IDES

*Improving water quality in the **D**anube river and its tributaries by integrative floodplain management based on **Ecosystem Services***

DTP3-389-2.1 – IDES

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Deliverable D-T1.1.1

Summary of a first list of sites and of maps with high relevance for water quality improvement and high potential for water quality actions

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1 Rationale

The deliverable aimed at identifying active floodplains along the Danube river and its main tributaries with relevance for water quality and its improvement. Floodplains are able to retain nutrients transported by rivers (i.e. from upstream sources) and may act as natural riparian buffer strips, intercepting nutrients from upslope sources. We defined “relevant areas” as floodplains of high nutrient retention potential located in areas of high nutrient pollution. The assessment focused on nitrogen (N) and phosphorus (P) for which a combination of indicators was derived to prioritise the areas on basin-wide and national levels. The indicators “(local) nutrient emission”, “floodplain retention (potential)”, “flooding days”, “in-stream retention”, and “nutrient concentration” were estimated for N and P with established models (Table 1). The indicator values were classified and the class values (ranks) further aggregated to retention ranks for N and P from upstream riverine and upslope catchment sources. High ranks indicate high prioritisation. The deliverable consists of several files which contain the ranking of floodplain (segments) and files to reproduce and visualise it (cf. section 6, p. 7). The aggregated basin-wide ranking is shown in four exemplary maps. This document is a brief description of the methods.

Table 1. Overview of indicators for site prioritisation and pattern of column name(s) in the output file Deliverable.xlsx (see list of files in section 6). Column names are explained in the output file.

Indicator	Scale	Source	Unit	Column name(s)	Comment
Nutrient emission erosion & surface runoff	Local	MONERIS	t/km²	Emission*	To account for the wide range of analytical-unit areas
Floodplain nutrient retention (potential)	Local	FP model	kg/ha/yr	Denit*, TPret*	Potential for denitrification & phosphorus deposition in floodplains
Flooding days	Local	FP model	d/yr	Flooding_days_mean	Estimated flooding frequency
In-stream retention	Local	(MONERIS)	rel.	*ret_river	Replaces MONERIS output
Nutrient concentration	Catchment	MONERIS	mg/l	*_conc	Emission + in-stream retention upstream

2 Defining the study area and the spatial units

We assessed the potential of active floodplains along river Danube and its main tributaries Tisza, Mura, Sava, and Yantra to improve the water quality. The active floodplains were obtained from the DTP project “Danube Floodplain” ([1], Figure 1). They consisted of areas larger than 500 ha which are inundated by HQ_{100} floods, i.e. floods whose discharges (Q) statistically occur once in a century. These floodplains were split into 10-km segments as a link to the ES assessments within IDES. The segmentation was realized by generating Voronoi polygons around points which were set every 10 km along the river courses.

“Analytical units” (AU) are the basic modelling units of the MONERIS model. The AUs of previous model applications for the Danube basin were adjusted to national boundaries of sub-catchments which resulted in 1727 AU for the whole basin. Their number and area differed widely among the countries (Figure 2 left). We assigned the floodplains to the AU along their main flow direction (Figure 2 right).

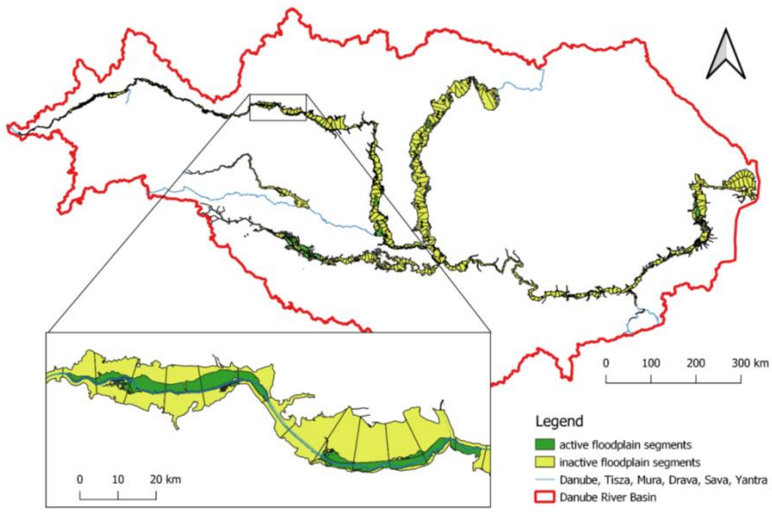

Figure 1. The active floodplains covered a small part of the theoretical floodplain.

