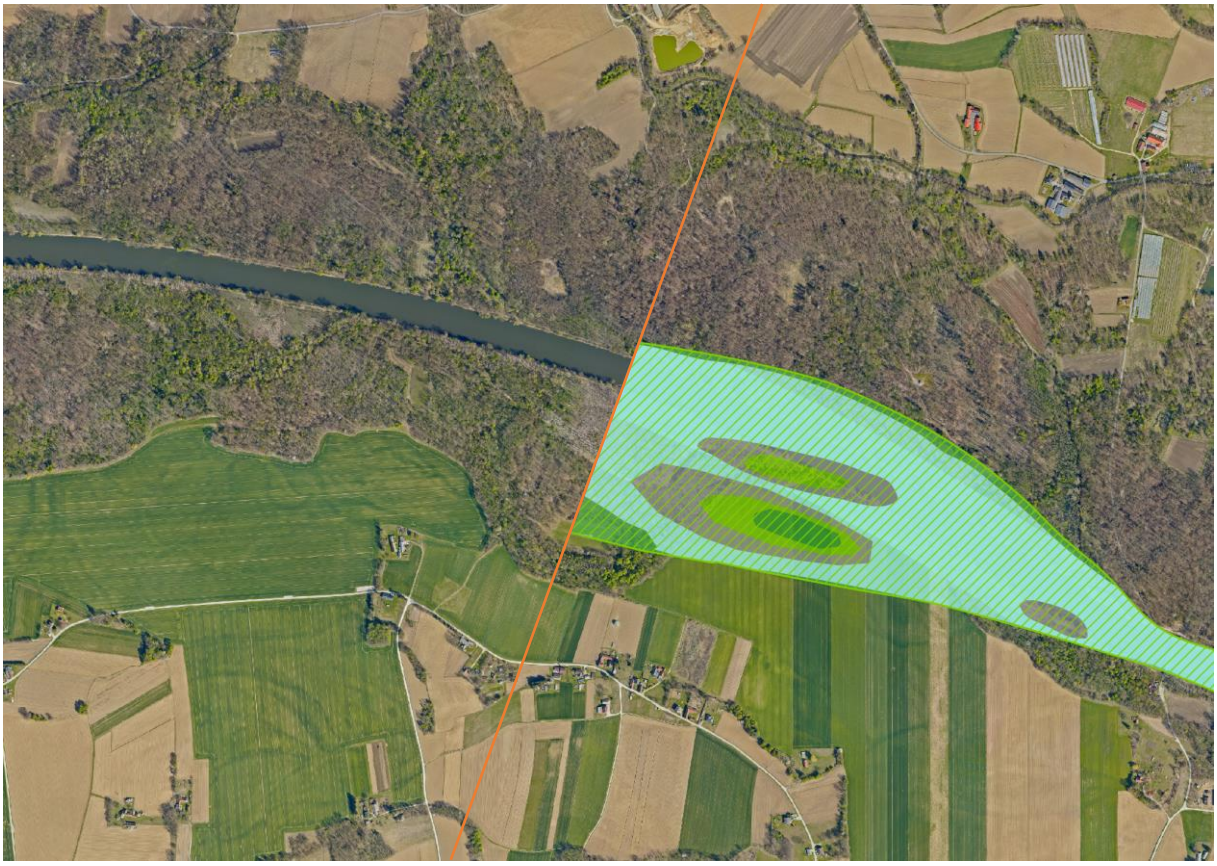

ČEZMEJNI NAČRT ZA INOVATIVNO TRAJNOSTNO UPRAVLJANJE MEJNE MURE IN IZBOLJŠANJE OBVLADOVANJA POPLAVNE OGROŽENOSTI

GRENZÜBERSCHREITENDER MANAGEMENTPLAN ZUR INNOVATIVEN NACHHALTIGEN BEWIRTSCHAFTUNG DER GRENZ-MUR UND ZUR VERBESSERUNG DES HOCHWASSERRISIKOMANAGEMENTS

Deliverable D.T1.3.1

Measure effectiveness assessment

Project goMURra (SIAT250) is co-funded by the European regional development fund within the cross border cooperation programme Interreg Slovenia-Austria VA

Abstract

In the preparation of the Management plan Border Mura 2030 within the project goMURra a measure concept was prepared that aims at reaching the defined strategic goals . In order to be able to assess how proposed measures contribute to reaching the defined goals a measure effectiveness assessment method was developed. In addition to the defined goals, the method considers also two other relevant factors (financial, spatial and temporal feasibility). The method was applied to assess two possible states: the current state of the riverbed with artificial bedload introduction and the target state that would develop after execution of proposed initial measures. In the report the results of the assessment for both analysed states are presented.

