Action D1: Socio-economic monitoring and eco-system services (ESS) monitoring

Assessing potential impacts of dam removal scenarios on ecosystem services delivery. Insights from the Lahn federal waterway, Germany

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Please note:

This document is based on the results of a study that investigated potential impacts of dam removal scenarios on ecosystem services delivery of the river and its floodplain for selected stretches of the Lahn federal waterway, Germany (BIOTA 2021). The study was commissioned by the Hessen State Ministry for the Enviromment, Germany, as part of the Integrated EU LIFE Project LiLa - Living Lahn.

1 Introduction

The ecological condition of many rivers and their floodplains in Germany still substantially deviate from the goals of a good ecological potential or status according to the EU Water Framework Directive (WFD) [1]. Addressing those challenges, and accelerating river restoration efforts will require considerable efforts and needs to take into account the diverse demands of various actors involved in, and affected bythe management of riverine landscapes. At the same time, the urgency and societal relevance of river restoration is increasingly promoted, most recently by European Commission’s guidance on Barrier Removal for River Restoration [2].

A topical example of ongoing initiatives to advance river restoration for people and nature in practice is the integrated EU LIFE project "LiLa Living Lahn - one river, many interests" (the LiLa project, for more information, see https://www.lila-livinglahn.de/). The LiLa project focusses on the Lahn river in the German Federal States of Hesse and Rhineland-Palatinate. The LiLa consortium includes the Hessian Ministry for the Environment, Climate Protection, Agriculture and Consumer Protection (HMUKLV) as the project coordinator, as well as the German Federal Institute of Hydrology (BfG) the Ministry of Environment, Agriculture, Nutrition, Viniculture and Forestry of Rhineland-Palatinate (MUEFF), the Directorate for Infrastructure and Approval North (SDG Nord), the Waterways and Shipping Office Mosel-Saar-Lahn (WSA Mosel-Saar-Lahn), and the Governmental Authory of Gießen (RPGI). The primary aim of the LiLa project is to support achieving the WFD objective “good status/potential” and to develop a so-called Lahn Concept that shall serve as a coordinated guiding concept to support decisions on the future development and maintenance of the Lahn. The development of the Lahn concept is coordinated by the Mosel-Saar-Lahn Waterways and Shipping Authority.

The Lahn concept will consider the Lower Lahn river section between the Badenburg weir near Giessen, Hesse, to the confluence of the Lahn into the Rhine near Lahnstein, Rhineland-Palatinate. This section (see fig. 1) has a length of 149 km, includes 29 dams, and is owned by the Federal Government as part of its system of Federal Waterways. The legal dedication as a federal waterway results from § 1 para. 1 no. 1 and para. 5 and § 2 para. 2 as well as Annex 1 of the Federal Waterways Act (WaStrG) [3]. The formal administrative responsibility for managing this Lahn waterway lies with the Mosel-Saar-Lahn Water and Shipping Authority which, as noted above, is also responsible for coordinating the development of the Lahn Concept.

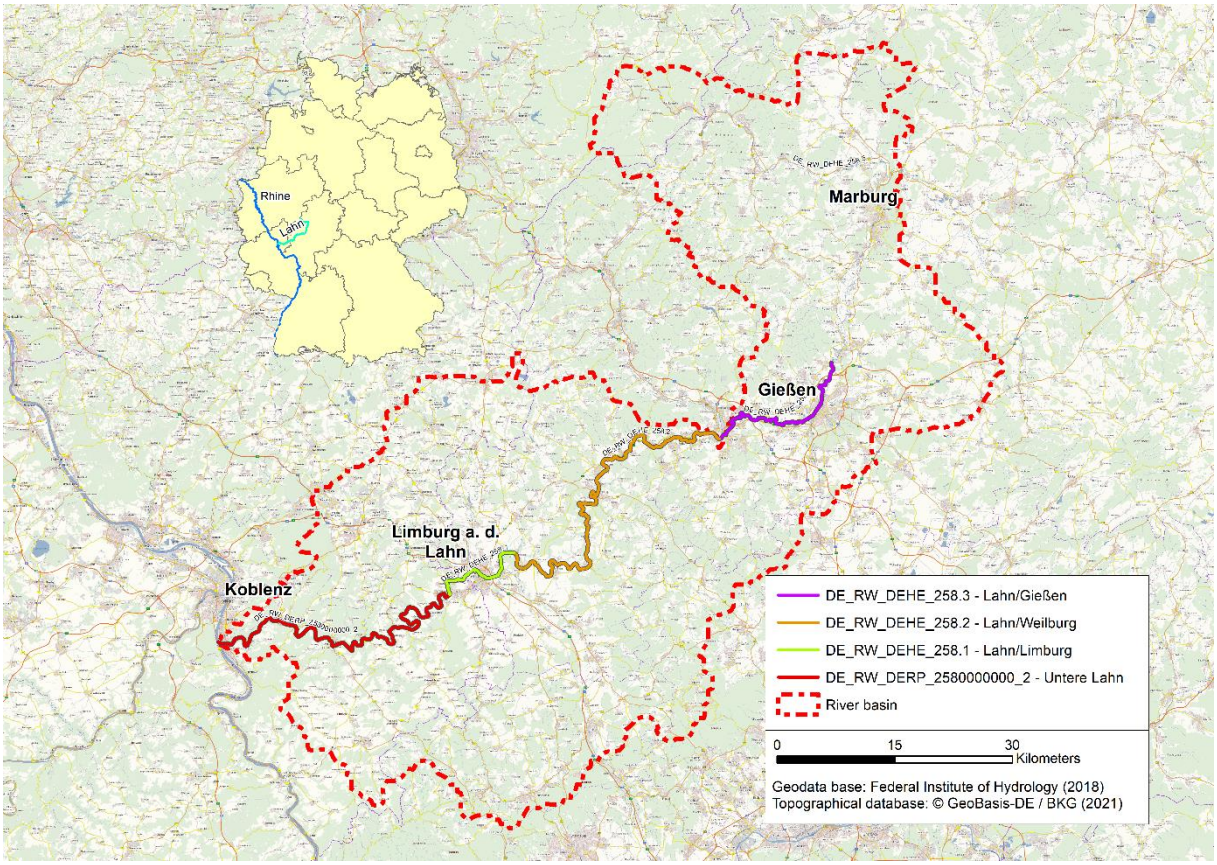

Figure 1: Map of the entire catchment area of the river Lahn (in Germany) and the area of the federal waterway (at the same time four water bodies according to WFD)

Freight navigation on the Lower Lahn was ceased in 1981. Current water traffic relates to leisure and tourism navigation as well as rowing or canoing. From a hydromporhpological and ecological perspective, the existing dams cause substantial impacts. The main causes for those impacts are that the dams inhibit a natural character of the water flow and suppress hydro- and morphodynamic processes. In consequence, the Lower Lahn has lost the richtness of structural form of the river bed and the floodplain that is naturally associated with this type of rivers of low mountain ranges in central Germany. Its ecological condition is currently evaluated as unsatisfactory to poor according to the WFD [1].

Enhancing the hitherto insufficient ecological condition of the Lower Lahn could be achieved through diverse river restorations actions, including dam alterations and removals. Such restoration activities are expected to re-connect the river with its floodplain, to support the reintroduction of floodplain-typical flora and fauna, and to increase longditudinal ecological connectivitiy with benefits for migrating species. At the same time, those alterations might negatively impact uses of the watercourse and its floodplain, for example to generate hydro energy or navigation.

Exploring potential different river development scenarios and their impacts for people and nature could be enhanced by the use of the concept of ecosystem services, understood here as the direct and indirect contributions of nature and landscape to human well-being [4]. Literature suggests that such ecosystem services information might also help communicating and considering the diverse impacts in discussion and decision-making processes [5].

A recent study [6, unpublished] aimed at creating hypothetical scenarios for alternative future developments of selected dams of the lower Lahn and at exploring their potential positive and negative impacts on ecosystem services delivery. The study intended to quantify the respective impacts on ecosystem services, and to complement this information with monetary valuations as far as possible. The study considered both conventional biotic ecosystem services such as water retention, recreation and habitats, and abiotic services [7, 8], primarily the use for navigation and hydropower.

