Danube Transnational Programme
Danube Floodplain

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Report on WP6 A 6.1

Complex evaluation of ecological and flood conditions, land use change possibilities on the pilot area on Middle Tisza section (Tiszaföldvár-Cibakháza) and cost benefit analysis of the restoration

Deliverable D 6.1.2 (Part I)

Floodplain Evaluation Matrix Tool tested and applied in pilot site to assess the restoration projects

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Content

Summary

Land use changes on a new pilot area in Hungary were tested in order to achieve an improvement in flood risk conditions and in state of drought prone area, thus in mitigation of more frequent extreme weather events.

The new pilot area was carefully selected based on detailed analysis of geographic position, infrastructure and current land use.

The delineated area affected no infrastructure, no buildings, the main land use type is agricultural. The area was of proper size to presume that it will effect also higher flood waves.

This was justified by the 2D hydrodinamic modelling which has also shown that the frequent floods (HQ2-5) are already provide inundation in a large area. The modeling scenarios were set up in light of this.

In lack of time the necessary infrastructure interventions for providing criteria of various land use change scenarios were included into the hydrodinamic modelling in a simple way which was based on inundation of the area through theoretical disrupted sections of the dyke, a theoretical sluiceway and to use the area as a flood reservoir to reduce the flood peak. Regulated water supply could be the solution to create the right hydrological conditions.

Also, land use change is planned with involvment of stakeholders – aim of the concept was that land owners would profit from prescence of the water.

Arable farming that is limited to a few crops and is characteristic for almost the entire area is a restrictive but not exclusive factor of the targeted and regulated inundation to improve the water balance of the soil. However, it would be more preferable if the cultivation structure would become more diverse as it is at present.

Concerning the possibilities of water recharge, the well-preserved trench and canal system together with the morphology determining the character of the landscape are favourable factors. A succession of the large wavy surfaces and plain plateau-like even surfaces and deep, old bed valleys connected with canals are of benefit for regulated periodical or more permanent inundation corresponding to the morphology of the surface.

Any change in connection with regulated inundation can cause problems for the farmers; it has an impact on the usual cultivation regime, technologies and can also cause a loss in income in some areas. This problem can only be compensated through a reliable and targeted system of agricultural subsidies.

Partial reactivation of the floodplain by regulated inundation necessitates alteration of the current cultivation structure. Improvements in the water balance bring long term benefits, but alteration of the system is only reasonable when the sustainability of the altered farming and land usage structure can be taken for granted.

Potential vegetation predictions obtained for the study area are in good accordance with expectations. However, individual details will be useful in supporting the planning of habitat restoration and sustainable land use.

The planned water regulation interventions create a similar environment to plants, whether calculated with unchanged or modified land use. It also means that the more eco-friendly modified land use does

not significantly change the site potential here. Land use clearly limit the realisation of potential vegetation into actual vegetation.

Expected changes due to river regulation interventions largely mean the increase of potentiality for wetland vegetation types. Additionally, alkaline vegetation that is already present in undisturbed patches will also benefit from the interventions, thus changes will support the natural capital as well. The expected MPV provides ample opportunities for ecological climate change mitigation as well as for ecological restoration of further stands of habitats, which are already present in patches and thus can support new stands by propagule availability.

Based on CBA analysis, the current land use is not the most advantageous one from a long term perspective, neither for the public nor, the landowners. Compared to the current state only the new land use without any inundation would generate supplemental benefits. All other scenarios are more costly, and neither the flood related benefits or CO2 emission reductions would be sufficient to compensate the loss of farming income and the flood defense infrastructure investment costs. Whether the non-monetised benefits of land use change coupled with frequent inundation would justfify the monetised costs, requires further analysis.

Present farmers on the first staleholder meeting spoke about their problems which are in connection with area-based payments: EU CAP doesn't support those areas wich are inundated, they need to irrigate but irrigation channels don't work. They would not do any agricultural activity there if the area was an active floodplain again because they can't report a vis maior in that case.

Summarizing the outcome of the event, people would like the idea of any water supply but Common Agriculture Policy (CAP) must serve the new land use system.

On the second stakeholder meeting discussion aimed at verifying feasibility of the technical solutions from water directorate land ownership and nature conservation perspective. All authorities are working under current legal conditions and could not change the whole structure at once. A step by step solution is needed where the first step would be to make the alternative land use types to be supportable.

The BAU scenario with the current land use and without any hydrological change represents substantial benefits to farmers, although much of it originates from agricultural subsidies (which are transfers). All other scenarios would reduce the benefits enjoyed by farmers, thus a compensation would be necessary.

Under the RS_none scenario, also without any change in hydrology, the economic position of farmers declines, but only moderately, as they change crop production to less productive meadow management, which is only partly counterbalanced by the shift to more productive forest management. Declining carbon emissions, however, generate substantial (global) social benefits. From the perspective of society this is the most attractive scenario.

Under CS_all and RS_all the floodplain area is frequently inundated which generates land use specific inundation damages and just as importantly requires the development local defense lines (levees) which turned out to be very expensive. At the same time, the flood related benefits are moderate, they do not compenate the costs related to the local defense line. These are the economically least attractive scenarios.

Under the sluiceway scenarios (CS_sluiceway, RS_sluiceway) inundation losses are much lower since only floods with a return frequency of at least 30 years are allowed to enter the floodplain area.

The inundation losses are similar in case of the CS_gate and RS_gate scenarios, but the flood related benefits are much higher, since the peak of the floods are cut. Still, these benefits are not enough to counterbalance the quantified costs of local defense line devepment. Moreover, there are substantial, yet unquantified costs of flood gate construction and maintenance, which further deteriorate the economic position of these scenarios.

In conclusion, compared to the current state (the BAU scenario) only the new land use without any inundation (RS_none) would generate supplemental benefits. All other scenarios are more costly, and neither the flood related benefits or CO2 emission reductions would be sufficient to compensate the loss of farming income and the flood defense infrastructure investment costs. Whether the non-monetised benefits of land use change coupled with frequent inundation would justfify the monetised costs, requires further analysis.

II. Introduction

In the frame of the Danubefloodplain project there was an opportunity to test the elaborated methodology on a new pilot site.

One of the new pilot sites was in Hungary along the Middle Tisza. By delineating of the new pilot more different aspects was taken into account, among which were not only geographic position but also the land use types and different conflict types between land owners, nature conservation, flood and drought protection.

After the delineation, 2D hydrological modelling of the area was performed for different returning periods of floods HQ2,5,10,30,50,100.

Results of the modelling were theinput for the modelling of potential vegetation of the area and the cost benefit analysis. This latter needed also the land use type changes which were mapped also from slight to more radical changes.

Inbetween two stakeholder meeting were held in Szolnok, Hungary, where results for local people, land owners and for professionals of different fields like CHamber of Agriculture, Water Directorate, mayors were presented. Stakeholders shared their problems and view of the topic.

This report includes all results of these evaluations and recommendations for taking further steps.

III. Study area

The study area is between the 296 and 303 river km of the Tisza River, on the former floodplain in Middle Tisza District. The pilot site came out of the active floodplain area during the river regulation and dike construction works that began in the late 18th century.

The uncovered crest width of the existing dyke is 5 m on the average, slope inclination on the water and former floodplain side is ~1:3 on the average. Combined width of the toe and body of the relatively properly handled and grass-covered dyke is 40 m on the average.

The total size of the pilot area is 2179 ha. The former riverbeds filled up after the river regulations. Most part of the area is currently under arable cultivation (90%). There is a much smaller proportion of pastures, forests and orchards in the area.

The settlement of Cibakháza and Tiszaföldvár in the southern/southeastern part of the area affected by the research is located in the central part of Hungary, in Jász-Nagykun-Szolnok county. The micro-region is a plain between 79.8 and 91.3 m above sea level. The surface has an extremely small average relative relief. In keeping with the floodplain nature of the micro-region, the predominant soil types are loess in the north and meadow soils with a clay and clayey loam composition in the south.

Pic. 1: Selected pilot area between Cibakháza and Tiszaföldvár

The Tisza's full gradient is 30 m (5 cm/km) in Hungary. Based on the Middle Tisza District Water Directorate (MTDWD)'s hydrometric data, the minimum discharge of the river is 46.9 m^3/s, and the maximum discharge is 2 610 m^3/s at Szolnok. The long-term average discharge is 532 m^3/s at this river section. The highest ever-measured water level was 1040 cm at Szolnok in 2000. The water level fluctuation is 1320 cm between the highest and lowest values. In terms of the climate of the micro-region, it is moderately warm-dry and located on the border of hot-dry belts.

The climatic vegetation is forest steppe. The flora and vegetation of the former floodplain and the floodplain are sharply different. The potential vegetation of the former is a forest steppe; the floodplain is a forest-swamp mosaic (forest with overweight). The area is rich in natural values and protected and Natura 2000 areas are home to many protected, highly protected animal and plant species.

VI. Selection of the project area and land use change possibilities (Béla Tallósi, Hortobágy National Park)

The project area designated in flood basin between Tiszafölvár and Cibakháza is mainly a deep floodplain. In lack of flood protection facilities and, in case of natural floodplain conditions, approximately 75% of the area would be frequently flooded. The area would be flooded even by yearly occurring flood waves that are under flood warning levels. In case of open floodplain circumstances, periodical floodings would occur approximately every two years in lower areas, mainly in the former river bed. The average altitude of this area of diverse topography is 79-80 masl. The average altitude of the higher areas is 81 masl, the lowest areas are at 77 masl. The only higher point of the area does not exceed 82 masl. The ratio of the low, i.e. 76-79 masl areas is 25%.

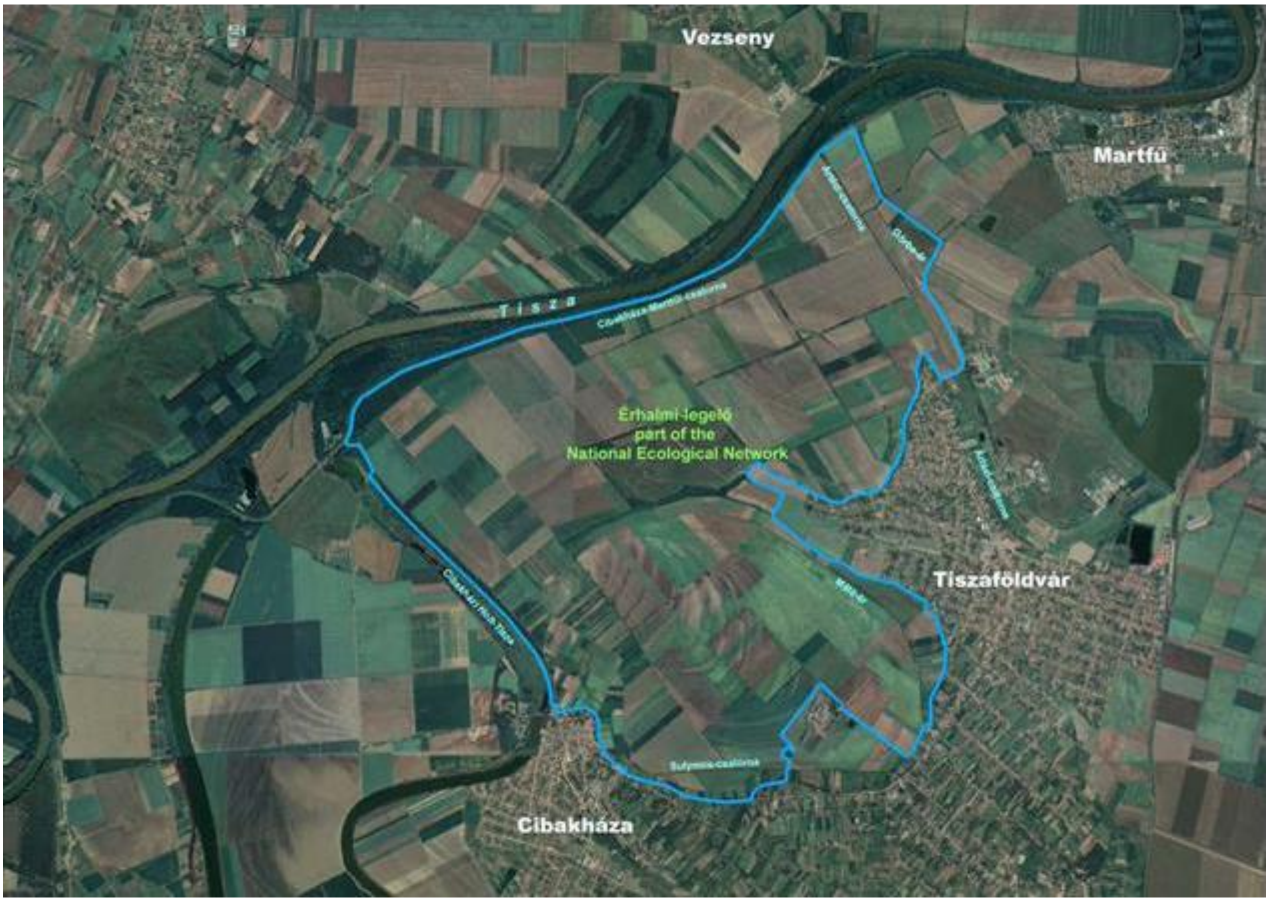
Crucial aspects at the definition of the project area:

- no roads in the area, therefore the road to the ferry Martfű-Vezseny lies outside the site and is the upper boundary of the area;
- no buildings, premises, farmsteads in the area, therefore farmstead Homokrét was left out of the area despite its relatively high location at the altitude of 79-80 masl;
- determining element of the flood basin Cibakháza Oxbow Lake could not be included in the area because it is a separate unit from the inundation and usage point of view, therefore its coastal part constitutes the lower boundary of the area;
- construction of flood protection facilities and dykes for the protection of areas that are not designated for inundation is not required;
- due to its higher nature protection significance, the Érhalmi pasture and its surrounding is included in the project area despite being located above the average altitude of the floodplain;
- already existing trench and canal system to become capable of regulated inundation and drainage without significant expenditures;
- have the theoretical possibility of gravitational flooding the area from the Tisza at moderate flood waves, and in the same way, of its drainage.

The principle of planning

The **BASIC** planning concept was to improve the water balance of the soil in flood basin mainly bordered by a high bank through the exploitation of natural opportunities, i.e. targeted and regulated watering and dewatering. Under **IDEAL** circumstances – if the ideas were realized – there would develop a cultivation structure adjusted to natural opportunities to a far greater degree than is currently. Thus, the principle is to establish sustainable land usage at a higher level through regulated inundation of the deep floodplain. Water losses due to permanent water shortage in this 2200 ha area of the flood basin would be mitigated by increasing the soil's water reserves. Regulated gravitation water supply from the Tisza is the primary condition of functional land usage at a higher level, which is also of advantage to arable farming determining the area. The intended ultimate objective is a more diverse landscape and sustainable land usage.

This project area is not included in project areas prepared for flood protection interventions by the Middle Tisza District Water Directorate (KÖTIVIZIG) and the General Directorate of Water Management (OVF). The width of the functional active floodplain of the river at this reach is on average 300 m. Although the average distance between the left dyke and the high bank Tiszajenő-Vezseny exceeds 1500 m, the effect of the more than 14.5 km long summer dyke constructed for protection against floods up to 9 m, can not be ignored. Enlargement of the narrow active floodplain through dyke relocation is not planned shortly. The nearest dyke relocation is planned in a distance of appx. 12 river km under Tiszakécske.



Pic. 2: Deep flood basin between Cibakháza and Tiszaföldvár and characteristic features of the area

The natural landscape and its ecological features

Morphology of the surface: The area is a deep floodplain of diverse surface morphology. Old riverbeds and heights formed by alluvial deposits are markedly outlined *(Pic. 3H)*. Predominantly these formations give the on a small scale changing wavy feature of most of the area.

Natural high bank: Natural high bank between Tiszaföldvár and Cibakháza stretching at the length of 11 km forms the eastern and southern boundary of the flood basin. With its height of 83-86 masl, it looms over the floodplain as a plateau *(Pic. 3G.).*

Wetland habitats: Although most of the area used to be a marshy wetland before the river training, it is now completely without stable wetland habitats.

Potential climax community: Without farming the climax community of the presently dominantly treeless landscape would be a willow-poplar floodplain forest habitat. Hardwood gallery forest would sustain in areas near grazing land Érhalmi and some higher areas at 81 masl. Reed-sedge swamp habitats permanently covered with water would be formed only in deep areas, i.e. on 10-15% of the area.

Nature protection characteristics

The natural area of national importance: The Tisza active floodplain contacting the area from the west entirely belongs to Central Tisza Landscape Protection Area – OKTH resolution 2/1978 on the establishment of the Central Tisza Landscape Protection Area and KvVM decree 59/2007 (X. 18.) on upkeeping the protection of the Central Tisza Landscape Protection Area, registration number: 158/TK/78. Upon the conservation and management plan, the purpose of the landscape protection area is – among others – to preserve the natural landscape and natural values in Central Tisza Region and to establish the accordance between water management and natural habitats.

Areas of European Community nature conservation: The active floodplain of the Tisza and the entire Cibakháza Oxbow Lake are natural conservation areas of the particular importance of the Central Tisza (HUHN20015) and are part of the bird protection area of the Central Tisza (HUHN10004) – government decree 275/2004. (X. 8.) on the areas of European Community nature conservation and instructions of the KvVM decree 45/2006 (XII.8.).

National ecological network: The 100 ha of the Érhalmi pasture, which is part of administrative area Tiszaföldvár, is part of the ecological corridor. The deeper valley in the grassland is a closed basin that is periodically covered with water is ex lege a saline lake and belongs to the central area of the ecological network *(Pic. 2., Pic. 3J.).*

Land usage and the structure of the landscape

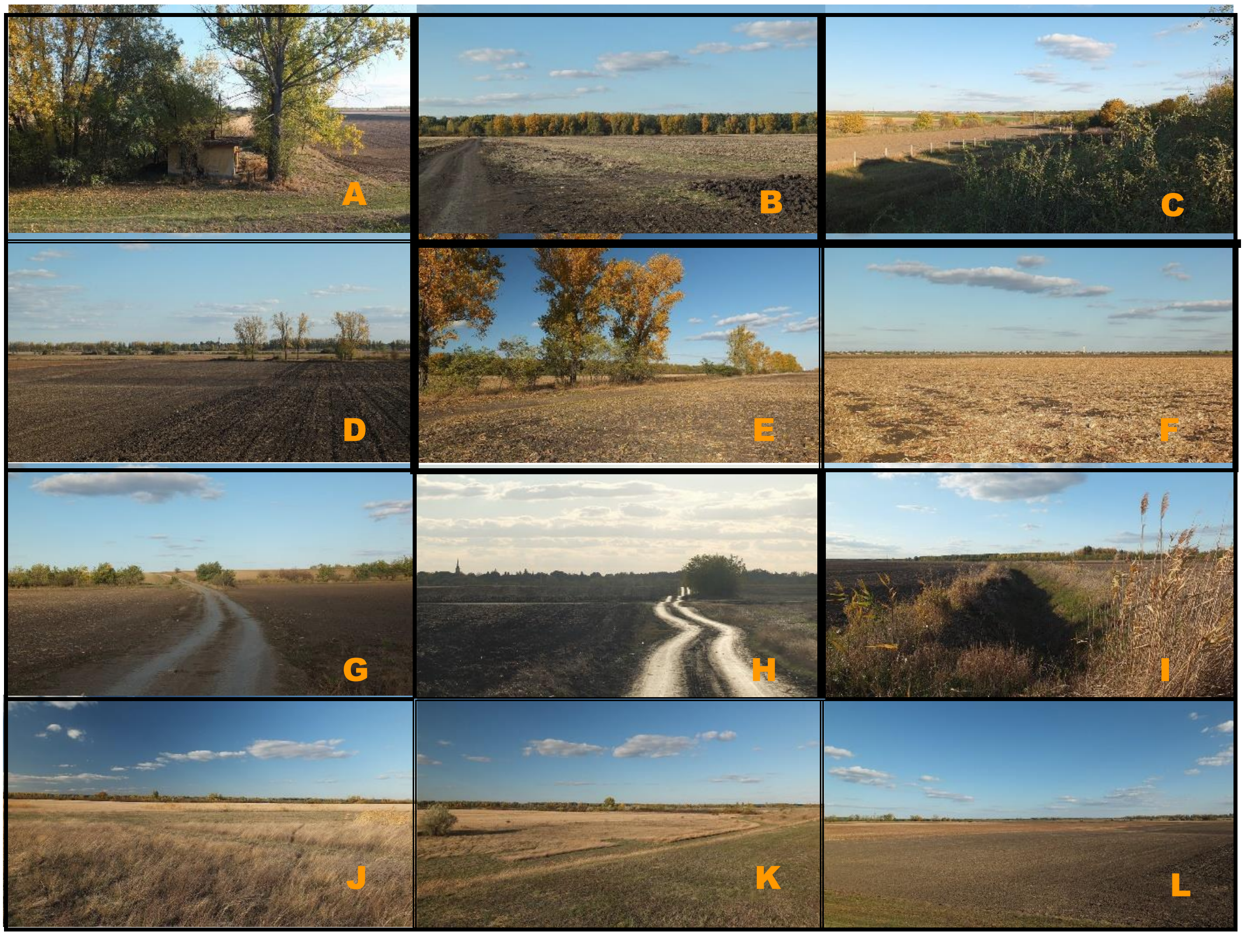
Agricultural land usage: Almost 90% of the project area is currently under intensive cropland cultivation (Chart 1.). Dominant crops are maize and sunflower. The proportion of cereals annually vary but is lower. The sowing area of the rape is increasing. Fodder, mostly lucerne, is grown only in small plots. The cultivation of meadows and pastures has been stopped. The almost 90 ha sodic grassland area of the Pasture Érhalmi was earlier used as a sheep pasture. In its central part are ruined animal husbandry buildings. The utilization of this diversified native grassland is delayed for at least a decade and a half. Due to sodic soil, it does not get weedy; its sections are periodically partly mowed. Production of vegetables is currently not ongoing in the area. Wine and fruit growing was earlier characteristic in garden plots along the high banks but these small plots now lie derelict, some of them were ploughed. The still existing 5 ha pear plantation in the active floodplain is a good example of fruit growing traditions in this area.