Kurzfassung

Im Rahmen der Vorbereitung des Managementplans Grenzmur 2030 im Projekt goMURra wurde ein Maßnahmenkonzept erstellt, mit dem die strategischen Planziele erreicht werden sollen. Um die Wirksamkeit der vorgeschlagenen Maßnahmen in Bezug auf die Erreichung der definierten Ziele zu bewerten, wurde eine Methode zur Bewertung der Maßnahmenwirksamkeit entwickelt. Diese Methode umfasst neben der Zielerreichung noch drei Kernaspekte (die finanzielle, räumliche und zeitliche Durchführbarkeit). Mit der Anwendung der erarbeiteten Methode wurde die Wirksamkeit für zwei geplante Zustände bewertet: die Erhaltung des bestehenden Zustands des Gerinnes mit einem künstlichen Geschiebeeintrag und der Zielzustand, der sich nach der Durchführung der vorgeschlagenen Initialmaßnahmen entwickeln sollte. Der Bericht legt die Ergebnisse der durchgeführten Bewertung der Maßnahmenwirksamkeit für beide Zustände vor.

Izvleček

V okviru priprave Načrta upravljanja Mejna Mura 2030 v projektu goMURra je bil pripravljen koncept ukrepanja s katerim bi se doseglo strateške načrtovalske cilje. Z namenom, da bi lahko ocenili učinkovitost predlaganih ukrepov glede doseganja opredeljenih ciljev je bila razvita metoda za oceno učinkovitosti ukrepov. Metoda obravnava poleg doseganja ciljev še dva ključna vidika (finančna, prostorska in časovna izvedljivost). Z uporabo izdelane metode je bila izvedena ocena učinkovitosti z dve predvideni stanji: ohranjanje obstoječe stanje rečne struge ob umetnem vnosu plavin in ciljno stanje, ki bi se razvilo po izvedbi predlaganih inicialnih ukrepov. Poročilo podaja rezultate izvedene ocene učinkovitosti za obe obravnavani stanji.

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1. INTRODUCTION

This report presents methodology and results of the effectiveness assessment of measures proposed for the border Mura within the activity T1.3 of the project goMURra.

The report includes an overview of the measure effectiveness assessment method developed within the project and its application in assessing effectiveness of two possible scenarios of future development of border Mura. The scenarios are the current state of the riverbed with direct artificial bedload input and the state that would develop after implementation of proposed measures as they are described by Senfter et al. (2021).

2. MEASURE EFFECTIVENESS ASSESSMENT METHODOLOGY

Currently, Border Mura is a free flowing river with biological longitudinal connectivity (except in the extreme upper part of the reach at Ceršak dam as the last in the series of multiple hydropower structures on Mura) and with preserved wide areas of alluvial forests.

Border Mura river bed has however been deepening for decades. This trend was temporarily stopped with execution of restoration projects (river widening with direct gravel introduction) in the 2000s. But since restauration activities stopped the river bed has continued to deepen, which is confirmed by the latest measurements of cross sections made in year 2018. The main pressures that cause river deepening are:

- Regulated river channel with concentrated flow at high velocities and high shear stresses (contributing to high bedload transport capacity). The majority of border Mura is regulated with an exception of the right bank in the upper reach (where Mura flows under the hills of Slovenske gorice and its banks are naturally stable) and on locations of restauration projects executed in the past (Oberschwarza, Weitersfeld, Gosdorf I, Gossdorf II, Donnersdorf, Segovci and Sicheldorf).
- Bedload discontinuity due to upstream transverse structures (contributing to diminished bedload input). Existing more than 30 dams on river Mura and its tributaries diminish coarse sediment input to the border Mura reach.

Riverbed deepening is considered as one of the main problems of border Mura, since the continuation of the trend prevents reaching other crucial goals of the Management plan border Mura 2030. Therefore, within the project goMURra, a proposal of measures to improve the current state has been prepared. This report presents the results of the activity to assess effectiveness of proposed measures in reaching the four defined core goals.

2.1. Methodological principles

In the development of the methodology, following starting points were used:

- The methodology should be able to assess how proposed measures contribute to all four core goals defined for Border Mura (Unterlercher et al. 2021).
- In addition to this, the method should cover also topics of financial, spatial and temporal feasibility.

Based on this it was decided to develop a method using following principles:

- The method should consist of indicators related to defined core goals;
- Indicators should cover all defined core goals;
- Indicators should be numerical if possible;

- Numerical indicators are to be assessed using tools developed within the project and other practical available tools;
- Non- numerical indicators are assessed based on expert judgement;
- For easier understanding of the results the assessment is presented in a user-friendly way (using --, -, o, -, + and ++).

