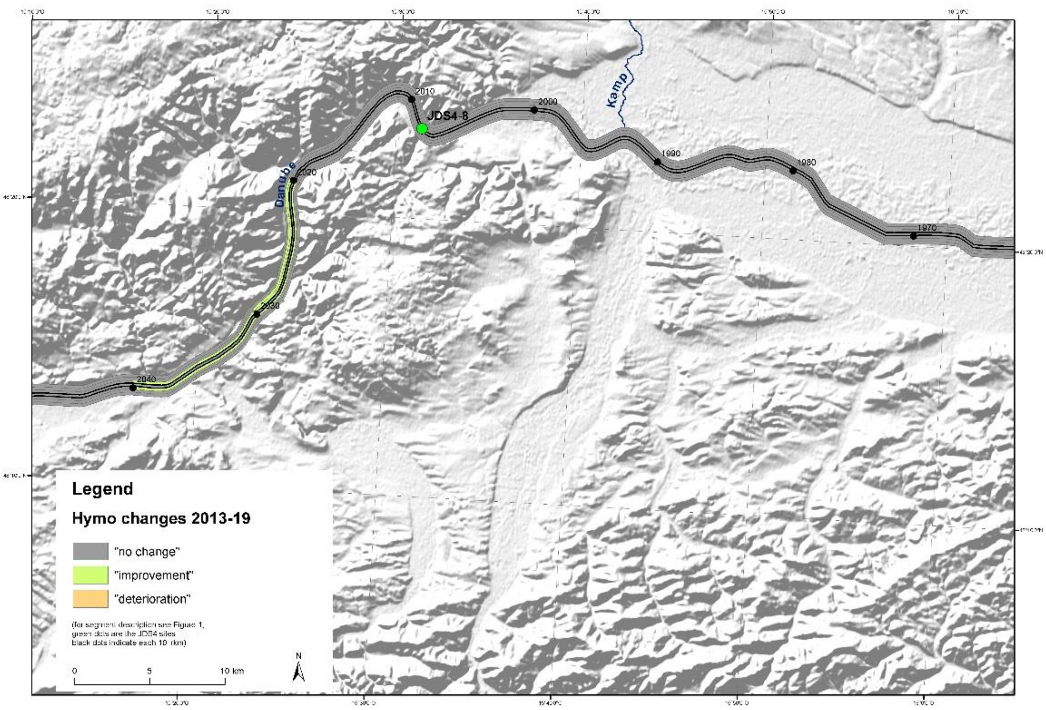

Figure 23: The free-flowing Wachau reach was and is subject of several restoration projects, mainly co-financed by Life projects. Aside of the creation of gravel bars, the deposition of gravel bars near the banks is characteristic for the restoration type of this reach. However, the incision downstream of the hydropower plant Melk is still considerable and most probably further additional Material must be supply.

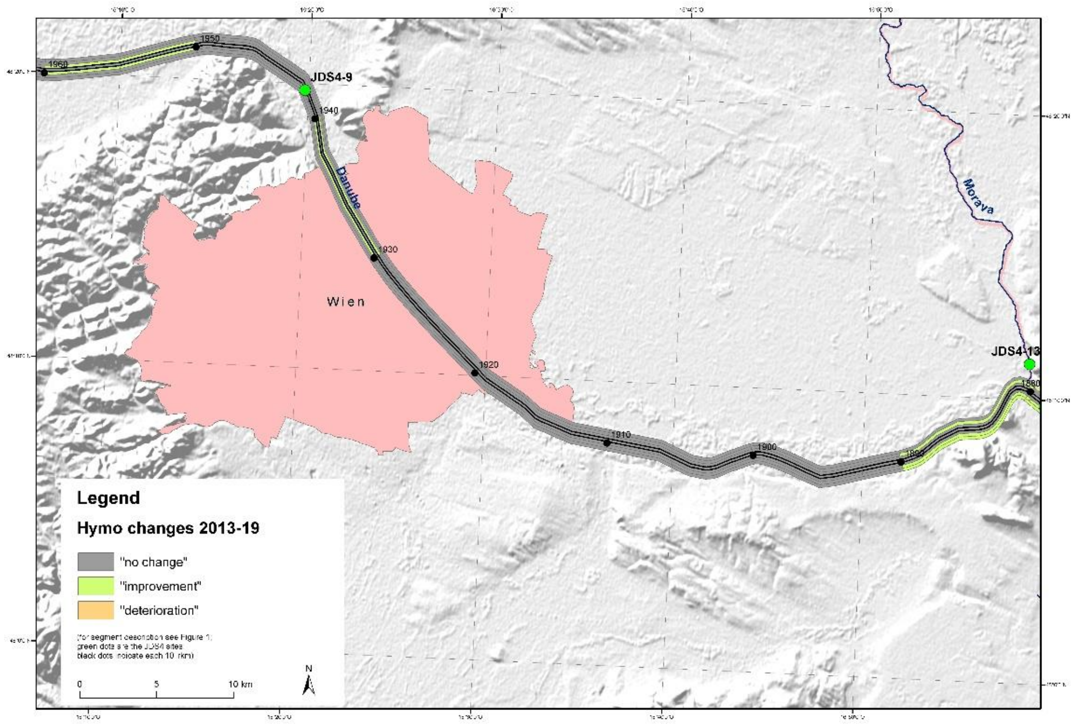

Figure 24: The fish pass in Greifenstein is the third dam equipped between 2013-2019 opening another barrier upstream. The Danube east of Vienna is subject of many restoration projects within the past 30 years and therefore a kind of pilot area at least within the Danube basin. Two segments tend to reach a better class in overall assessment and the two large scale side-channel connections near Haslau and Stopfenreuth will realise this goal in the next years.

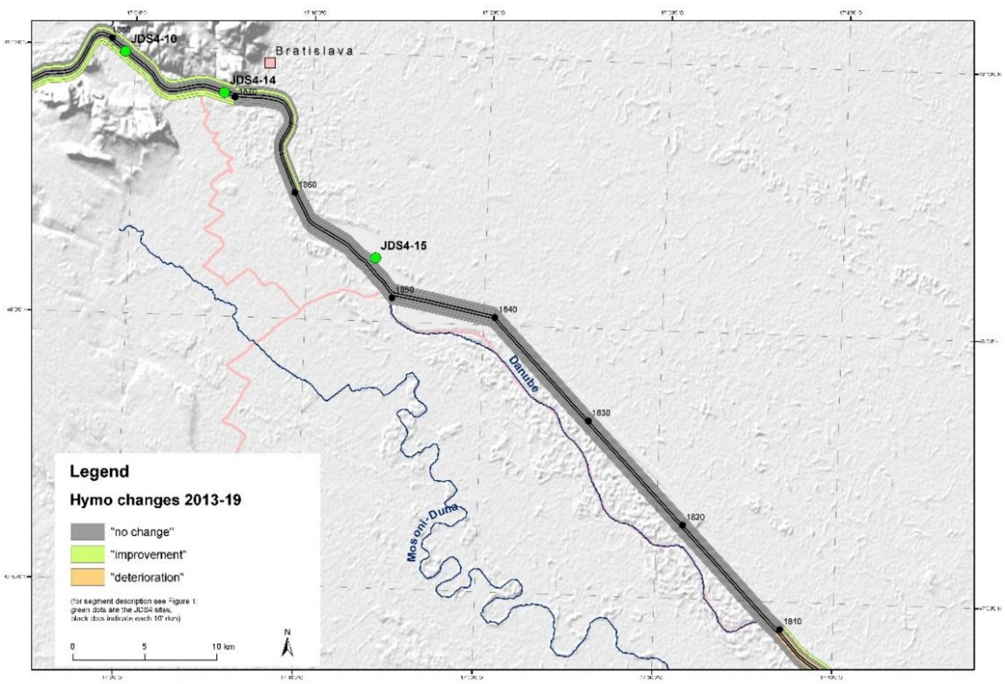

Figure 25: Also alongside the AT-SK border stretch restoration activities can be recorded on both side of the river, bevor the Gabčikovo backwater begins in Bratislava.

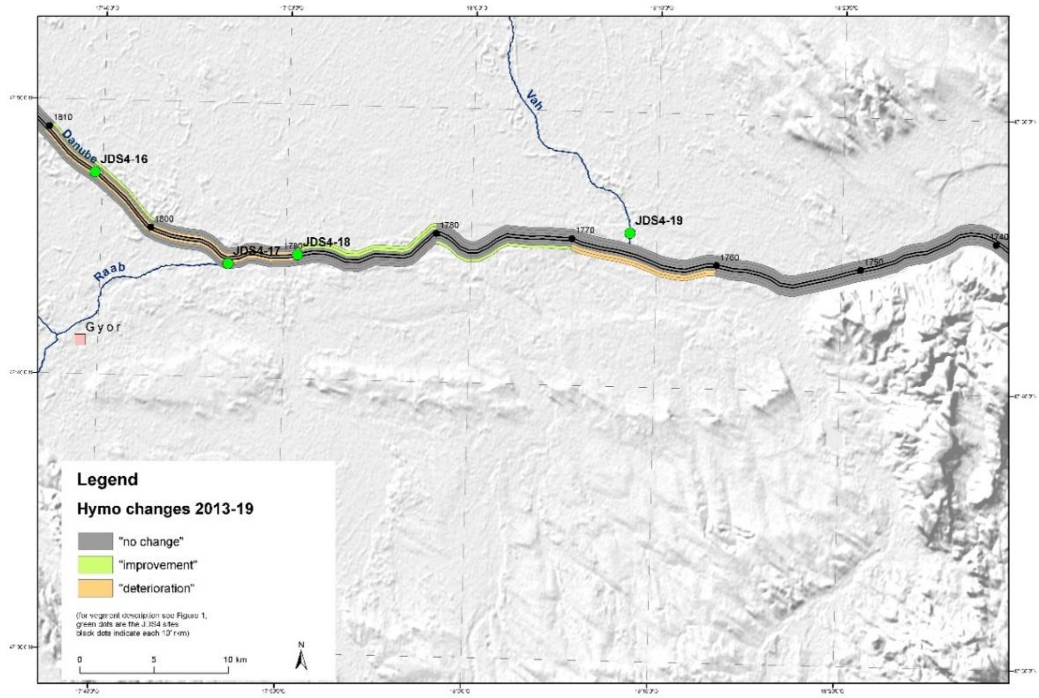

Figure 26: The border stretch SK-HU is characterised by the restoration of two larger side channels in SK and one floodplain improvement in HU. However, the ongoing deepening of the channel downstream of the Gabčikovo dam "neutralize" from an international viewpoint the development. In Komárom new flood protection reduces the right floodplain area.

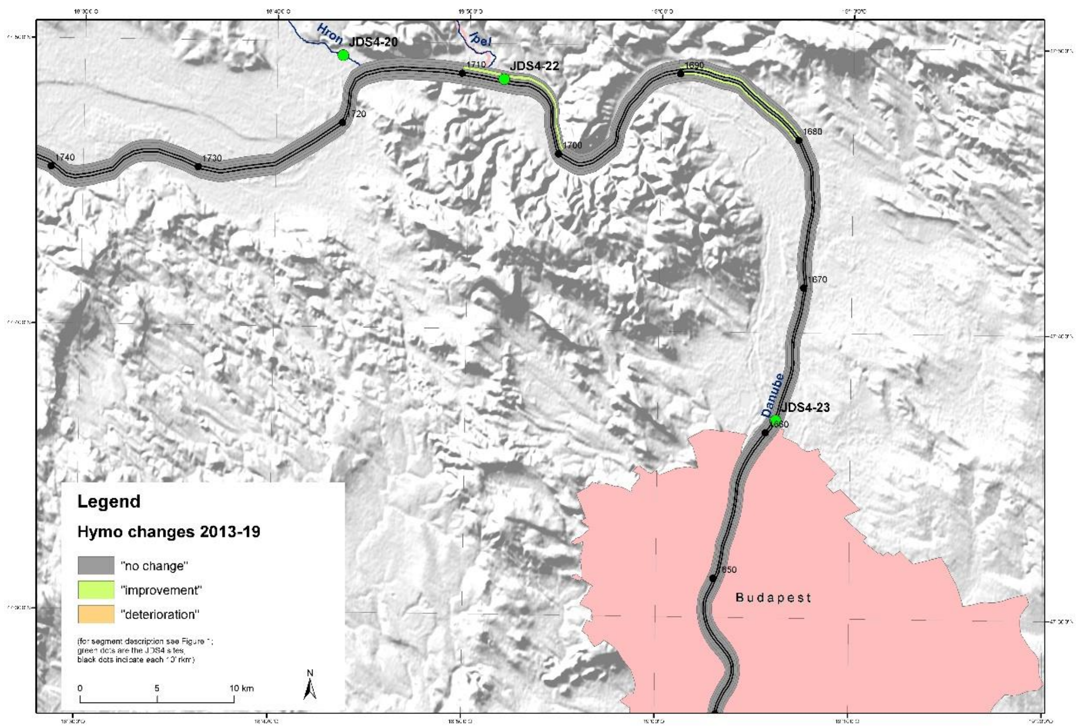

Figure 27: in the Danube bend, several smaller improvements on banks and channel can be registered, but not leading to improvements of assessments.