Forestry: Wood-like areas cover less than 5% of the area. Most of them are in narrow stripes along the protected side of the dyke (*Pic. 3B*.). For the most part, they are of mixed stands with a significant proportion of green ash. Smaller poplar plantations can be found in woods that belong to Cibakháza. Stands of a planned wood can be found by the Oxbow Lake Cibahkáza and in the surrounding of the pasture Érhalmi. The latter are mostly locust trees. Stands at a higher level of

naturalness can be found in an area bounded by Channel Cibakháza-Martfű and the dyke. Part of them are willow-poplar alluvial forests of a natural origin with a significant proportion of green ash and boxelder. Their lower vegetation levels are featureless.

Plot structure: Small plot structure determines the area. There are only a few larger plots. No one of them reaches the area of 100 ha (*Pic. 3F*.). The area of the plots is between 60 and 85 ha. Joint cultivation of smaller plots is characteristic and significant. There are many plots smaller than 0.1 ha in areas belonging to Cibakháza. Most of them are also jointly cultivated.

Network of canals and trenches: There are a few canals and trenches in the area. Bigger and almost constantly wet canals are Cibakháza-Martfű Canal, Sulymos Canal, Brook Máté and Ártézi Canal. Most of them are at the edge of the area. Deep trenches that lead inside the area are usually dry, their function is mostly drainage (*Pic. 3I*.). Despite being no permanent irrigation equipment, there is occasional irrigation on larger plots. Water comes through Martfű Canal *(Pic. 2*.).



Pic. 3.: Typical features of the project area: A- the reach of the Ártézi Canal with flood control structure crossing the dyke; B- forest belt bordering the western side of the area; C- garden plots by the high bank Cibakháza; D- north edge of the area with old black poplars by the Martfű Canal; E- an upper reach of the Cibakháza-Martfű Canal; F- the plane surface of the central part of the area with large plotted croplands; G- high bank Tiszaföldvár with locust trees in the foreground; H- wavy surface characteristic in the lower part of the area; I- one of the deep dry trenches characteristic for the inner area; J- a natural part of the Érhalmi pasture with mowed areas; K- a recultivated landfill at the outer edge of the Érhalmi pasture; L- jointly cultivated plots at the lower part of the area

Closed basins: Water that occasionally appears in the former riverbed is led towards bigger canals through drainage trenches. There are no areas covered with water for a longer period.

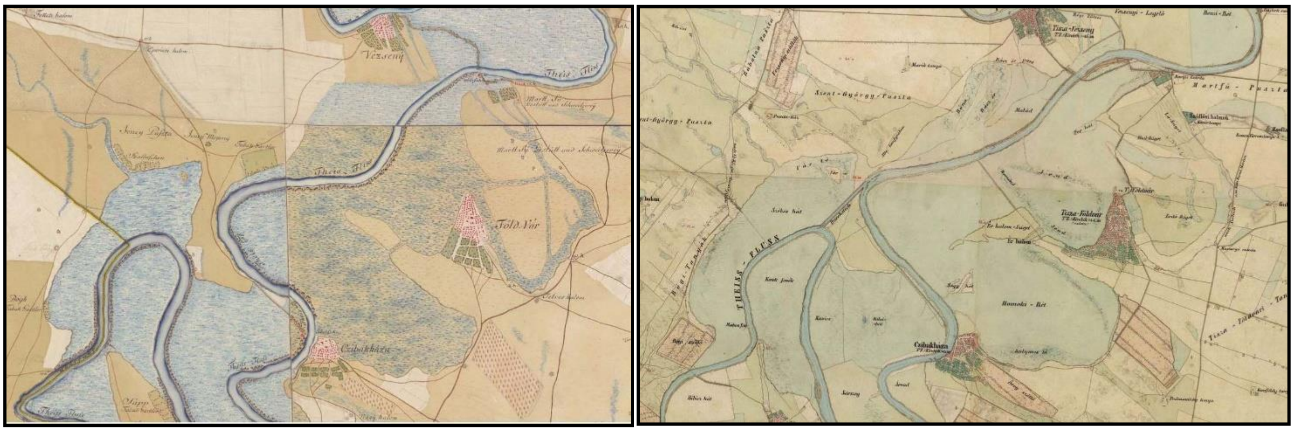
Active floodplain-floodplain communication: The Ártézi Canal with steady water levels, crosses the upper part of the area. This canal with its regulated control structure (*Pic. 3A.*) drains the water from the interior of Tiszaföldvár and the Tiszaföldvár fish pond towards the Tisza. The structure obtains only unidirectional flow towards the river. Its condition has deteriorated significantly.

Plot ratio: There are only in Érhalmi pasture some ruined animal husbandry buildings. The unused sheepfold and the other smaller buildings are in the area at 80 masl that stands out from its surrounding. Farmstead Homokrét in Tiszaföldvár does not belong to the project area. This is also situated at a relatively higher altitude of 80 masl.

Environmental problems: The recultivated landfill Tiszaföldvár is at the edge of the area (*Pic. 3K.)*. This area is in the Érhalmi pasture. Its footings are at 82-83 masl., i.e. at a much higher level than the deep floodplain level. Therefore, the regulated inundation of the area does not have an impact on it. The other environmental problem is caused by the Ártézi Canal, an important element in active floodplain-floodplain communication. This canal occasionally brings water of uncertain composition from the settlement.

Landscape history of the project area

The project area that includes the upper part of the floodplain between Cibakháza and Tiszaföldvár is situated on the border of two local sites. Its upper part is counted into Szolnok-Túr plain, the lower part belongs to Tiszazug. The annual average temperature characteristic in the area is 10.2-10.4 °C; in the vegetation period is 17.4-17.6 °C. The annual average frost-free period lasts 196-200 days. The average annual absolute temperature maximums are 34.0-34.5 °C, the minimums are -16.5 és -17.0 °C. The multi-annual average rainfall is 490-510 mm, in the vegetation period is around 300 mm. This is the aridest area in the Carpathian Basin. The aridity index is around 1.40. Irrigated cultivation gets emphasis due to the dry climate and the increasingly dropping groundwater levels (DÖVÉNYI, 2010). Concerning geographical categories, divergences in the area's natural landscape and its characteristics along the borderlines of the two local sites are not observable. They present more or less a uniform picture.



Pic.4.: Surroundings of Cibakháza and Tiszaföldvár during the First Military Survey (1763-1787) and the Second Military Survey (1806-1869)

source: https://mapire.eu/hu/

The landscape history of the area is in many respects similar to other areas in the Central Tisza Region. This area was regularly flooded before the river training. Permanently marshy places and those exposed to floods could be present in significant spots in floodplain under the high banks. In its insignificant areas, there could be some meadow cultivation. On the maps of the First Military Survey (1763-1787) (*Pic.4.*), the whole area under high banks is marked as a swamp, a frequently flooded area. Detailed maps made in the first half of the 19th century provide a more exact overview of the surface structure of the area. The river curve by Cibakháza had been already cut when the Second Military Survey (1806-1869) took place, but the dyke system was not complete yet. Several unambiguous markings refer to steadily marshy areas that are not appropriate for cropland cultivation (*Pic.4.*). On recent topographical models, these areas can be observed as deeper as the average with an altitude of 76-78 m. In low areas which are likely a residue of an old bed, under the high bank at Cibakháza, the Sulymos Lake is marked as a permanent swamp. In a still conspicuous residue of an old bed by Tiszaföldvár wast swamps, named Románd and Jend are marked. On the latter mentioned map the area of Érhalmi pasture is outstanding as a part situated at a higher altitude named Ér-halom Island.

Pic. 5.: Surroundings of Cibakháza and Tiszaföldvár during the Third Military Survey (1869-1887) and the Military Survey of Hungary (1941)

source: https://mapire.eu/hu/

Pic. 6.: Surroundings of Cibakháza and Tiszaföldvár in the 1960s in photos by the CORONA surveillance satellite and in present in the GoogleEarth (2019)

source: https://mapire.eu/hu, GoogleEarth

Dyke system had been completed by the end of the 19th century. No swamps, only several smaller wet parts are marked in the former floodplain on the map of the Third Military Survey (1869-1887). Farmsteads are not built in the deep floodplain, there is only one farm-like site on a higher part belonging to Cibakháza, named Nagy hát (*Pic.5.*). Most of the canals that are currently in use can be identified on this map. By these times most of the area was likely to be under cropland cultivation. Uncultivated Érhalmi pasture is mentioned and marked under this same name. The area was the wettest under the high banks, therefore the areas nearby the settlements were not appropriate for alluvial orchards. Vineyards and orchards were characteristic of higher sandy soils.

Based on the Military Survey from 1941, the canal and trench network in the area was completed. There were no flooded parts in the area and except the Érhalmi pasture, the whole flood basin was cropland (*Pic.5*.). It is possible that pasturing was not significant in the area, but the depiction of several swipe wells indicate its presence. Farmstead in the Nagyhát area existed then.

After WWII efforts were orientated to include as large areas into cultivation as possible. In satellite photos from the 1960s, it is obvious that almost the whole former floodplain is under large plot cultivation. Except for Érhalmi pasture, there is no sign for meadow cultivation. Prominent is the almost total absence of trees. Wood-like habitats can only be found in the active floodplain along the river and the surroundings of the barrow pits. Buildings disappeared from the Nagyhát area, but the Homokrét farmstead is there. Based on the maps, the almost total absence of trees is prominent (*Pic. 6*.).

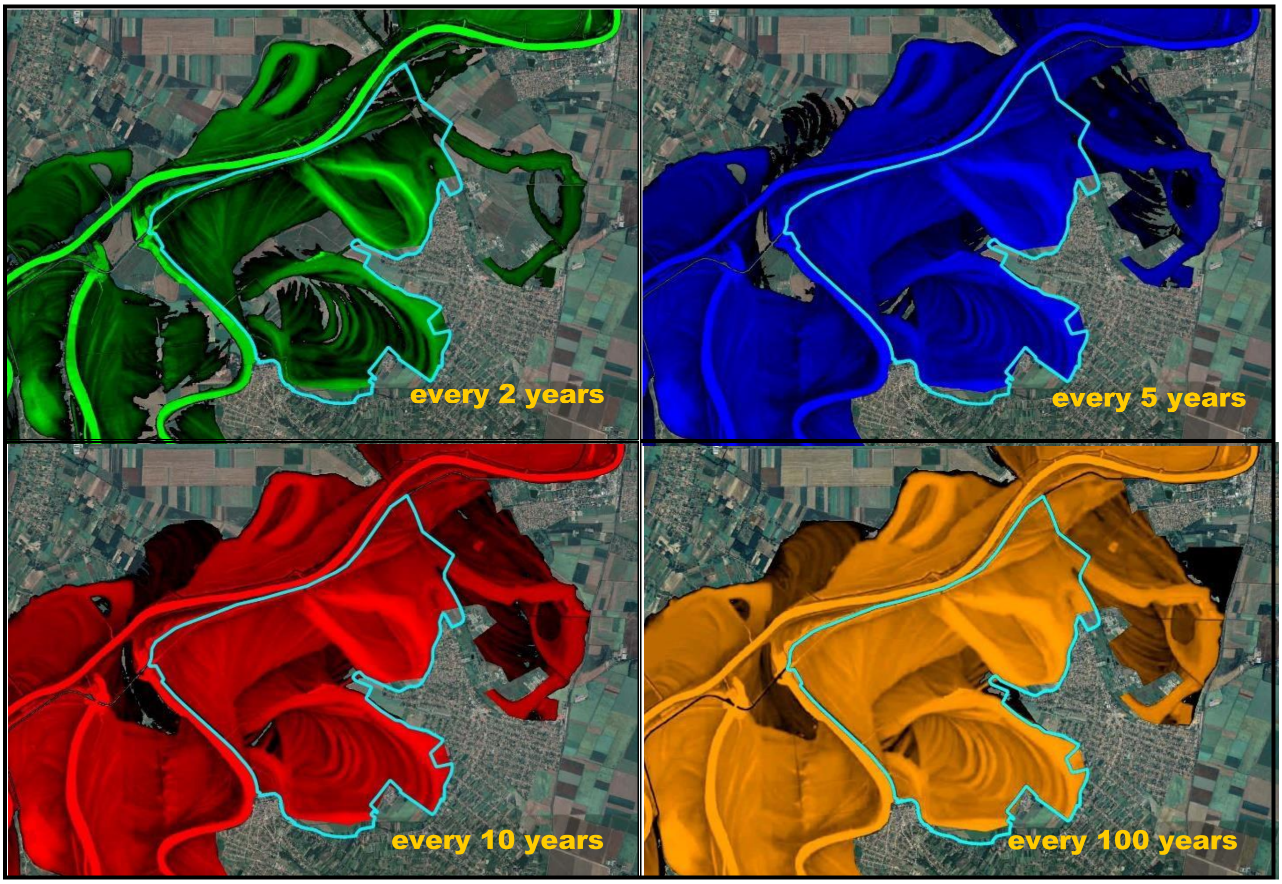
The land usage in the area hardly changed in the period from the changeover until the present. The only significant alteration had been the tree stands that appeared in wet spots without an outlet in the 1970s and 1990s when subsequent floods and rainy years resulted in limited land usage (*Pic. 6.*). Although in some places thinned and in poor natural condition, these stands are still bright spots of the landscape (*Pic.3E.)*.

Climatic, hydrological and ecological framework of the landscape management and land usage

Deep floodplains at 80 masl are determining at least 70% of the project area. The ratio of the parts at higher altitudes that are free from inundation at open flood basin conditions is not significant. With a relatively varied surface morphology and without dyke protection, floods occurring averagely every two years would cause in a significant part of the flood basin, i.e. in its 30% at least one periodical flooding in a year. Inundation models made for floods occurring every five years indicate relatively deep and permanent flooding on 60-70% of the area. Upon the calculations, flood periods every 10 and 100 years would cause deep flooding with a substantial amount of water in the whole area. Only such areas as Érhalom near Tiszafoldvár and Nagyhát near Cibakháza woud remain relatively dry or with shallow inundation (*Pic.7.*).

According to the flood basin characteristics of the local site, the soil is mainly floodplain soil with varying humus content. In the area of Érhalmi pasture, which is native grassland, the salinification of the soil is significant. Around high banks, there are loess and sand soils in narrow stripes. The lack of semi-natural habitats as a general criterion for the entire area roots in the increasingly determinant and intense cropland farming during the last century. Although indigenous tree species in various ratios occur both in the area between Cibakháza-Martfű Channel and the protected dyke side at the former floodplain, they can not be considered as softwood or hardwood gallery forests. Except for constantly wet, artificial canals, there are no stable wet habitats in the area. Canals and other permanently wet areas located in the project area can not be considered as shallow eutrophic lakes; not even in wet periods when some of the characteristic plants permanently appear on them. In permanent wet years, spots of swamps or swamp-like wet habitats appeared and lasted up to some years, but these were ploughed when the

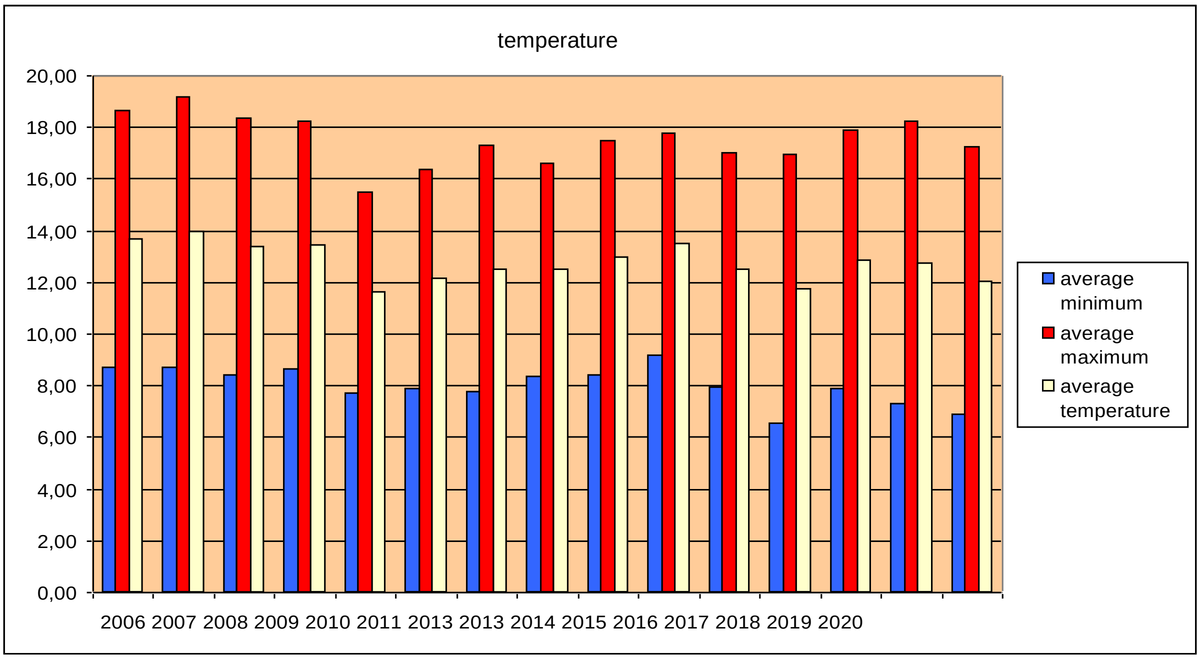
climate became drier. Although stabilized, but substantially secondary grasslands can be found only on slopes of the dykes and along bigger canals. These grassland communities are at some places relatively rich in species. The most valuable grass area is the Érhalmi pasture, as a native grassland. This area of nature protection importance is not used for years. Due to its saline soil, it does not get weedy but there are already some smaller ploughed parts at its edge. Arthropod species characteristic for loess grasslands and meadows are the species of the highest natural and scientific value of the area. The division of the flood basin exacerbates the impacts of the climate anomalies and water levels varying between extreme values. Habitats in the active floodplain formed and maintained under artificial conditions, are relatively natural. However, during the periodic full inundations, some plant and animal communities can not find shelters that are at least sub-optimal for surviving the inundation period at their habitats. During high permanent summer floods, many plant and animal species steadily disappear from the active floodplain because even mobile species are unable to find appropriate habitat in a nearby ploughed former flood plain. Disappearance can be temporarily latent when some individuals can survive and in some years their number can reach the detectable level. The permanent disappearance of some species from the given area can not be excluded, too. Semi-natural habitats in lower parts of the former floodplain during permanently rainy periods are flooded for longer or shorter periods. Regulated inundation of the flood basin also causes flooding of the habitats at the lowest areas and those along the channels and dykes. Terrestrial flora and fauna of these habitat spots can not find shelter in nearby intensively cultivated croplands as well as those settled in the active flood plain during floods.