2.2. Analysed states

The developed method was applied to assess changes between two states that would both provide a solution to the ongoing problem of riverbed deepening. These states are:

- Current state with sufficient sediment supply:
  This includes the current state of the riverbed with direct (artificial) sediment supply in sufficient quantities that would secure a stable riverbed (no deepening).
- Target state that will develop after execution of proposed measures:
  This state proposes that the current riverbed is altered by reaching three types of target state (Types A, B and C) along border Mura, which aim at widening the river corridor, increasing curvature and decreasing slope. The execution of initial construction measures will provide the further development of the target state through natural erosion / deposition processes. The proposed concept of measures is described in detail by Senfter et al. (2021).

Figure 1: Depiction of the current state of the riverbed near Apače.

Figure 2: Representation of the target state near Apače.

2.3. List of indicators

Based on the described principles a measure effectiveness assessment methodology was developed. The method includes 13 indicators. 9 of these cover 4 core goals for border Mura (as defined in Unterlercher et al. 2021), while the remaining 4 cover additional aspects (financial, spatial and temporal feasibility). In the following table (Table 1) all 13 indicators are presented.

Table 1: Mesure effectiveness assessment indicators.

Core goal	Indicator	
Core goal 1: River bed in dynamic balance	i.1.1	need for direct bedload input
	i.1.2	river radii and braiding
	i.1.3	"soft" river banks with potential for side erosion
	i.1.4	change of river bed altitude
Core goal 2: Improved ground water situation	i.2.1	wetted area in the river corridor
Core goal 3: Reduced flood risk	i.3.1	flood risk change
Core goal 4: Good ecological status and improved riparian habitats	i.4.1	presence of gravel bars
	i.4.2	distribution of flow variables
	i.4.3	length of Border Mura in slightly modified or natural HYMO state
Addittional aspects	i.5.1	rough costs estimation
	i.5.2	land demand
	i.5.3	time of execution
	i.5.4	time-wise effectiveness

2.4. Indicator assessment method

2.4.1. Indicator i.1.1: need for direct bedload input

As a crucial element for riverbed stabilisation (stopping river bed deepening and reaching a dynamic riverbed equilibrium) the need for direct bedload input has been assessed. The assessment was carried out based on numerical simulations of sediment transport and river morphology (deliverable T1.3.2). The modelling analysis was carried out on the pilot reach of the border Mura where the current state of the riverbed and three types of measures were analysed (types A, B and C as described in Senfter et al 2021) and results obtained. Based on

these computations, the results were extrapolated to the whole border Mura. The executed modelling analysis is described in detail by Klösch et al. (2021).

2.4.2. Indicator i.1.2: river radii and braiding

As an indicator of the presence of morphodynamics, an analysis of radii (river curvature) and braiding was carried out. The size of river radii determines the presence of outer bank situation and presence of bank erosion. Bank erosion creates steep banks, which can be habitat for bird species breeding in banks, and introduces woody debris, which in turn can provide local morphodynamics and form shelters for fish. At the same time, a self-dynamic widening and a shifting of the bank lines due to bank erosion continuously causes changed boundary conditions for the flow in the channel, and thus also for the morphology of the riverbed. On the other hand, the tendency towards braiding indicates a dynamic of gravel banks and islands, which in turn are suitable for gravel-breeding bird species, pioneer vegetation and succession to a riparian forest.

Based on this reasoning the radii and braiding index were assessed using the geometries of the current state of the river bed and the proposed measure types that form the target state proposal. The process is further described by Klösch et al. (2021).

2.4.3. Indicator i.1.3: "soft" river banks with potential for side erosion

Within this indicator the extent of river banks on which there is the possibility of side erosion has been assessed. The following principles were used:

- on artificial riverbanks (riverbanks along border Mura are stabilised in majority with rip-rap structures made of natural or artificial material, on some locations also more rigid structures are used: concrete or masonry walls) there is no possibility for side erosion.
- on some natural river banks side erosion is also not possible (e.g. rocky banks at hill foots)

Based on this concepts the assessment for the current and target state was made. For the current state the assessment was made using GIS tools on the available data on water infrastructure and the available results of activity T1.1: digital terrain model, orthophoto and spherical imagery (Supej et al. 2020). For the target state the assessment was carried out using GIS tools on the prepared maps of the target state (Senfter et al. 2021). It was supposed that proposed widening of the river corridor that includes relocation of existing bank protection to the hinterland provide a near-natural riverbank with potential for side erosion.

Based on this the following calculations were made:

- length of artificial banks (for left and right side)
- length of (near)natural banks (for left and right side)
- length of riverbanks with potential for side erosion (for left and right side)

2.4.4. Indicator i.1.4: change of river bed altitude

Change in riverbed altitude was assessed based on numerical simulations of sediment transport and river morphology. The executed modelling analysis is described in detail in Klösch et al. 2021.

2.4.5. Indicator i.2.1: wetted area in the river corridor

As an indicator of infiltration of water into the aquifers along border Mura, an assessment of wetted area of the Mura river was executed by using GIS tools. For the current state the wetted area was assessed based on the data produced within activity T1.1 (Supej et al. 2020). For the target state the representation of the target state was used (as depicted in Senfter et al. 2021).