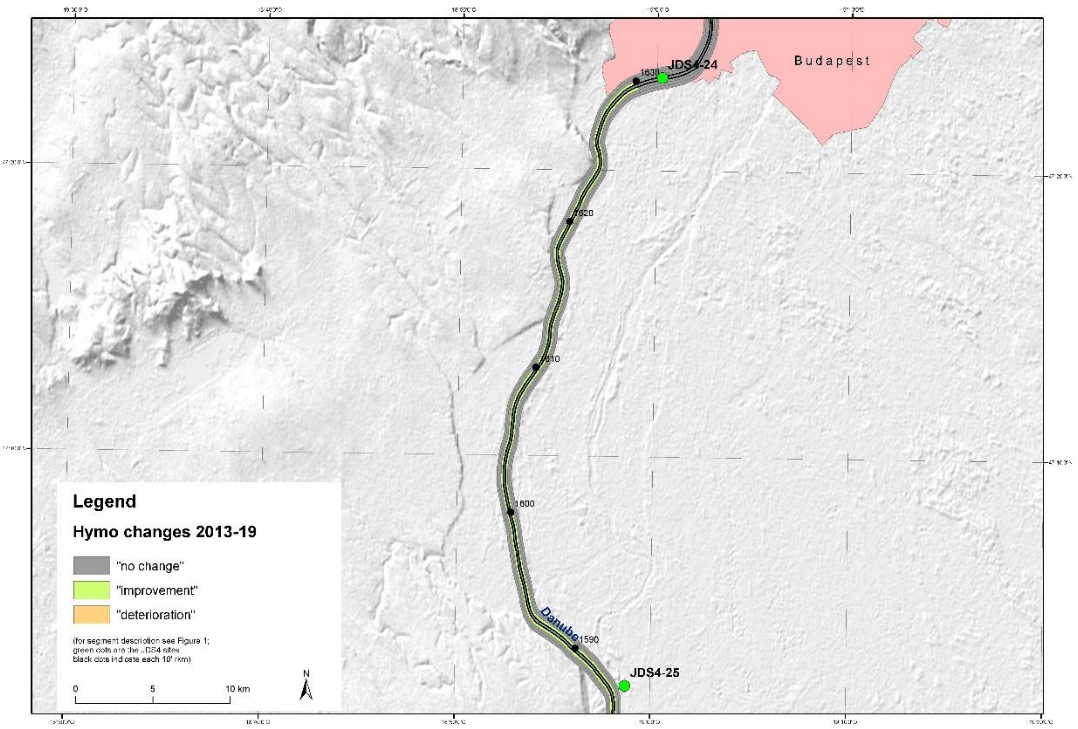

Figure 28: South of Budapest several improvements on channel and side-channels/floodplain connectivity can be recorded. The biggest one is the restoration of a longer island near Adony (right bank near rkm 1,595).

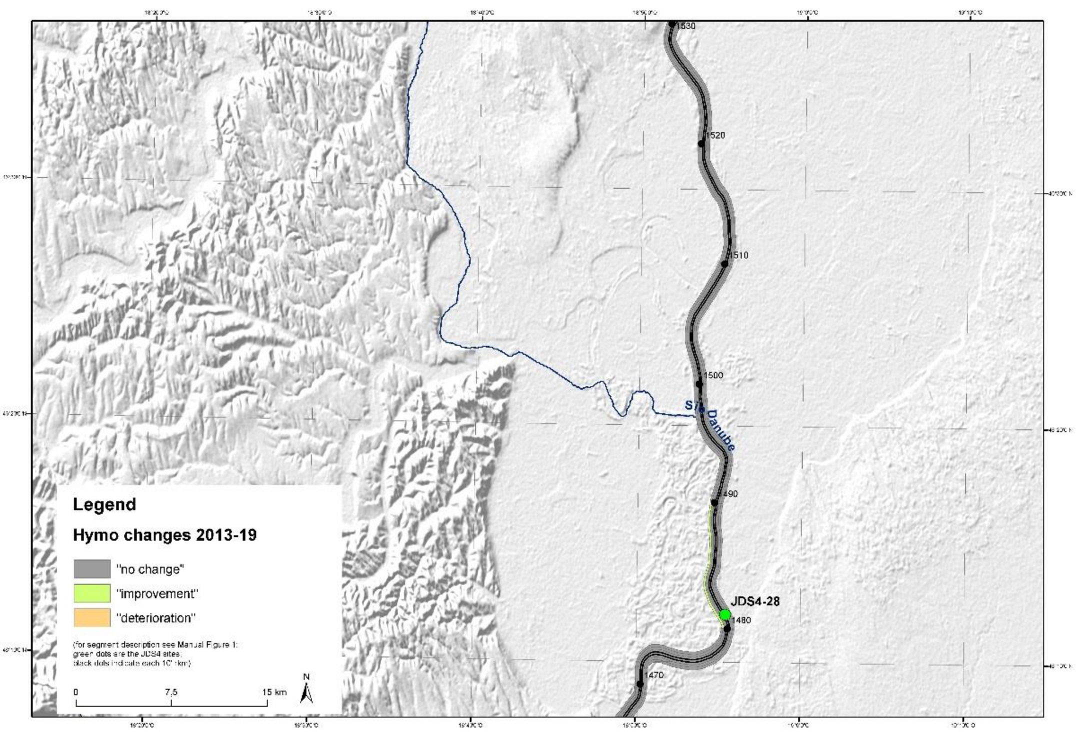

Figure 29: Within the Gemenc area extensive restoration works were implemented.

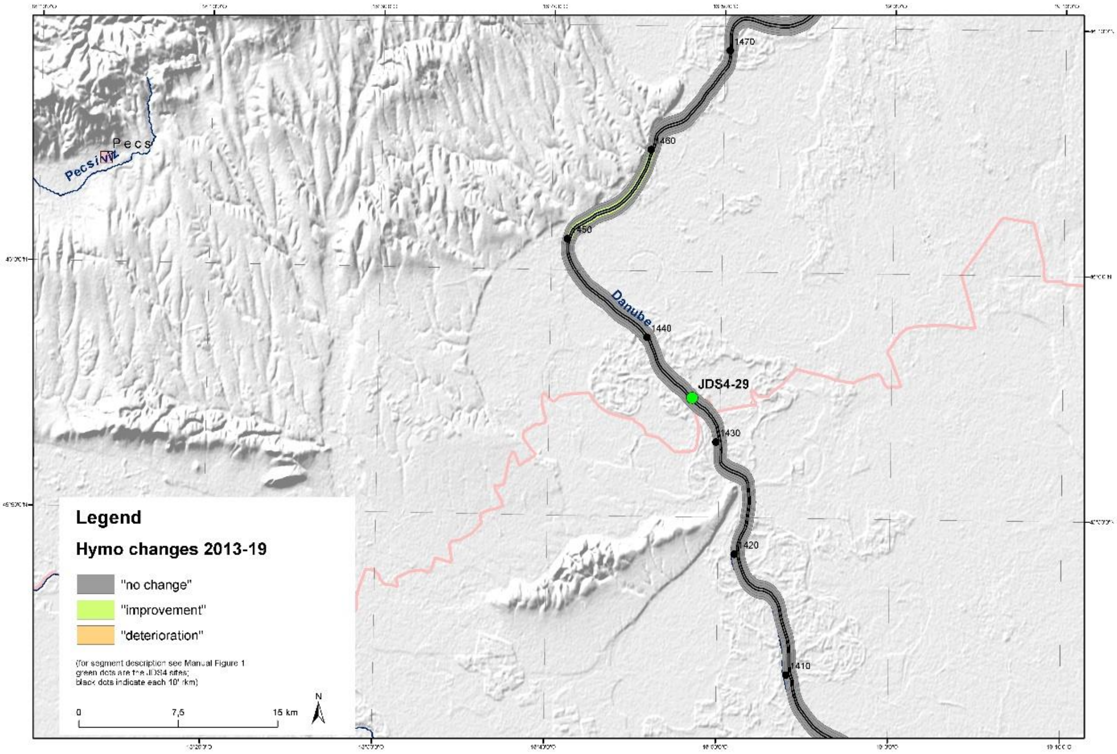

Figure 30: Upstream Mohacs (rkm 1,450) along the right bank, a side channel was subject of restoration works.

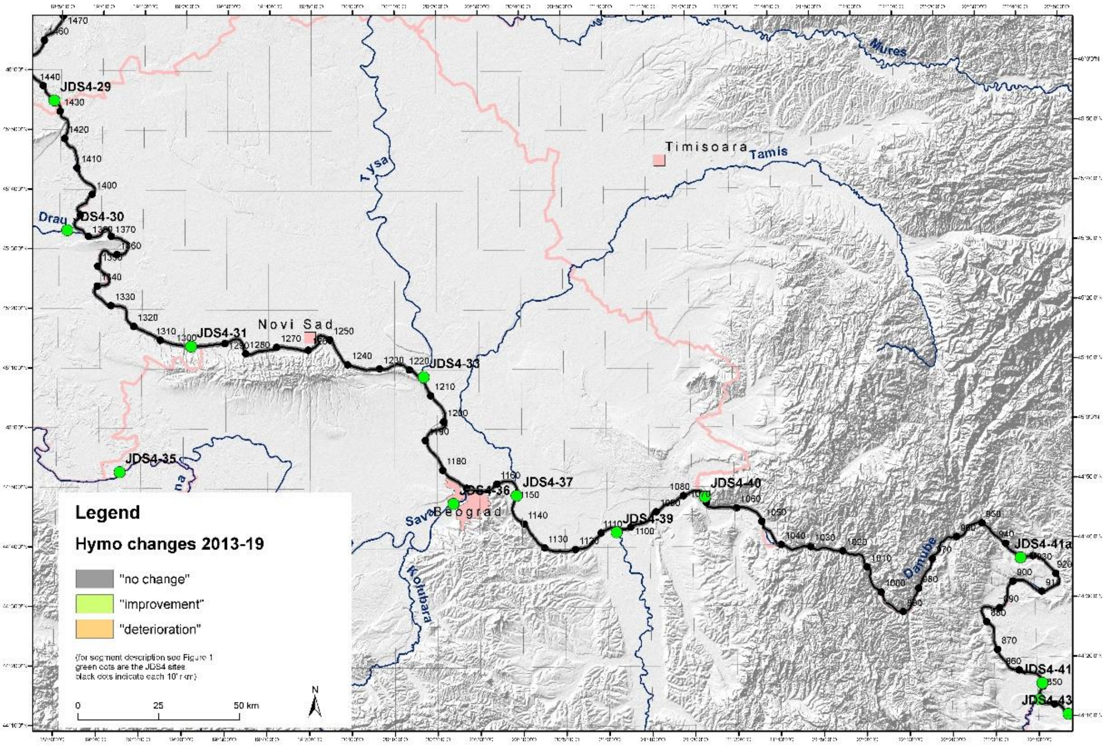

Figure 31: No changes are submitted for the free flowing stretch of Danube in Croatia and Serbia. Aside of minor groyne and Vukovar's bank wall renovation works before 2013, the upcoming period will bring new changes with the Waterway improvement programme, which is under way.

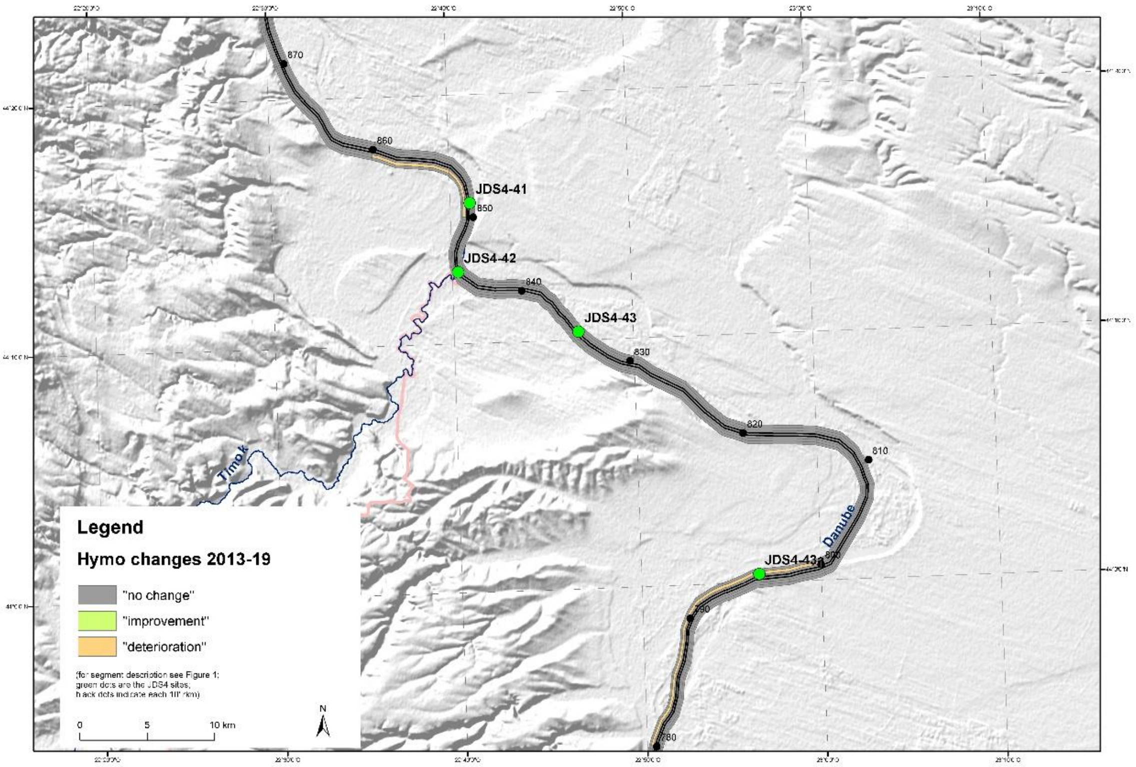

Figure 32: The only record for RS is given for a flood defence work just downstream of Iron Gate dam II, further deteriorations can be find downstream in BG.