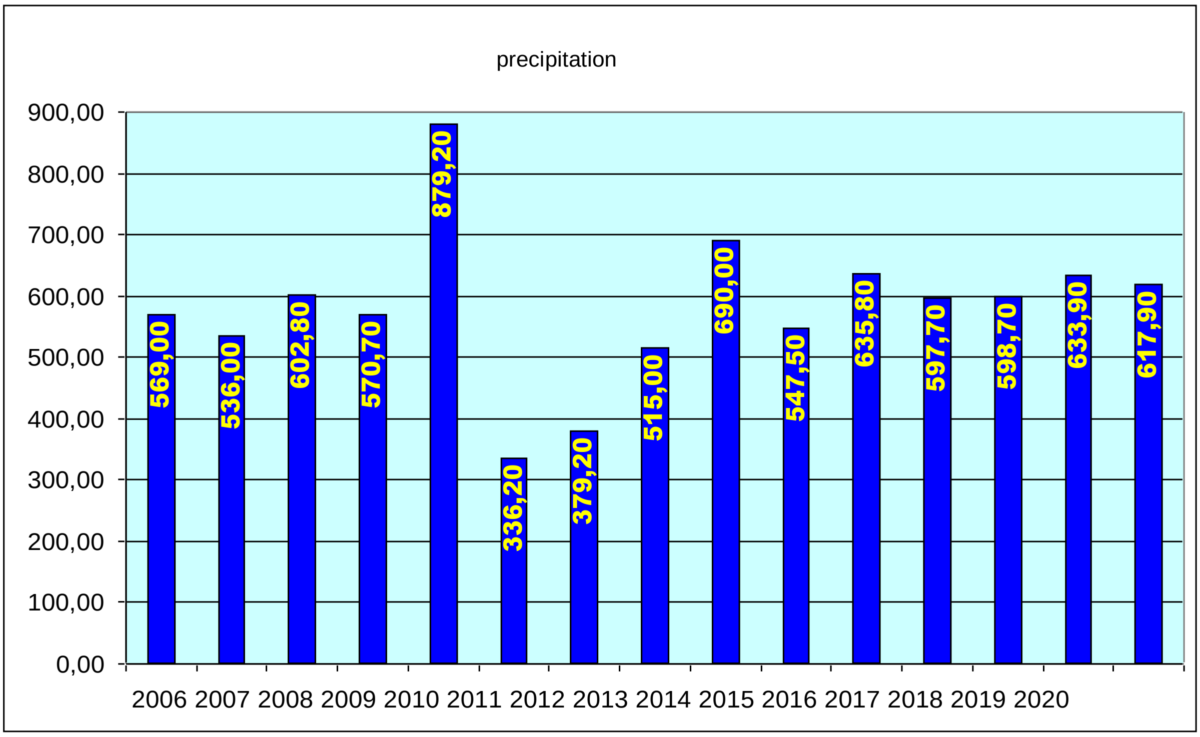


Pic. 7.: Inundation models of the project area: size of the inundation area in floods occurring every 2, 5, 10 and 100 years and water depths at flood peak

Potential vegetation is cardinally determined by sudden, in some cases up to several metres deep floods that occur in active floodplain even in growing and breeding season. On carbonated flood plain soil the relatively low level of diversity, in general, characterizes the structure of the naturally settled vegetation and the vegetation of the active floodplains as well. However, the bio production of the vegetation is usually very high. Alluvial deposit that regularly arrives with the river means renewable nutrient supply. Along with the best water supply of the soil, the relative humidity is higher and the temperature is more balanced. Under these circumstances at a relatively low number of flora species, the vegetation grows fast. Flood protection guarantees the security of agricultural production, but therefore, the above mentioned beneficial effects do not prevail.

Due to human factors that are generally present, recurrent and often intense in the active floodplains, the significant ratio of the plant-based vegetation is constituted by such invasive species as false indigo-bush, green ash, boxelder, riverbank grape (frost grape), wild cucumber, species of spiny cocklebur, species of devil's beggarticks, etc. Despite these exogenous species mostly appearing as pioneer species, they often prevail or determine the vegetation of the active floodplain area. These highly bio-productive plants are also present in the wet spots of the former floodplain and along the canals. Moreover, they can rapidly become prevalent in disturbed habitats. Different invasive alluvial tall forb vegetation and later the rapidly spreading false indigo-bush and green ash appear as the first sign of the afforestation in those parts of the area which are for some reason left uncultivated for several years.

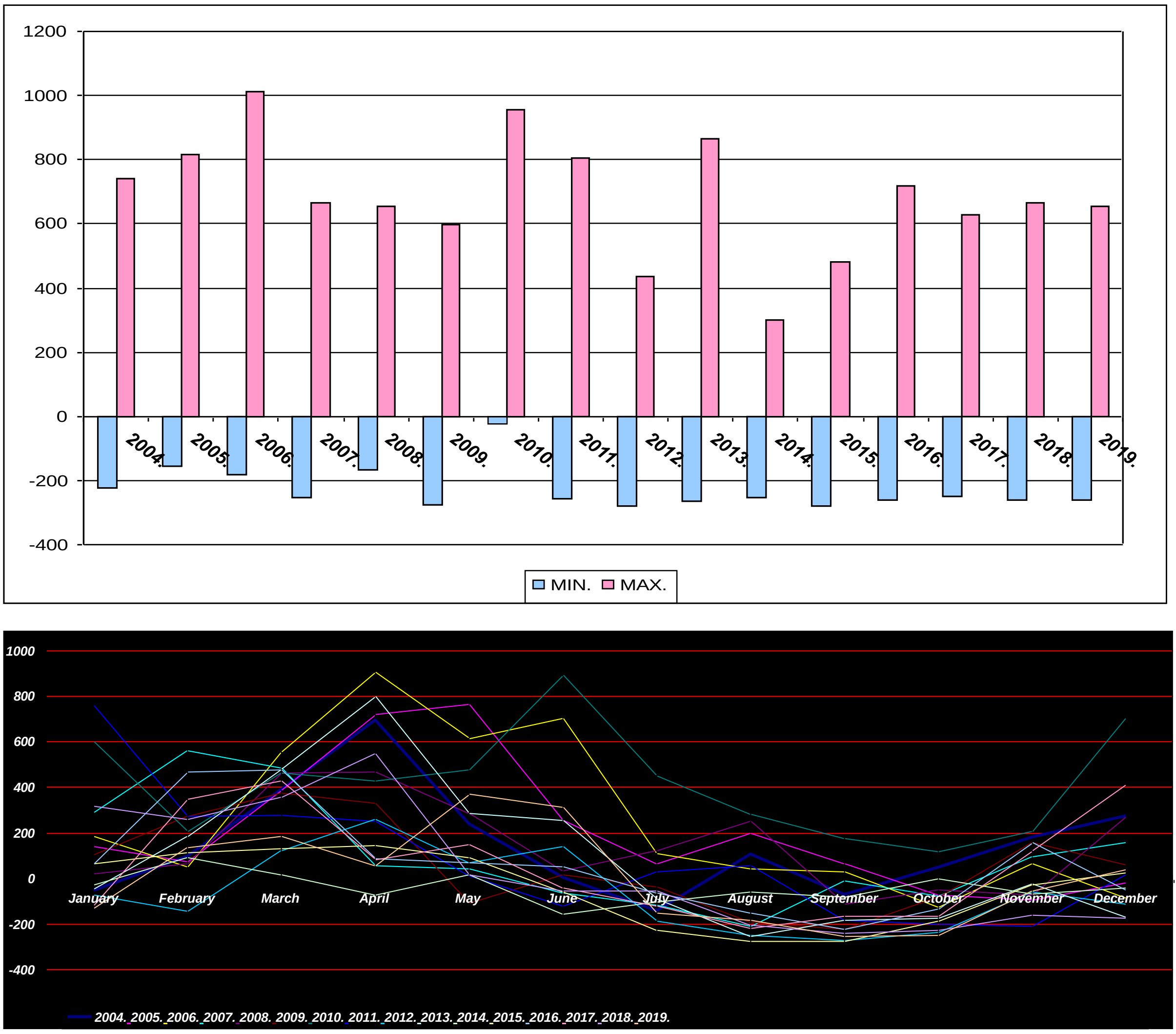




Pic.8.: Average temperatures and yearly precipitation between 2006 and 2020 detected at measuring point Szolnok-Szandaszőlős appx. 10 km far from the project area

The majority of invasive species spread in the Central Tisza Region are exotic species from North America. They cause the most severe problem in wet active floodplain habitats, but also in unused croplands in the former floodplain, along with irrigation and drainage canals, trenches and the roads.

Aggressively spreading invasive species are mostly massively present in highly disturbed habitats of the project area. The most frequent species: false indigo-bush (*Amorpha fruticosa*), boxelder (*Acer negundo*), green ash (*Fraxinus pennsylvanica*), hackberry (*Celtis occidentalis*), white maple (*Acer saccharinum*), common ragweed (*Ambrosia artemisiifolia*), daisy fleabane, (*Erigeron annuus*), common fleabane (*Erigeron philadelphicus*), horseweed (*Erigeron canadensis*), common milkweed (*Asclapias syriaca*), spiny cocklebur (*Xanthium italicum*), rough cocklebur (*Xanthium saccharatum*), devil's beggarticks (*Bidens frondosa*), riverbank grape (*Vitis riparia*), wild cucumber (*Echinocystis lobata*). In the project area, these species are significant in uncultivated areas and along the trenches and canals.



Pic. 9.: The annual average minimum and maximum water levels (above) and change of the annual average of monthly water levels between 2004 and 2019

(original data source: www.hydroinfo.hu)

This region of the Great Plain is the aridest in the Carpathian Basin. Typical annual and periodical deflections of the continental climate became more extreme in recent decades. Climate extremities have a severe impact both on the natural wildlife and on farming in the area. Low precipitation is causing most of the problems among rapidly changing environmental factors. Although precipitation more above averages occur in sporadic short periods or years, values close to or lower than 500 mm long-term averages become more frequent. Frequent extremities are characteristic of both the temperatures and the precipitation distribution. Linear variation in average temperatures is not evident, but extreme summer values are frequent. Especially in recent years, summer temperature maximums appear as a significant limiting factor (*Pic.8*.). The more frequently occurring lack of moisture in the first, sensitive phase of the vegetation period means an increasing problem in consideration of the survival of the wildlife and also the farming. The deepening river separated from the best part of the floodplain is not able to compensate for water shortage originating from the low precipitation. Water surplus caused by the floods is utilised in the landscape to a minimum extent at most. Therefore, water shortage is usual even after flood propagation (Balogh, 2001).

Because of the deepening river bed and the narrow space between the two dykes, the drainage of the groundwater is faster in the active floodplains. Therefore, in dry periods these areas become faster dehydrated than the former floodplain. Due to the division of the flood basin, the up to yearly occurring water surplus quickly disappears even from the active floodplain. Shorter floods of the river do not significantly increase the groundwater level. Moreover, on the other hand, the deepening river Tisza itself contributes to the progressive fall of the groundwater level in the former floodplain.

During the last more than a decade, there were no permanent, high flood peaks. Parallel to increasing dehydration that is characteristic of the whole river basin, extreme low summer water levels are more common. Flood propagations follow the precipitation of varying quantities that show significant divergences even within subregions. Natural conditions of the entire floodplain are cardinally determined by the fact, that floods that exceed 800 cm upon the flood gauge did not occur in the last 11 years. There were no such permanent floods that would have flooded the entire active floodplain, including the areas above 83-85 masl (*Pic. 9*.). Permanent high water coverage has a positive impact on the former floodplain's degree of dampness and above all, on the permanent rise of the groundwater level. Such a condition arises during rare floods (*Pic. 7. and 9.*).

Cultivation structure and farming methods characteristic of the project area in the framework of current natural conditions

Complete flood management together with the drainage trench and canal network ensure favourable conditions for arable farming in most of the flood basin for at least a century. Concerning the characteristics of the area, this land usage method is not likely to be changed within a foreseeable period. Pasturing on the high nature value Érhalmi pasture was ceased at least for a decade ago. Despite hay of high-quality growing here, the grass area is mowed only in small spots (*Pic. 3J*).

Concerning farming, the system of agricultural subsidies is of great importance. Ideally, it takes into consideration the function of the given area, the typical and possible cultivation methods and also the flow regime and moisture conditions in the area. Subsidies under valid regulations must be available both for agricultural and environmental management measurements and modification of the area's land usage structure along with its maintenance. In this regard, subsidies connected to agricultural and environmental management systems are of decisive role (Ángyán, 2003).

This significant proportion of the flood basin is situated in a deep floodplain with most of the surfaces under average altitude, especially along old riverbeds. Agricultural utilisation is not significantly limited by the deep position of the area within the current landscape structure. Permanent rainy seasons rarely occur. These only temporary make cultivation difficult causing water cover on limited areas. A bigger and increasing problem is dehydration caused by precipitation deficit and drastic fall of the groundwater level. Deterioration of topsoil water balance also limits productivity.

From a historical perspective, pasturing was the most profitable and widespread farming method in this floodplain region of the Great Plain. A brief period of inundation fertilised the woods, orchards, lands, pastures and grasslands (Molnár, 2011). Temporary inundated pastures and grasslands produced high yields of grass and were ideal for animal husbandry. Pasturing or regular mowing those areas that are not appropriate for forestry or crop cultivation is an obvious solution for the repression of invasive shrub and tree species causing severe problems to the flood management as well. Extensive organic and bio-production of local breeds could also become widespread in the active floodplains or in former floodplains that are exposed to inundation. In this respect, the ability of initiation and situation awareness of the decision-makers responsible for the determination of the land usage together with the existing actual social needs in the area are of essential prerequisite (Tóth, 2010).

Besides chronic moisture deprivation characteristic for the area and under current farming structure, on the larger plots, irrigation is the only solution. Not only the high costs and the technical difficulties but also the high level of plot fragmentation appear as a problem difficult to resolve. Inaccessibility to groundwaters increases drought damages, especially in longer and more frequent periods without significant and permanent floods. This latter problem could be mitigated by sustaining the groundwater level at a much higher level and this would improve the water balance of the area. Hypothetically, by partial reactivation of the floodplain, if winter or early spring floods within regulated frameworks would be let into deep bed valleys of the former floodplain and the water would be let out - also under regulated circumstances-, the area after fast dehydration of the surface would be suitable for the production of even early spring plants. A higher level of moisture in the soil would have a favourable impact on production yields during droughts (Balogh, 2002).

Regulated water recharge opportunities of the former floodplain

In a project area situated partly in a deep floodplain, the current cultivation structure is a serious limitation to partial reactivation of the floodplain. Concerning the possibilities of water recharge from the active floodplain during floods, the well-preserved trench and canal system together with the morphology determining the character of the landscape are favourable factors. A succession of the large wavy surfaces and plain plateau-like even surfaces (*Pic. 3F. and 3H*.) and deep, old bed valleys connected with canals are of benefit for regulated periodical or more permanent inundation corresponding to the morphology of the surface.

Arable farming that is limited to a few crops and is characteristic for almost the entire area is a restrictive but not exclusive factor of the targeted and regulated inundation to improve the water balance of the soil. However, it would be more preferable if the cultivation structure would become more diverse as it is at present. Natural conditions for structures of more diverse usage are given in the area, only the social and economic realities are those, that are sustaining the current structure as the only alternative.

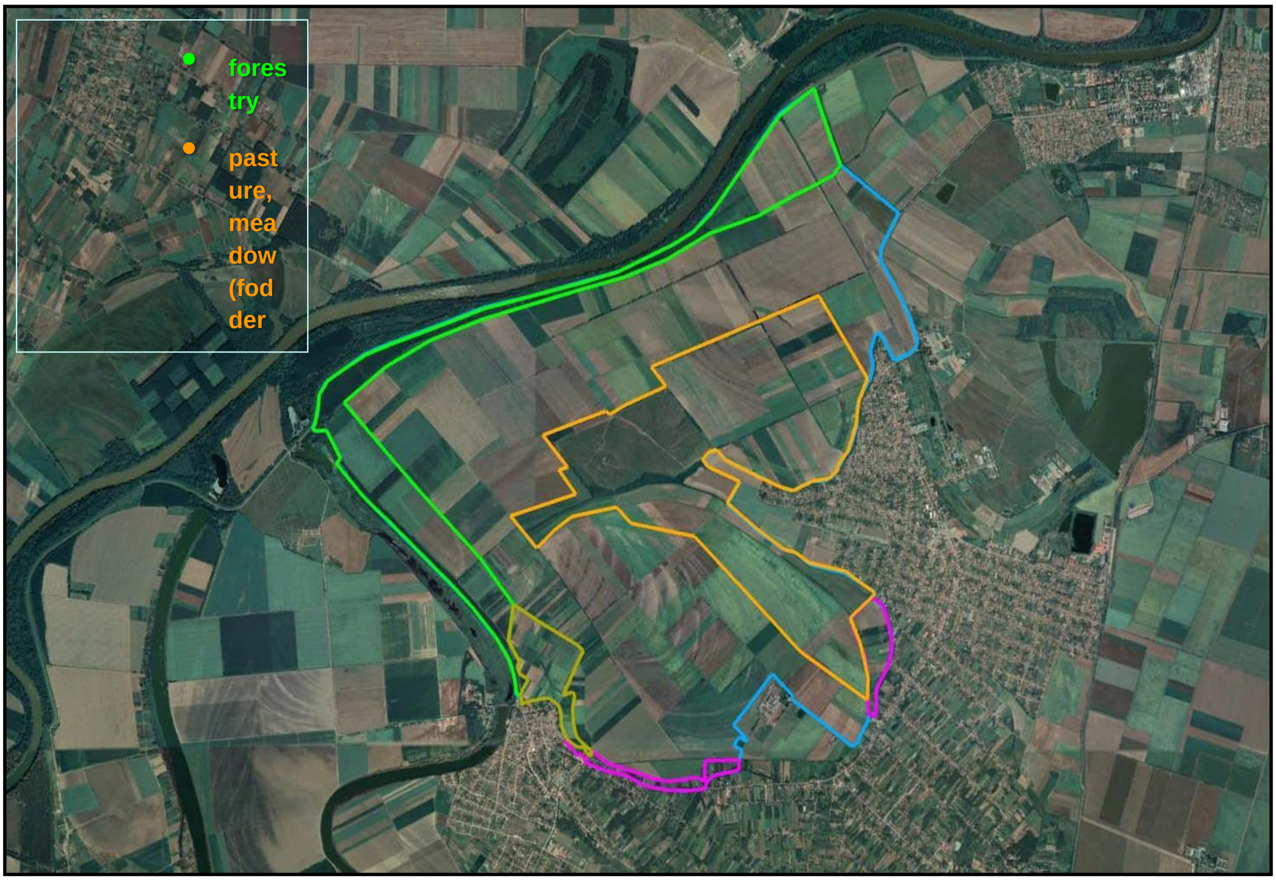
Chart 1. Land usage methods in a part of the flood basin Cibakháza-Tiszaföldvár belonging to the project area

CULTIVATION, USAGE	CURRENT CULTIVATION STRUCTURE		IDEAL CULTIVATION STRUCTURE	
	hectares	%	hectares	%
arable farming	1955	90	1268	58
grassland, gallery grassland, fodder plant production	84	4	564	26
forest, tree plantation	107	5	249	11
production of vegetables	0	0	48	2
garden, orchard	23	1	40	2
road, canal and trench	10	0	10	0
TOTAL AREA	**2179**	**100**	**2179**	**100**

Considering the land usage and production circumstances there are two possible basic cases of the regulated water recharge for improving the water balance of the area:

1. Barriers and necessities derived from the current social and economic surroundings can not be neglected by the actions of the near future. Taking these facts into consideration and assuming that technical conditions of water recharge will be given, the reality for water recharge is only possible with the full regard of the croplands. The current cultivation structure of the area provides only limited possibilities for regulated water recharge. Arable farming, at around 90 % (Chart 1.), provides at most the opportunity to improve the water balance of the soil by uploading the existing trench and canal network during winter and early spring floods and by keeping the water in them which would sustain the groundwater at a higher level even in draughts at least until mid-summer.

2. Sustainable and efficient mitigation of negative impacts of the water deficit in longer periods will result in significant alteration of cultivation structure. Partial reactivation of the floodplain is only possible with temporary inundation of mainly lower areas. These areas are former river beds. A trench and canal network is constructed for drainage and the periodical prevention of damage caused by excess water. It connects all lower areas. During moderate and quickly subsiding winter or spring floods regulated water recharge would be possible through these systems at relatively low costs. Drainage would be executed also through this system upon a previously defined regime. Agricultural subsidies and incentives together with targeted forms of support are the most important basis of the operationality of this system. The system of agricultural subsidies together with a more sustainable cultivation structure would improve the productivity and stability of farming in the area. Instead of current monotonous land usage aiming towards an ideal state, inundation tolerating pasture management and fodder plant production would be preferable on a wider scale in the first place. Improvement of the water balance of the soil and easier accessibility to irrigation would increase possibilities for the production of vegetables in lower areas nearby Cibakháza. In areas with less advantageous opportunities, mostly along oxbow lakes and rivers, forest management – especially poplar – would have the most reality (*Pic.10.*).



Pic. 10.: Cultivation structure that is more adapted to natural and landscape features and is allowing wider usage of regulated inundation (upon current cadastre borders)

The most important factor determining the land structure in the flood basin is the morphology of the surface. This is the determining factor of the water balance of the area and has an impact on frames of regulated inundation and farming opportunities. The inevitable or preferable cultivation method can not be determined in advance. When setting up such a pattern, besides inundation models (*Pic.7.*), possibilities for utilization of the opportunities of the land, size of current cultivation area, ecological features and plot structure also have to be taken into consideration. It is also important that the active floodplain band, especially the surrounding of the point bars by the river, is situated usually at the highest altitude as in this area at 85-86 masl. The floodplain is on altitude 77-81 masl i.e. on average on 79 masl. Concerning the inundation, it is also important that the average altitude of the former floodplain - the areas at the river's side - is at least 1- 1.5 m higher than the average altitude of the inner parts of the project area. At regulated inundation, an important factor in drainage is that the lowest parts are situated farther from the river in direction of high banks on the western side of the flood basin. Concerning inundation and drainage, it is also important, that the Cibakháza-Martfű Canal, as the biggest body of surface water in the area, leads nearby the dyke more or less parallel to it. The role and operation regime of this canal as well as the other big body of surface water, the Ártézi canal, is currently strictly regulated in water legislation implementation permit.