This manuscript presents key results from the technical report [6 in German] and consists of a translated synthesis of two paper manuscripts based on the technical report (Mehl et al. 2022a and b, also in German [9, 10]).

2 Methodology applied for assessing ecosystem services

Ecosystem services, and their significance for human well-being can be assessed and valued in various ways. This manuscript attemtps to quantify and economically value the delivery of ecosystem services in the status quo and in alternative future scenarios for selected river stretches. The generated information is expected to provid additional information to enable a better structured inform and decision-making process for future river development [5, 11, 12, 13, 14].

Economic valuation is thereby used as a means to reflect societal demand for ecosystem services [15]. The demand can be expressed either in the actual consumption or use of a good or service, or in the sole appreciation of environmental goods or services even without direct use of enjoyment, for example to preserve such services for future generations [11]. People show their appreciation for the improvement of an environmental condition through their (maximum) willingness to pay or their (minimum) compensation demand for the deterioration of an environmental condition [15]. A nessesary precondition for economic valuation is to consider the so-called ecosystem services of ecosystem processes and structures, ecological functions, ecosystem services, benefits, and impacts on human well-being [16].

In a first step, ecosystem services were quantitatively assessed (for detailed descriptions of the methods, pelase see [6]) and then qualitatively evaluated on a six point Lickert scale, usually in a linear appraoch (**Figure 2**). The minimum level (0) means no or very limited ecosystem services delivery, while the maximum level (5) represents the highest potentially possible level. Established assessments methods from the fields of landscape ecology, geosciences and biosciences were used wherever possible, thereby taking typical Germany-wide ecosystem conditions as a reference. The assessment focused on the morphological floodplain of the Lahn, including its former or historic floodplain, the active floodplain, and the river (**Figure 3**).

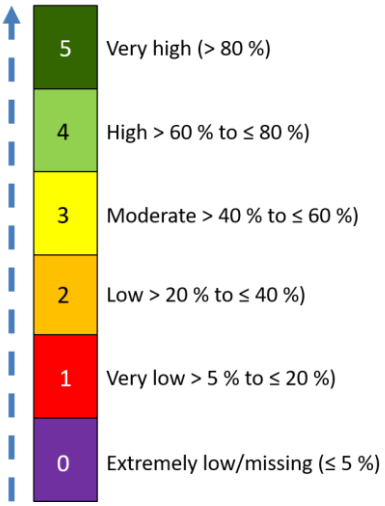

Figure 2: Six-level scaling in the (relative) valuation of ecosystem services, extended according to [12]

A second step applied economic valuation approaches to estimate ecosystem services values in monetary terms. Methods applied in the monetary valuation included market analyses as well as price- and cost-based approaches. Although market analyses can only depict a part of the overall economic value, they nevertheless provide valuable first indications of the overall economic significance. This consideration is important for the interpretation of the values, especially when they are compared with the results of preference analyses. Another important conisideration is to focus economic valuation on marginal changes – i.e. scenario-induced changes in costs and benefits but not absolute values. For example, economic valuation should consider the impacts of the marginal change of cutting a small part of a forest, but not the total value of the entire forest per se. Thus, when considering alternative options for action, costs and benefits can be compared with each other and used as decision-support information, or the costs and benefits of an individual measure can be put in relation to each other. The changes from the status quo to scenarios (options for action) as well as the difference between the scenarios are therefore decisive for the economic evaluation.

In a third step, the effects of changes between the current baseline situation and future scenario conditions were assessed, assuming a situation 20 years after implementing a hypothetical set of actions in each scenario. Applying such a uniform time period is essential for the comparability of the different scenarios from a qualitative and economic point of view. The applied time period of 20 years takes into account the fact that ecosystems require a certain development time (processes) and development maturity (structures) in order to fulfil the respective ecosystem functions and to provide ecosystem services. The implementation of measures associated with the respective scenario must also be achievable within the selected time period. For pragmatic reasons, the most recent and highest quality data available was considered the current or baseline state.

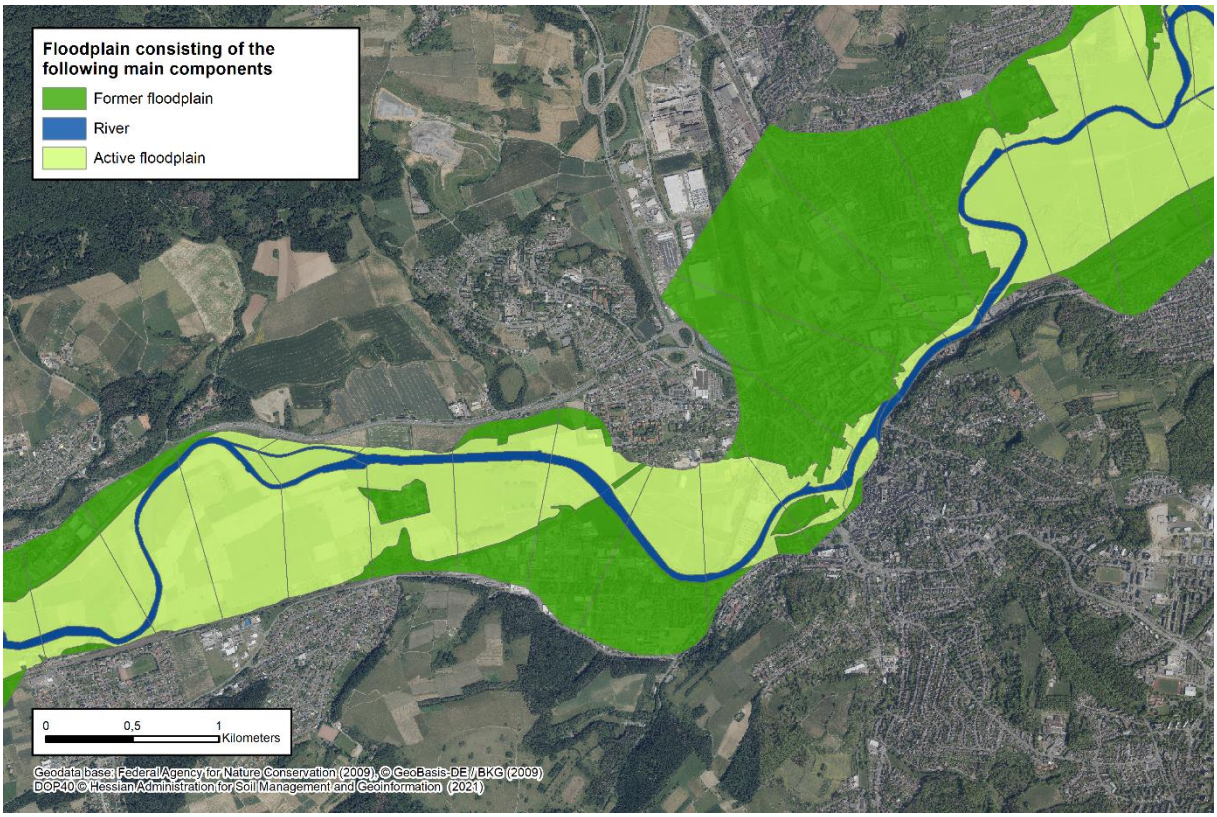

Figure 3: Spatial zoning of the floodplain according to [17], exemplary for a section of the river Lahn

The study considered all ecosystem services that are already or could potentially be used by people within the morphological river floodplain (**Table 1**). Special attention had to be paid to the fact that the selected ESS should, as far as possible, be subject to changes between the actual/initial state and the future scenarios, here understood as potential forecasted states based on two alternative courses of action and the corresponding hydromorphological necessities in relation to the measures/options.

Data processing was implemented predominantly using a Geographical Information System (GIS). Technical data and geodata were provided by the federal states of Hesse and Rhineland-Palatinate, the Federal Institute of Hydrology and the Federal Waterways and Shipping Administration (WSA). Access to the WSA's "Lahn-GIS" was very valuable.