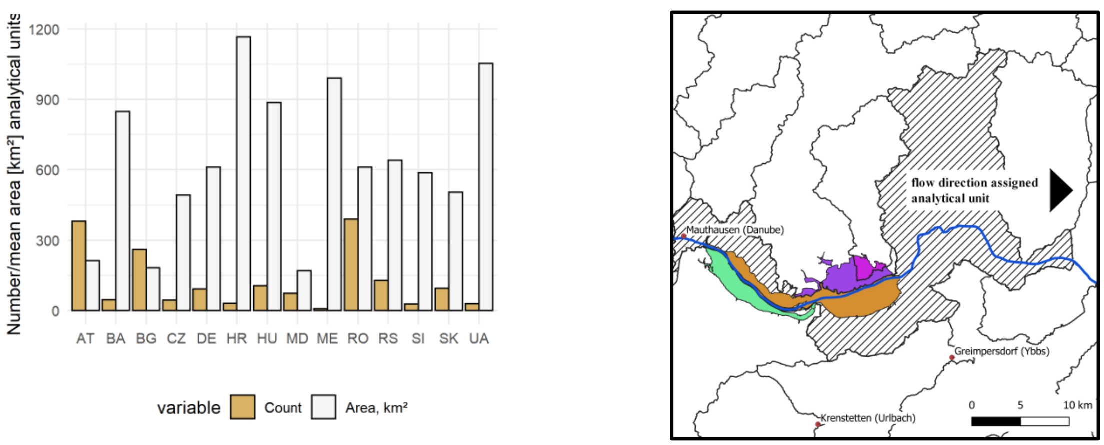

Figure 2. Left: Number and average area of analytical units (AU) of MONERIS in the main Danubian countries. Right: an exemplary active floodplain (FP) in Austria with multiple overlapping AUs (AUs in white, overlaps in different colours). The whole FP was assigned only to the hatched AU because this AU represents the main river (blue line). The location of FP within the assigned AUs – the shown FP is located in the upstream part – was considered in the processing of the MONERIS outcomes.

3 Indicators and ranking

The five indicators for the ranking of the floodplains in Table 1 were derived from the output of established models which were applied to the whole Danube basin and the active floodplains. These indicators take into consideration how much is emitted locally (i.e. upslope) and upstream from the catchment into the river system and how much is or can be retained in-stream and in the floodplains.

For the ranking, we calculated the area-weighted means of the nutrient emission as well as concentration from the nutrient load and water discharge. This step was required as the spatial resolution of the nutrient model MONERIS differs from the modelling of the floodplains. As floodplains can be located at (near) the outlet, inlet, or in the middle of AU, we considered the load and discharge of the assigned AU and / or its upstream neighbours to estimate the appropriate nutrient concentration. The local emissions were estimated as area-weighted means.

For each nutrient-specific indicator, the absolute (modelled) values were split into 3 equal classes (terciles, Figure 3) with 1 being the lowest class (rank) and 3 the highest. Floodplains or segments with high ranks for all indicators have a high potential for water quality actions. The class values for the indicator were further aggregated to indicators reflecting the local and the catchment scales (Table 2) from which a final average rank was calculated.