Conditions and barriers of the reactivation of the floodplain and regulated inundation

Plans, interests and real opportunities of the landowners and farmers: Short term interests and plans of the landowners, farmers, state trustees and other interest groups do not correspond to those changes in land usage that will limit their activities in the former floodplain. Even if they have long term recoverable benefits, ideas that have an impact on the method and frames of current yet profitable arable farming can easily confront short term plans and expectations of the stakeholders in the area.

Circumstances that disturb routine farming and may cause losses of income: Any change in connection with regulated inundation can cause problems for the farmers; it has an impact on the usual cultivation regime, technologies and can also cause a loss in income in some areas. This problem can only be compensated through a reliable and targeted system of agricultural subsidies.

Sustainability of the operational farming structure: Partial reactivation of the floodplain by regulated inundation necessitates alteration of the current cultivation structure. Improvements in the water balance bring long term benefits, but alteration of the system is only reasonable when the sustainability of the altered farming and land usage structure can be taken for granted.

Acceptance of the alterations in the structure of the landscape needed for realization and operationality: Occurring alterations in the structure of the landscape over time derived from the system development can result in a situation that must correspond to the relevant needs of the farming. Such demands or needs can be: enlargement of forest plantation, further irrigation demands, upholding the current structure of the croplands, enlargement of the sowing area of favoured crops, the introduction of new agricultural techniques.

Structures and canals, the pillars of the system: Regulated inundation and drainage of the inundated area are possible above all through the existing trench and canal system that is enabled for this kind of utilisation. A significant problem may be that the present purpose and operation regime of the main canals, like Cibakháza-Martű, Ártézi Canal and other bigger ones do not correspond to the regulated inundation and drainage system. The role and operation regime of these canals are currently strictly regulated in water legislation permit.

The compatibility of gravity-based filling and draining structure with the flood protection function of the main dyke: Construction and long-term operation of the gravity-based, two-directional structure of a high permeability shall be entirely consistent with the flood security requirements.

Regulated dewatering can cause a bigger problem than regulated inundation during protracted floods: The water level of the river can be so high for weeks during the occasional protracted floods at flood warning levels I and II that causes difficulties in water recharge and makes the operation of the structure for dewatering impossible. In these cases, above all, the regulated dewatering of the area meets obstacles and expensive pumping also might be necessary.

Network of dirt roads in the area: Dirt roads linking the croplands are crossing the low-situated bed residues that are permanently inundated by regulated inundation. Parallel to the operation of the water recharge system accessibility of the croplands has to be granted. This need will result in some further demands and other issues that are to be solved.

Cost cover of planning and construction: Reactivation of the floodplain must be executed upon carefully prepared plans. The preparatory studies that underpin planning, measurements and planning itself will have significant costs. The construction of inundation and drainage structures is a costly investment in itself and enabling the canals and trenches for their new function together with the construction of structures will raise the costs.

Maintenance of technical facilities: Other tangible and labour costs arise from obtaining the operation regime of structures and canals that are essential for the operation of the system and

their regular maintenance. The system should only be operated in such a way as to ensure the ability of operation of water recharge and drainage.

Water management interoperability: The majority of the floodplain reactivation interventions and the system of operation must not infringe on the applicable water management legislation that is valid in the area. These have to correspond with flood protection and drainage principles.

Potential local profits and the fulfilment of their enabling conditions

Improvement of the water balance is expected in the area due to the partial reactivation of the floodplain by regulated inundation and drainage systems. Implementation of the system itself is relating to changes in land usage to a greater or lesser extent. The extent of these changes depends on the location of the inundated areas and their size. Changes resulting from the operation of the system will also determine the methods of land usage. Along with developing flow system and humidity conditions, farming methods that are the best for exploitation of the area's potentials will become preferable together with those corresponding to current social and economic requirements. Furthermore, keeping the highest proportion of water is essential with a view to ecological potential and land usage. Basins permanently covered with water will not remain in the area. Regulated inundation is followed by regulated drainage. The aim of water recharge and water retention is to improve the water balance of the soil and to provide high groundwater levels.

1. **Arable farming**: it is dominant in 90% of the lands in the deep floodplain covered with an alluvial deposit of a varying thickness. Their ratio is unlikely to be significantly changed soon. An increase of these areas is only possible in currently unused Érhalmi pasture. Due to poor soil, the breaking of the grassland has no sense. On the other hand, there are nature protection pediments, since the area belongs to the National Ecological Network and there is a periodic sodic lake on it. Enlargement of ploughlands is also unlikely at the expense of the forest areas. Farming will be restricted to a lesser degree due to regulated inundation, but crop production risks are not likely to grow. Improved humidity conditions are likely to have a positive long-term effect and according to expectations will also improve agricultural production yields. The ideal change in farming structure would result in the ratio of arable farming at not more than 60% in this part of the flood basin. Current agricultural subsidies and the social-economical environment do not favour alternative land usages at the expense of arable farming. This farming method will likely remain dominant in the flood basin for a long time.

In case the project is implemented, the inundation will determine the sorts of produced crops, especially in temporarily inundated lower parts of the area. Late sowed root crops will better succeed than winter cereals or rapeseed. Experience shows that sunflower and maize are usually produced in croplands in the active floodplain of the Tisza.

2. **Cultivation of meadows:** Although their sustainability and environmentally favourable, the current social-economical environment not even in deep floodplains favour the cultivation of meadows. In contrast to the huge difficulties arable farming is facing, meadow cultivation or fodder production would be more profitable especially in deeper, poorer areas. In the current agricultural environment, diminishing of this kind of land usage is not likely to change in a foreseeable period. Free-range rearing disappeared and the demand for hay is decreasing. Meadow cultivation as a farming method is rapidly disappearing everywhere, despite its low investment costs and lower other risks. Upon the morphology and inundation-drainage characteristics, meadow cultivation would be possible on the entire area. It is the most realistic

in Érhalmi pasture, on poorer soils of its surrounding and in low, periodically inundated areas. The above-described problems of grassland farming are even more emphasised concerning grazing livestock. Fodder and shelter during the winter are crucial for grazing livestock. A significant amount of hay could be harvested in the appropriate or adaptable fields of the flood basin. The animal husbandry site in Érhalmi Pasture is in poor condition.

New mowing techniques caused new, formerly unknown problems and challenges for natural grassland systems. A new challenge is, that these new mowing technologies are ecologically more harmful than hand mowing or traditional mowing. Machines that are passing fast across the area cause havoc not only in ground-nesting birds but also in arthropod communities. The most drastic impact is the fast disappearance of these communities from the area. Small vertebrate animals also suffer from these mowing and hay harvesting methods. Feed deficiency at some specialized herbivorous species has an indirect but relevant effect. Besides the disappearance of animal communities, these mowing techniques of high performance harm the composition of the vegetation as well. These techniques contribute to the homogenisation of the species composition and often to the disappearance of valuable dicotyl species.

3. **Production of vegetables**: It has firm traditions in Cibakháza. Irrigated production of vegetables is present in large areas of the inner basin of Oxbow Lake. The low parts under the settlement seem to be appropriate for these purposes in the project area. This area is irrigable from the Sulymos Brook. Although small vegetable gardens are present in the former floodplain near the settlements on loose, good water balanced soils, these are isolated examples that have almost no relevance to the floodplain land management.

4. **Fruit growing**: Clayey alluvial deposit limits the sort of growable fruit. Besides proprietary conditions, the low location of the area is also a disadvantage for the planting and maintenance of orchards. There are several smaller orchards at neighbouring higher parts. All sorts of regionally produced fruit are present in the area, but only in small gardens. The only positive exception is an old, productive pear plantation in the active floodplain of the Tisza.

5. **Forest management**: Alluvial willow-poplar forests dominate both the active floodplain and the lower areas of the former floodplain. This type of forest in semi-natural structure can only be settled on fresh alluvial deposits. Ageing stands are not able to renew. Their artificial, structure-keeping and gentle renewal are currently in an experimental stage. Such stands are at the river's side of the flood basin, but the ratio of the invasive tree species is significant. The ratio of forest management in the former floodplain between Cibakháza and Tiszafoldvár is sporadic. The poplar is widespread in the surrounding areas. Here it occupies only insignificant areas. From nature conservation and wildlife protection aspects, it is worth keeping such stands at least in those parts by the dykes and canals that are neutral from the water management point of view. These stands are in many cases of natural origin. They are productive in good habitats and their preservation is cost-effective. Taking into consideration the mainstream trends in the area, plantation of trees is likely in parts of the flood basin with unfavourable growing conditions of the soil. Poplar plantations are favoured, but in higher parts, like nearby Érhalom, the appearance of the locust is more likely. Intensive forest management is likely to spread in those parts on which arable farming is not profitable. Taking into consideration the habitat conditions, selected poplar sorts grown after the whole preparation of the soil and subsequent intensified techniques are the most popular. It is also characteristic, that such stands are planted in an unmixed loose network without vegetation levels. Surely, this will be the applied method of production if forest management becomes of higher importance in the area. It is reasonable to assume that irrespective of land usage changes in connection with regulated inundations, the ratio of tree stands is going to double (*Chart 1*.) in the flood basin in the following one or two decades.

Farming structure in the area and differentiation of the forest management methods can be predicted only broadly in the present. However, it is sure that favoured forest management methods on each subdivision, besides the economic factors, will be subordinated to the water balance of the soil.

Chart 2.: Conditions of potential local profits, economic needs and reality of their implementation in the project area

0 – no reality, 1- low need and reality, 2- significant need and reality, 3-high need and reality

	NATURAL FEATURES	ECONOMIC ENVIRONMENT AND NEEDS	ECOLOGICAL AND NATURE PROTECTION PRINCIPLES
ARABLE FARMING	2	3	1
CULTIVATION OF MEADOWS – gazing	2	1	3
CULTIVATION OF MEADOWS – grassland, fodder	2	1	2
PRODUCTION OF VEGETABLES	2	1	1
FRUIT GROWING	2	1	2
FOREST MANAGEMENT – semi-natural	1	0	3
FOREST MANAGEMENT - plantation	2	2	0

6. **The exploitation of fisheries**: There are no constant water bodies in the project area that are suitable for the exploitation of fisheries. Possible temporal inundation in the area is not entailing to the forming of such water habitats, that would be suitable for fish. Bigger canals are suitable for fish only to a limited extent. This situation is not going to change in the future.

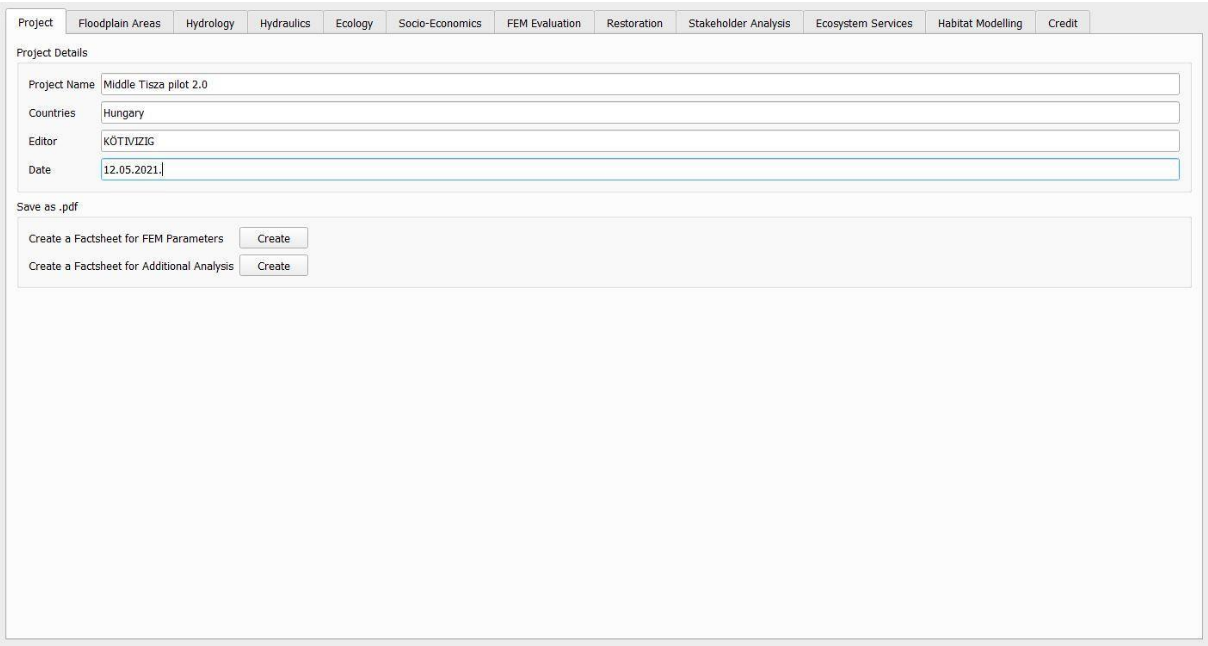
7. **Wildlife management:** Current features of the area do not particularly favour wildlife management. The big game that can be hunted is roe deer and wild boar, but neither of them is present in larger stock. The characteristics of the area are relatively adverse to the small game as well. Along with the diversification of farming structure, the range of habitats grows and this brings better life conditions to wild game.

VI. FEM analysis

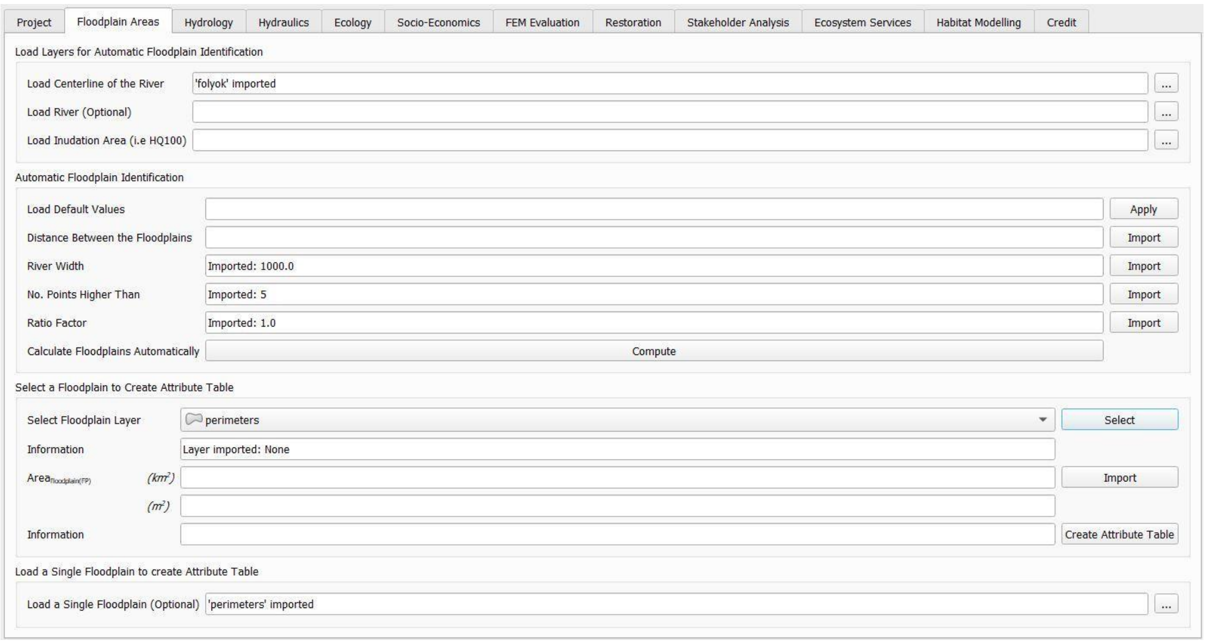
6.1 Results of applying the FEM-Tool

In order to apply FEM-Tool the input data set has been prepared. All the data were used to calculate the FEM parameters (FEM minimum and one additional parameter) for both current and restored state according to FEM-parameters handbooks.

In order to install and use the FEM-Tool the open-source QGIS software has been used. The FEM-Tool have been successfully applied for Middle Tisza pilot area.

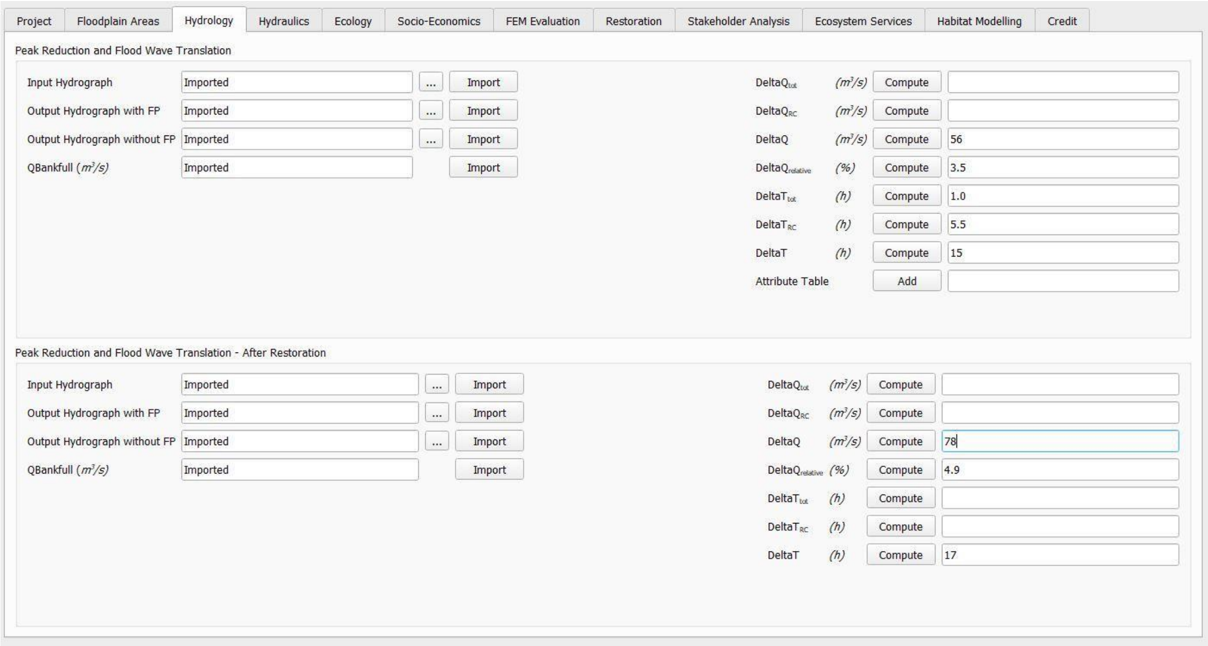


Pic 11.Project informations in the FEM tool

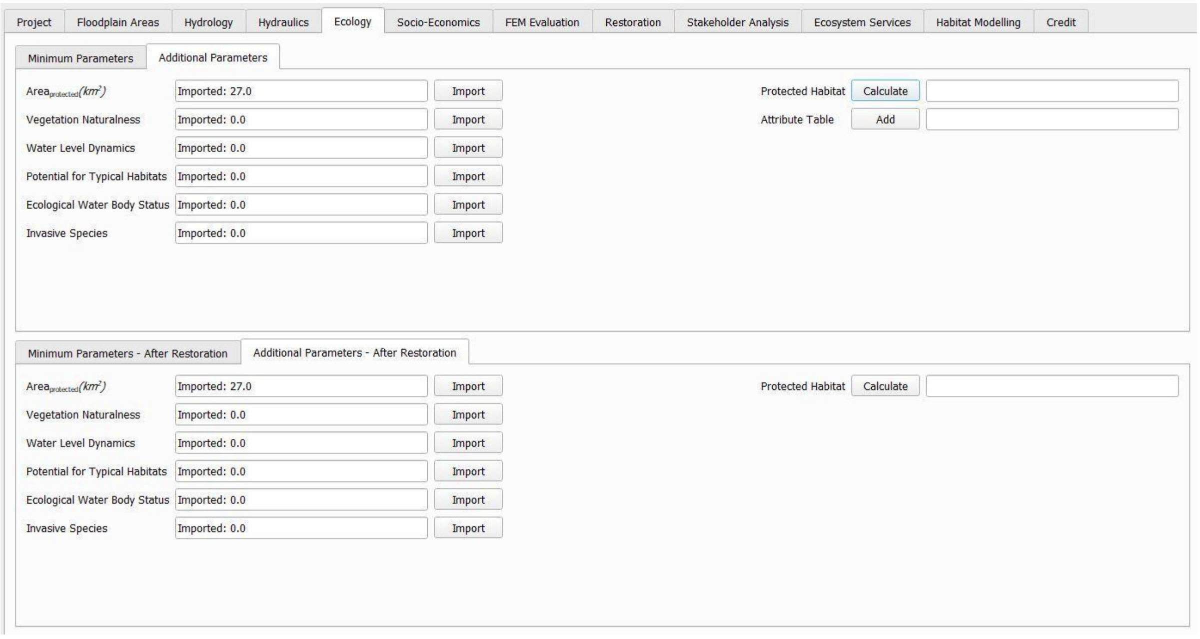


Pic 12.Floodplain area calculations in the FEM tool

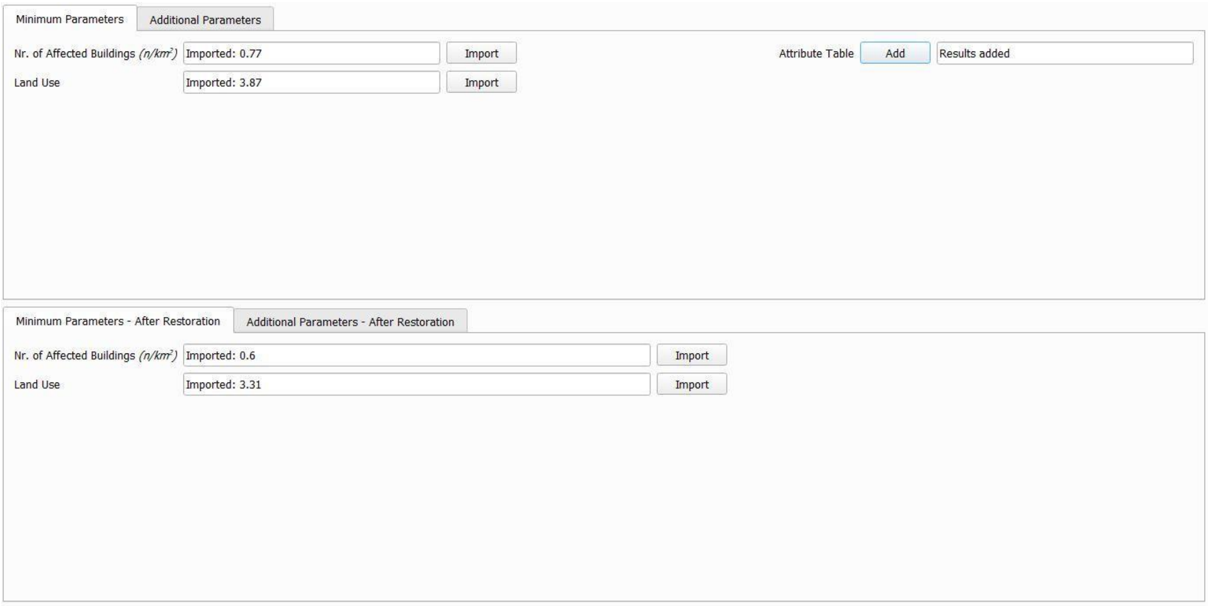
The calculation of hydrological, hydraulic, ecology and socio-economics parameters was successfully performed with the tool:



Pic 13.Hydrology calculations in the FEM tool

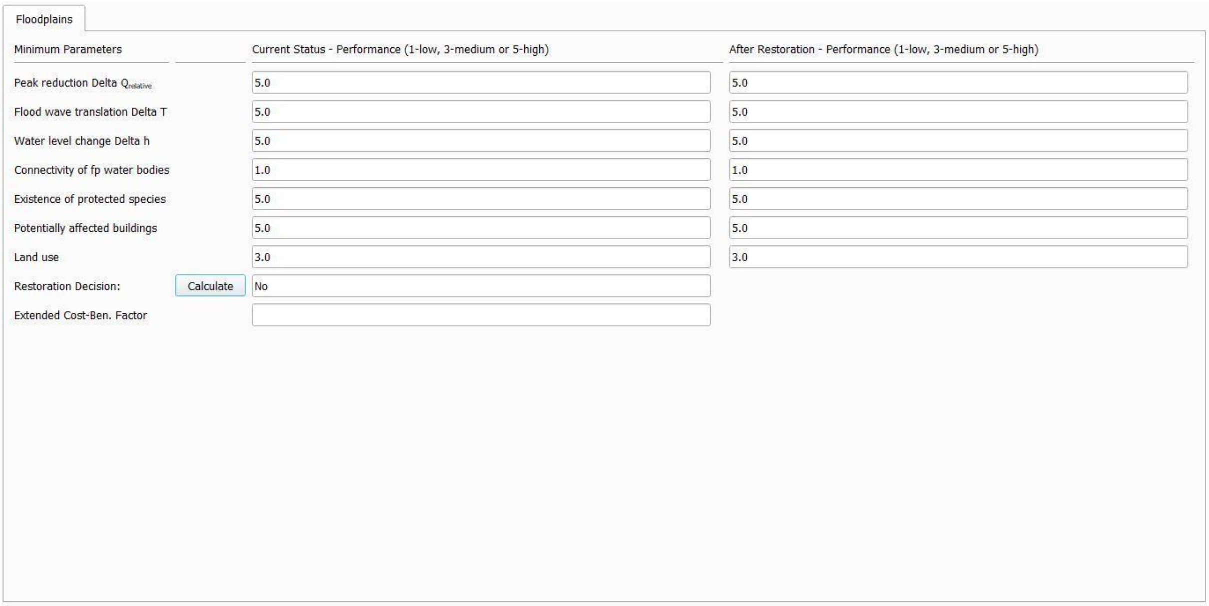


Pic 14.Ecology calculations in the FEM tool



Pic 15.Socio-economics calculations in the FEM tool

The final evaluation of the floodplain was also done successfully with the FEM tool:



Pic 16.FEM analysis results for current and restored status

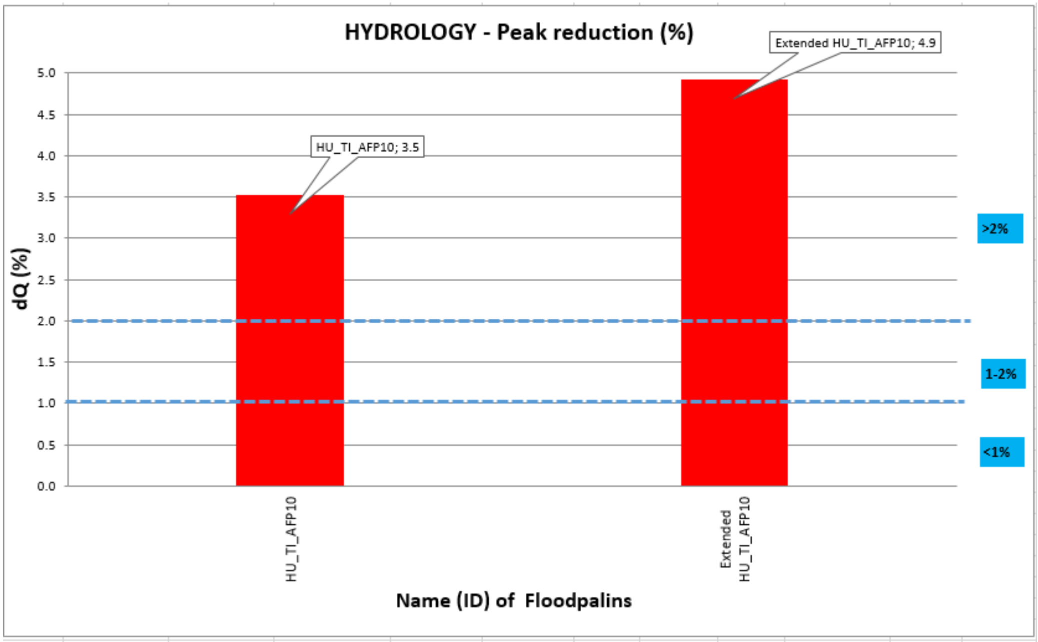
The next chapters will present the results of the FEM analysis in details.

6.2 Hydrology

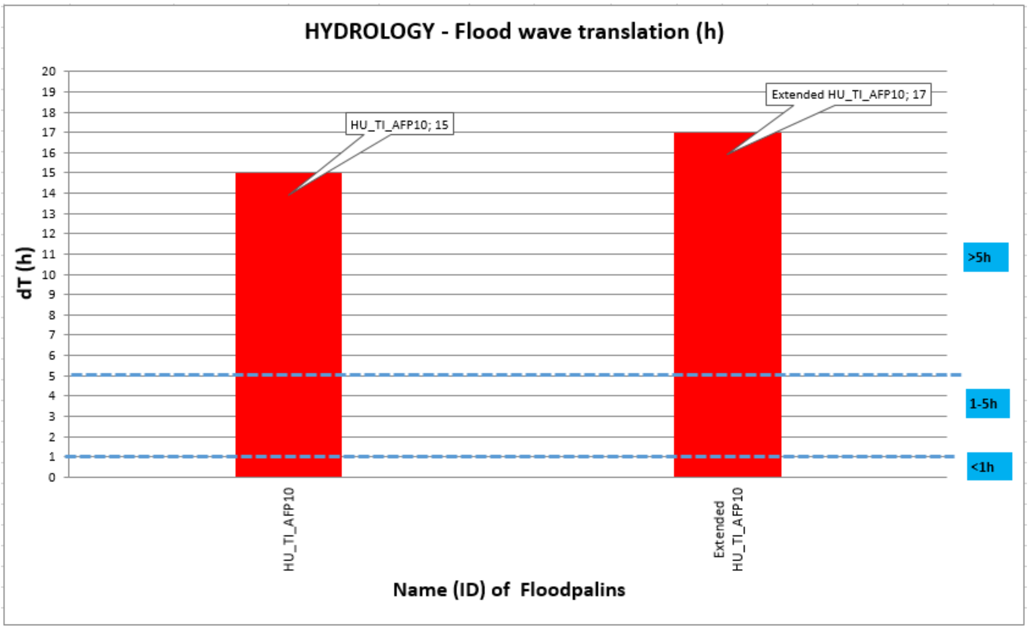
6.2.1 Flood peak reduction – ΔQ and Flood wave translation – Δt

The recommendations of BOKU were taken into account in the overall assessment. For example, we also recalculated the dQ parameters based on the $Q_{bankfull}$ flow.

Result of the evaluation of active and potentional floodplains related peak reduction FEM parameter:



Pic 17. Evaluation of Floodplains (ΔQ FEM parameter)



Pic 18. Evaluation of Floodplains (ΔT FEM parameter)

The flood peak reduction (ΔQ) increases due to the extension of the active floodplain that can be seen in general as positive. However, in some sections along the Hungarian Tisza, the flood peak could increase after a restoration because the floodplain is flooded earlier, resulting in a lower flood peak reduction. A detailed investigation of the hydrological and hydraulic effects for each restoration project is necessary, ensuring a successful project for all involved partners.

6.3. Hydraulics

6.3.1 Water level change - Δh

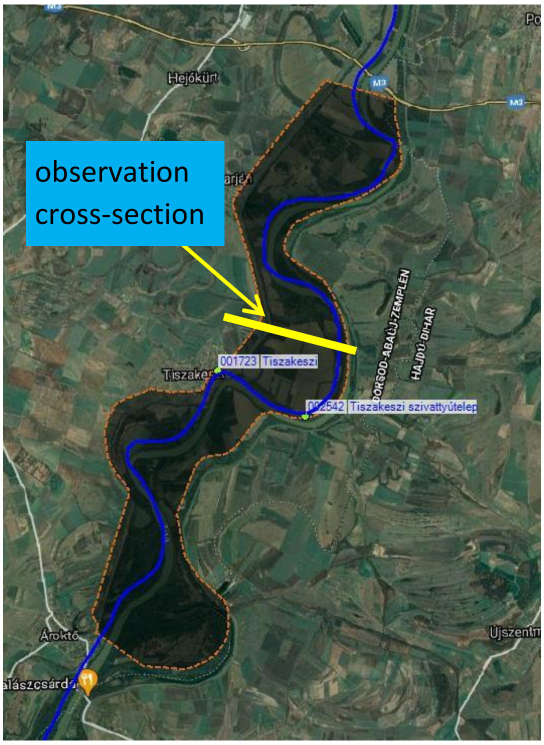
A hydrodynamic numerical model is used to determine the influence of changes in floodplain geometry (for example: dyke shifting or removing that). Reducing or extending floodplain widths by modelling of fictive dykes exhibits how big changes in the water level surface of the scenarios (dH) can be. The observed values can be calculated in a cross section at the middle of the floodplain. In this section we want to show the effects of a total loss of a floodplain in case of water level changes.

All the partners should be used for the river channel model the same hydrograph as for the current state. In that case you just have to start the separate models of the river channel models with the same input hydrograph, which was used for the current state. [1]

Comparison of the water levels of different scenarios we have used the original 1D and a new 2D HEC-RAS models results. We do it this way because of the comparability with the original FEM calculatons.

Workflow:

1. Calculating water level profile for HQ100 with active floodplain
2. Calculating water level profile for HQ100 without active floodplain (inserting virtual dykes along the main channel)
3. Calculating the Δh (m)



Pic 19. Checking cross section at mid of selected AFP related to water level change FEM parameter

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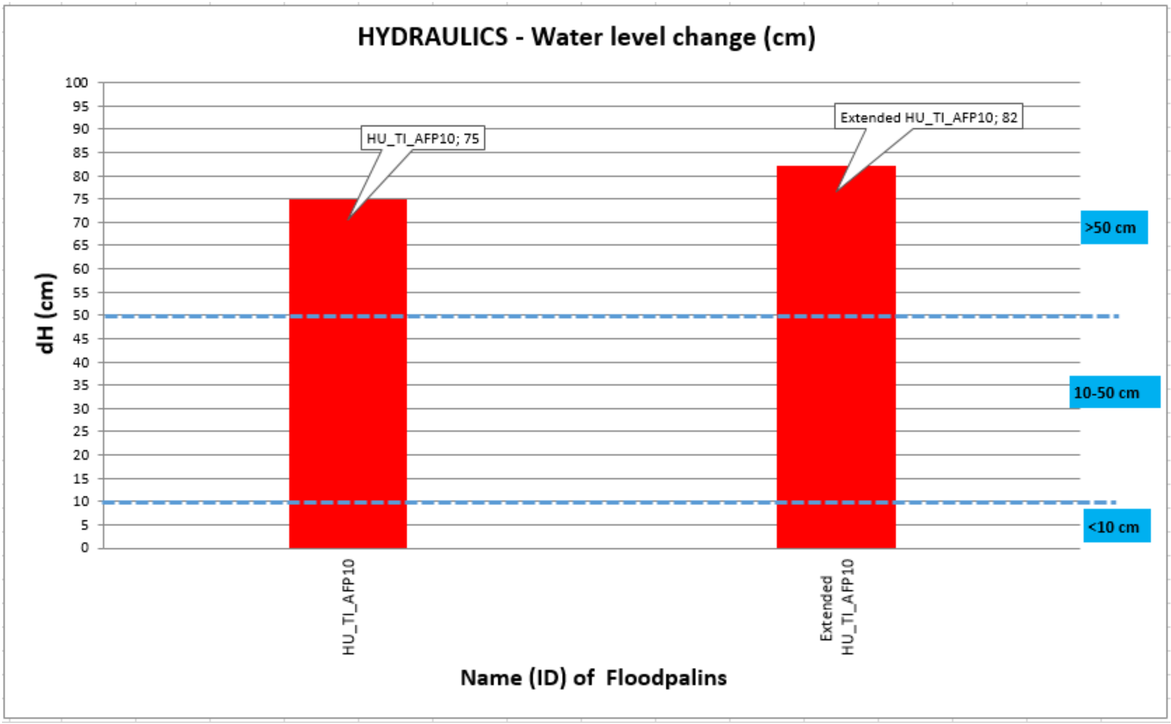
[1] *In case of Tisza River (Hungarian section) we have used different working method regarding the hydraulic parameters. We assumed a hypothetical loss of all floodplains along the Tisza and we used this scenario to calculate the water level change, which is a different approach as the other partners had.*



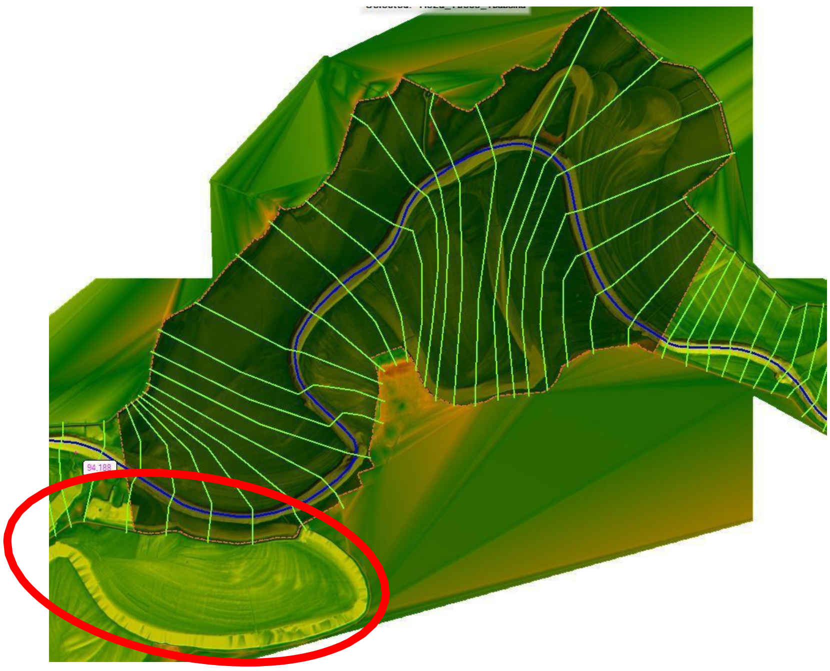
.Pic 20. Evaluation of Floodplains (Δh- FEM parameter)

6.4. Ecology

6.4.1 Connectivity of floodplain water bodies

Connectivity is crucial for the functioning of riverine ecosystems. The longitudinal connectivity describes the connectivity in the up- and downstream direction and is especially relevant for the exchange of populations of water organisms and their migration during their life cycle, the lateral connectivity refers to the connection of the river channel and the floodplain and the vertical connectivity is the connection of the river channel and the ground water table in the floodplain (which might be crucial for small temporary water bodies in the floodplain). For simplification, the connectivity of floodplain water bodies will be investigated only in the lateral direction with the help of 3 Scenarios:

1. mean water level (from gauging stations)
2. bankfull flow (1D/2D modeling)
3. above bankfull flow



Pic 21. Example for downgrading procedure on selected the middle Tisza AFP (results of the "regulation" works on the middle of 19th Century, lots of bends,curves had cutted-off by dykes)

We have used 1D hydraulic model (HEC-RAS numerical model developed by USACE source: https://www.hec.usace.army.mil/software/hec-ras/)to determine the 3 waterlevel profile.

We calculated the three profile in the previous step. Based on these discharge and water level conditions, we have decided the class of the each floodplains.

For determination the "natural (historic)" status of water bodies on the floodplain historic maps were checked. Out of 4 possible outcomes on the comparison between the current status and the historic status:

1) No "natural" (historic) water bodies on the floodplain
2) Existing water bodies on the floodplain (historic and current status)
3) On the historic maps "natural" (historic) water bodies existed, but at the active floodplain no water bodies are left, due to human activity (e.g. dykes etc.)
4) On historic maps "natural" (historic) water bodies existed and are still existing, but were cut off by a dyke

Table 1: Floodplains evaluation – Connectivity of floodplain water bodies AFP – FEM Category:

Floodplain ID	**Classification**
HU_TI_AFP10	1
HU_TI_AFP10 + pilot area	1

6.4.2 Existence of protected species

A floodplain is valuable and should be preserved if red list species or species and habitats (recognized by Natura2000) are found on the area.

For this parameter, the Natura 2000 database was used (http://natura2000.eea.europa.eu/). From this database were used the EC Bird Directive and the Habitats Directive also.

On the active floodplain and on the pilot area was count all species from Birds and Habitats Directive that are listed in the databases. After was generated the summarized protected species, that is an overall number for the floodplain. In the next tables are presented the results of protected species on with and without the extended area too. Because the pilot area connect to the active floodplains, we calculated this parameter in relevant sites together also.

Table 2: Protected species and FEM evaluation with and without the pilot area

Active Floodplains				
Floodplain ID	**Habitats Directive (pcs)**	**Birds Directive (pcs)**	**Total (pcs)**	**FEM Evaluation**
HU_TI_AFP10	29	24	**53**	**5**
HU_TI_AFP10 + pilot area	29	24	**53**	**5**

6.4.3 Existence of protected habitats

This parameter shows how much of the floodplain area is protected according to the Natura 2000 and the national protection sites.

For this parameter, the Natura 2000 database (www.eea.europa.eu) and the national protection areas were used.

These parameters were calculated with GIS analysis. With a GIS tool was created the overlapping protected habitats area on active and floodplain and on the pilot area. After this method was calculated the protected area in all floodplains and create the percentage of protected habitats. In the next tables are presented the results of proportion of protected areas. Because the pilot area connect to the active floodplains, we calculated this parameter in relevant sites together also. The size of the protected areas did not increase with the reconnection of the pilot area.

Table 3: Protected habitats and FEM evaluation on active floodplains

Active Floodplains				
Floodplain ID	**Flooodplain area (ha)**	**Protected habitats (ha)**	**proportion of protected areas (%)**	**FEM Evaluation**
HU_TI_AFP10	7330.88	2704.29	**37**	3
HU_TI_AFP10 + pilot area	9509.88	2704.29	**28**	**1**

6.5. Socio-Economics

6.5.1 Land use

Land use that is adapted to future inundation will minimize the socio-economical vulnerability of the floodplain. Therefore, flood-adapted land use gets the highest rating, non-adapted the lowest (crop farming, settlements). The different types of land uses are aggregated proportional to their areas to one evaluation value for the whole floodplain.