Table 1: Total list of selected ecosystem services (extended according to [13, 14]) and monetary valuation methods used

Main group	Subgroup or class	Ecosystem service	Monetary valuation method
Provisinoing ecosystem services	Food	Crops	Market price method
		Plant biomass for use in agriculture	Market price method
	Raw materials	Plant raw materials for processing	Market price method
	Energy	Plant-based energy raw materials from agriculture, short rotation coppice, timber industry	Not applicable (low relevance for the study area)
Regulating ecosystem services	Extreme runoff	Flood regulation	Replacement cost approach
		Low water regulation	Is not evaluated in monetary terms (impact correlations unclear)
	Sediments, soils and their nutrient retention	Sediment regulation in the water system	Is not evaluated in monetary terms (impact correlations unclear)
		Soil formation	Is not evaluated in monetary terms (impact correlations unclear)
		Retention of nitrogen (N)	Abatement cost approach
		Retention of phosphorus (P)	Replacement cost approach
	Biological self-purification, oxygen conditions in the water body and in the interstitial zone	Biological self-purification	Is not evaluated in monetary terms (impact correlations unclear)
	Global climate	Retention of greenhouse gases/carbon sequestration	Damage cost approach
	Regional/local climate	Cooling effect (water bodies and soils)	Is not evaluated in monetary terms (impact correlations unclear)
	Biological diversity	Habitat provision	Is not evaluated in monetary terms (impact correlations unclear)
Cultural ecosystem services	Landscape experience	Landscape aesthetics	Not valued in monetary terms (difficult to distinguish from general recreational benefits).
	Heritage and sentimental value	Natural and cultural heritage	Is not evaluated in monetary terms (impact correlations unclear)
	Recreation and tourism	General recreation and tourism	Is not valued monetarily due to the high data and information requirements (order of magnitude of value estimate can be derived from study overview)
		Specific forms of recreation, sport and experience	Market price method
	Intellectual interactions	Education and science	Is not evaluated in monetary terms (impact correlations unclear)
Other (abiotic) ecosystem services	Navigation	Motorised navigation	Market price method
	Energy	Hydropower	Market price method

3 Scenarios for the future development of dammed river stretches

The study focused on the effects of possible alternative courses of action in dealing with three selected, representative dams and the potentially associated changes in ecosystem services. Since all alternative courses of action entail changes to the status quo, the changes had to be modelled. This means that the level of detail of the sub-models (dimension, space-time scales or scale) is adapted to the given demand. Due to the focus on ecosystems, deterministic modelling approaches were adopted as far as possible. In other words, a simplified, preferably "physical" representation of the relevant processes was strived for. In addition to a consideration of the status quo (referred to as scenario 0 in the following), two future scenarios with different scope and intensity of measures were examined.

An essential dimension for alternative courses of action in dealing with river dams of the Lahn is the degree of achievement of the WFD targets [1] ("degree of target achievement"). One of the scenarios should theirefore illustrate a high degree of proximity to the targets of Article 1 of the WFD, while the other scenario should take greater account of existing uses and thus cannot achieve the same high degree of implementation of the WFD objectives. In this respect, the following two stylized scenarios as potential courses for action were considered in addition to the status quo (scenario 0) (**Figure 4**):

(1) Scenario 1: the good ecological potential (GEP) according to Annex V WFD (if the current framework conditions for the use of the Lahn are maintained); this corresponds to the current management objectives for the relevant WFD water bodies.

(2) Scenario 2: good ecological status (GES) according to Annex V WFD (if existing dams are hypotheticaly removed, including the removal of existing hydropower plants. Notably, however, this is not a WFD management objective for the respective Lahn water bodies, according to their current HMWB classification. However, since there is no commercial navigation any more and taking into account the demand of the EU Guidance document on restoring 25.000 km of free flowing rivers within the EU [2] this objective seems to be worth also to be taken into consideration. Especially, when it might bring additional benefits for the society in general.

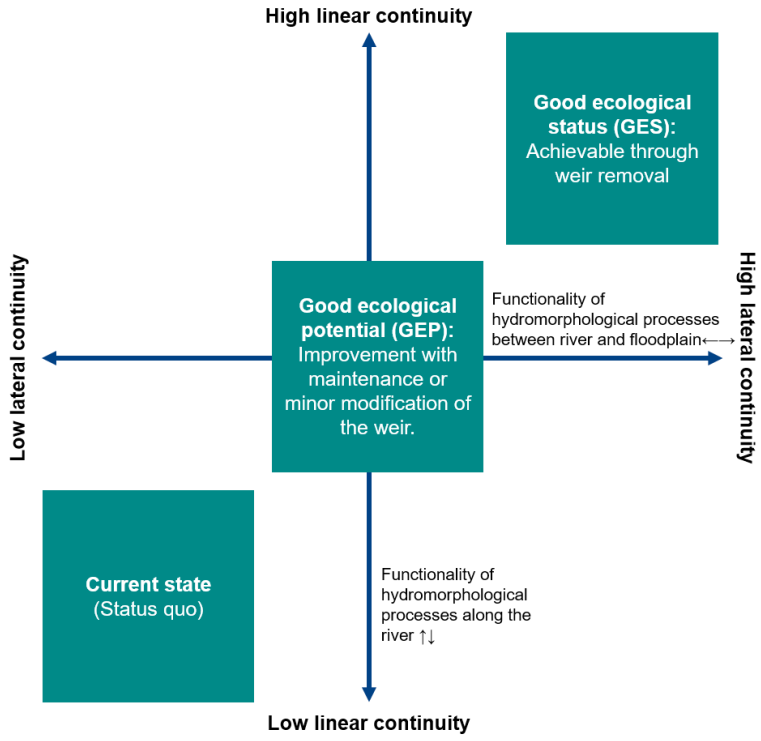

Figure 4: Three scenarios as alternative courses for action for the future of Lahn river dams and consequences in terms of potential attainment of the objectives of the WFD [1]

In scenario 1, the proposed measures assume GEP conditions - given that navigation on the Lahn and hydropower utilisation of dam-regulated waters persist. The development of measures to achieve GEP conditions could draw on an already existing concept for floodplain structuring [18], which specifies ecological improvement measures. In addition, it is assumed for the GEP that ecological continuity (linear and aquatic, in particular fish upstream and downstream) is established at the dams through technical installations.

Scenario 2 is characterised by more natural hydromorphological conditions at least in a larger part of the adjacent floodplain, thus attaining the GES condition. The hypothetical implementation therefore relies on the following measures:

1. dam removal and river bed levelling to compensate for the historical wedge dredging on the Lahn; furthermore creating a longitudinal gradient of the Lahn that is typical for the natural environment including removal of buildings and installations connected with the dams or locks from the floodplain in order to minimize constraints (except for individual monuments, e.g. as for cultural heritage protection and/or environmental education)

2. establishment of more natural water structural conditions in the Lahn (bed, banks, surroundings)

3. arrangement and more natural design (height zoning, substrate conditions, hydro- and morphodynamics) of a watercourse development corridor in the sense of a (minimum) space requirement (watercourse type-specific space requirement)

Regarding the arrangement and more natural design of a type-specific watercourse development corridor, a methodological recommendation of a working group of federal and state representatives working on river management issues (the so called LAWA) for determining the space required for near-natural river flows [19] was used. This recommendation builds on the determination of today's potential natural watercourse width, including the meander length, the winding as well as a dynamic factor. The derivation includes a whole series of steps of GIS analyses (e.g. valley bottom slope, oscillation amplitude), calculation (e.g. water discharge assuming the current hypothetical natural river condition) and the exclusion of built-up areas.

From an ecological point of view, and according to the systematics of WFD [1] and German law on the protection of rivers (OGewV) [20], the watercourse development corridor enables the establishment of hydromorphological structures and processes that represent good ecological status; in other words, it forms the ‘ecologically active recent floodplain’. Information on the structural ecological characteristics can be found, for example, in the water body type-specific profiles and related classifications for good status of the German Federal Environment Agency [18]. For the further analysis, the following steps were carried out:

- Further horizontal zoning of the watercourse development corridor according to the ecologically effective subspaces (e.g. altitudinal stages, hydromorphism, flooding regime).