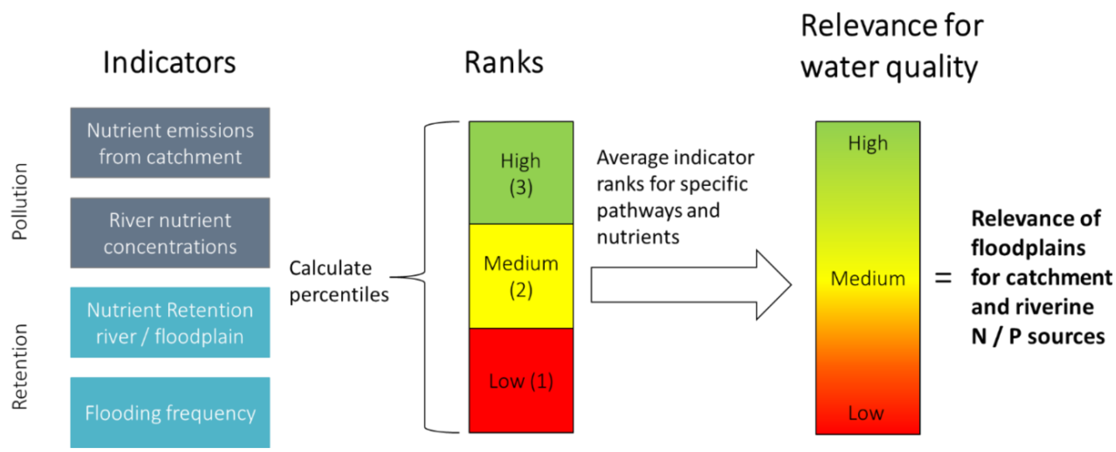

Figure 3. Evaluation scheme for estimating the relevance of active floodplains for water quality.

We ranked the floodplains and their segments on the basin and the national scales as high national ranks can be of only medium basin-wide significance. For the national prioritisation, the floodplains and their segments were assigned to countries. Transboundary floodplains and segments – located in up to 3 countries – were considered in each of their countries. Occasionally, segments also belonged to two floodplains and were treated accordingly. As only one contiguous floodplain existed in Slovenia, we set its ranks from low (1) to high (3) in the national assessment.

The data aggregation and processing is implemented and documented in a script which is part of the deliverable. It was written in the freely available programming language R [2] and can be used to reproduce or modify the results.

Table 2. Aggregation of the ranking of the indicators listed in Table 1, either on basin-wide or national level. The output Deliverable.xlsx (cf. section 6) contains indicator and aggregated ranks.

Aggregated ranking	Column name	Based on indicator ranks (column names)
Mean rank reflecting retention of upslope nitrate emission	NO3_emission_rel	Emission_NO3_rank, Denit_WaW_mean_rank
Mean rank reflecting retention of riverine	NO3_conc_rel	ConcNO3_mgL_rank, Denit_WaW_mean_rank, Flooding_days_mean_rank, DINret_river_rank

nitrate concentration		
Mean rank reflecting retention of upslope phosphorus emission	P_emission_rel	Emission_TP_rank, TPret_mean_rank
Mean rank of riverine phosphorus concentration	P_conc_rel	ConcTP_mgL_rank, TPret_mean_rank, Flooding_days_mean_rank, TPret_river_rank

4 Nutrient modelling with MONERIS

The nutrient concentration in the river segments along the floodplains is – generally speaking – the result of their mobilisation and transport within the whole catchment including the upstream river network. Many interacting processes and factors make the emission of nutrients into the surface water, the retention, and eventually the concentration highly variable. In absence of measured data, we relied on a basin-wide modelling.

The model MONERIS estimates monthly emissions of total N (TN) and total P (TP) (also dissolved inorganic nitrogen, DIN) via different pathways and the resultant loads and concentration in rivers. The semi-empirical, conceptual model was developed by FVB.IGB for regional to continental applications [3]. It was repeatedly applied for the Danube River Basins to provide input for the Danube River Management Plans (DRBMP) of the ICPDR (International Commission for the Protection of the Danube River, ASP1). For IDES, the model setup for the upcoming 3^{rd} update of the DRBMP [4] – to be published in the beginning of 2022 – was used.

For the setup, FVB.IGB closely collaborated with ICPDR and its experts groups, Deltares (DTP project Danube Hazard m^3c [5]), as well as BOKU Vienna. Based on national and international datasets, the model database was comprehensively updated compared to previous applications. Most noticeable data changes were

- Revised boundaries of analytical units (Figure 2 left)
- Reference period 2015-2018 (except hydrology)
- Modelled hydrology 2003-2013, a subset of the HYPE model output was compiled by van Gils et al. (2020) [6] and adjusted to observed discharge (2015-2018) [1]
- Regional net nitrogen balances of agriculture partly calculated by BOKU Vienna
- Regional statistics for connection rates to (independent) waste-water treatment and collection
- New soil-loss maps and river network
- New land-cover maps for Ukraine and Moldova

Given the discrepancy between hydrology and the rest of the setup, we calculated emissions, loads, and concentrations for average conditions[2]. The AU area, the availability and resolution of input data, as well as the (national) approaches to derive this data greatly differ within the Danube basin. This hampers e.g. the comparison of model results for different countries. Moreover, various

[1] In absence of modelled data for the reference period, local discharge had previously been estimated from observed discharge using a simple water-balance approach. The estimated discharge not only depends on the (variable) density of stations but typically shows artefacts due to the complex hydrology and inconsistencies in observation data.