For this was used the CORINE land cover database, that was created in 2018. For all floodplains was created the overlapping layers from CORINE database. Each category was then given a FEM grade (1, 3 or 5) depending on the degree of suitability for such type of land use to be used as a potential flood retention area. Generally speaking, built-up areas were graded as being unsuitable (grade 1), intensive agricultural land as being partly suitable (grade 3), and the rest as being very suitable (grade 5). The details are shown in the following table.

Table 4: Assigned grades to land use categories

Landuse Category	Corine code (Level 1)	Grade
Artificial surfaces	1	1
Agricultural areas	2	3
Forest and semi natural areas	3	5
Wetlands	4	5
Water bodies	5	5

After the specific land use categories were aggregated and graded, the total surface area of all the land use categories with the same grade (1, 3, and 5 respectively) were calculated within each of the floodplains. The three areas within a specific floodplain were then divided by the total area of that floodplain, yielding percentages of the floodplain marked with certain grade. Every percentage and its respective grade in turn yield subtotal grade. Summing up all the subtotal grades of a specific floodplain yields the final FEM assessment as shown in the following table. A significant portion of the new area is arable land so the grade is greatly reduced but did not cause change in FEM value.

Table 5: Land use assessment and FEM evaluation with and without the pilot area

Floodplain	Grade (avg)	FEM Evaluation
HU_TI_AFP10	**3.87**	**3**
HU_TI_AFP10 + pilot area	**3.31**	**3**

6.5.2 Potentially affected buildings

This parameter determines the number of buildings on each active floodplain. The more buildings are affected, the higher is the potential damage.

In the Hungary the Department of Geodesy, Remote Sensing and Land Offices, under the Government Office of the Capital City Budapest created a database with the buildings in whole country (in vector polygon file). For this parameter was used this database.

From the database was identified all building that it finds on active floodplain and on the pilot area. After this collection method was count the total numbers of buildings. With this number and the areas of floodplains was dividing the buildings by the area of the floodplain (for a comparing results). The number of buildings was not increased with the pilot area because it was an important aspect to not affect built environments with the reconnection.

Table 6: Analysis of affected buildings and FEM evaluation with and without the pilot area

Active floodplains					
Floodplain number	Area_ha	Area_km2	number of buildings	buildings/km2	**FEM Evaluation**
HU_TI_AFP10	7330.88	73.31	57	**0.77**	**5**
HU_TI_AFP10 + pilot area	9509.88	95.10	57	**0.60**	**5**

6.6. Final ranking

For fulfilling of the requirements of the overall ranking of **Active floodplains**, a method of a 2-step approach is used:

- **Step 1:** Identifying the need for preservation

  → If at least one parameter of the minimum set is evaluated with a 5 (high performance), than the floodplain **has to be preserved**.

  The analyses showed that every single AFP considered with FEM evaluation and applied thresholds, has at least one parameter evaluated with 5, therefore all of floodplains have **a need for preservation.**

- **Step 2:** Identifying the restoration priority of the **Active floodplains**

  → divided into 3 groups of:

  - **Lower demand → AFPs in this group have the lowest priority for restoration measures**
  - **Medium demand → AFPs in this group have a medium priority for restoration measures**
  - **Higher demand → AFPs in this group have the highest priority for restoration measures**

A priority list with potential preservation degree was made. The FEM final values for the active floodplain area and with the new area were categorized according to this criterion:

Lower demand: max 1x low (1) and 2x medium (3); Min Sum Value: 27

Medium demand: max 2x medium (3) and 2x Low (1); Min Sum Value: 23

Higher demand: all below Medium Demand; Below Sum value: 23

FP	AREA [ha]	PEAK REDUCTION ΔQ	FLOOD WAVE TRANSLATION Δt	WATER LEVEL Δh	CONNECTIVITY OF FP WATER BODIES	PROTECTED SPECIES	PROTECTED HABITATS	LAND USE	AFFECTED BUILDINGS	Restoration priority
HU_TI_AFP10	7330.9	5	5	5	1	5	3	3	5	**Low**
HU_TI_AFP10 + pilot	9509.9	5	5	5	1	5	1	3	5	**Low**

Pic 22. Results of FEM Floodplain Evaluation for the active floodplain nr. 10 and with the new pilot area

Middle Tisza pilot 2.0 FEM Fact Sheet

Countries: Hungary
Editor: KÖTIVIZIG
Date: 12.05.2021.

Need For Preservation	Restoration Demand
No	Lower Demand

Hydrology	
Peak Reduction	5
Flood Wave Translation	5

Hydraulics	
Water Level Change	5
Flow Velocity Change	0
Bed Shear Stress Change	0

Ecology	
Connectivity of FWB	1
Protected Species	5
Protected Habitat	3
Vegetation Naturalness	0
Water Level Dynamics	0
Potential for Typ. Habitats	0
Ecological Water Body Status	0
Invasive Species	0

Socio-Economics	
Affected Buildings	5
Land Use	3
Presence of Doc. Pl. Int.	0

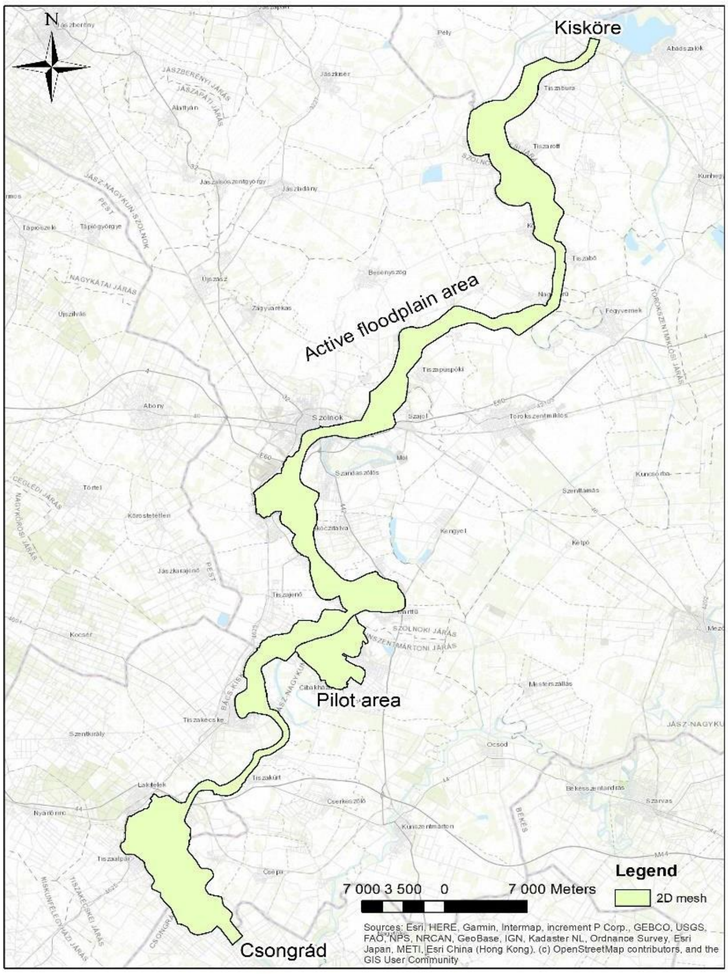
FEM Rating Performance	Ranking
High	5
Medium	3
Low	1

Pic 23. FEM fact sheet about the calculations with the new FEM tool

VII. Hydrodynamic modeling

Evaluating different planned versions of an intervention is a complex process. In designing the present measurement, we developed a multi-step estimating system. As a first step, we studied different conditions by hydrodynamic modeling. This made it possible to quantify the impact of the measurements on the hydrology of the river (e.g. flood peak reduction, changes in run-off conditions). The hydrodynamic model provided different data for further estimation. The cost-benefit analysis used water level time series from the modelling. The potential vegetation modelling used as input data velocity, water depth, water level, and duration result rasters.

The Hydrologic Engineering Center (HEC) of the US Army Corps of Engineers develops the HEC-RAS modelling software. The program has been successfully used for one and two dimensional modelling in the United States of America for all major rivers, and also used in the Danube Floodplain project (US Army Corps of Engineers 2016).



Pic.24.: Modeled area between Kisköre and Csongrád (with the active floodplain and the pilot area)

The model includes approximately a 156 km long river section of the Tisza from Szolnok (402 river km) to Csongrád (246 river km) (Pic.11.). The model has two main parts: a 2D mesh between Kisköre and Csongrád, this mesh only includes the active floodplain area between the dikes, so there are no significant settlements in the area. The other part is the concrete pilot site, which is currently part of the former floodplain. The two areas combined with theoretical interventions: demolished dike, sluiceway and flood gate.

Under the „demolished dike" scenario it is reconnected and high waters can enter the floodplain area without obstacle. In case of the "sluiceway" version only floods exceeding the 30 year return period will be able to enter the floodplain area, while the "flood gate" scenario relies on a flood gate to cut the peak of the flood and release only the peak into the floodplain area. With the exception of the "no modification" scenario all measures require local defense lines on the border of the floodplain, to avoid flooding external areas unintentionally.

We developed three different geometry for the scenarios (current state, demolished dike and dike with structures). The current state version does not include any dike relocation and longitudinal structures. This model geometry represents the state of current active floodplain area with a one meters resolution. The connected pilot site has a 5 meters resolution from a hydrodem.

The geometries have a 2D flow area with 25x25 meters wide computation point spacing. The default Manning's value is set during the calibration and validation. The 2D mesh is the same in the different scenarios (except the original state).

We determined the cultivation branches on the active floodplain and on the pilot site from the Corine land use and by aerial photographs, i.e. by ortho-photographs, as well as by the results of on-site inspections. The roughness factor was changed crosswise according to flood plain cultivation branches. The roughness (smoothness) factor assigned to these was determined on the bases of the prescriptions of the Hungarian standard, as well as on the bases of values applied also by HEC-RAS and proposed by *Chow (1959)*. The smoothness factors assigned to individual cultivation branches overlap each other as there is no possibility for making sharp difference between the categories of "sparse thicket" and "dense thicket".

We used a real event as a basis of our hydrological data The Middle Tisza District Water Directorate has made monitoring along the Tisza River. The following events were simulated: HQ2, HQ5, HQ10, HQ30, HQ50, HQ100. Each HQ is based on the same flood wave of 2000. We modified the flood peak according to the HQ values and modelled a 3 months long period. We have the official HQ values for Kisköre, which is the upstream boundary condition in the model.

The main problem during the calculation was that there is not any remarkable flood wave since some dike relocations were finished on the Middle Tisza region. The other challenge to determine the correct roughness on the floodplain areas where the vegetation is quite dense. We had 2 calibration stations: Martfű, and Tiszaug. The average difference between the computed and the observed data is 0-10 cm at each control point which was considered as a good result.

Introduction of modeling scenarios

Scenario "current state"

The current state scenario represents the current status of the Tisza River. There are no connection between the active floodplain area and the pilot site.

The active floodplain area has a geometry with one meters resolution, and the land use data represents the current conditions.

The results of this scenario (velocity, water depth, duration) were used for CBA and potential vegetation calculations as "0" version.

Scenario "demolished dike"

This version represents the simplest connection between the river and pilot area. The pilot site reconnected to the floodplain by demolishing the primary embankment at 100 meters. The water flows into the area depending on the water level and the terrain.

Two different land use scenarios studied on the pilot area:

- Current state (CS) – based on the Corine 2018 land use data
- Idealistic (RS) –land use based on the geometric, climatic, and hydrological characteristic by the National Park

The results of this scenario (water depth, duration) were used for CBA and potential vegetation calculations.

Scenario "sluiceway"

This version represents a controlled connection between the river and pilot area. The pilot site reconnected to the floodplain by a sluiceway in the primary embankment. The water flows into the area above a specific elevation.

Two different land use scenarios studied on the pilot area:

- Current state (CS) – based on the Corine 2018 land use data
- Idealistic (RS) –land use based on the geometric, climatic, and hydrological characteristic by the National Park

The results of this scenario (water depth) were used for CBA calculations.

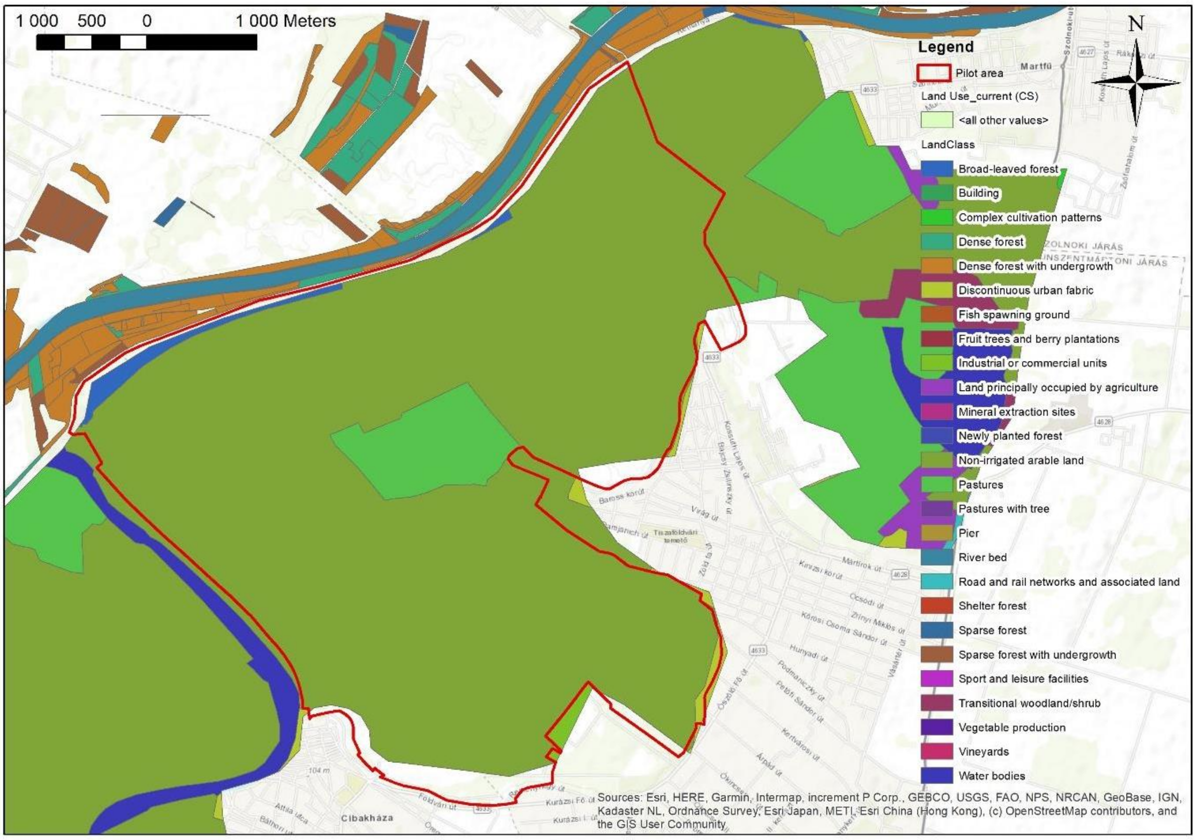
Scenario "flood gate"

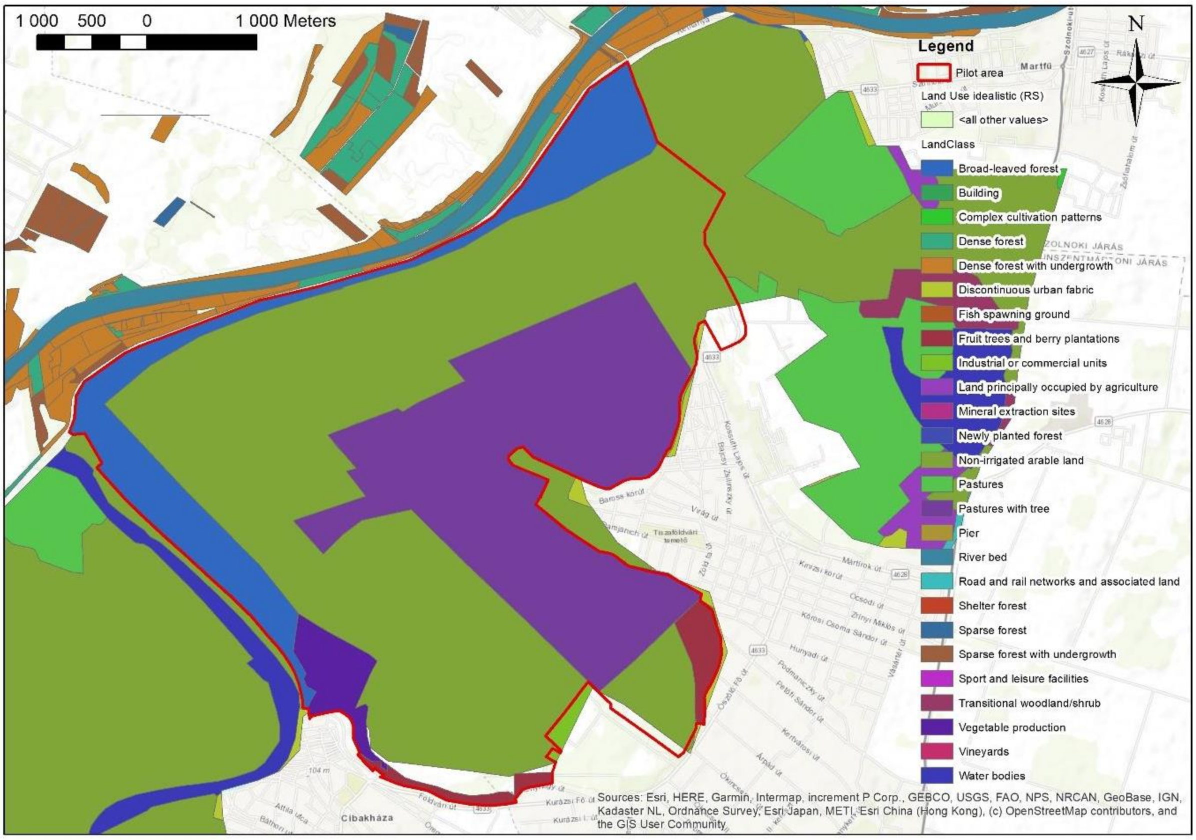
This version represents a controlled connection between the river and pilot area to reduce the flood peak. The pilot site reconnected to the floodplain by a flood gate in the primary embankment. The water flows into the area through a gate and release only the peak into the pilot area.

Two different land use scenarios studied on the pilot area:

- Current state (CS) – based on the Corine 2018 land use data
- Idealistic (RS) –land use based on the geometric, climatic, and hydrological characteristic by the National Park

The results of this scenario (water depth) was used for CBA calculations.





Pic.25.: Land use scenarios: current state (up) from Corine land use, and idealistic (down)

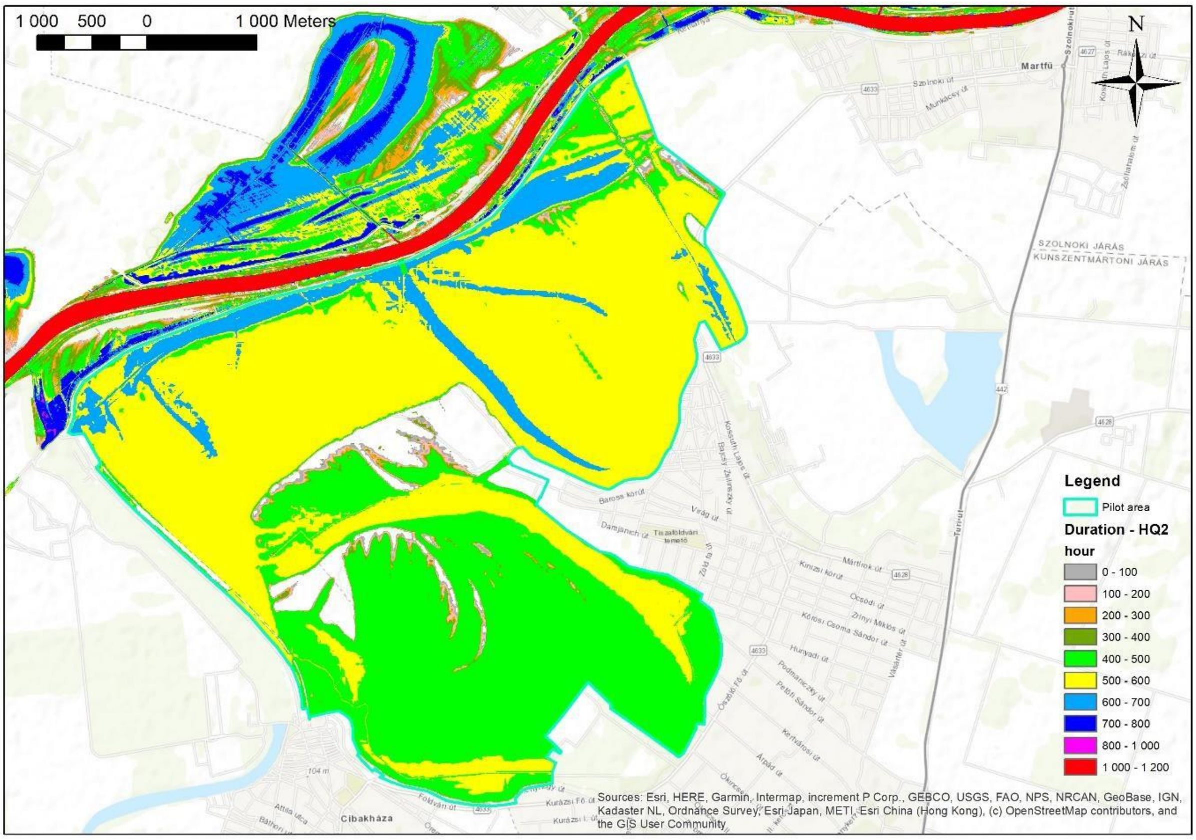
Hydrodinamic modeling results

Hydrodynamic modeling is only the first step in this pilot action, providing important input to the potential vegetation modeling and to the CBA analysis. HEC-RAS easily allows raster export of different result data types.