- Implementation of the watercourse development corridor into the three-dimensional elevation model of the individual dammed river stretches in order to model realistic elevation conditions of an ecologically functional watercourse development corridor in the sense of the principles formulated above.

Since both scenarios were then used for three selected dams, some additional conditions had to be defined. The assumtions concerned, for example, the given longitudinal continuity with regard to the sediment regime (ecological continuity for sediments) as well as with regard to ecological continuity. It was further assumed that the Lahn river still provised sufficient recolonisation potential for all species (aquatic, terrestrial, semi-terrestrial). Property issues, legal considerations as well as technical and financial costs were disregarded in this conceptual and

hypothetical scenario study. Instead, the focus was on the assessment and evaluation of scenario effects on ecosystem services delivery.

4 Dams selected for investigation

In agreement with the LiLa project consortium, three dams and associated river stretches were selected for the scenario study by choosing from the total of 29 existing dams in the Lower Lahn river (**Figure 5**) (technical data: WSA):

1. Lahnstein (Rhineland-Palatinate): the Lahnstein dam at Lahn-km 135.700 forms the lowest dam of the Lahn (**Figure 6**). The water level is 66.06 m above sea level with a drop of approx. 5.9 m.
2. Kirschhofen (Hesse): the Kirschhofen dam is located at Lahn km 45.280 (**Figure 7**). The target level is 126.77 m above sea level with a head of approx. 3.5 m.
3. Altenberg (Hesse): the fixed and single-span weir Altenberg at Lahn-km 15.877 is the uppermost of the three selected dams (**Figure 8**). The target level is 144.408 m above sea level with a head of approx. 1.4 m.

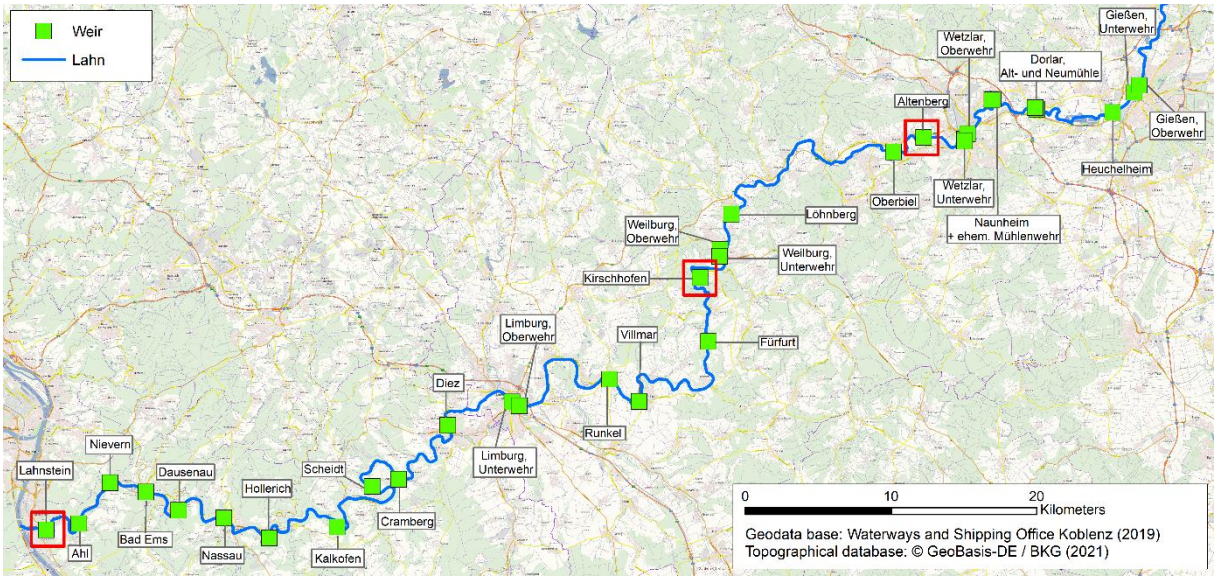

Figure 5: Location of the three selected Lahn dams (red frames)