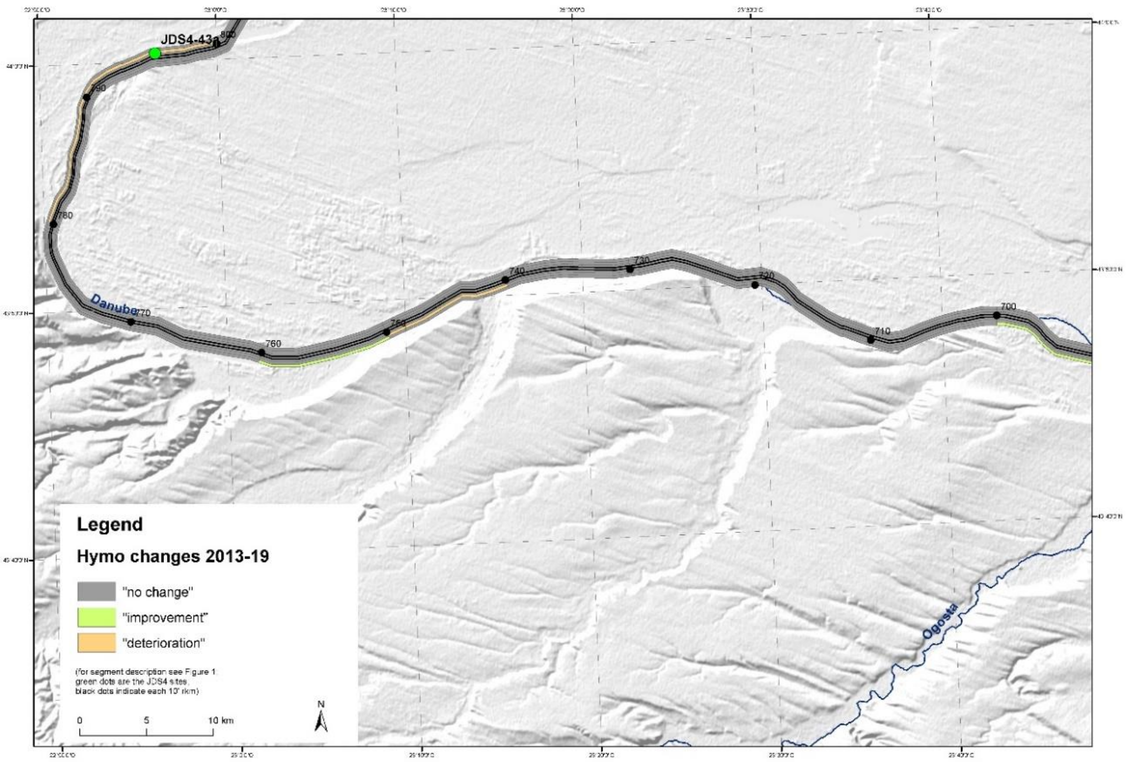

Figure 33: Some floodplain improvements can be find on BG river side.

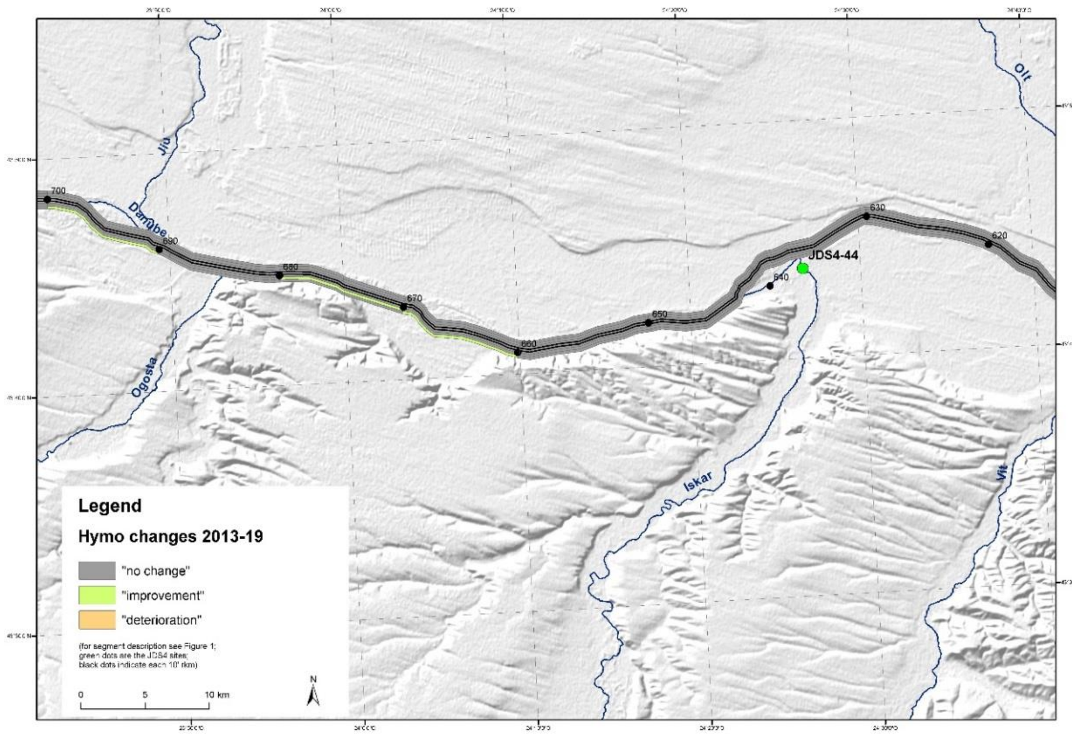

Figure 34: Bank and floodplain improvements prevail downstream.

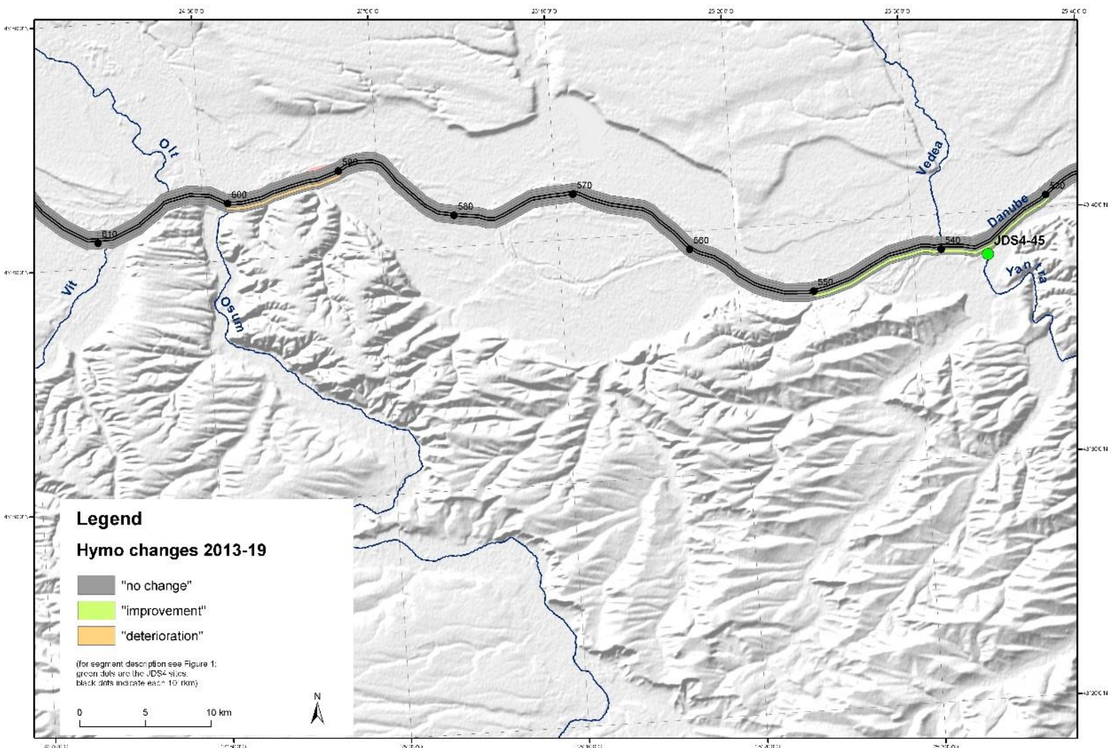

Figure 35: Same picture further downstream, some deteriorations in form of bank reinforcement are reported.

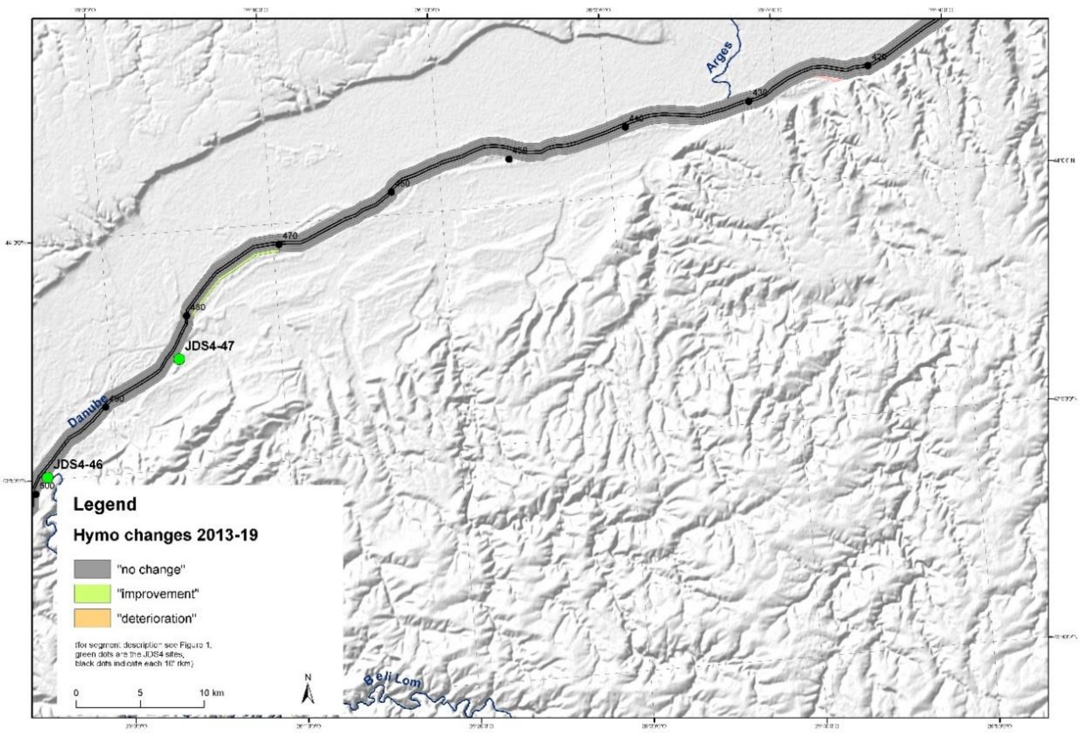

Figure 36: And another floodplain improvement in BG further downstream. Two short deteriorations at rkm 490-500 and 400-410 on Bulgarian side (50/90 meters long) are not included in the map.