[2] MONERIS can calculate for specific years and for (multi-)annual average conditions.

suspicious values were identified even in officially reported data, discussed, and at least partly resolved. Together with ICPDR and national experts, we therefore strived for acceptable results and a meaningful selection of national data.

Unlike the nutrient emission to surface waters, the modelled loads can be compared to observation data. While daily water discharge was generally available, nutrient concentrations in the Danube basin were typically measured only monthly which made the calculated loads uncertain and the load comparison unreliable. We identified 17 stations[3], mostly from the Trans-National Monitoring Network (TNMN) with ~bi-weekly samplings of TN and TP.

The TN load was found to be acceptable. However, the current and previous modelling approaches for the in-stream TP retention either over- or underestimated the observed TP load. Therefore, the HL (hydraulic load) approach for main rivers (MR) and tributaries (Trib) [3] were recalibrated using the available station data. HL (m/month or year) is the ratio of water discharge (in m^3/month or year) and water surface area (in m^2). For main rivers, we took the average slope (β, %) into consideration assuming that the retention is higher in flat terrain than in steep terrain. In a first step, we estimated the net retention R (as relative value) as

$$R_{TP,MR} = 1 - (56.3/\beta \; HL_{MR}^{-1})^{-1}$$

$$R_{TP,Trib} = 1 - (56.3 \, HL_{Trib}^{-1})^{-1}$$

The above equations were further modified for MONERIS assuming that R equals a gross retention minus a remobilisation. The coefficient was increased to 60.0 for the gross retention. The remobilisation was estimated from changes in the monthly discharge. As a result, the modelled loads and concentrations increased and the overall agreement to observed loads slightly improved.

Nonetheless, we used the first approach to re-estimate the TP (and the nitrate) retention for the indicator “in-stream retention” (cf. Table 1) because a) IDES aims at average annual and not monthly conditions and b) the modelled loads are almost perfectly correlated meaning that the prioritisation and the selection of sites is not affected by the retention approach but rather by the more accurate water surface area available for the floodplains compared to MONERIS.

The deliverable is based on input data received until the beginning of September 2021.

5 Floodplain model

For the estimation of the indicators for the N and P retention potentials in active floodplains, we depicted and estimated rates of the most relevant processes using available data for the whole Danube river basin. For the N retention, denitrification is a key process which permanently removes nitrate (NO_3) by ultimately converting it into gaseous N_2 [7]. Nitrate is the dominating form of nitrogen emitted from diffuse and point sources and transported in the Danube River [8]. Regarding the P retention, the deposition of particulate bound P in floodplains is important. Particulate P represents a

[3] The TNMN station RO12 at r. Someș exhibited a general problem with extreme values. An exceptionally high concentration of 2 mg/l resulted in January 2016 in a monthly load of 2500 tons which equals the total load of the years 2015, 2017 and 2018. The specific circumstances under which such extreme loads may occur require further assessments. They are typically not reflected in the input data and / or the monthly resolution of the model.

significant share of total P (TP) in the Danube River [9]. In floodplains, particles are deposited during high flows when the flow velocity is reduced and trapped by vegetation [10].

To take into consideration the dependency of nutrient retention on the transport of nutrients into the floodplains, we applied a semi-empirical estimate of the flooding frequency (indicator: “flooding days”) using the difference between mean water levels and the elevation of the floodplains [11]. To calculate the elevation difference, mean water levels (in m a.s.l.) were extracted at all rivers from a digital terrain model [12] and validated with measured water tables (1981-2010) at 22 gauging stations along the Danube, the Tisza and the Mura rivers ($r^2>0.99$, NSE=0.996). Using the estimated flooding frequency in combination with the NO_3 and TP concentrations modelled by MONERIS, floodplains of high, medium and low nutrient input were determined.