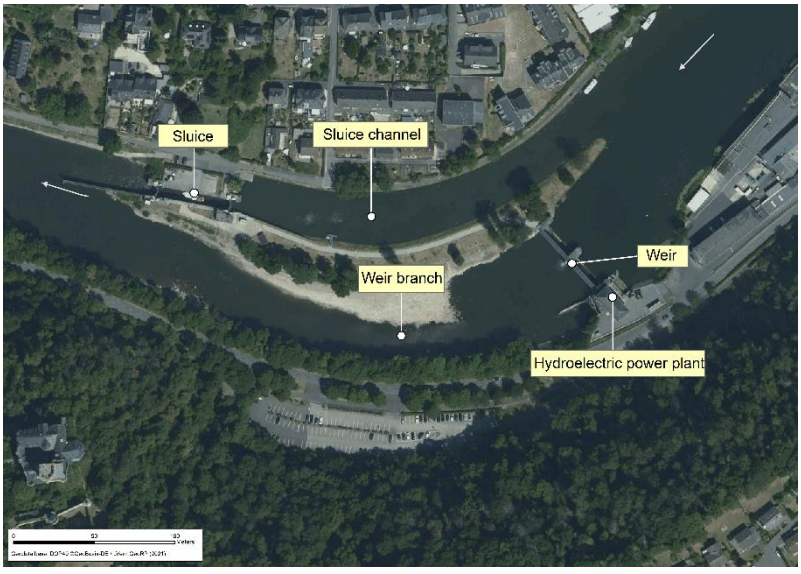

Figure 6: Lahnstein dam with weir and lock facility

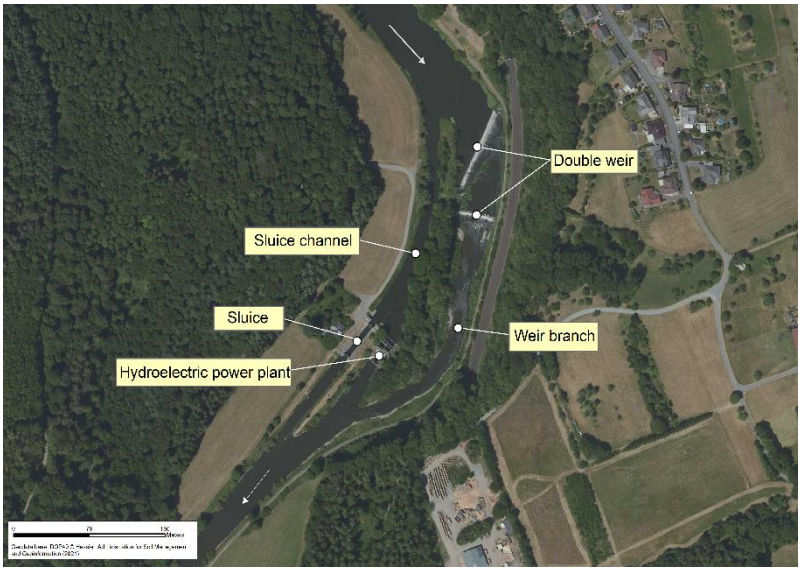

Figure 7: Kirschhofen dam with weir and lock system

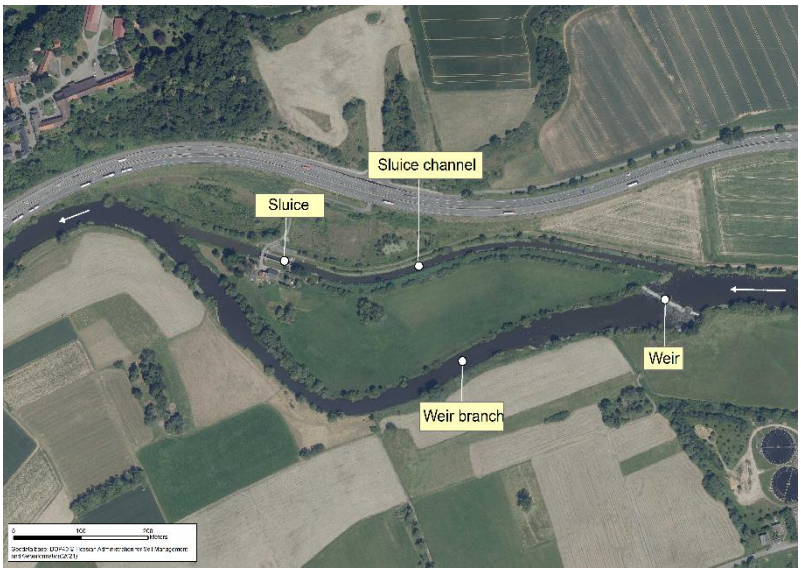

Figure 8: Altenberg dam with weir and lock system

All three dams can be passed by ships using the locks provided. The dams are representative of the different conditions on the federal waterway Lahn, both in geographical and natural terms (location in the study area, shape of the valley, type of watercourse, type of floodplain, as well as with regard to the condition of the watercourse, the importance for motorised navigation and hydropower, and with regard to the use of the floodplain).

For evaluation and comparison purposes, the results were converted into basically equidistant floodplain sections/segments analogous to [12, 13, 17] and provided with a segment ID. For this purpose, 500 m floodplain sections were formed, whereby the principle of "upstream and downstream" of dam structures was also taken into account (**Figure 9**). In this way, no subdivisions were to be created that would have arbitrarily and technically unsystematically assigned essential area properties (above all of the actual condition). Dams were pragmatically considered as boundaries of floodplain sections. Accordingly some slight deviations in the length of river sections of 500 m occured, but those minimal differences were expected to incur no significant distortion of the assessments due to the evaluation results were normalized to the area size of each river segment. On the contrary, this leads to more appropriate results.

Finally, with this procedure, the results, preferably weighted by area (area size), could be condensed into results and evaluations of the respective floodplain section.

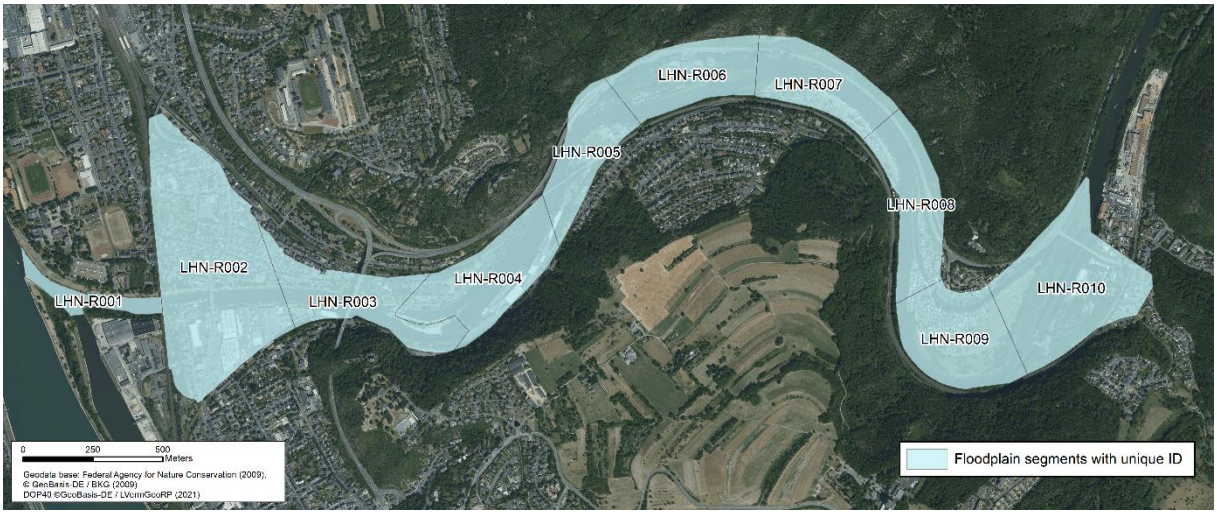

Figure 9: Implemented 500 m sectioning, exemplary for the Lahnstein dam

5 Scenario impacts on ecosystem services

For purposes of methodological illustration, this manuscript focuses on the assessment results for the Lahnstein dam. For this dam scenario 1 (good ecological potential - GEP) cannot be based on measures of the existing reservoir structuring concept [20], as no additional measures were identified due to the existing spatial situation. The comparison with scenario 1 is therefore obsolete. However, for the two other dams in Kirschhofen and Altenberg, scenario 1 has been assessed additionally.

Scenario 2 (good ecological status - GES) is conceptually based on a (hypothetical) floodplain structure, as described in [21]. Assumptions were made about appropriate slope compensation by drawing on existing survey and model data (data source: Federal Institute of Hydrology). An overview of this is shown in **Figure 10**; here, the slope compensation was carried out up to the Rhine valley (in the tailwater area) and beyond the Ahl dam (in the headwater area).

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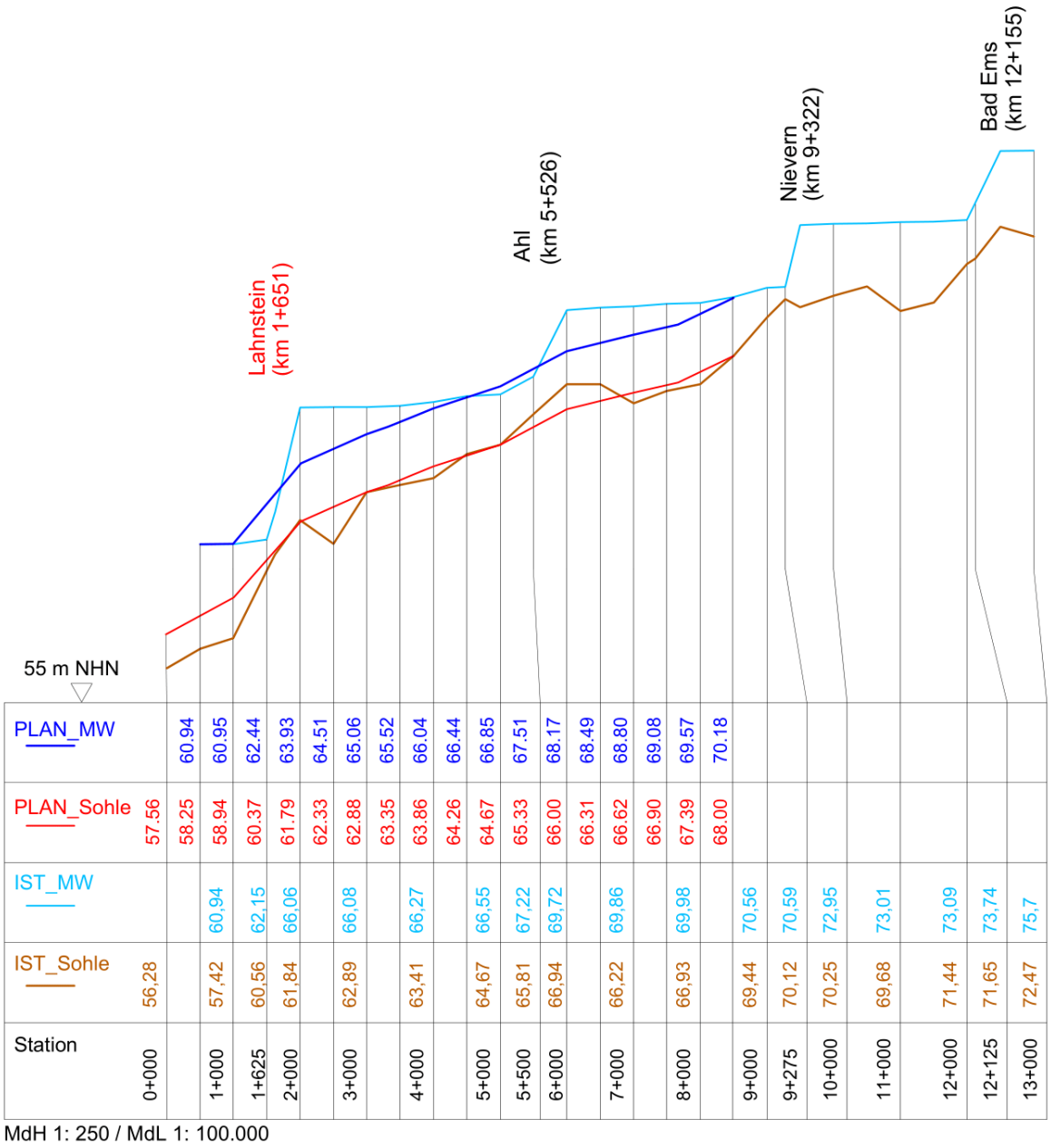