2.4.6. Indicator i.3.1: flood risk change

This indicators shows effects of possible executed measures on flood regime of border Mura. Sadly it was not possible to execute a full analysis of changes in flood hazard between the current and target state within the goMURra project. It was possible however to assess changes by applying simplified 1D numerical modelling of the current and future states. Calculations were made for two scenarios based on two presumptions of the development of the target state: a realistic and an extremely pessimistic scenario. For the current state and both scenarios of the future states, the calculations were made using a 100-year discharge. The analysis is further described by Klösch et al. (2021).

2.4.7. Indicator i.4.1: presence of gravel bars

The extent of gravel bars in the current state was made by applying GIS tools on the date from activity T1.1: digital terrain model and orthophoto imagery (Supej et al. 2020). For the target state the extent of gravel bars was assessed based on the representation of the target state (Senfter et al. 2021).

2.4.8. Indicator i.4.2: distribution of flow variables

As an indicator of the status of aquatic habitats in the riverbed an analysis of water flow variables was executed. The distribution of flow variables can provide an insight in the presence and diversity of aquatic habitats in the river bed.

Within the sediment transport analysis (D.T1.3.2) a 3 dimensional numerical model of hydrodynamics was developed on the pilot reach for the current state and three proposed target states (type A, B and C). Based on hydrodynamic modelling results the following analysis were carried out: distribution of water flow velocities at water surface; distribution of water depths; distribution of bottom shear stresses. Based on this computations the diversity of aquatic habitats was assessed for the whole border Mura by extrapolation of modelling results and expert judgement. The executed analyses are further described by Klösch et al. (2021).

2.4.9. Indicator i.4.3: length of Border Mura in slightly modified or natural HYMO state

The assessment was executed by using the methodology for assessing hydromorphological features as developed within goMURra activity T1.2 (for more info see Ulaga et al. 2021). The methodology was applied on the current state of the river bed and also on the representations of the future state of the river bed. According to the methodology, the state of is assessed per 500m long river reaches of Border Mura and also for the whole border Mura stretch (water body). The following results are used in the indicator:

- Assessment of HM alteration of the whole Border Mura stretch;
- No. of reaches in natural state;
- No. of reaches in slightly modified state;
- No. of reaches in moderately modified state and
- No. of reaches in heavily modified state.

2.4.10. Indicator i.5.1: rough costs estimation

To compare different states the assessment of costs was made. This includes:

- maintenance costs: maintenance of existing water infrastructure and maintenance of proposed measures was assessed by Senfter et al. (2021);
- costs of artificial direct gravel introduction was assessed based on the following presumptions:
  - for the current state, the assessed quantities of needed bedload are artificially introduced into the river on a yearly basis. The price of the introduced sediment was roughly assessed with considering the following factors: the material need to comply with all qualitative demands, the source of the material is currently unknown (possible long transport routes).
  - for the target state it is assessed that within the measure areas large quantities of suitable material is available. Artificial activation of some of this material is already included in the investment costs for executing proposed measures. After execution of initial measures, it is presumed that the needed material would be introduced into the river by side erosion (no human intervention needed). Side erosion will be introduced by sound detailed planning of measures and possible minor alterations executed within maintenance works.
- investment costs: the target state is reached by executing initial measures as described by Senfter et al. (2021) where investments costs have also been assessed.

Within the constraints of the goMURra project it was not possible to carry out a full cost benefit analysis that would include also possible other costs and especially economic and societal benefits as well as effects on the environment and biodiversity.

2.4.11. Indicator i.5.2: land demand

As an important aspect of executability the question of spatial requirements for execution of measures was included in the assessment. The following themes were included: needed land to execute measures, land use and land ownership. For assessing land use, CORINE data was used. Land ownership was analysed by using layers of publicly owned land in Slovenia and Austria that were obtained during execution of goMURra project.

2.4.12. Indicator i.5.3: time of execution

With this and the next indicator the temporal component is included in the assessment. Although both indicators cannot provide quantitative results, the intention was to bring forward time-related issues that might be relevant in forming decisions for future management of border Mura.

Within this indicator it was assessed how the two assessed states can be executed and/or maintained during time. This qualitative assessment was made by expert judgement.

2.4.13. Indicator i.5.4: time-wise effectiveness

Within this indicator an assessment was made on how efficient are the two states (current and target state) in providing solutions to existing problems in the temporal dimension. This qualitative assessment was made by expert judgement.

3. MEASURE EFFECTIVENESS RESULTS

In the following two chapters the results of measure effectiveness assessment is presented for both analysed assessment states:

- current state with sufficient sediment supply and
- target state that develops after execution of proposed initial measures.