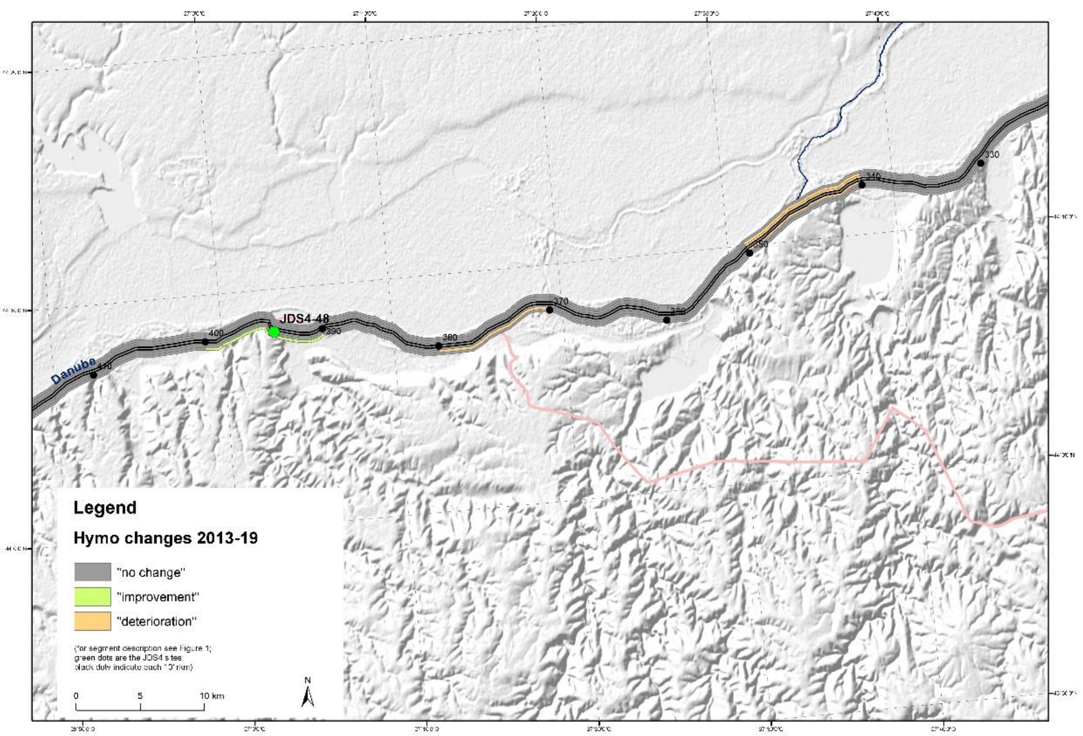

Figure 37: The Bala branch project with the introduction of a massive ground sill and the subsequent bank regulation of the channel entrance deteriorate the segment, even the sill is constructed in the Bala branch and not the assessed southern branch.

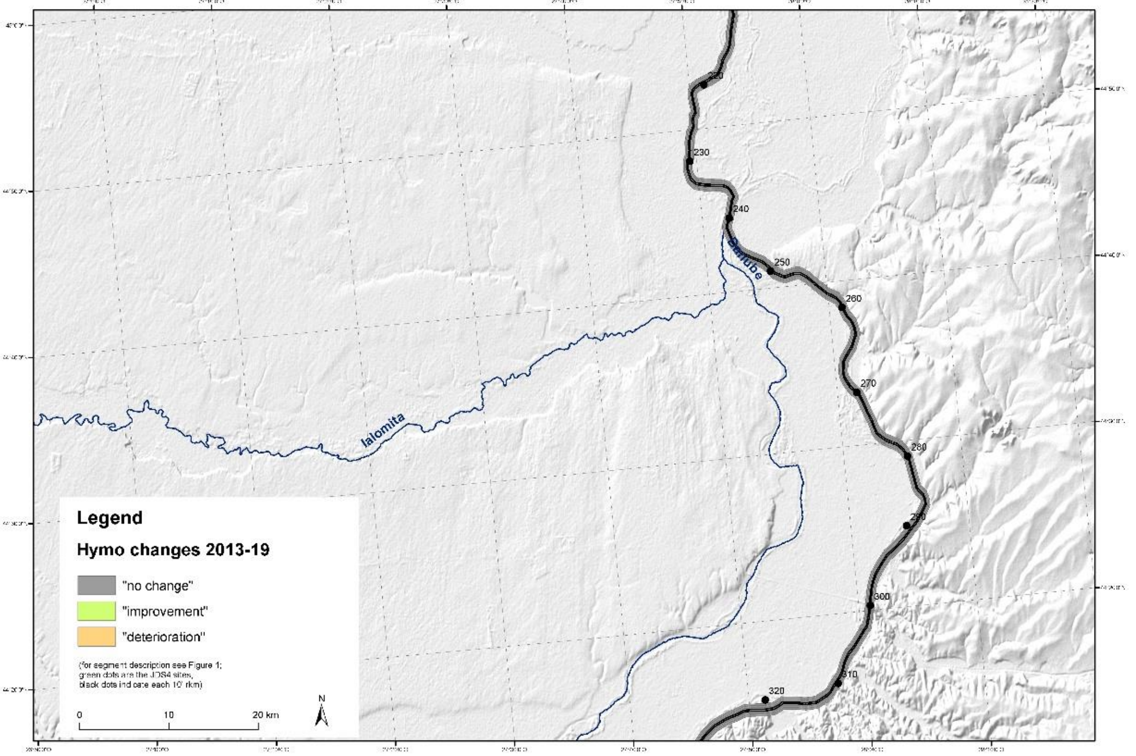

Figure 38: No change downstream to Braila.

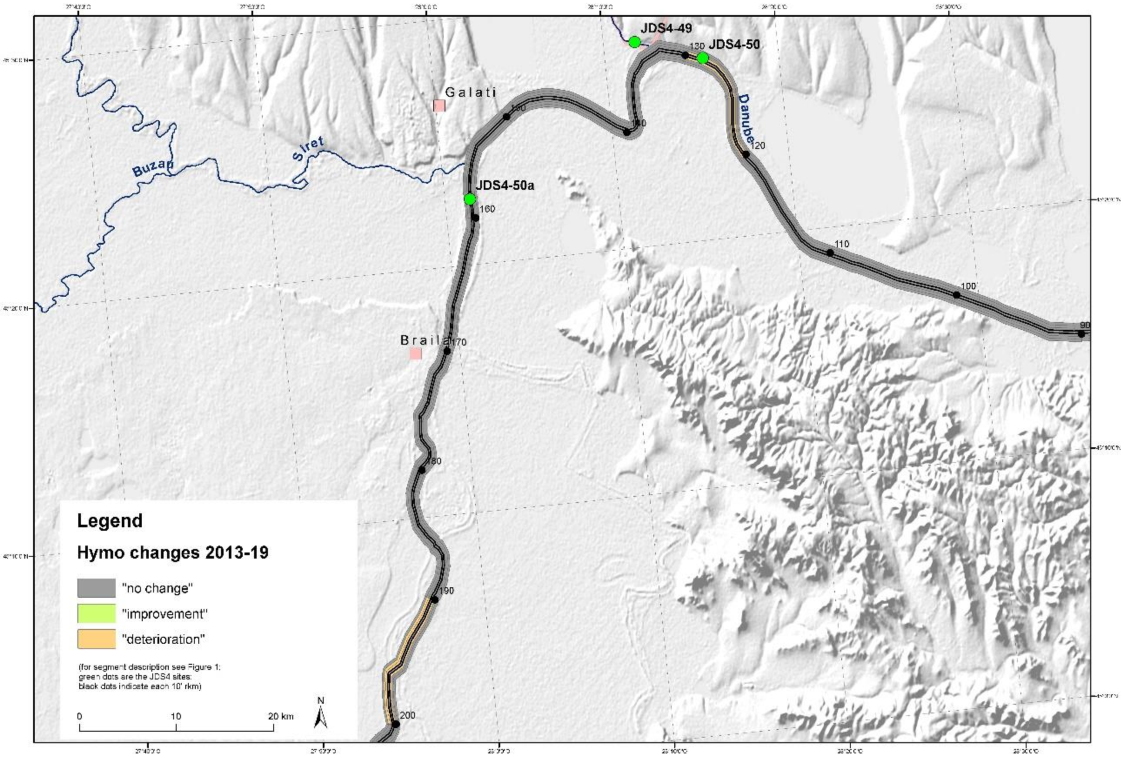

Figure 39: The only change recorded, by UA for the sea port Reni with is under expansion, which makes extraordinary dredging necessary.

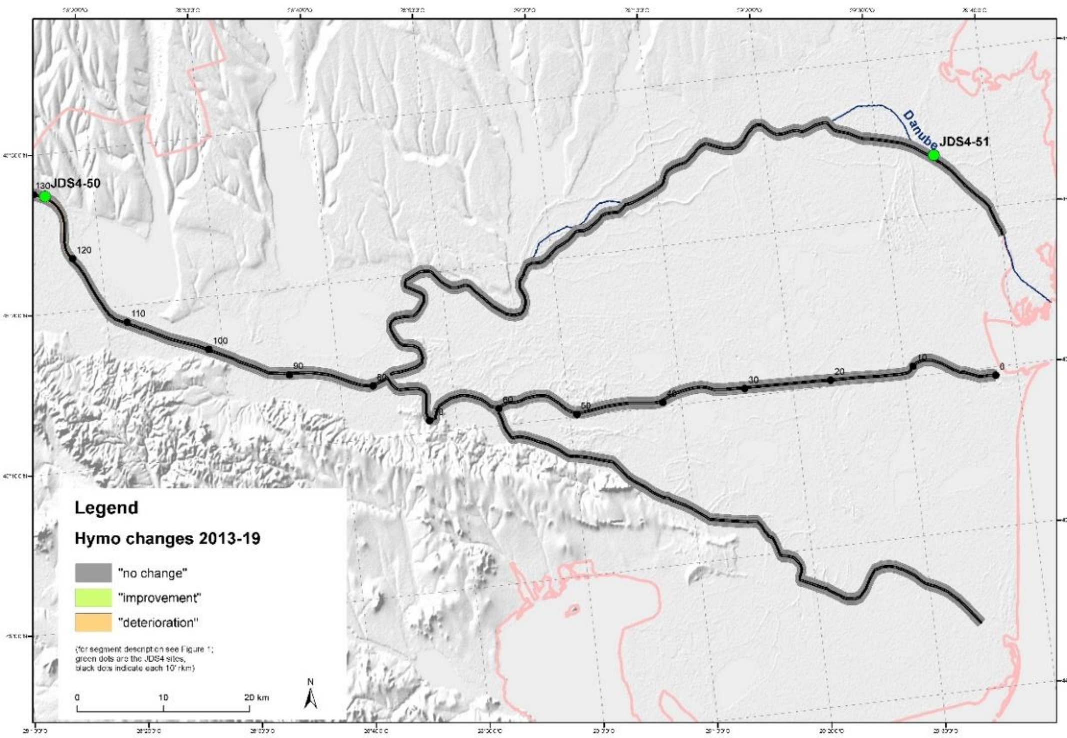

Figure 40: No changes recorded for entire delta.

2.2.4 Maps of reassessment

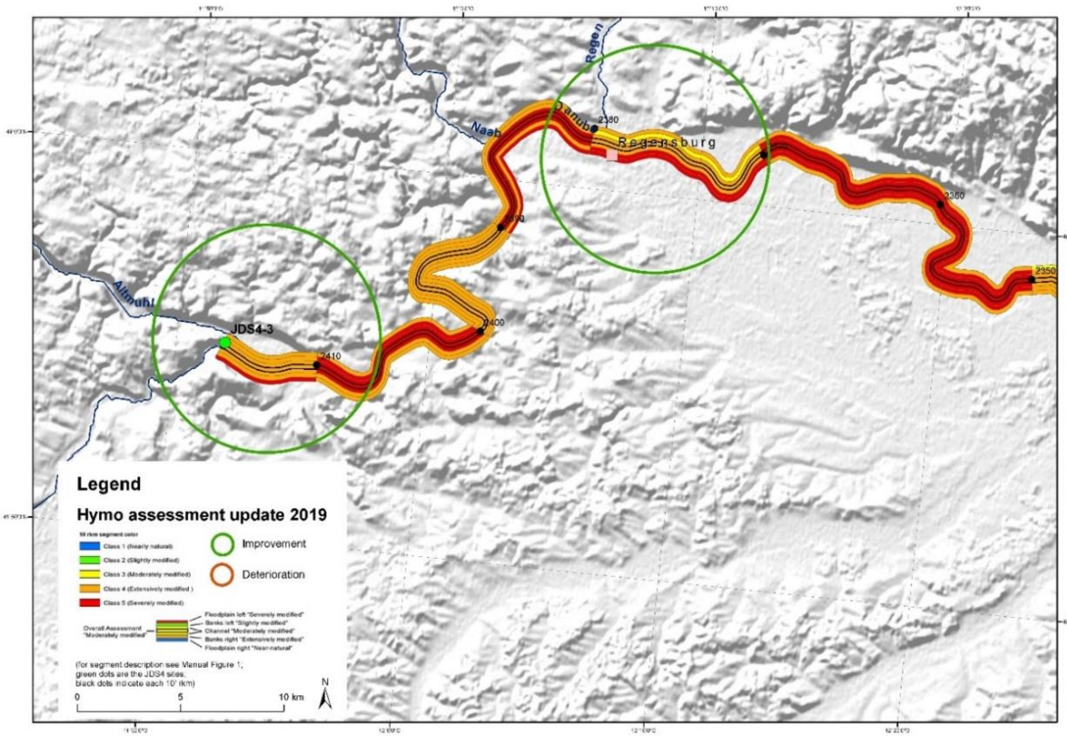

Figure 41: Two improvements for left floodplain and left river bank can be assumed for the Regensburg region.