Figure 10: Data on the actual condition for riverbed levels and mean water level (MW) in the lower section of the federal waterway with a focus on the Lahnstein dam (data source: Federal Institute of Hydrology) as well as the assumed riverbed levels and mean water levels for a planned condition in the event of dam removal (scenario 2: good ecological status); dark blue line: mean water level in the planned condition, red line: bed heights in the planned state, light blue line: mean water level in the actual state, brown line: riverbed heights in the actual state

The results of the spatial modelling of the scenarios 0 (current condition) and 2 are illustrated in **Figures 11 and 12**, respectively, based on the assumptions and methods described above (for details, see [6]). A further detailed representation of a potential future condition in scenario 2 is represented in **Figure 13**, illustrating the location, width and zoning of the watercourse development corridor as required in this scenario. In addition, a hypothetical adjustment of the three-dimensional elevation and terrain model was performed, based on an idealized horizontal and vertical zoning of the watercourse development corridor (**Figure 14**).

Figure 11: Lahnstein dam in its actual state, illustrative spatial section - graphic principle representation as CAD oblique image

Figure 12: Lahnstein dam in scenario 2 (good ecological status) without dam and with established watercourse development corridor, illustrative spatial section - schematic diagram as CAD oblique image

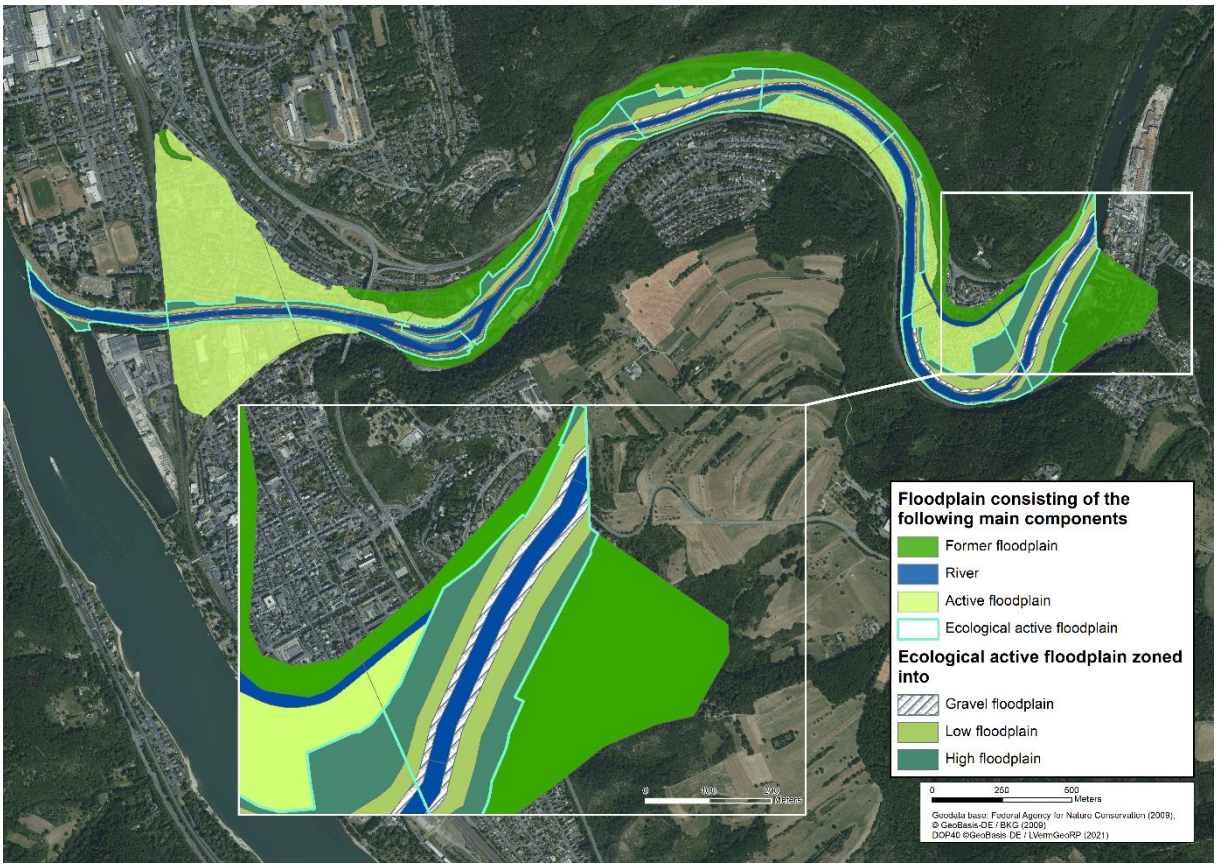

Figure 13: Lahnstein dam in scenario 2 (good ecological status) without dam, with established watercourse development corridor (= ecologically active recent floodplain) and spatial-functional subdivision - aerial view as GIS map representation

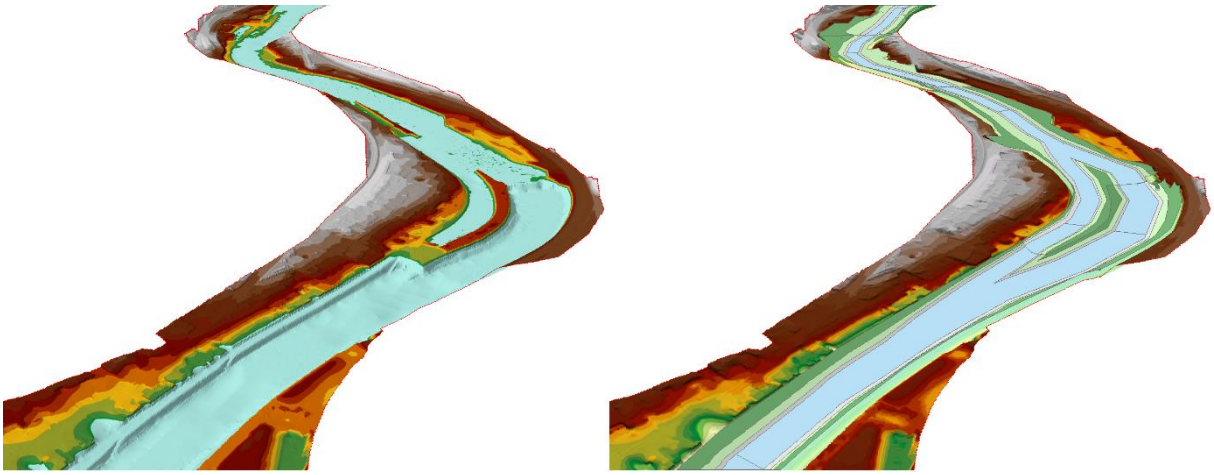

Figure 14: Three dimensional elevation model of the Lahn floodplain in the area of the Lahnstein dam (spatial section for visualisation): left: Current state, right: with projected watercourse development corridor in scenario 2; data basis: WSA

Applying the ecosystem services assessment and evaluation methods (see above, and described in detail in [6]) provided detailed accounts of the level of ecosystem services provision in each river segment in both the current condition and the projected scenario 2 (**Figure 15**). Key findings include that moving from the status quo to scenario 2 might result in

- a decline in the river segments' capacity to deliver provisioning ecosystem services (see **figure 16** for an example of the natural yields ecosystem services maps),

- a mayor decline in the delivery potential of abiotic services due to a loss of capacities for motorised navigation and hydropower uses,
- a very strong increase across all floodplain river segments regarding their capacity to provide regulating ecosystem services,
- a substantial increase in most floodplain river segments regarding their capacity to provide cultural ecosystem services.