3.1. Current state (with sufficient sediment supply)

- i.1.1 need for direct bedload input
  Based on executed sediment modelling analysis on the reference reach and extrapolation of data to the whole border Mura reach the quantity of needed direct sediment input to stabilise the riverbed equals: 45.000 m^3/year.

- i.1.2 river radii and braiding
  The analysis of the current riverbed geometry on the pilot reach gives the following results (Klösch et al. 2021):
  - radii: over 2000 m
  - braiding index: 1.0 (no branching)

- i.1.3 "soft" river banks with potential for side erosion
  In current state the majority of border Mura riverbanks are stabilised by some sort of structures (mainly rip-rap made of rock or concrete elements, on some locations more rigid structures, such as concrete walls etc.). The remaining bank that is in natural or near natural state does not always have erosion potential (rocky banks at hill foots at the right bank). An assessment was made based on available data on water infrastructure and GIS analysis on D.T1.1.1 products (digital terrain model, orthophoto and spherical imagery along Mura). The assessment shows:
  left bank:
  - artificial: 88%
  - (near)natural: 12%
  - erosion potential: 12%

  right bank:
  - artificial: 89%
  - (near)natural: 11%
  - erosion potential: 2%

- i.1.4 change of river bed altitude
  With sufficient direct introduction of gravel into the river, the riverbed would be stabilised (no altitude change). Without the continuous gravel introduction the ongoing of the current deepening trend is expected.

- i.2.1 wetted area in the river corridor
  In the current state the wetted area is limited to the main river channel with an

almost uniform channel width of ca 75 meters. The wetted area equals 2,64 km^2

- i.3.1 flood risk change
  In the assessment of this indicator the current state was taken as a reference.

- i.4.1 presence of gravel bars
  In the current state of the riverbed 17 gravel bars with total area of 53.000 m^2 have been identified.

- i.4.2 distribution of flow variables
  The analysis of the current state of the riverbed at a one year discharge gives the following results (Klösch et al 2021):
  - surface flow velocities: narrow distribution with most frequent velocities between 2,75 m/s and 3 m/s;
  - water depths: narrow distribution with the most frequent depths between 3,75 and 4 m;
  - bed sheer stresses: a narrow distribution with the most frequent range between 35 N/m^2 to 40 N/m^2.

- i.4.3 length of Border Mura in slightly modified or natural HYMO state
  The results of the assessment of hydromorphological alterations in the current state gives the following results (Ulaga et al. 2021).
  - the whole border Mura is in moderately modified HYMO state;
  - 0 reaches (0 km) of border Mura are in natural state;
  - 16 reaches (8 km) of border Mura are in slightly modified state;
  - 50 reaches (25 km) of border Mura are in moderately modified state and
  - 3 reaches (1,5 km) of border Mura are in heavily modified state.

- i.5.1 rough costs estimation
  The costs for the current state of the riverbed with direct gravel introduction include:
  - maintenance costs: 300.000 € per year
  - Costs of gravel introduction: 1,8 mio € per year

- i.5.2 land demand
  In maintaining the current state of the riverbed, no new land needs to be acquired.

- i.5.3 time of execution
  Looking at the time dimension of the current state that includes maintaining the current dimensions of the riverbed and providing sufficient artificial bedload supply, it is evident that this state can be implemented without any time delay. On the other hand maintaining this state is heavily dependant on the availability of material for artificial bedload supply. If such a state is to be maintained for a long period of time, this problem (as there are no evident ample sources of sediment available locally) is expected to increase.

- i.5.4 time-wise effectiveness
  Regarding the time effects of maintaining the current state it is evident that artificial introduction of sediment supply has only short-term effects. Therefore continuous introduction of bedload material is needed. This possible solution is heavily dependent on the stability of sediment provision, since as soon as artificial sediment supply is stopped, the continuation of negative trends (and deepening of existing problems) is expected.

3.2. Target state

- i.1.1 need for direct bedload input:
  Based on executed sediment modelling analysis on the reference reach and extrapolation of modelling results to the whole border Mura reach the quantity of needed direct sediment input to stabilise the riverbed at the target state equals: 32.500 m^3/year.

- i.1.2 river radii and braiding
  The analysis of the three measure types on the pilot reach gives the following results (Klösch et al. 2021):
  - radii: type A = up to 1300 m, type B = up to 400 m and type C = up to 200 m.
  - braiding index: type A = 1,8 , type B = 1,8 and type C = 1,9.

- i.1.3 "soft" river banks with potential for side erosion:
  The target state that would be reached by implementation of proposed measures along border Mura shows a substantial difference in the diversity of morphological features, including the percentage of near-natural river banks. The assessment shows:

  left bank:
  - artificial: 34%
  - (near)natural: 66%
  - erosion potential: 66%

  right bank:
  - artificial: 47%
  - (near)natural: 53%
  - erosion potential: 43%

- i.1.4 change of river bed altitude:
  The target state provides a substantial decrease in river bedload capacity. Therefore with supplying sufficient bedload, the deepening of the river bed is stopped.