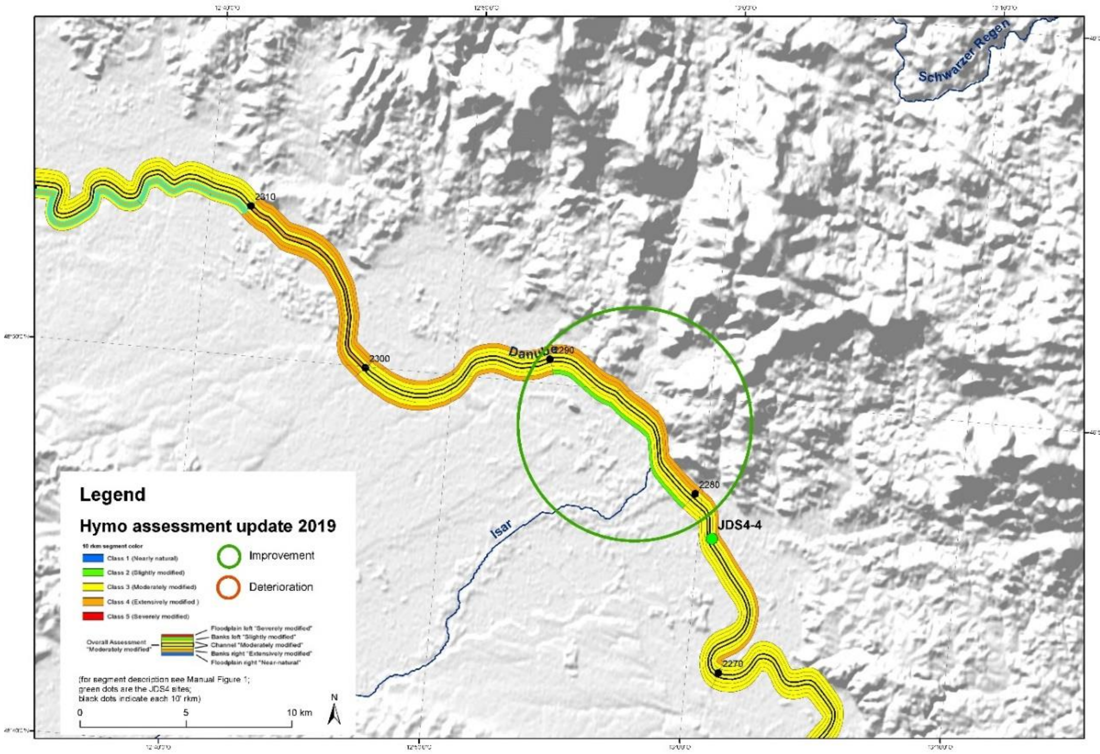

Figure 42: Even the lateral expansion of the floodplain opposite to Deggendorf is limited, the whole complex with the Isar mouth become much more quality, leading to raise in assessment.

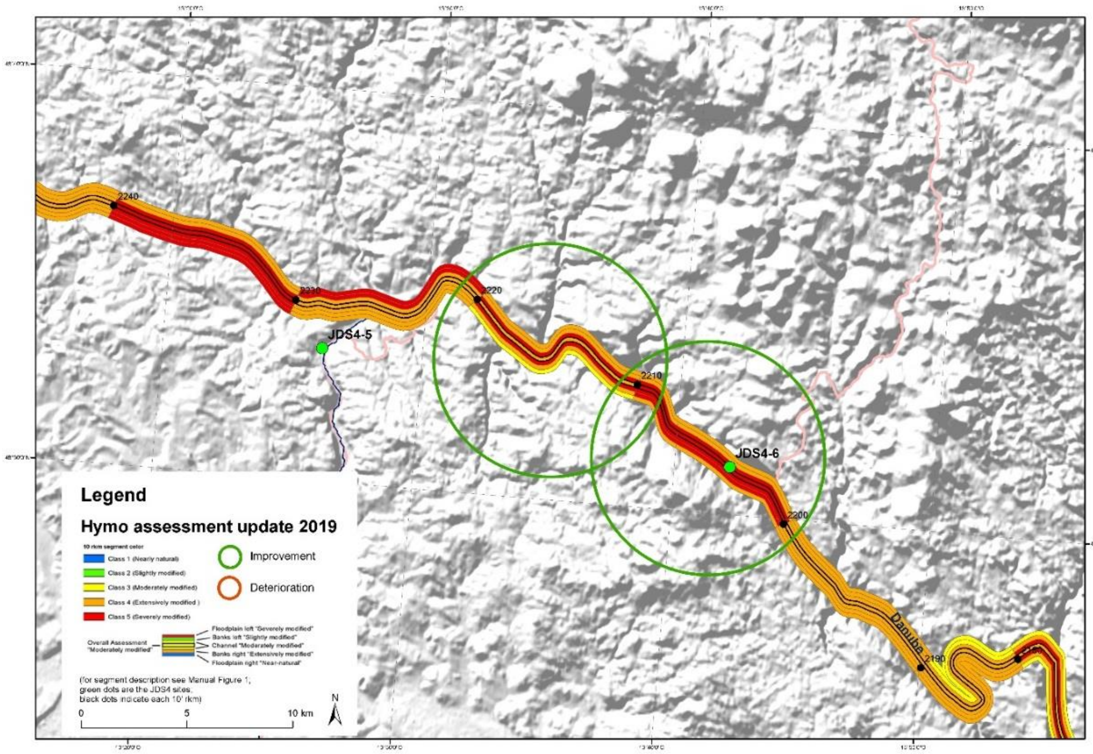

Figure 43: The two segments in the DE-AT border reach are improved within the right floodplain and left bank respectively. No change in overall assessment

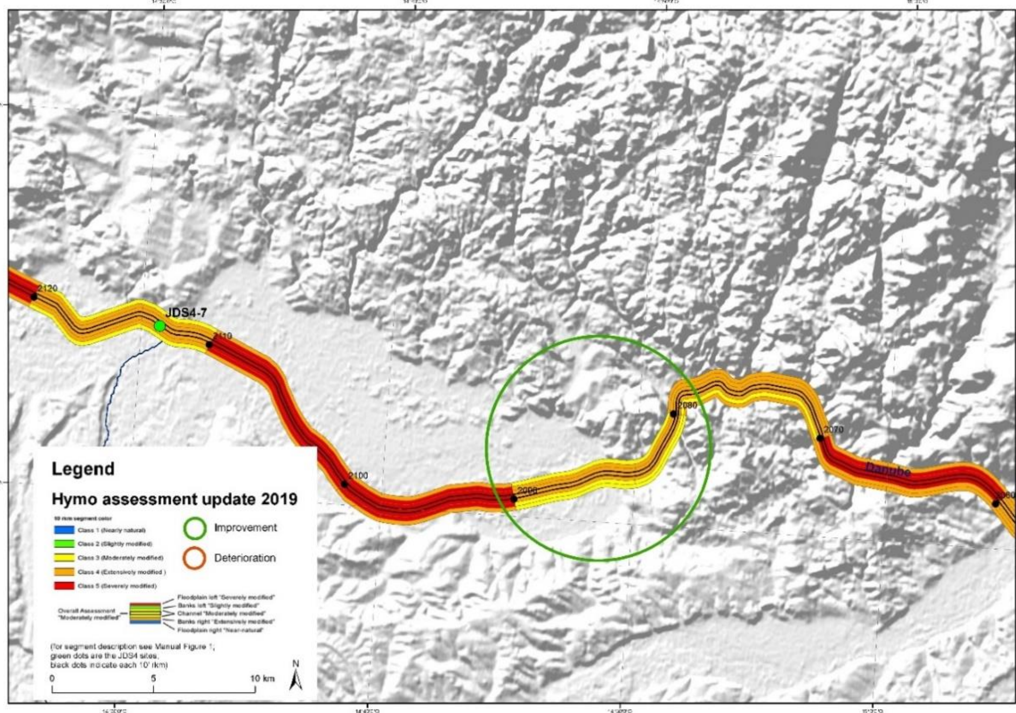

Figure 44: Also to no overall change lead the bank improvement in the upper backwater of Ypps-Persenbeug dam, At this point it must be stated that the two fish passes built in the red segments upstream do not lead to a class change of channel, as many parameters are evaluated. However, the WFD 3-digit assessment (see chapter 3.2.2 above) was lifted in the class 3, as partial restored continuity (for fish, but not for sediment).

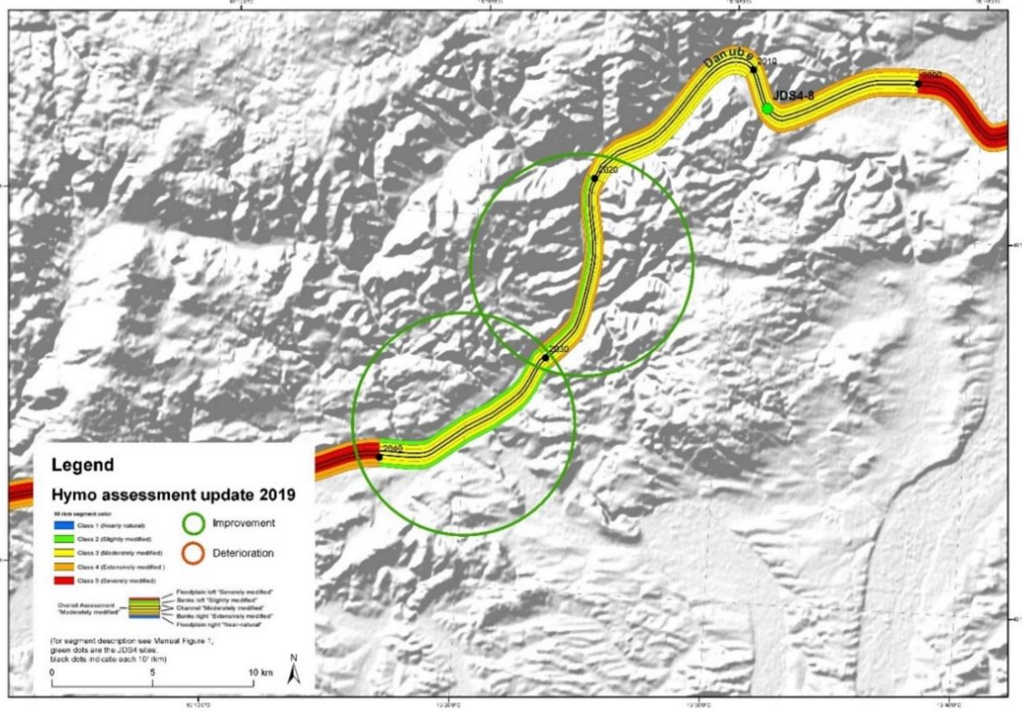

Figure 45: The Wachau reach has improved by bank and bar restoration as well as the introduction of gravel bar deposits.

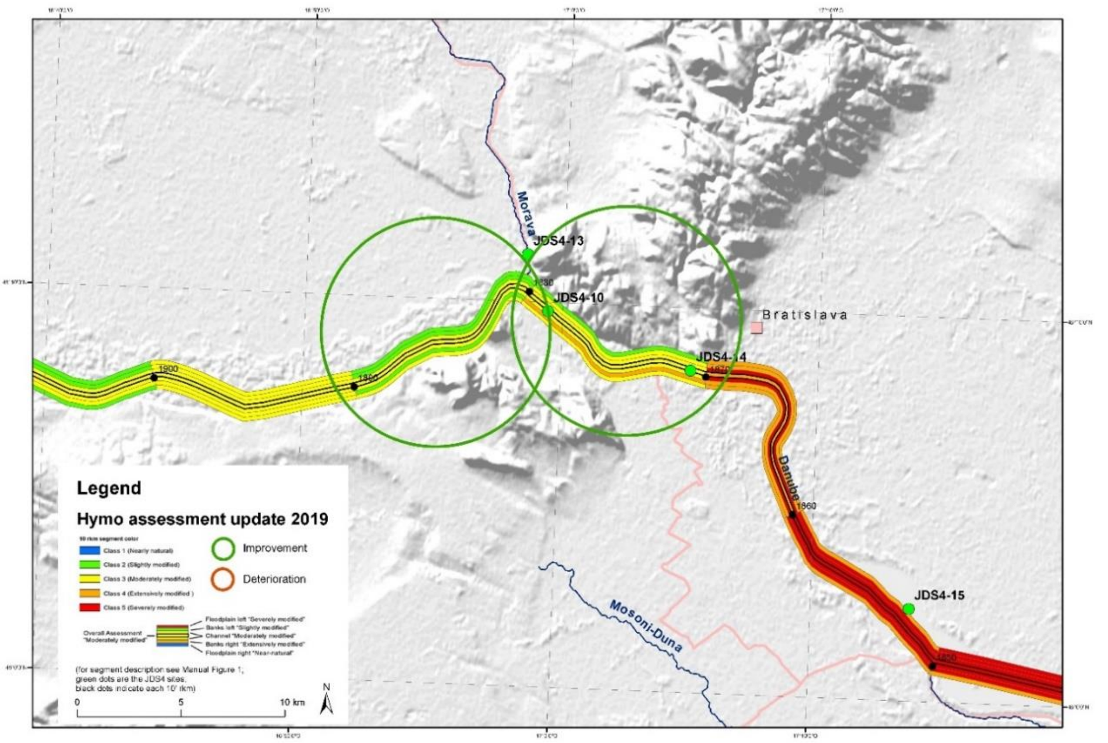

Figure 46: As mentioned the restoration works in the Hainburg 10-km reach raise the assessment of right bank (Johler side-channel and restoration). In future both segments visible in the map will be further restored by side-channel connections and rip-rap bank removal.