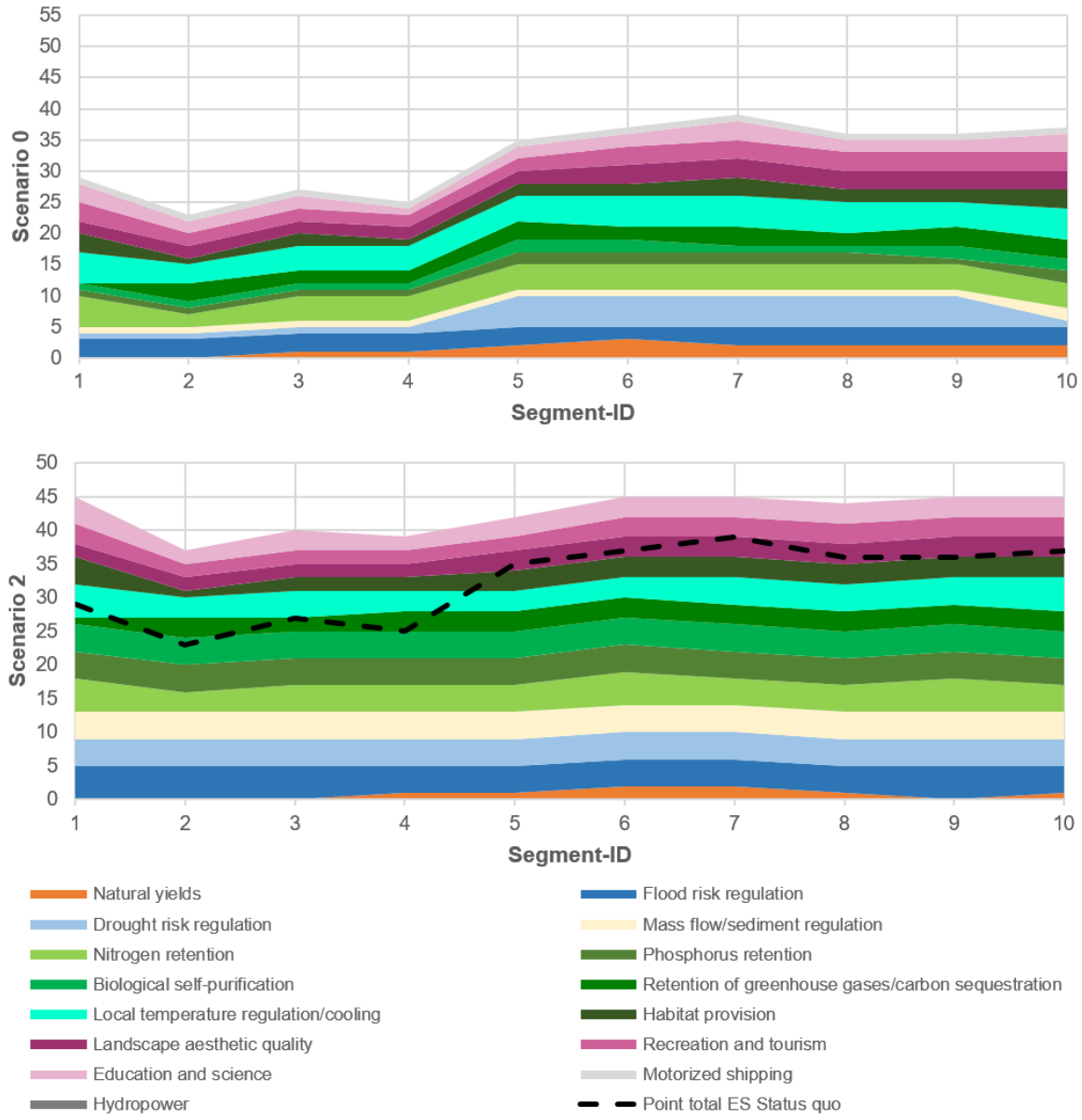

Figure 15: The results of the ecosystem services assessment in individual and cumulative representation for each segments of the morphological floodplain at the Lahnstein dam, top: actual condition, below: scenario 2 (good ecological status), flow direction of the Lahn from right to left

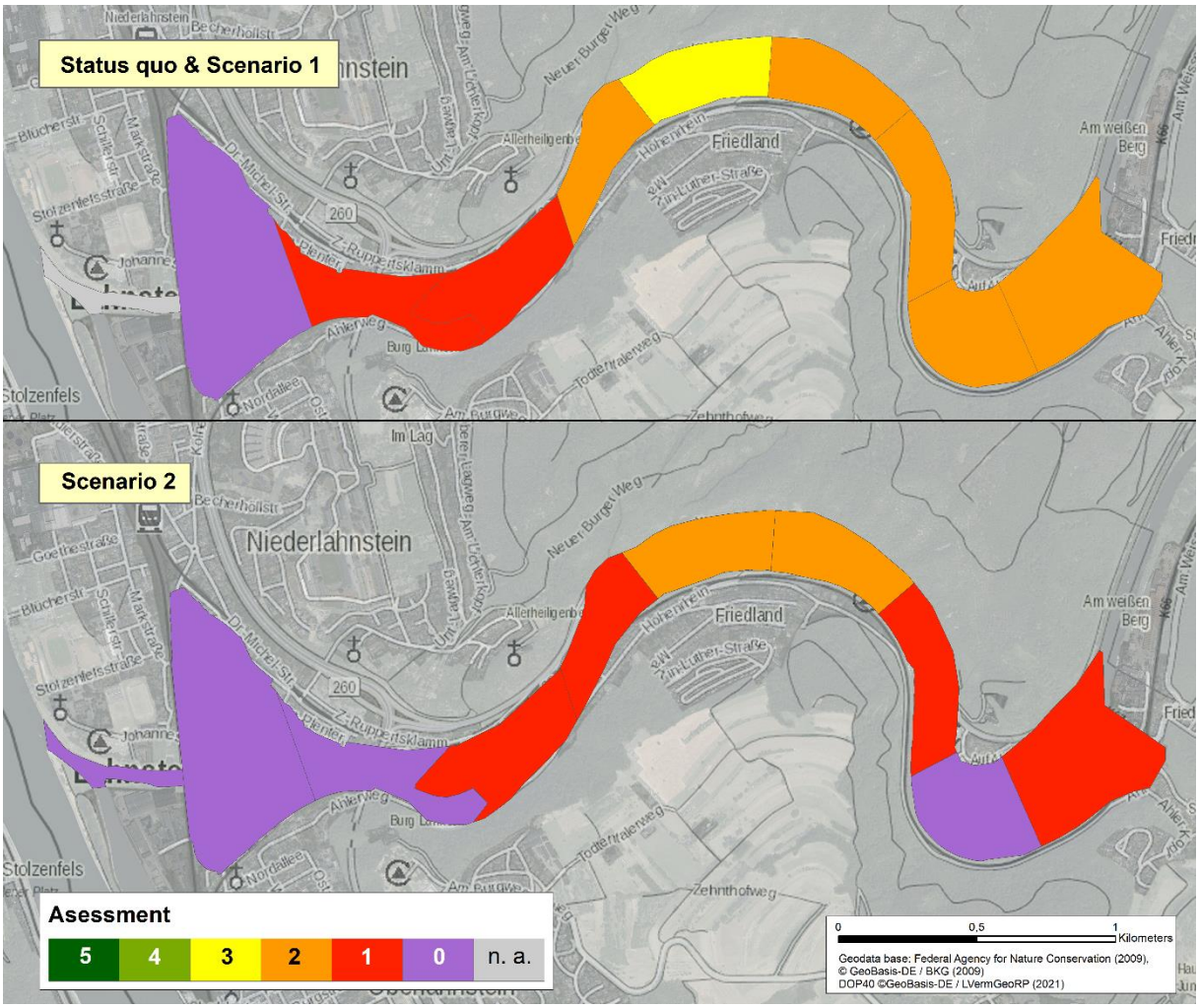

Figure 16: Example of an evaluation (yield potential) at the Lahnstein dam in the actual condition and scenario 2 (good ecological status), spatial reference: morphological floodplain

6 Results of the economic evaluation

An overview of the economic evaluation results for both scenarios for the Lahnstein dam is provided in **Table 2**. For each ecosystem service considered, the table illustrates the change in the monetary value in comparison between scenario 0 (the status quo) and scenario 2, taking into account a 20-year period and discounted approaches in each case.