The following data types were required for further analysis:

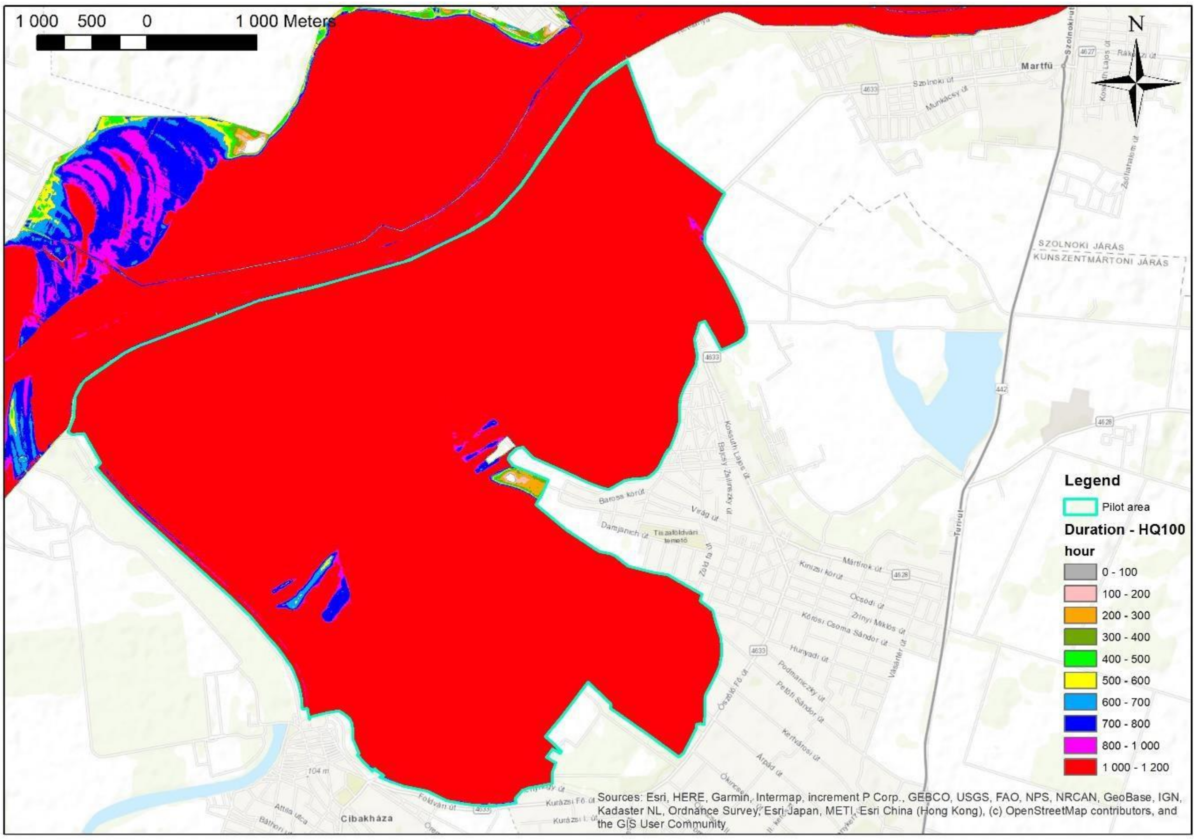
- water depth,
- duration (the period of time when the cell is inundated during the computation).

The floods with frequent return period caused inundation in a large area due to the pilot is a low-lying area. The different land use options did not differ in the characteristic of the different modeling scenarios; the same flood depths were developed.



Pic.26.: Calculated duration with HQ2 hydrological scenario

There is a very significant difference in the duration of the flood waves with the different return periods. The duration varies between 0 and 700 hour with HQ2 and more than 1000 hour with HQ100.



Pic.27.: Calculated duration with HQ100 hydrological scenario

Potential Vegetation

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The concept of Potential Vegetation and its dependence on river regulation modifications

Potential Natural Vegetation (PNV) means the vegetation that would survive without human management, under the abiotic environmental conditions of a given time point. However, by tradition, PNV applies to the present if not indicated otherwise (Tüxen 1956). Therefore, PNV

- means vegetation that is self-sustainable without human management;
- is able to persist, thus it is not a precondition to be able to develop by spontaneous succession at the examined area, for instance in the case of abandonment of previous land use. The propagule availability is not investigated either.
- applies to the present or a specific period, thus it is not corresponding to the prehuman vegetation (i.e. the vegetation before anthropogenic landscape forming activity).

For a more complete discussion of Tüxen's original definition and overview of later interpretations, please refer to Somodi et al. (2012, 2021).

PNV may be different from the actual, observable vegetation. However, in the optimal case, actual vegetation means a subset of the potentially persistable vegetation types. If the PNV of an area does not include the actual vegetation present, sustaining the actual vegetation requires significant amount of management efforts. Chytrý (1998) termed the vegetation that is self-sustainable under certain human management and environmental conditions, potential replacement vegetation (PRV). As the latter usually hosts diverse vegetation types and plays important role in the survival of flagship species, PRV is also an important factor when assessing the landscape’s vegetation potential, particularly regarding future conservation applications.

Initially, PNV was defined as a single vegetation type per site based on the theory claiming deterministic relationship between the vegetation and the environmental conditions. Somodi et al. (2012) introduced an extension of the approach to adapt it to modern ecological knowledge. They interpreted PNV as a probability distribution of multiple vegetation types per location and termed this concept Multiple Potential Natural Vegetation, MPNV. Similarly to PNV, PRV can be understood in a probabilistic framework, as well. Thus, hereinafter we call the union of PNV and PRV as potential vegetation, and abbreviate the corresponding multiple potential vegetation as MPV.

MPV retains the feature of PNV that it depicts the potential of the contemporary abiotic environment to maintain particular vegetation types of any time horizons. Therefore, both PNV and MPV takes anthropogenic modification of the abiotic environment into account, i.e. dikes along a river. In the latter example, both the presence of dikes and their impact on the waterflow are considered when estimating PNV. The term potential vegetation refers to present potential vegetation unless indicated otherwise, thus it applies to present conditions only. However, potential vegetation can be estimated for any time periods and scenarios corresponding to the specific abiotic environment. Scenarios can reflect either climate change expectations or other kind of particular alterations of the abiotic environment (e.g. change caused by rewetting of previously existing wetlands). In the current project, we aimed at assessing the potential changes to the range of vegetation types that could persist under altered hydrological conditions assuming planned river regulation modifications. The specific goals of using the MPV models in this study are

- estimation of the MPV of the designated floodplain site at Tiszaföldvár (hereinafter: prediction site) considering the planned river regulation modifications;
- comparison of the MPV after the proposed river regulation modifications and the current MPV to analyse the impact of the interventions on the potential vegetation;

Modeling the Potential Vegetation

Potential vegetation is estimated through either expert knowledge or correlative models (Somodi et al. 2012). Correlative models try to find the relationship between the predictors i.e. abiotic environmental variables and the response variable i.e. occurrence of the studied object (e.g. species or vegetation type) (Guisan and Zimmermann 2000). These models convert the combination of explanatory variable values into an estimation of the presence value of the studied object through an appropriate function.

Model training is the procedure of selecting the most optimal function from the potential ones; hence, the information in the training data should fit the best. Therefore, when estimating the potential distribution of vegetation types, the environmental preferences of vegetation types are identified by the resulting model. From that model, potential vegetation values can be predicted either for the 'baseline', i.e. the conditions it was trained on, or for hypothetical scenarios by updating the values of the predictors reflecting the scenario. In the case of the current study, the scenario is the modification of the river regulation that is taken into account through the change in water availability in the model. However, the assumptions of this modelling approach has to be considered. As anthropogenic impact and the constraints related to spontaneous succession are not included in the model, the estimation reflects solely the vegetation response to the abiotic environment. Neither are possible outcompetition caused by invasive species and the human effort to hinder their spread considered.

Multiple Potential Vegetation model of Hungary

The present potential vegetation data of the current study are based on the MPV models of Hungary. The initial models (n=38) regarding only PNV were developed by Somodi et al. (2017). Models regarding PRV (n=9) were developed somewhat later on. All the MPV models that take into account both potential natural and potential replacement vegetation types are continuously updated by the authors. MPV yields an estimate whether a vegetation type can be considered as member of the potential vegetation distribution. Table 7. contains the examined 47 vegetation types covering the full range of (semi)natural vegetation of Hungary. Vegetation types were defined originally according to the Hungarian Habitat Classification System (Á-NÉR; Bölöni et al. 2011). However, several vegetation types of Á-NÉR were merged for MPV due to training data properties. The codes of the resulting vegetation types contain the codes of the parent vegetation types separated by underscore(s).

Presence/absence data of vegetation types for the modeling procedure were derived from the Hungarian Actual Habitat Database (MÉTA; www.novenyzetiterkep.hu/english/node/70, Molnár et al. 2007, Horváth et al. 2008). The database was compiled as a result of an exhaustive field survey of the (semi)natural vegetation of Hungary between 2003 and 2006. It contains vegetation data in a ca. 700 m hexagonal grid covering the country (hereinafter: MÉTA grid).

Table 7. The 47 (semi)natural vegetation types modeled in the MPV of Hungary. The third column indicates whether a vegetation type potentially is present at the study site according to the current potential vegetation (i.e. without modifying the river regulation). The fourth column shows a grouping reflecting life form and wetness.

Code	**Name**	**Potential occurrence**	**Habitat category**
B1a	Eu- and mesotrophic reed and *Typha* beds	×	wet/herbaceous
B1b	Oligotrophic reed and *Typha* beds of fens, floating fens		
B4	Tussock sedge communities		
B5	Non-tussock tall-sedge beds	×	wet/herbaceous
B6	Salt marshes	×	wet/herbaceous
D1	Rich fens	×	wet/herbaceous
D2	*Molinia* meadows		
D34	Mesotrophic wet meadows	×	wet/herbaceous
D5	Tall-herb vegetation of stream banks and fens		
D6	Tall-herb vegetation of floodplains, marshes and mesic shadowed forest fringes	×	wet/herbaceous
E1	*Arrhenatherum* hay meadows		
E2_E34_E5	Colline acidofrequent grasslands		
F1a	*Artemisia* salt steppes	×	dry/herbaceous
F2	Salt meadows	×	dry/herbaceous
F4	Dense and tall *Puccinellia* swards (alkaline vegetation)	×	dry/herbaceous
F5	Annual salt pioneer swards of steppes and lakes	×	wet/herbaceous
G1	Open sand steppes	×	dry/herbaceous
G2	Calcareous open rocky grasslands		
G3	Siliceous open rocky grasslands		
H1	Closed rocky grasslands, species rich *Bromus pannonicus* grasslands		
H2	Calcareous rocky steppes		
H3a	Slope steppes on stony ground		
H4	Semi-dry grasslands, forest-steppe meadows		

H5a	Closed steppes on loess, clay, tufa	×	dry/herbaceous
H5b	Closed sand steppes	×	dry/herbaceous
J1a	Willow mire shrubs		
J2	Alder and ash swamp woodlands	×	wet/woodland
J3_J4	Riverine willow shrubs and willow-poplar woodlands	×	wet/woodland
J5	Riverine ash-alder woodlands		
J6	Riverine oak-elm-ash woodlands	×	wet/woodland
K1a_K2_K7b	Oak - hornbeam woodlands		
K5_K7a	Beech woodlands		
L1_M1	Downy oak woodlands		
L2a_L2b	Turkey oak woodlands		
L2x_M2	Closed mixed steppe oak woodlands on foothills and open variants on loess		
L4a_L4b	Acidofrequent oak woodlands		
L5	Closed lowland steppe oak woodlands	×	dry/woodland
LY1	Forests of ravines (mesic rocky forests rich in sycamore maple)		
LY2	Mixed forests of slopes and screes		
LY3	Limestone beech forests		
LY4	Mixed relic oak forests on rocks		
M3	Open salt steppe oak woodlands with openings	×	dry/woodland
M4	Open sand steppe oak woodlands with openings	×	dry/woodland
M5	Poplar-juniper steppe woodlands		
M6	Continental deciduous steppe thickets		
M7	Continental deciduous rocky thickets		
N13	Acidofrequent coniferous forests		

Explanatory variables for the MPV models were calculated from datasets on soil (Pásztor et al. 2015), hydrology, topography (USGS 2004) and climate. All the non-climatic explanatory variables were aggregated in, or extracted to the centre of hexagons of the MÉTA database. Climate data for the model training represent the period between 1971 and 2000. These were acquired from the CarpatClim-Hu database (Szalai et al. 2013) in daily temporal and 0.1° (approx. 10 km) horizontal resolution. After aggregating the climate data to monthly variables averaged over the 30-year period, they were statistically downscaled to the resolution of the MÉTA grid through regression kriging.

The considered environmental predictors originated from the initial set of 68 variables and were selected by limiting pairwise Pearson correlation to 0.7, Variance Inflation Factor (VIF) to 10, and condition number (CN) to 10. Table 8. summarizes the selected 21 explanatory variables.

Table 8. The 21 environmental variables chosen for the MPV model training. The right column indicates relevant variables regarding the proposed river regulation modification.

Environmental predictor	**Potentially affected by river regulation modification**
Isothermality (ratio of mean diurnal range and temperature annual range)	
Maximum temperature of warmest month	
Minimum temperature of the coldest month	
Precipitation of wettest quarter	
Precipitation of driest quarter	
Presence of carbonate bedrock within a hexagon	
Presence of volcanic acidic bedrock within a hexagon	
Presence of volcanic neutral bedrock within a hexagon	
Presence of volcanic alkaline bedrockwithin a hexagon	
Presence of siliciclastic sedimentary and pyroclastic bedrock within a hexagon	
Maximum of sand fraction ratio of the top (0-30 cm) soil layer within a hexagon	
Mean organic matter content within a hexagon	
Mean depth of ground water level within a hexagon	×
Maximum of rooting depth within a hexagon	
Distance of the hexagon centroid to the closest river	×
Distance of the hexagon centroid to the closest stream	
Distance of the hexagon centroid to the closest canal	
Distance of the hexagon centroid to the closest lake	
Distance of the hexagon centroid to the closest non-built (natural) water body of any type (lake, river, stream)	×
Distance of the hexagon centroid to the closest water body of any type (lake, river, stream, canal)	×

Standard deviation of the Topographic Position Index (TPI) within a hexagon	

MPV models were trained for the area of Hungary at the resolution of the MÉTA grid.

Boosted Regression Trees (BRT; a.k.a. Gradient Boosting Model, GBM; Friedman et al. 2000, Friedman 2002, Schapire 2003) were built following the optimization process published by Elith et al. (2008). BRT is a rather robust and flexible modelling approach with outstanding predictive power (Elith et al. 2006, Bühlmann and Hothorn 2007, Velásquez-Tibatá et al. 2016). First, hexagons without any recognisable (semi)natural vegetation were removed. Then, prior to modeling, the remaining data (36.46% of the country) were divided into equal-sized training and evaluation sets by random sampling with prevalence stratification to be able to evaluate the performance of the model in predictions to the reference period. Altogether 47 individual BRT models were trained and evaluated for the 47 examined vegetation types.

Model performance was assessed on the evaluation dataset based on a widely applied (Mouton et al. 2010, Kaymak et al. 2012) goodness-of-fit measure, the Area Under the ROC Curve (AUC; Hanley and McNeil 1982). AUC is between 0 and 1, where 1 indicates the perfect fit. The AUC of the 47 individual models were within the range of 0.811–0.991 with a mean value of 0.940. The models performed excellent according to the AUC method (Swets 1988).

The models predict the probability of occurrence. Therefore, the predictions are within the interval [0; 1]. These raw probability values, however, are not comparable directly across vegetation types. In order to ensure comparability, raw predicted data interpreted on ratio scale were rescaled to a five level ordinal scale. Since the rescaling procedure was performed to each vegetation type separately, different thresholds were calculated for the rescaling of the vegetation types based on the presence/absence data. The interpretation of the values of the resulting ordinal scale:

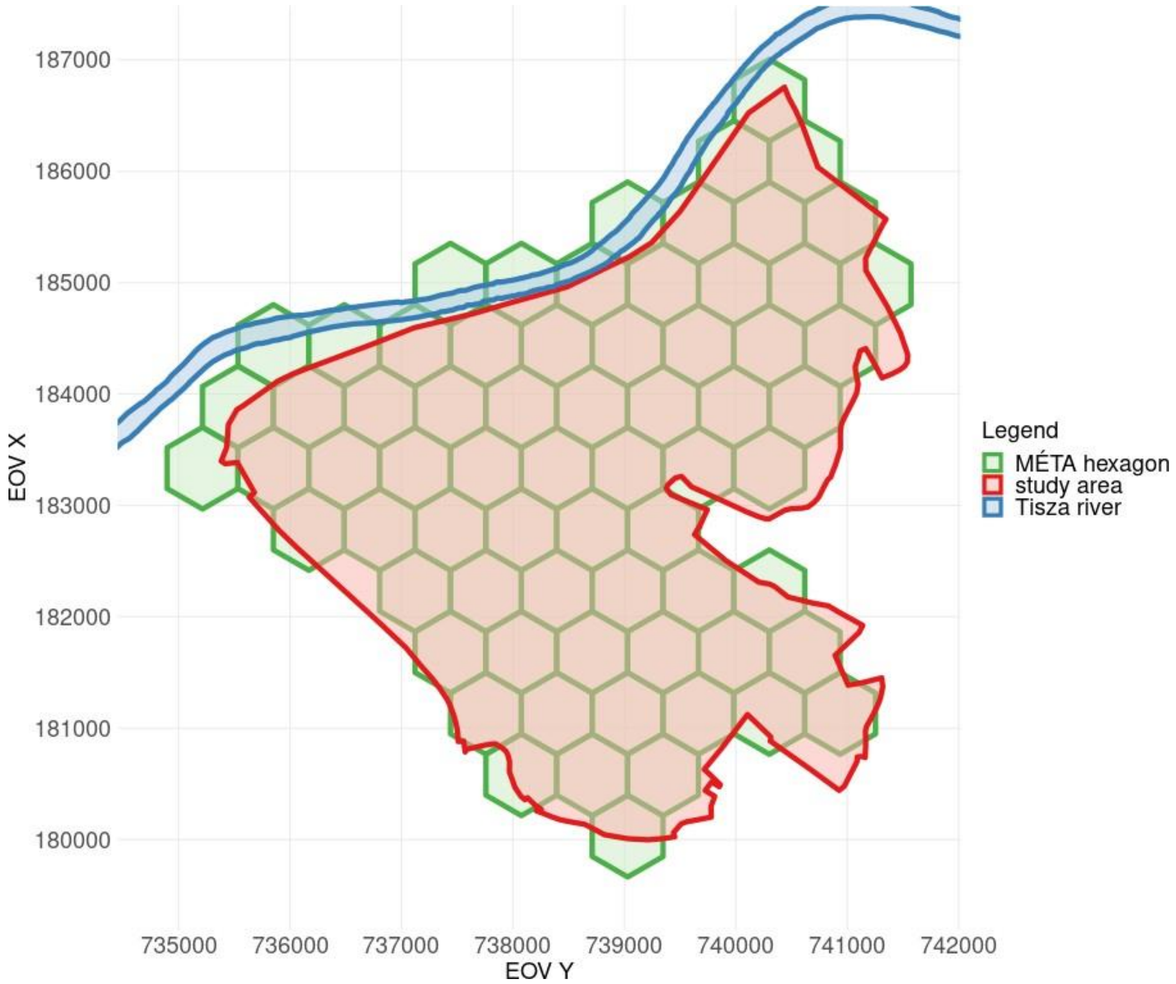
- 0 and 1: not potential;
- 2: fairly potential;
- 3: certainly potential;
- 4: surely potential.

Decision has to be made for each application on which level to consider as fully potential in the case of each study. For the current research, we accept all of the ranks above 1 as potential occurrence. However, we retain their ranks to show relative potentiality.