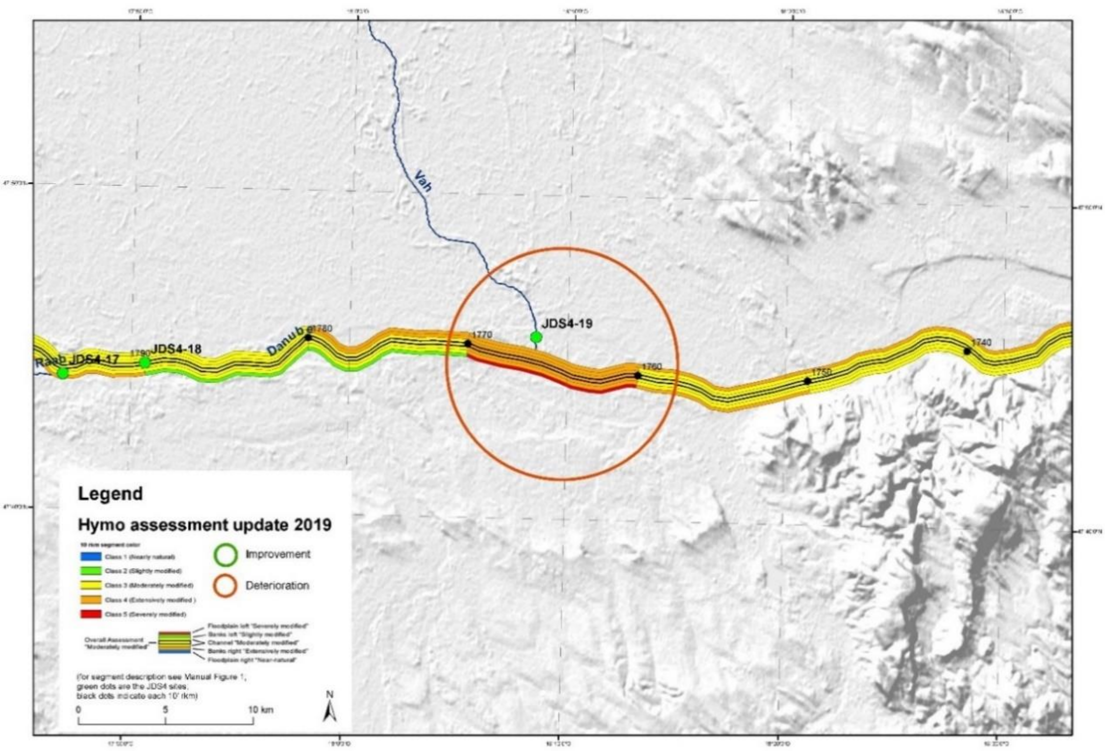

Figure 47: The flood defence (after the critical situation during the 2013 flood) east of Komarom lead to the first deterioration, visible in the assessment.

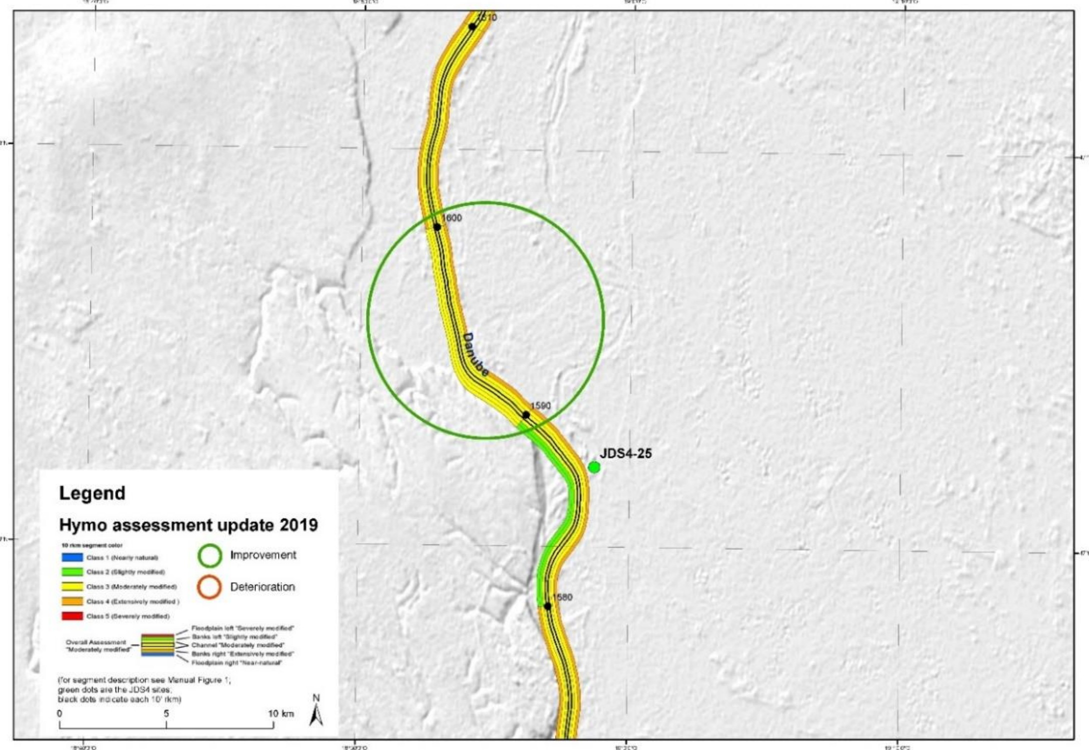

Figure 48: The Adony side-channel restoration raise the assessment for floodplain in the segment.

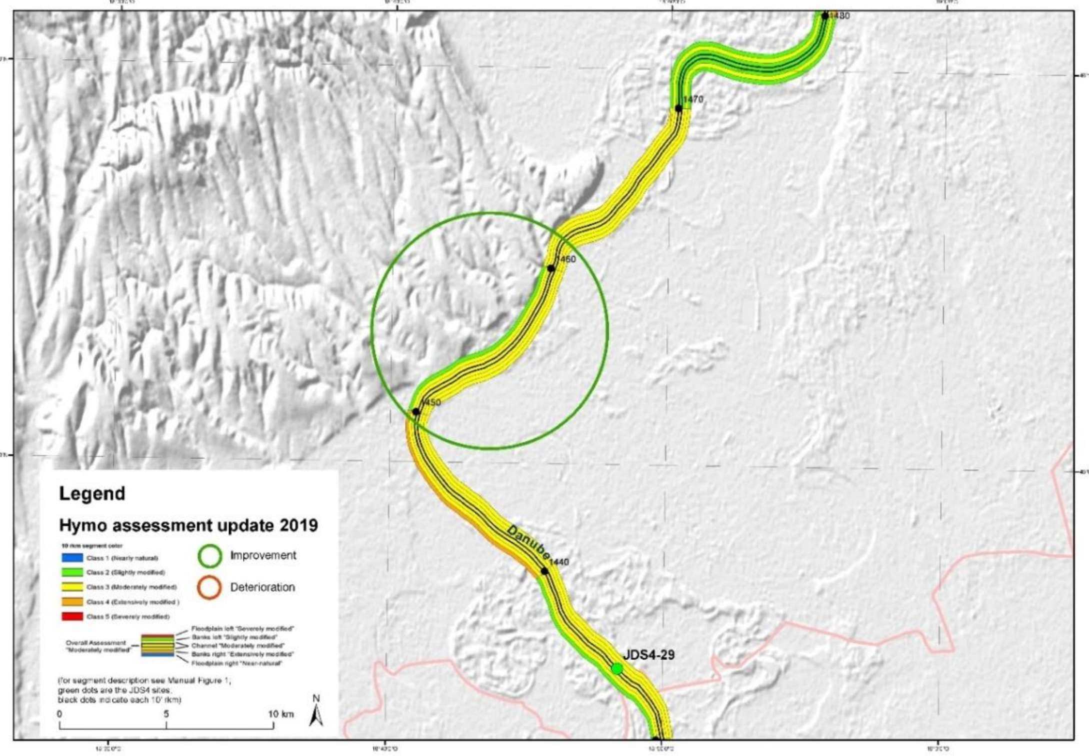

Figure 49: Upstream Mohacs another right wing side-channel within the Duna-Drava National park is subject of a restoration project.

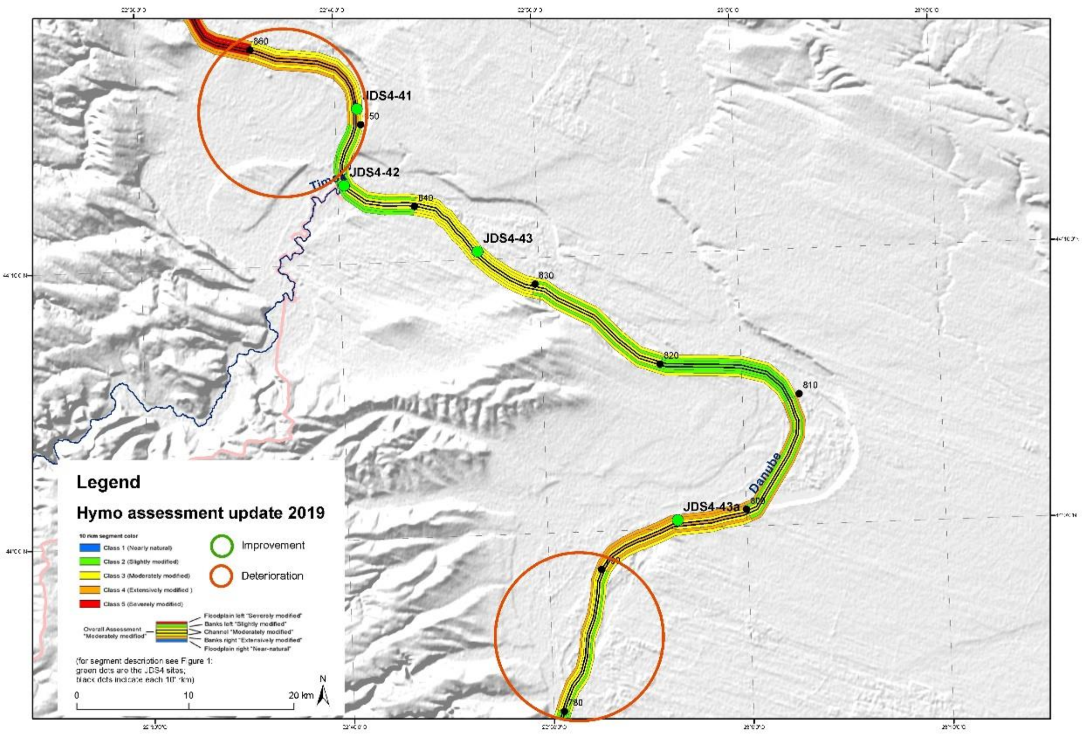

Figure 50: Downstream of Iron gate II dam a nearly 3 km flood defence on right side lead to the shift in overall channel assessment. Downstream in the Vidin area in BG, deteriorations lead to changes in bank section only, the city reach was already assessed in class 4 before.

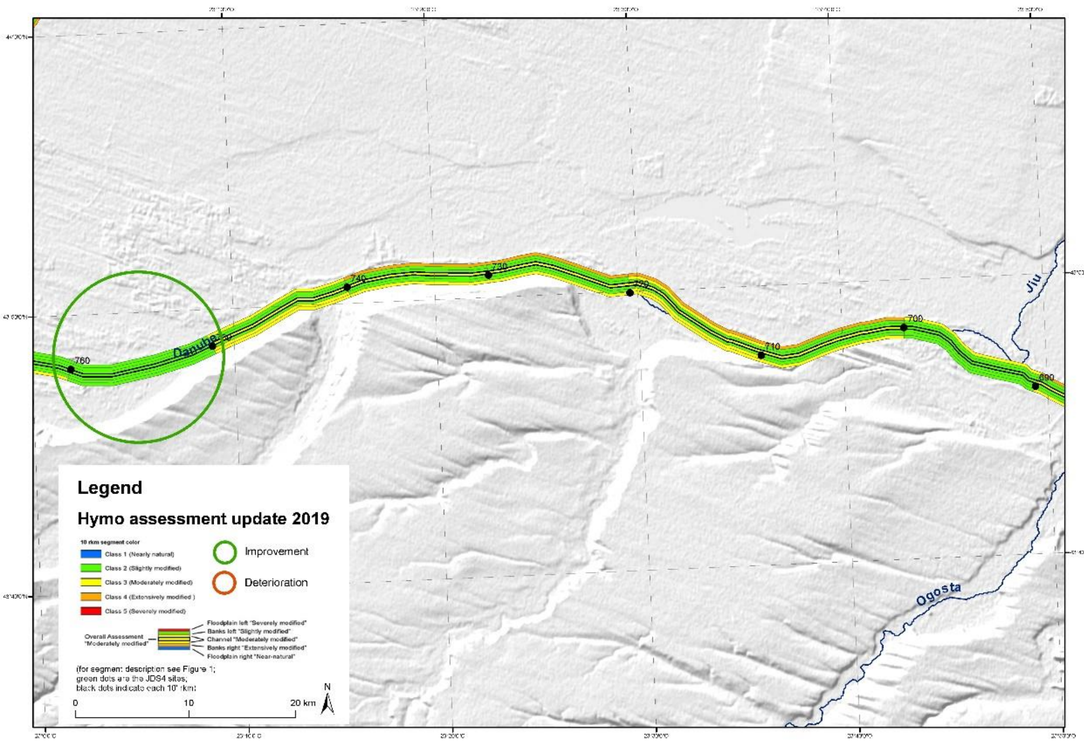

Figure 51: Three changes were recorded for the visualized reach but only the uppermost lead to a sub-segment change in right floodplain, but not for overall assessment.