- i.2.1 wetted area in the river corridor
  The target state proposes changes in the riverbed that would widen the river corridor, increase curvature and thus emulate the historic state of an anabranching river system. The wetted area is thus significantly enlarged and equals 5,4 km^2.

- i.3.1 flood risk change:
  The results of the simplified flood level analysis (Klösch et al. 2021) show that in the more likely scenario the water surface elevation of the hundred-year flood event is significantly reduced (by 1,34 m in type A, by 1,77 m in type B, and by 2,54 m in type C). Also in the extreme scenario a slight reduction in flood levels is predicted (0,10 m in type A, 0,19 m in type B, and 0,07 m in type C).

- i.4.1 presence of gravel bars
  In the prognosis of the target state 45 gravel bars with total area of 890.000 m^2 are present.

- i.4.2 distribution of flow variables
  The analysis of the three measure types at a one year discharge gives the following results (Klösch et al 2021):
  - surface flow velocities: a wider distribution of velocities including also low velocity areas (the most frequent velocities at type C are between 1,75 m/s and 2 m/s);
  - water depths: a wider distribution of water depths, with increase of shallow water areas;
  - bed sheer stresses: a wider distribution with dominant areas with lower bed shear stresses (in range between 15 N/m^2 and 20 N/m^2).

- i.4.3 length of Border Mura in slightly modified or natural HYMO state:
  Using the developed methodology for assessing hydromorphological alteration (Ulaga et al. 2021) an additional assessment was carried out on the representations of the target state. This assessment gives the following results:
  - the whole border Mura is in slightly modified HYMO state;
  - 7 reaches (3,5 km) of border Mura are in natural state;
  - 40 reaches (20 km) of border Mura are in slightly modified state;
  - 22 reaches (11 km) of border Mura are in moderately modified state and
  - 0 reaches (0 km) of border Mura are in heavily modified state.

- i.5.1 rough costs estimation:
  - maintenance costs: 300.000 € per year
  - measure implementation costs: 188,13 mio €
  - direct gravel input costs: 0 €

- i.5.2 land demand
  The measure corridor within which the target state is to be reached and maintained extends over the area covered by the current riverbed. To execute the proposed measures and reach the target state 532 ha of land need to be secured (292 ha in Austria and 240 ha in Slovenia).
  Regarding land use this areas are currently: forest (72%), water and banks (22%), fields (5 %) and grasslands (1%).

Although the majority of required land is in private ownership (55%) also a large percentage of the land is in public ownership (44%) with a minor par (1%) in mixed ownership (private and public).

- i.5.3 time of execution
  It is evident that the execution of initial measures and formation of the target state demands time. When the establishment of the target state can be expected is a question that cannot be answered clearly. Implementation and further development of the target state is dependant of several conditions that are very difficult to predict (elapsed time before the start of implementation, which is dependant on several levels of decision making and availability of resources; needed time for land acquisition; time for detailed planning of measures; time for execution of initial measures; time for establishing the target state through natural erosion processes, which is dependant also on hydrological conditions etc.).

- i.5.4 time-wise effectiveness
  Regarding the time-wise effectiveness of once established target state, it is assessed that the provided measures will provide at least a mid-term solution and during that time no major additional measures on border Mura would be needed. It should be noted, that without establishing sediment continuity on upper reaches of river Mura, all local measures on border Mura have time-limited effects. It should be noted too, that based on the assessment of available material in river surroundings (within the measure areas) and the yearly need for bedload input for the target state, there is sufficient amounts of material available locally for several decades.

3.3. Comparison between analysed states

- i.1.1 need for direct bedload input:
  The execution of proposed measures and reaching the target state of the riverbed presents an important decrease in the needed bedload input to reach a stable riverbed (from 45.000 m^3/year to 32.500 m^3/year). In addition to the reduction of the required sediment input, the execution of the measures also provides the needed material locally (gravel deposits on measure locations) and by sound measures, planning the gravel can be introduced into the river without direct human intervention by imposing side erosion. Although the measures proposed to reach the target state provide a significant improvement, they do not provide a definite long lasting solution as long as sediment continuity in the upper sections of the Mura is impaired.
  For this indicator the current state is assessed as very poor (--).For the target state the situation is assessed as good (+).

- i.1.2 river radii and braiding
  In the target state of the riverbed, an important decrease of river radii is observed (especially on locations where measures of type C are envisaged). With decreased radii

bank erosion processes are expected on several locations, which in turn provides the formation of steep banks (crucial habitats for certain bird species) and introduction of woody debris into the river which can form fish shelters. In addition, the increase of the braiding coefficient (especially in areas with measures of type C) indicates presence of river dynamics within the defined river corridor with formation of dynamic gravel banks and islands. This in turn provides suitable conditions for gravel-breeding bird species, formation of pioneer vegetation and succession to riparian forests. Increased morphodynamics causes lateral exchange of sediment, so that more sediment participates in the morphodynamics.
For this indicator the current state is assessed as poor (-). The target state provides a significant improvement and the situation is assessed as very good (++).