We calculated the actual denitrification potential (columns Denit*, cf. Table 1) in kg N/ha/yr using a simple model [13] which was adapted to floodplains [1] and EU datasets:

$$aD = pD \cdot f_1(pH) \cdot f_2(St) \cdot f_3(W) \cdot f_4(T) \cdot f_5(F) \cdot f_6(NO_3)$$

It consists of the potential denitrification (pD), which is a function of the soil organic carbon (SOC) of floodplain soils [14, 15] and the dimensionless reduction functions f_x representing the controlling factors for denitrification, namely soil pH [16], clay and silt content (soil texture St) [17], soil wetness (W) [18], surface temperature (T [19]), flooding frequency (F), and nitrate concentration (NO3). These functions were calibrated using literature values [13, 20, 21] or the frequency of observations [18]. The functions were applied to the gridded input data in a GIS environment.

The potential of TP deposition (columns TPret*, Table 1) was estimated using a proxy-based approach [22]. The approach used hydraulic roughness as a substitute for flow velocity and the ability to trap sediments. The TP retention proxies assigned to various land cover types were derived from literature values. We used a land use/cover map of the riparian zone [23] to assign values in kg P/ha/yr (Figure 4). All spatially explicit model results were aggregated to the floodplains and their segments before the ranking.

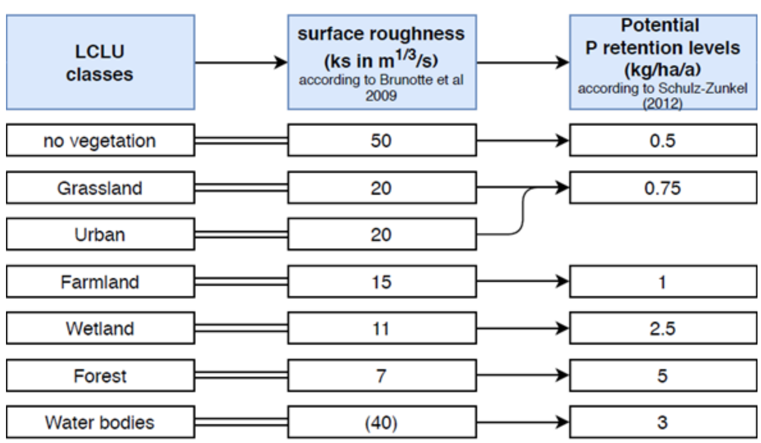

Figure 4. Schematic overview of the proxies assigned to land cover types, adapted from [22].

6 List of files

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R script which reads… IDES_Prioritization_floodplains_for_water quality_151021.R

- Prepared MONERIS output: export_fp_Sep_2021_E-HYPE_LT_adjusted_buffer_monthly_merged_fixed.txt_monthly_merged_loads_no_remob_2021.txt
- Assignment of analytical units (AU) to floodplains: AU_intersect_FP_DRSV_edit.txt
- Assignment of AUs to floodplain segments: AU_intersect_Seg.txt
- Modelled nutrient retention in floodplains: Mean_retention_flooding_days.csv
- Modelled nutrient retention in segments: Mean_retention_flooding_days_seg.csv
- Water surface area for floodplains: River_area_aFP.csv
- Water surface area for segments: River_area_segments_aFP.csv
- Water temperature in AUs: AU_Wassertemperatur.csv

… and calculates and exports the ranking

- Floodplains: Output_Floodplain_WQ_relevance.csv
- Segments: Output_Segment10km_WQ_relevance.csv

Output of R script sorted by rank Deliverable.xlsx

Geodata (shapefiles)

- All active floodplains from DTP Danube Floodplain: AFP_IDES.shp
- 10-km segments of active floodplains, rivers and former floodplains: Segmentation_AFP_10km.shp

Maps of the prioritization on basin scale Maps_Prioritization_BasinScale.pdf

The R script reads the input files created from the model input and output as well as the assignment of floodplain (segments) to analytical units and countries. After assigning the MONERIS output to the floodplain (segments), percentiles are used to convert the absolute values to class values (n=3) separately for N and P as well as national and basin-wide scales. The final ranking is derived as average class value. The R script allows reproducing and modifying the ranking and calculating weighted average ranks.

The Excel file contains the sorted output of the R script. The Excel files offer the option to sort the indicators for different purposes, and even derive other indicators from the original input data. The floodplain id (DFGIS_ID) and segment id (IDESGIS_ID) can be used to link the tables to the shapefiles in order to produce maps. This has been exemplarily done to create the maps of the rankings on the basin scale (Maps_Prioritization_BasinScale.pdf).

7 References

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