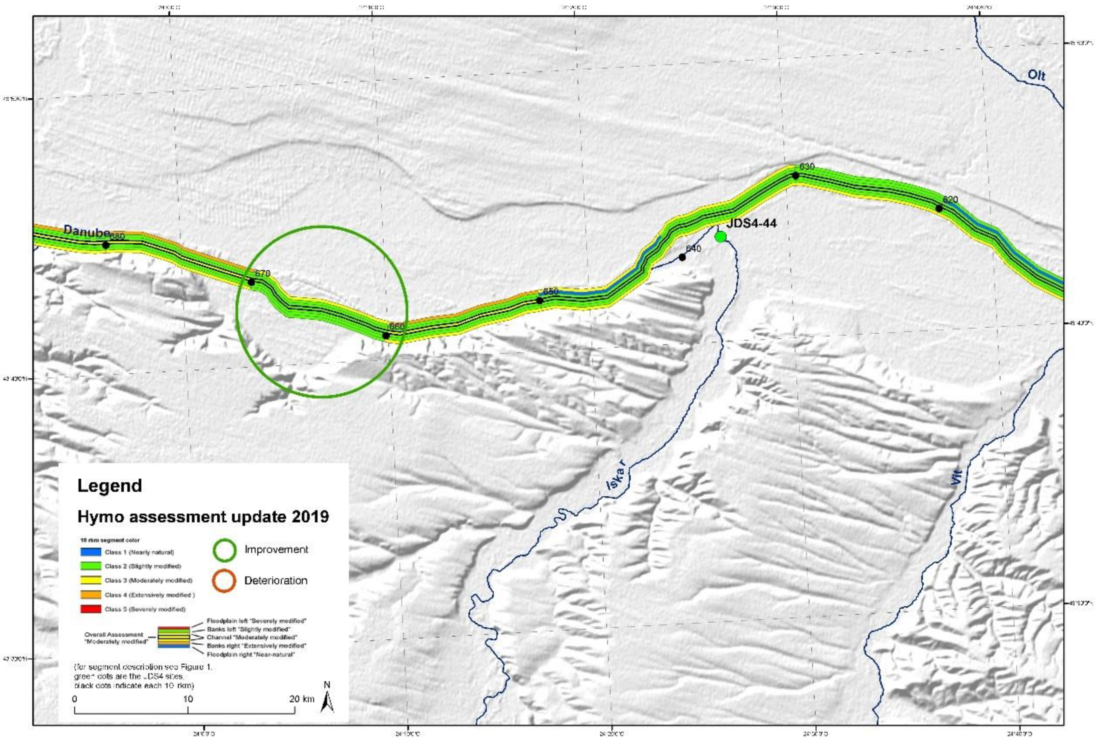

Figure 52: Regarding the two improvements on BG river side only one lead to an assessment improvement for right floodplain.

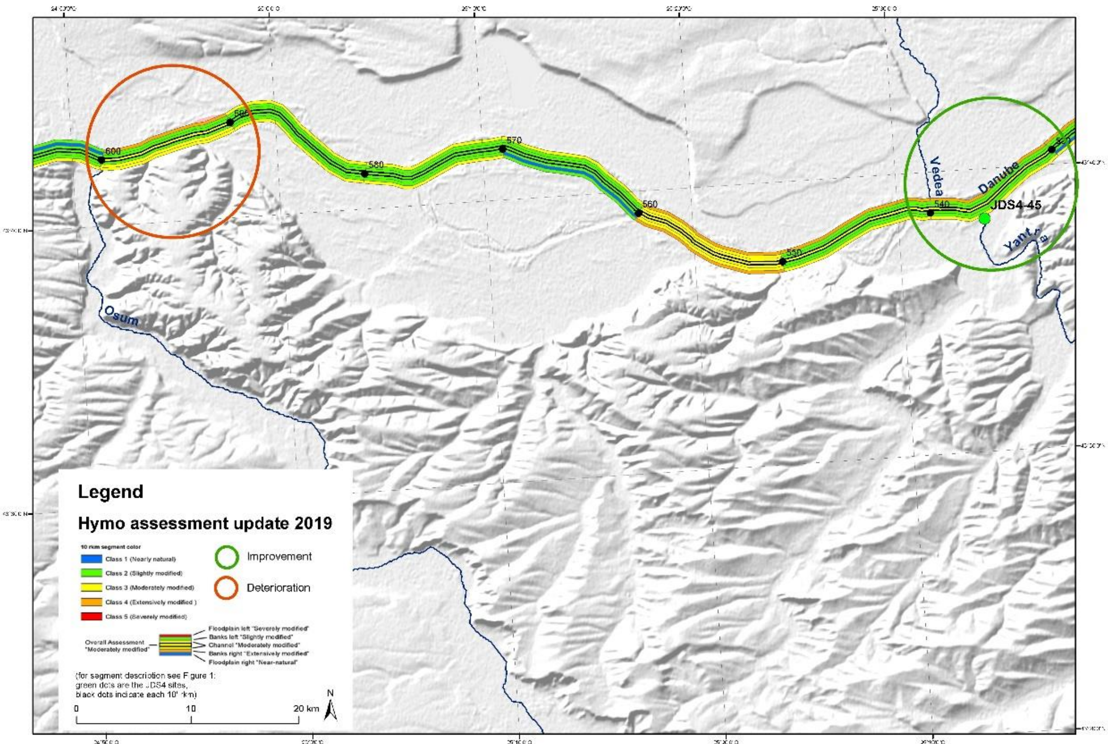

Figure 53: Out of three changes in the respective reach only two lead to changes for bank segments, no change in overall assessment.

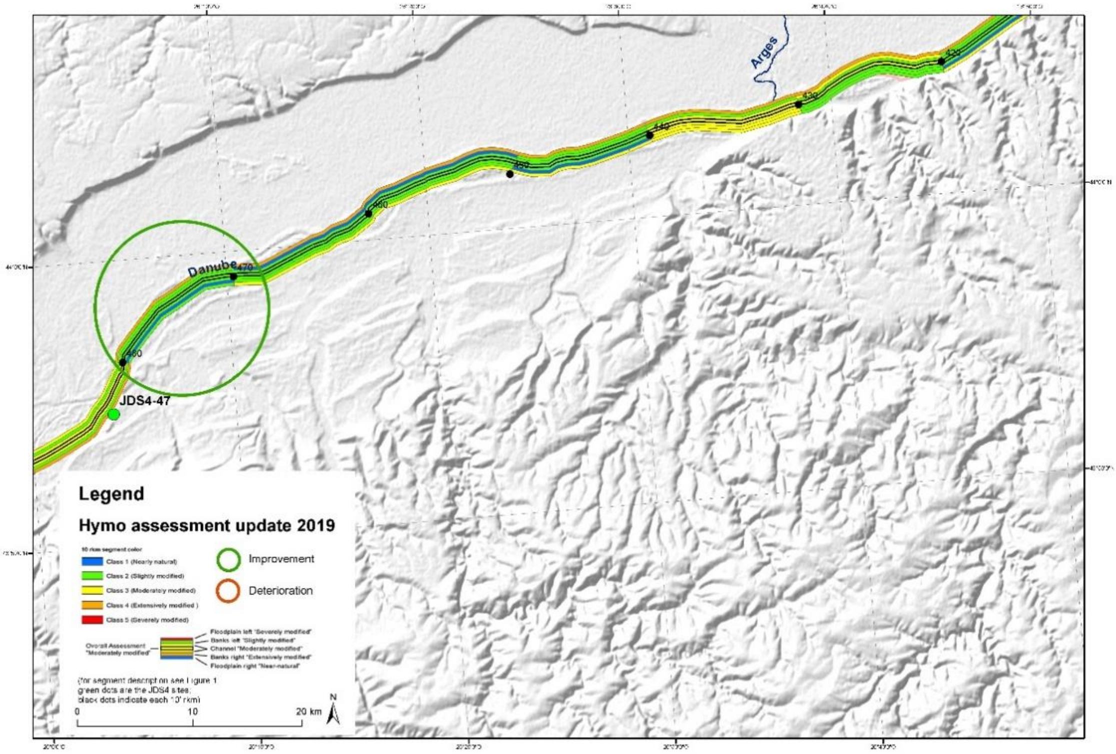

Figure 54: The right floodplain improvement in BG does not change the overall assessment.

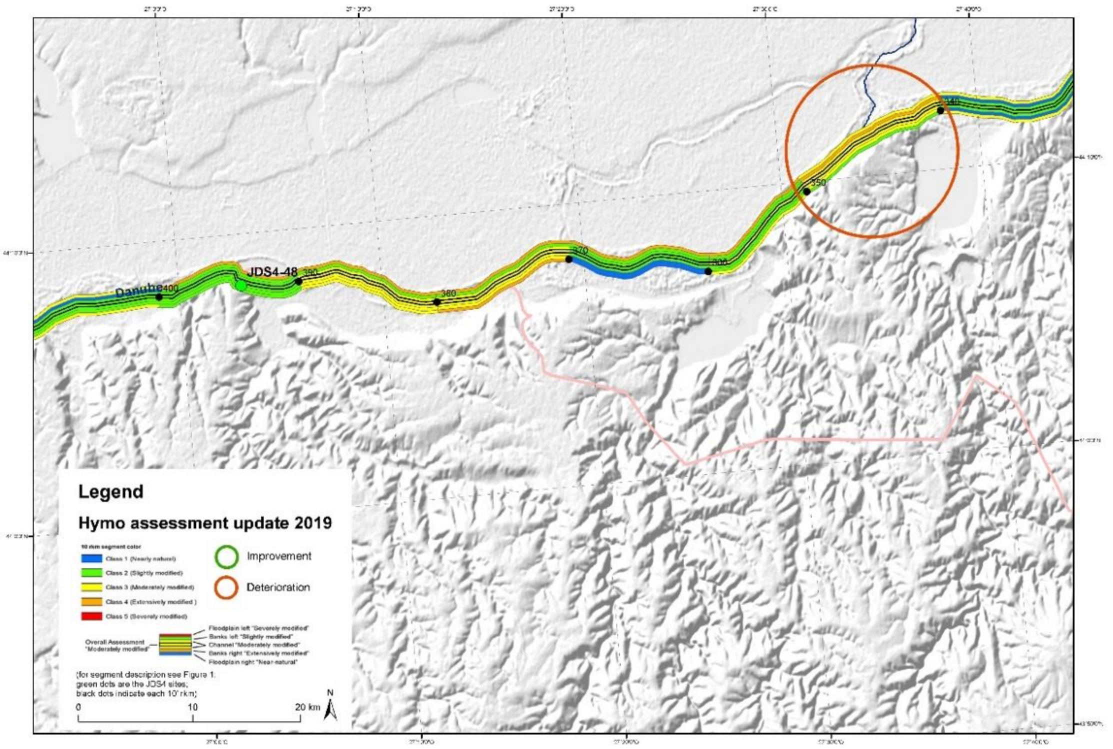

Figure 55: Bank revetments limiting the Bala branch entrance (with the ground sill just downstream) and deteriorate the left bank. The two recorded changes on BG side in this reach want raise or lower existing assessments.