Two aspects are of particular importance for the interpretation of the economic assessment results. Firstly, only changes in monetary value are considered that result from changes in the capacity of provide ecosystem services between both scenarios are considered. The costs necessary for implementing scenario 2 are not taken into account. It can be assumed that substantial implementation costs will occur for both scenarios 1 and 2. Scenario 1 would also involve considerable modernisation costs for the existing facilities (weirs, locks). Secondly, monetary valuation could only be performed for about half of all ecosystem services considered in the study. The reasons were that the data basis was too limited, and the research budget did not allow for costly empirical data gathering as would have been required, for example, to perform preference-based valuation of cultural ecosystem services. It can be assumed that the overall benefits incurring from the implementation of scenarios 2 would be substantially greater if the changes of all ecosystem services could have been taken into account in the monetary valuation.

As table 2 illustrates, implementing Scenario 2 (GES) – i.e. removing the Lahnstein dam – would be associated with dramatic increases in the monetary value derived from regulating

ecosystem services (approx. +44.9 million €), while the monetary value of provisioning ecosystem services would decrease marginally (approx. -0.1 million €) and decrease substantially for abiotic services (approx. -36.0 million €). Overall, however, Scenario 2 would result in a cumulative gain in monetary ecosystem services values of about +8.8 million €. This gain is relatively small compared with the gain in monetary ecosystem services value estimated for the implementation of Scenario 2 at the other two dams (details reported in [6]) with +89.0 million € and +75.1 million €, respectively).

Table 2: Changes in monetary ecosystem services values between the current condition (Scenario 0) and Scenario (good ecological status). Amounts rounded to the nearest 100.00 €.

Ecosystem service	**Changes between Scenario 0 and Scenario 2**
Crops (on arable and horticultural sites)	0 €
Plant biomass for agricultural use (on grassland sites)	-4,400 €
Plant raw materials for processing (forest sites)	-119,600 €
Plant-based energy raw materials from agriculture, short rotation coppice, timber industry	-
Total change of monetary values for provisioning ecosystem services	-124,000 €
Flood regulation	18,877,000 €
Low water regulation	-
Sediment regulation	-
Nitrogen retention	247,200 €
Phosphorus retention	10,116,000 €
Biological self-purification	-
Retention of greenhouse gases	15,707,000 €
Cooling effect	-
Habitat provision	-
Total change of monetary values for regulation ecosystem services	44,947,200 €
Landscape aesthetics	-
Recreation and tourism	-
Education & Science	-
Total change of monetary values for cultural ecosystem services	-
Motorised navigation	-28,084,700 €
Hydropower	-7,934,000 €
Total change of monetary values for abiotic ecosystem services	-36,018,700 €
Total change of monetary values	8,804,500 €

7 Discussion

The research reported here represents one of the first systematic, quantitative and economic valuation of hypothetical dam removal projects in Germany. The assumptions that nessessarily needed to be made seem to be highly plausible from the perspective of water management, landscape and water ecology. For example, a study by the Federal Institute of Hydrology has already confirmed that dam removal measures in the Lahn river would result in improvements of flood discharge ecosystem services capacities [22]. The fact that dam removals and the creation of a morphologically imprinted watercourse development corridor (enlargement of the volume of the recent floodplain, roughening) also results in improved flood water retention is proven by numerous studies, e.g. [23, 24].

The study resulted in only slight changes in cultural ecosystem services values between scenario 0 and scenario 2, which may be due to methodological and conceptual reasons and challenges. Accordingly, also economic assessments of those services often show substantial uncertainties. More reliable insights into the potential effects of dam removals, and river restoration actions more generally, will require more specific studies focusing explicitly on those perceptional effects and taking into account local preferences and considerations, for example with survey-based preference analyses through willingness-to-pay analyses of choice experiments. Apart from some issues of accessibility and visbility, ecological improvements can generally be expected to also enhance the deliverly of cultural ecosystem services.

The low levels of capacity to provide abiotic services in Scenario 0, the current condition, are also highly plausible. The Lower Lahn is only assigned a very low waterway class level anyways solely for recreational and sport boat navigation.

Hydropower generation capacities must also be considered low – taking into account that the energy generation capacity of all existing hydropower plants of the Lahn river could be replaced by four to six modern wind power plants already or about 1,000 rooftop photovoltaic systems (for a corresponding example calculation, see [6]). At the same time, the adverse effects of hydropower on nature conseration are increasingly discussed, as illustrated, for example, in the recent memorandum by leading German water researchers [25].

Furthermore, the basic conflict between the interests of stakeholders interested in recreational and sport boating versus the needs for biodiversity protection and the enhancement of ecological functioning seems to be, in essence, a conflict between navigation traffic and biodiversity. Recent studies have shown that fish fauna is often highly impacted by recreational navigation traffic as most of this traffic usually occurs in spring and summer months which are, at the same time, the sensitive months of the breeding season for most fish species. Recent meta studies, considering data sets from 16 European rivers, showed strong correlations between the number of motorized recreational boads and the population densities of especially eurytophilic and rheophilic, but also lithophilic fish species. Gravel-spawning fish species were particularly negatively affected [26, 27]. Causes for those impacts are pressures resulting from sediment resuspension and displacement in river beds and impacts on shore areas.

The assessment results suggest that implementing scenario 2 would result in a considerable increase of ecosystem services provision capacities, and an associated increase in monetary ecosystem services values. Vice versa, those potential values derived from imple-menting Scenario 2 could also be interpreted as opportunity costs for maintaining the status quo. As noted above, the potential costs for implementing scenario 2, as well as the potentially added value revealed when considering all ecosystem services, also still need to be consid-ered. This also applies to assessments still required on the climate-damaging release potential of methane gas from the reservoirs of dammed river stretches.

8 Conclusion and implications

According to the current River Basin Management Plans of Hesse and Rhinland-Palatina the good ecological potential is specified as management objective for all water bodies of the Lahn. The reason is that the Lahn was originally designated as a waterway for nagivation. However, this designation could eventually be changed as part of the usual review process according to

Article 4 of the Water Framework Directive. The potential impacts of proposing and implementing a scenario for good ecological status are exemplarily explored in this study.

Looking across the results for all three dams considered in the full report, scenario 2 (good ecological status with mandatory dam removal) emerges as the more advantageous option with regard to achieving the objectives of the Water Framework Directive and the range of ecosystem services considered. Scenario 2 comprehensively and ecologically effectively reflects the development goal of "restoring rivers and floodplains" [29] proposed in the federal "Blue Belt" programme for tributary waterways. At the same time, scenario 2 also yields higher monetary ecosystem services values than scenario 0 or 1 (good ecological potential with retention of the dam). It is therefore of high likelihood that the costs of dam removal and restoration actions in scenario 2 would be compensated by the high societal benefits from increases in ecosystem services values, in particular given that current and future challenges such as climate change and biodiversity loss likely further increase the value of ecosystem services provision. In addition, potential losses of of the abiotic ecosystem service ‘navigability for motorized recreartional boats’ concerns only a comparatively small group of stakeholders, but the associated costs for preserving the status quo for the society at large is very high.

As shown elsewhere, state investments in ecosystem restoration could achieve considerable long-term benefits with good cost-benefit ratios through targeted investments.

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