- i.1.3 "soft" river banks with potential for side erosion
  The comparison shows an important increase in soft river banks in the target state. While the assessment of the current state shows that, almost all river banks (93 % of total length) are fixed due to man-made bank protection structures (and partly due to natural terrain specifics). The target state presents a clear improvement, where more than half (64 %) of bank length is represented with soft river banks with potential for side erosion.
  For this indicator the current state is assessed as very poor (--). The target state provides significant improvement, the situation is assessed as good (+).

- i.1.4 change of river bed altitude
  Both assessed states propose that the river bed deepening trend is stopped. It should be noted, however that without introduction of bedload into the system at the current state, the riverbed deepening will continue.
  For this indicator both states show equal results (both assessed as good).

- i.2.1 wetted area in the river corridor
  The wetted area in the target state is significantly enlarged compared to the current state of the riverbed (5,42 km^2 compared to 2,64 km^2 – a more than 2 fold increase). This indicates a rise of exfiltration of surface water from river Mura to the surrounding aquifers. Although it was not possible to quantify beneficial effects on ground water levels in the surrounding aquifers directly, it is assessed that the target state will provide significant improvement.
  For this indicator the current state is assessed as poor (-). While for the target state the situation is assessed as very good (++).

- i.3.1 flood risk change
  Based on the executed analysis (which should be upgraded in the future) an improvement of flood risk situation is to be expected. The results of the executed simplified modelling analysis show that the target state provides a slight to significant decrease in water levels at a 100-year event. Additional benefits can also be expected due to increased water retention along border Mura although this was not analysed.

For this indicator the current state is assessed as neutral (0). For the target state the situation is assessed as good (+).

- i.4.1 presence of gravel bars
  The comparison of results shows that the expected number of gravel bars more than doubles the number of existing gravel bars. Regarding the total area of gravel bars, the difference is even higher, since in the assessment for the target state shows a 16-fold increase. Presence of gravel bars is identified over several sections of the border Mura which also indicates beneficial distribution of diverse aquatic habitats.
  For this indicator the current state is assessed as poor (-). Since the target state provides significant improvement, the situation is assessed as very good (++).

- i.4.2 distribution of flow variables
  The current state shows a very narrow distribution of depths and velocities. Mainly areas with high depth and high flow are observed. The assessment for the target state shows more heterogeneous distribution, which indicate higher availability of wide variety of habitats. Thus, also areas of shallow water and low velocities can be observed. Such waters provide more refuge areas and protection for juvenile fish populations. The high variance and, at the same time, smaller values of the bed shear stresses suggest dynamics that regularly mobilise and also redeposit gravel and, due to the fresh, loose bedding, are suitable for gravel-spawning fish species to strike spawning pits.
  For this indicator the current state is assessed as poor (-). For the target state the situation is assessed as very good (++).

- i.4.3 length of Border Mura in slightly modified or natural HYMO state
  Comparison of executed assessments of HM alterations shows that the target state provides a significant improvement. Regarding the assessment for the whole border Mura, the state is improved from moderately modified to slightly modified HYMO state. Looking at the finer assessment per river sections, in the current state the majority of the river is in moderately modified (74%) and slightly modified (24%) state with some sections in heavily modified (4%) and none in natural state. At the target state the situation changes so that the majority of the river is in slightly modified (59%) and moderately modified (32%) state with several sections in natural (10%) and none in heavily modified state.
  For this indicator the current state is assessed as poor (-). For the target state the situation is assessed as good (+).

- i.5.1 rough costs estimation
  The comparison of costs between the current and target states was made using a time period of 50 years. The following costs were assessed:
  - current state: ~ 105 mio €
  - target state: ~ 203 mio €

Comparison of the assessed direct financial costs shows that the target state is about 2-times more costly. However it should be considered that an appropriate cost-benefit assessment that would consider also societal gains (reduction of flood risk, improved safety of drinking water supply, possibilities for developing sustainable tourism etc.) and ecological benefits (improved ecological status of the river, improved status of protected Natura 2000 habitats and species etc.) could give significantly different results.
For this indicator the current state is assessed as neutral (o). For the target state the situation is assessed as poor (-).

- i.5.2 land demand
  Maintaining the current state does not require any land acquisition, since no measures on terrain envisaged. To reach the target state within the proposed measure corridor land needs to be obtained. The predominant land use in the corridor is forest. A substantial part of required land is already in public ownership (44 %), which can form a good basis for further land acquisition.
  For this indicator the current state is assessed as neutral (0), while the target state is assessed as poor (-).