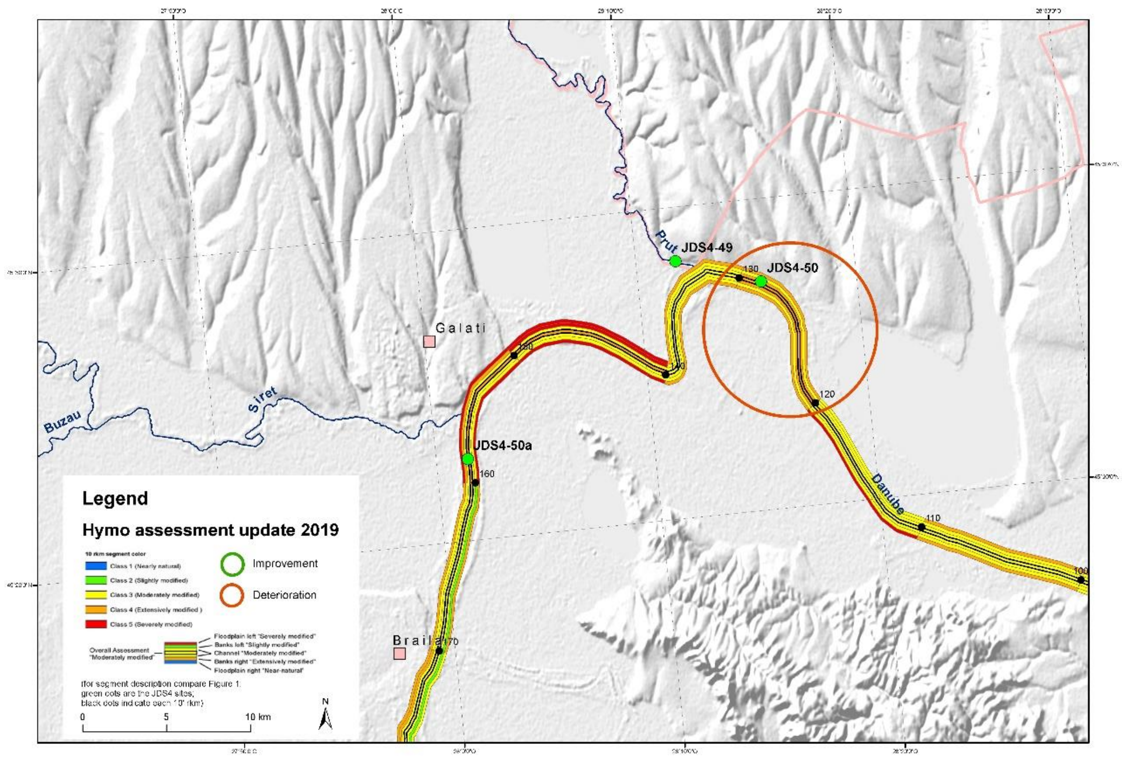

Figure 56: The expansion of Reni Sea port requires extraordinary dredging the respective segment.

2.3 Recorded restoration and infrastructure projects

The following table 3 summarise the recorded projects for the time span 2013-2019, most of projects are already finished but some are ongoing. Important future projects such as the implementation of regulation works on the Middle and Lower Danube or new Life restoration projects on the Austrian Danube will fall in the next six years period.

Table 3: Recorded restoration and infrastructure projects for the period 2013-2019

Country	Project code	Title	Project purpose	Implementation year	Description
Germany		Hochwasserschutz Deichrückverlegung Natternberg	Restoration project F1. Removal/ slicing/ setting-back flood dikes for floodplain reconnect-tion	2013 to 2015	
Germany		Measure 10: Old river bed	Restoration	2013	

Country	Project code	Title	Project purpose	Implementation year	Description
		of the Danube along Kelheim-winzer (Donaualt-wasser entlang von Kelheim-winzer)	project CB2. Reconnection of side channels		
Germany		Measure 11: Side-arm of the Danube near by nature (Naturnaher Seitenarm der Donau)	Restoration project CB3. Reactivation of channel dynamics through removal of bank protection	2014	
Austria		LIFE Netzwerk Donau	Restoration project CB8. Restoration of continuity	2018 to 2019	Fish passes for Danube hydropower plant dams.
Austria		Life Wachau	Restoration project CB3. Reactivation of channel dynamics through removal of bank protection	2013 to 2016	EU-Life projects in the Wachau to restore banks, side channels/tributaries and gravel balance
Austria		Pilot project "Naturversuch Bad-Deutsch-Altenburg"	Infrastructure project, Others	2014	Combination of bank rip-rap removal, groyn removal and reconstruction, side channel reconnection as well as grannulumetric bed sediment improvement within the overall "Flußbauliches Gesamtkonzept Donau östlich Wien".
Slovakia	LIFE 07 NAT/ SK/00 0707	Danube birds conservation - Conservation of Endangered Bird Species Populations in Natural Habitats of the Danube Inland Delta	Restoration project CB2. Reconnection of side channels	2009 to 2015	
Slovakia	LIFE 12 NAT/	LIFE BeeSandFish - Restoration of nesting and	Restoration project CB3.	2014 to 2019	The project’s main objective is to improve the conservation status and population characteristics of target bird species by restoring their habitats. The conservation actions, including suitable restoration

Country	Project code	Title	Project purpose	Implementation year	Description
	SK/00 1137	feeding habitats of Sand Martin, Kingfisher and European Bee-eater in Danube-Morava region	Reactivation of channel dynamics through removal of bank protection		management, will lead to active nature protection and promotion of natural values in the region. The project actions will be implemented in six Natura 2000 network sites in the Danube-Morava region, five in Slovakia and one in Hungary.
Slovakia	LIFE 10 NAT/ SK/08 0	Restoration of NATURA 2000 sites in cross-border Bratislava capital region	Restoration project » CB2. Reconnection of side channels	2012 to 2018	
Hungary		Habitat rehabilitation with dredging in the Rezéti-Duna side arm	Restoration project CB2. Reconnection of side channels	2013 to 2015	The Rezéti-Duna side arm - with its 14 km lenght - was originally the main channel of the Danube. It became cut off during the river bed regulation works around 1850 but remained on the active floodplain. Due to sedimentation in the the side arm during floodings the volume of the river bed decreased to one tenth while the Danube river bed incision caused additional loss of river bed - side arm connections. As foreseen in the project, the dredging of the Rezéti-Duna arm removed 200.000 m3 sediment (which was reintroduced into the Danube main channel) and lowered the bottom level of the bed by 2 m. It now makes possible for Danube water to enter the side arm also in case of low Danube water levels. Through inlets and outlets of the Rezéti-Duna arm further oxbow lakes are supplied by water on the active floodplain (Lassi lakes, Malomtelelő (Water mill wintering), Décsi-Nagy-Holt-Duna (Décs-Large-Oxbow lake), Zsubrik-lake, Janika-lake, Keszeges-lake) which could also be ensured by the project results. The project is the largest rehabilitation project of the Middle Danube region.
Hungary		Rehabilitation of Bezerédi Danube side arm	Restoration project CB2. Reconnection of side channels	2016 to 2019	The main activity within the project was the partial dredging of the side arm. The dredged material was reintroduced into the Danube or deposited in abandoned pits. Southern section of the side arm is provided with a structure that serves water retention and directing purposes making water supply of the side arm possible in case of low water situations. The project also incorporates forest rehabilitation

Country	Pro-ject code	Title	Project purpose	Imple-menta-tion year	Description
					(forest structure rehabilitation and planting of native tree species).
Hungary	HU22 358	The improvement of flood safety in Komárom - Almásfüzitő flood protection area	Infrastruc-ture project Flood protection	2013 to 2015	The purpose of the project is to improve flood safety in the Komárom–Almásfüzitő flood protection area, namely the improvement, strengthening and reconstruction of the flood protection levee and the associated facilities (weir keeper's site, sluices, pump stations). The investment is carried out on behalf of the North -Transdanubian Water Directorate (ÉDUVIZIG) supported by the European Union and the Hungarian State amounting to 7 182 377 859 HUF. The project is located in Komárom–Esztergom County, in the northwest of Hungary. The intervention protects against the floods on the Danube.
Hungary	HU22 358	The improvement of flood safety in Komárom - Almásfüzitő flood protection area	Restora-tion project CB2. Reconnec-tion of side channels	2013 to 2015	In the framework of the project freshwater habitat restoration work was carried out at the mouth of Concó-stream near Ács in the flood plain of the Danube. Its necessity was ordained by the licensing authority on the basis of the Danube-Ipoly National Park Directorate to compensate the disturbed habitats during the works of the flood protecting levee. Within the scope of habitat restoration natural dredging of the 0.7 km long branch of Danube at Ács was applied with varying slope inclinations and cut widths, deepening the bed or leaving an islet where it is required. To achieve appropriate water flow in the branch, at the bottom a direct connection with the freshwater supply from the Danube was created and during the two-thirds of a year water inflow from above can be solved. Moreover, a water habitat was created in 3.1 hectares on the lower alluvial plain of Concó-stream of which constant water supply is ensured by a gullet from Concó-stream applying an overflow dam. The free longitudinal passage of fish is ensured over the dam.
Serbia		Construction of the protection dike upstream of the Jasenicka river confluence, for protection of Radujevac settlement from high water of the Danube River	Infrastruc-ture project Flood protection	2016	Construction of the protection dike upstream of the Jasenicka river confluence, for protection of Radujevac settlement from high water of the Danube River
Romania	SMIS 55991	Improvment of navigation conditions in the Danube	Infrastruc-ture project	2017	Critical navigation point (PC01) Bala - conducting dyke

Country	Pro-ject code	Title	Project purpose	Imple-menta-tion year	Description
		River between Calarasi and Braila , km 375-km 175	Naviga-tion		

Some pictures on the following pages should illustrate restoration works in DE, AT and SK.

Figure 57: Floodplain restoration near Deggendorf/DE (Google Earth (2019): Satellite images worldwide. DigitalGlobe 2019. http://www.earth.google.com)

Figure 58: Bank restoration in the Wachau/AT ViaDonau

Figure59: Introduction of gravel bars in the Wachau/AT, ViaDonau

Figure 60: Restoration of side-channel connection along the Slovakian Danube https://broz.sk/obnova-prveho-ramena-klucoveckej-ramennej-sustavy/

3. Conclusions

3.1 General conclusions

- All significant changes regarding pressures and restoration along the 241 10-km-segments of the Danube were collected for the time period 2013-2019 and it was possible to update the hydromorphological assessment of JDS3. Even before the JDS4 start, a draft documentation of changes was submitted to the national BQE teams, supporting their assessment of the JDS4 sites.

- In total 55 main 10-km-segments have been recorded to be subject of changes (43 improvements, 12 deteriorations). Finally, only 22 changes lead to shifts in the individual assessment groups (channel, banks, floodplain), while only two segments on the Lower Danube shift in overall assessment, from class 3 to class 4. Regarding the WFD 3-digit assessment four segments profit from fish passes in Austria, reconnecting in total seven segments (70 km) for fish migration.

- In general, improvements prevail on the Upper and Middle Danube, while on the Lower Danube, with exception of some improvements in Bulgaria, slight deteriorations have been recorded (two segments shift in overall assessment). This trend is understandable looking at the previous assessments, indicating many more alterations along the Upper and Middle Danube, while the Lower Danube keeps over long distances a character of fewer alterations (less stabilized banks and rectification of channel, more bars and islands).

- Several small deteriorations (and renovation of already existing structures) as well as some improvements fall under the thresholds and cannot be considered for the overall assessment. In addition, the limited dredging data for various purposes (navigation, flood, commercial, and restoration) cannot be clearly addressed to obvious changes (compare evaluation by the DanubeSediment project, Habersack et al. 2019 & 2020). Therefore, a general clear trend for the entire Danube cannot be observed for the given period, however the intensified restoration activity on the Upper and Middle Danube and the slight deterioration of the Lower Danube suggest a positive outlook.

- The pressure and restoration update should encourage further detailed in-situ measurement and assessment work (which has to be applied according to WFD finally on waterbody level). It serves as a general estimation of trends along entire Danube.

- The collection of restoration and infrastructure projects improve the understanding of changes. The number of restoration projects is high in particularly in the Upper Danube but also more and more further downstream in the Middle Danube. Along the Lower Danube, restoration projects in the past focussed on floodplain restoration, namely in the Danube Delta, but also other areas.

3.2 Technical conclusions for the next JDS

- To document the changes and having a monitoring tool for the six-year WFD cycle, the approach is feasible and affordable.

- To scope and fulfil the requirements as under the new CEN Standard (CEN 2018) the methodology has to be further developed to keep previous assessments and to apply the new topics, namely the process based assessment of fluvial systems. The DanubeSediment project delivered many extremely valuable quantitative hydromorphological data and made first technical proposals how to assess sediment transport, to improve monitoring, both essential parts of the future hydromorphological assessment.

- The outcomes of the DanubeSediment Project (Habersack et al. 2019 & 2020) point towards necessary monitoring and assessments of morphology including morphology and quantitative sediment aspects. One out of more potential applications and synthesis of the descriptive and pressure- oriented CEN analysis of JDS HYMO on the basis of 10-km-segments and the quantitative and process- based continuous analysis of the river within the DanubeSediment projects, in particular regarding the longitudinal profile and channel development could be the German ValMorph approach, as applied to the Lower Rhine river (Quick 2019).
- It is recommended to take into consideration the Interreg Danube Transnational Programme DanubeFloodplain project outcomes and related solutions for the improvement of floodplain connectivity with the river.

3.3 Recommendations for measures

- The monitoring and evaluation of previous restoration projects should be used to improve new projects.
- Taking into account the situation of the large European rivers, which are severely altered to a large extent, it should be taken care that the remaining less altered water bodies along the Danube will be managed considering the environmental objectives.
- In addition to morphological restoration measures, a management of the sediment balance is needed at Danube basin-wide scale.
- Prevention of fresh bank revetments and reinforcement should be managed to the absolute minimum.
- The continuation of restoration measures improving the hydromorphological conditions to meet the good ecological status/potential along the entire Danube is from great importance.
- Restoration of floodplains should be a long-lasting goal for ecological and flood mitigation planning (DanubeFloodplain project).

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