- i.5.3 time of execution
  When considering the question on when the assessed states can be introduced, the current state (with direct artificial bedload supply) can be implemented very soon, while reaching the target state can take a long period of time.
  For this indicator the current state is assessed as good (+). For the target state the situation is assessed as poor (-).

- i.5.4 time-wise effectiveness
  When we consider the time component in maintaining both states it is evident that maintaining the current state (with direct artificial bedload supply) for long periods of time can be problematic, while in maintaining the target state no evident time-wise issues arise.
  When considering the effects of both states in the view of time-wise effectiveness it is evident that at the current state there is a constant need for human intervention in order to maintain its effects for river bed stabilisation. On the other hand when the target state is established, it should provide effective dynamic riverbed stabilisation without the need for direct human intervention (apart from maintenance) for a long period of time.
  It should be noted however, that even the target state cannot provide a long-term solution as long as sediment continuity on the level of the whole Mura basin is not secured.
  For this indicator the current state is assessed as neutral (-). For the target state the situation is assessed as good (+).

The described results are presented in the table below (Table 2).

The comparison of both states shows that for 9 of the 13 indicators the target state was assessed better than the current state. In 3 indicators the current state was assessed higher than the target state, while for one indicator both states were assessed equally. When looking at results per defined core goals it can be observed that for all 4 goals the target state received higher scores. The indicators dealing with additional aspects (financial, spatial and temporal feasibility) show that the current state received higher score.

Measure	Indicator		Assessment result		Comments
			Current state	Target state	
Core goal 1: River bed in dynamic balance	i.1.1	need for direct bedload input	--	+	Needed bedload input in target state is significantly lower (28%) than in the current state.
	i.1.2	river radii and braiding	-	++	Target state provides a significant decrease in radii and increase of braiding.
	i.1.3	"soft" river banks with potential for side erosion	--	+	In the target state more than half (64%) of the river banks have erosion potential, which is significantly higher than in the current state (7%).
	i.1.4	change of river bed altitude	+	+	Both current state with direct gravel introduction and the target can stop riverbed deepening.
Core goal 2: Improved ground water situation	i.2.1	wetted area in the river corridor	-	++	The target state presents a more than 2-fold increase in the wetted area from the current state.
Core goal 3: Reduced flood risk	i.3.1	flood risk change	o	+	The target state provides a slight to significant decrease in water levels at a 100-year event compared to the current state.
Core goal 4: Good ecological status and improved riparian habitats	i.4.1	presence of gravel bars	-	++	The number of gravel bars is doubled, while the area of gravel bars shows a 16-fold increase in the target state.
	i.4.2	distribution of flow variables	-	++	In the target state a significantly more heterogeneous distribution of flow variables indicates higher availability of wide variety of aquatic habitats.
	i.4.3	length of Border Mura in slightly modified or natural HYMO state	-	+	The length of border Mura in slightly modified of natural HYMO state in the target state is significantly improved compared to the current state (69% compared to 24%).
Addittional aspects	i.5.1	rough costs estimation	o	-	Costs of implementing the target state are 2 times higher than maintaining the current state. A complete cost-benefit analysis could give different results.
	i.5.2	land demand	o	-	Reaching the target state requires a lot of land that is currently predominantly forested. An important part of the required land (44%) is public ownership.
	i.5.3	time of execution	+	-	Reaching the target state can take longer periods than implementing artificial sediment input at the current state.
	i.5.4	time-wise effectiveness	-	+	While introduction of sediment at the current state has short-term effects and constant action is needed. Execution of measures to reach target state can have long lasting effects.

Table 2: Results of the measure effectiveness assessment.

4. SYNTHESIS

In the preparation of the Management plan Border Mura 2030 within the project goMURra a measure concept was prepared that aims at reaching defined strategic goals . In order to be able to assess how proposed measures contribute to reaching the defined goals a measure effectiveness assessment method was developed.

The assessment of the 12 developed indicators was executed on two possible states: the current state of the riverbed with artificial bedload introduction and the target state that would develop after execution of proposed initial measures.

The assessment results show that for 9 of the 13 indicators the target state received better results than the current state. In 3 indicators the current state was assessed higher than the target state, while for one indicator both states were assessed equally. When looking at results per defined core goals it can be observed that for all 4 goals the target state received higher scores. The indicators dealing with additional aspects (financial, spatial and temporal feasibility) show that the current state received higher score.

Based on the executed assessment it can be concluded that although the riverbed can be stabilised also in the current dimensions of the riverbed (by ample artificial sediment supply), the proposed measures that would result in formation of the target state provide a definite contribution to all four defined goals of the Management plan border Mura 2030.

It should however be noted that even the execution of all proposed initiation measures and subsequent development of the analysed target state does not provide a long lasting solution. For securing a long-term solution to the existing problems, also measures on the upper section of the river basin (measures to restore bedload continuity) are required.

5. LITERATURE

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