Modified environmental characteristics of the prediction area

The planned modifications of the river regulation affect the potential vegetation by changing the water availability. Altered water availability is reflected by certain environmental predictors. Four of the 21 predictors used by the MPV model, are potentially modified by the interventions (Table 8). In the current project, prediction with the MPV models were made for the 69 hexagons intersecting with the study area (hereinafter: 'prediction hexagons'; Pic. 28). Environmental predictors were recalculated for the prediction hexagons according to the ‘CS’and 'RS' flood water regulation scenario. The former reflects unchanged land use, the latter modified land use according to expert advice.

The predictor 'Mean depth of ground water level within a hexagon' measured as the distance from the surface was recalculated by training BRT models and using that for predictions to the scenarios. These models were trained on a broader area (Pic. 29) surrounding the prediction site so as to ensure sufficient input data to parametrise the models yielding ground water levels. This way we took an empirical approach where original values were related to water regime parameters from the initial setting by a correlative model and new values of the explanatory variable were determined by feeding the water regime predicted for the scenario into the correlative model. Because this model is highly empirical, it might reflect site-specific relationships.



Pic. 28. Locations of hexagons taken into account for the prediction area.

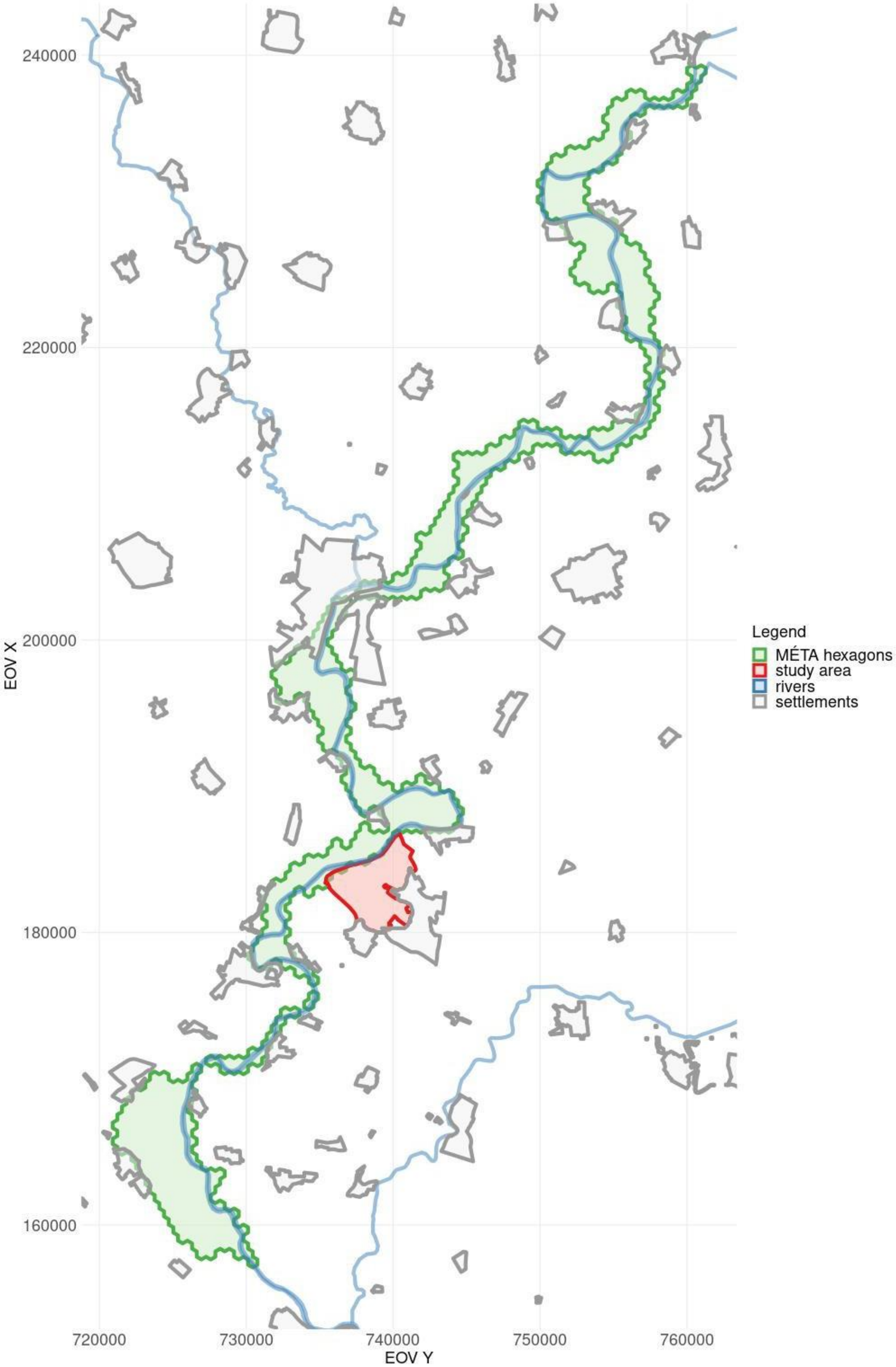
We applied the following calculation steps:

- selection of all the hexagons (n=713) of which more than the half of the hexagon area were covered by the raster of the HQ2 flood of the original scenario. HQ2 was chosen because the largest territory was affected by this flood event;
- for covariates of the model, flood duration and water depth of HQ2, HQ5 and HQ10 flood events of the scenarios were selected;
- BRT model with 2000 trees of three levels, 0.00001 learning rate, normal distribution and 50% bag fraction was trained using the mean depth of ground water level of the 713 hexagons as response variable;

- prediction to the 69 prediction hexagons with the trained BRT model was achieved using flood duration and water depth of HQ2, HQ5 and HQ10 flood events of the CS and RS scenario as covariates.

Original and recalculated predictor values of the 69 prediction hexagons are summarized in Table 9 and Table 10 for the CS and RS scenario respectively.

All analyses were done with the usage of R statistical software (R Core Team 2020), using packages 'concaveman' (Gombin et al. 2020), 'gbm' (Hijmans et al. 2016), 'ggplot2' (Wickham 2009), 'raster' (Hijmans 2015), 'scatterpie' (Yu 2019), 'sf' (Pebesma 2018) and 'sp' (Pebesma and Bivand 2005, Bivand et al. 2013).



Pic. 29 Training area used for ground water models.

Table 9. Original ('orig.'), recalculated ('recalc.') predictor values of the 69 prediction hexagons and their difference ('diff.') for the CS scenario. For the full description of the predictors, please refer to Table 2.

hexagon ID	**mean depth of ground water level**			**distance to the closest river**			**distance to the closest non-built (natural) water body**			**distance to the closest water body**		
	orig.	**recalc.**	**diff.**	**orig.**	**recalc.**	**diff.**	**orig.**	**recalc.**	**diff.**	**orig.**	**recalc.**	**diff.**
191471	2.953	2.414	-0.539	5028.821	4954.294	-74.528	1711.748	1711.748	0.000	1711.748	1711.748	0.000
189647	2.907	2.413	-0.493	3692.875	3609.567	-83.309	317.685	317.685	0.000	317.685	317.685	0.000
189898	2.854	2.413	-0.441	4290.892	4210.065	-80.827	641.861	641.861	0.000	641.861	641.861	0.000
189901	2.743	2.413	-0.330	3826.895	3740.581	-86.314	940.465	940.465	0.000	940.465	940.465	0.000
190488	2.531	2.413	-0.118	4431.278	4348.195	-83.083	1261.704	1261.704	0.000	1261.704	1261.704	0.000
190492	2.780	2.413	-0.367	3954.163	3878.240	-75.923	1571.998	1571.998	0.000	1571.998	1571.998	0.000
191475	2.633	2.413	-0.219	4566.805	4489.296	-77.509	1891.902	1891.902	0.000	1891.902	1891.902	0.000
191478	2.755	2.413	-0.342	4125.328	4045.816	-79.511	2068.614	2068.614	0.000	2068.614	2068.614	0.000
192239	2.629	2.413	-0.215	4348.938	4275.232	-73.706	2426.139	2426.139	0.000	2393.641	2393.641	0.000
192383	2.578	2.413	-0.165	4631.291	4551.364	-79.927	2879.196	2879.196	0.000	1953.379	1953.379	0.000
189242	2.642	2.413	-0.228	2518.482	2433.105	-85.378	493.993	493.993	0.000	493.993	493.993	0.000
189815	2.758	2.413	-0.345	3098.591	3015.827	-82.765	349.683	349.683	0.000	349.683	349.683	0.000
189818	3.004	2.413	-0.591	2609.076	2528.176	-80.900	924.490	924.490	0.000	924.490	924.490	0.000
189651	2.944	2.413	-0.531	3217.310	3132.531	-84.779	849.078	849.078	0.000	849.078	849.078	0.000
189655	2.976	2.413	-0.563	2749.569	2668.899	-80.669	727.974	727.974	0.000	727.974	727.974	0.000

189904	2.965	2.413	-0.552	3346.876	3272.329	-74.547	1263.793	1263.793	0.000	1263.793	1263.793	0.000
189907	2.861	2.413	-0.447	2890.368	2808.788	-81.581	798.964	798.964	0.000	798.964	798.964	0.000
190496	2.743	2.413	-0.329	3507.800	3424.152	-83.649	1433.391	1433.391	0.000	1433.391	1433.391	0.000
190499	2.646	2.413	-0.233	3086.279	3011.738	-74.541	1197.817	1197.817	0.000	1197.817	1197.817	0.000
191481	2.647	2.413	-0.234	3717.391	3642.793	-74.598	1804.526	1804.526	0.000	1804.526	1804.526	0.000
191485	2.636	2.413	-0.222	3360.344	3281.462	-78.882	1740.716	1740.716	0.000	1733.045	1733.045	0.000
192243	2.586	2.413	-0.173	3995.778	3916.297	-79.481	2292.550	2292.550	0.000	1795.104	1795.104	0.000
186493	2.586	2.414	-0.172	710.259	648.184	-62.075	0.000	0.000	0.000	0.000	0.000	0.000
187175	2.370	2.413	0.043	1151.311	1074.567	-76.744	372.061	372.061	0.000	346.606	346.606	0.000
188266	2.515	2.413	-0.101	1763.131	1691.313	-71.818	316.559	316.559	0.000	316.559	316.559	0.000
188270	2.464	2.412	-0.053	1332.324	1261.234	-71.090	941.052	941.052	0.000	769.679	769.679	0.000
187787	2.551	2.413	-0.138	1932.518	1855.767	-76.750	684.641	684.641	0.000	684.641	684.641	0.000
187791	2.579	2.413	-0.166	1421.341	1338.037	-83.304	1108.425	1108.425	0.000	1097.179	1097.179	0.000
189246	2.698	2.413	-0.285	2011.432	1927.937	-83.495	814.407	814.407	0.000	814.407	814.407	0.000
189250	2.796	2.413	-0.382	1537.075	1450.711	-86.364	505.919	505.919	0.000	505.919	505.919	0.000
189822	3.076	2.413	-0.663	2146.586	2060.709	-85.877	290.051	290.051	0.000	290.051	290.051	0.000
189825	3.007	2.414	-0.593	1664.975	1590.370	-74.605	216.422	216.422	0.000	216.422	216.422	0.000
189659	2.994	2.413	-0.580	2275.522	2198.929	-76.594	171.495	171.495	0.000	171.495	171.495	0.000
189663	2.907	2.414	-0.494	1833.396	1759.738	-73.658	440.787	440.787	0.000	440.787	440.787	0.000

189909	2.761	2.413	-0.348	2457.455	2383.165	-74.289	649.236	649.236	0.000	649.236	649.236	0.000
189912	2.775	2.413	-0.362	2089.953	2011.928	-78.024	990.940	990.940	0.000	990.940	990.940	0.000
190507	2.536	2.413	-0.123	2430.294	2346.313	-83.981	1605.590	1605.590	0.000	1385.862	1385.862	0.000
186497	2.475	2.413	-0.063	539.832	457.448	-82.384	426.515	426.515	0.000	275.561	275.561	0.000
186501	2.472	2.413	-0.060	138.639	43.201	-95.437	138.639	43.201	-95.437	138.639	43.201	-95.437
187179	2.327	2.413	0.086	737.799	644.269	-93.529	737.799	644.269	-93.529	148.429	148.429	0.000
187183	2.469	2.413	-0.055	250.653	180.084	-70.570	250.653	180.084	-70.570	158.831	158.831	0.000
188273	2.404	2.413	0.009	846.698	756.913	-89.785	846.698	756.913	-89.785	469.174	469.174	0.000
188277	2.410	2.413	0.003	329.988	246.722	-83.266	329.988	246.722	-83.266	60.535	60.535	0.000
187795	2.432	2.413	-0.019	927.797	846.285	-81.511	927.797	846.285	-81.511	679.039	679.039	0.000
187799	2.382	2.413	0.031	466.276	379.659	-86.617	466.276	379.659	-86.617	239.844	239.844	0.000
189253	2.530	2.413	-0.117	1067.859	988.673	-79.186	774.360	774.360	0.000	774.360	774.360	0.000
189257	2.470	2.413	-0.057	598.236	520.811	-77.426	598.236	520.811	-77.426	418.871	418.871	0.000
189829	2.807	2.413	-0.394	1215.668	1132.624	-83.045	827.786	827.786	0.000	827.786	827.786	0.000
189832	2.456	2.413	-0.043	819.845	742.394	-77.450	819.845	742.394	-77.450	638.843	638.843	0.000
189667	2.629	2.413	-0.215	1454.898	1377.161	-77.737	1069.630	1069.630	0.000	1069.630	1069.630	0.000
189672	2.541	2.413	-0.127	1169.016	1089.678	-79.338	1169.016	1089.678	-79.338	913.704	913.704	0.000
189915	2.577	2.413	-0.164	1797.937	1718.826	-79.110	1528.372	1528.372	0.000	1452.390	1452.390	0.000
189918	2.447	2.413	-0.034	1603.446	1516.284	-87.162	1603.446	1516.284	-87.162	918.054	918.054	0.000

190510	2.386	2.413	0.027	2218.354	2123.383	-94.971	2082.313	2082.313	0.000	882.666	882.666	0.000
190514	2.471	2.413	-0.058	2089.985	2001.179	-88.805	1844.008	1844.008	0.000	352.054	352.054	0.000
188281	2.299	2.413	0.114	143.089	80.852	-62.236	143.089	80.852	-62.236	143.089	80.852	-62.236
187804	2.444	2.413	-0.032	15.750	0.000	-15.750	15.750	0.000	-15.750	15.750	0.000	-15.750
189261	2.408	2.413	0.004	184.791	109.300	-75.491	184.791	109.300	-75.491	7.693	7.693	0.000
189265	2.455	2.413	-0.042	73.648	0.000	-73.648	73.648	0.000	-73.648	73.648	0.000	-73.648
189836	2.373	2.413	0.040	542.398	458.999	-83.400	542.398	458.999	-83.400	277.987	277.987	0.000
189840	2.378	2.413	0.035	409.535	324.530	-85.004	409.535	324.530	-85.004	82.893	82.893	0.000
189676	2.554	2.413	-0.141	1000.857	917.891	-82.966	1000.857	917.891	-82.966	537.041	537.041	0.000
189680	2.398	2.413	0.015	933.820	849.077	-84.743	933.820	849.077	-84.743	163.501	163.501	0.000
189921	2.497	2.413	-0.084	1499.822	1416.555	-83.266	1499.822	1416.555	-83.266	368.731	368.731	0.000
189924	2.553	2.413	-0.140	1463.498	1389.339	-74.160	1463.498	1389.339	-74.160	54.192	54.192	0.000
190518	2.707	2.414	-0.294	2034.118	1949.673	-84.446	1654.014	1654.014	0.000	181.158	181.158	0.000
189844	2.227	2.413	0.186	366.627	295.147	-71.480	366.627	295.147	-71.480	366.627	295.147	-71.480
189848	2.303	2.413	0.111	299.889	221.571	-78.318	299.889	221.571	-78.318	299.889	221.571	-78.318
189684	2.414	2.414	0.000	885.000	808.858	-76.141	885.000	808.858	-76.141	143.036	143.036	0.000

Table 10. Original ('orig.'), recalculated ('recalc.') predictor values of the 69 prediction hexagons and their difference ('diff.') for the RS scenario. For the full description of the predictors, please refer to Table 2.

hexagon ID	**mean depth of ground water level**			**distance to the closest river**			**distance to the closest non-built (natural) water body**			**distance to the closest water body**		
	orig.	**recalc.**	**diff.**	**orig.**	**recalc.**	**diff.**	**orig.**	**recalc.**	**diff.**	**orig.**	**recalc.**	**diff.**
191471	2.953	2.414	-0.539	5028.821	4954.294	-74.528	1711.748	1711.748	0.000	1711.748	1711.748	0.000
189647	2.907	2.413	-0.493	3692.875	3609.567	-83.309	317.685	317.685	0.000	317.685	317.685	0.000
189898	2.854	2.413	-0.441	4290.892	4210.065	-80.827	641.861	641.861	0.000	641.861	641.861	0.000
189901	2.743	2.413	-0.330	3826.895	3740.581	-86.314	940.465	940.465	0.000	940.465	940.465	0.000
190488	2.531	2.413	-0.118	4431.278	4348.195	-83.083	1261.704	1261.704	0.000	1261.704	1261.704	0.000
190492	2.780	2.413	-0.367	3954.163	3878.240	-75.923	1571.998	1571.998	0.000	1571.998	1571.998	0.000
191475	2.633	2.413	-0.219	4566.805	4489.296	-77.509	1891.902	1891.902	0.000	1891.902	1891.902	0.000
191478	2.755	2.413	-0.342	4125.328	4045.816	-79.511	2068.614	2068.614	0.000	2068.614	2068.614	0.000
192239	2.629	2.413	-0.215	4348.938	4275.232	-73.706	2426.139	2426.139	0.000	2393.641	2393.641	0.000
192383	2.578	2.413	-0.165	4631.291	4551.364	-79.927	2879.196	2879.196	0.000	1953.379	1953.379	0.000
189242	2.642	2.413	-0.228	2518.482	2433.105	-85.378	493.993	493.993	0.000	493.993	493.993	0.000
189815	2.758	2.413	-0.345	3098.591	3015.827	-82.765	349.683	349.683	0.000	349.683	349.683	0.000
189818	3.004	2.413	-0.591	2609.076	2528.176	-80.900	924.490	924.490	0.000	924.490	924.490	0.000
189651	2.944	2.413	-0.531	3217.310	3132.531	-84.779	849.078	849.078	0.000	849.078	849.078	0.000
189655	2.976	2.413	-0.563	2749.569	2668.899	-80.669	727.974	727.974	0.000	727.974	727.974	0.000

189904	2.965	2.413	-0.552	3346.876	3272.329	-74.547	1263.793	1263.793	0.000	1263.793	1263.793	0.000
189907	2.861	2.413	-0.447	2890.368	2808.788	-81.581	798.964	798.964	0.000	798.964	798.964	0.000
190496	2.743	2.413	-0.329	3507.800	3424.152	-83.649	1433.391	1433.391	0.000	1433.391	1433.391	0.000
190499	2.646	2.413	-0.233	3086.279	3011.738	-74.541	1197.817	1197.817	0.000	1197.817	1197.817	0.000
191481	2.647	2.413	-0.234	3717.391	3642.793	-74.598	1804.526	1804.526	0.000	1804.526	1804.526	0.000
191485	2.636	2.413	-0.222	3360.344	3281.462	-78.882	1740.716	1740.716	0.000	1733.045	1733.045	0.000
192243	2.586	2.413	-0.173	3995.778	3916.297	-79.481	2292.550	2292.550	0.000	1795.104	1795.104	0.000
186493	2.586	2.414	-0.172	710.259	648.184	-62.075	0.000	0.000	0.000	0.000	0.000	0.000
187175	2.370	2.413	0.043	1151.311	1074.567	-76.744	372.061	372.061	0.000	346.606	346.606	0.000
188266	2.515	2.413	-0.101	1763.131	1691.313	-71.818	316.559	316.559	0.000	316.559	316.559	0.000
188270	2.464	2.412	-0.052	1332.324	1261.234	-71.090	941.052	941.052	0.000	769.679	769.679	0.000
187787	2.551	2.413	-0.138	1932.518	1855.767	-76.750	684.641	684.641	0.000	684.641	684.641	0.000
187791	2.579	2.413	-0.166	1421.341	1338.037	-83.304	1108.425	1108.425	0.000	1097.179	1097.179	0.000
189246	2.698	2.413	-0.285	2011.432	1927.937	-83.495	814.407	814.407	0.000	814.407	814.407	0.000
189250	2.796	2.413	-0.382	1537.075	1450.711	-86.364	505.919	505.919	0.000	505.919	505.919	0.000
189822	3.076	2.413	-0.663	2146.586	2060.709	-85.877	290.051	290.051	0.000	290.051	290.051	0.000
189825	3.007	2.414	-0.593	1664.975	1590.370	-74.605	216.422	216.422	0.000	216.422	216.422	0.000
189659	2.994	2.413	-0.580	2275.522	2198.929	-76.594	171.495	171.495	0.000	171.495	171.495	0.000
189663	2.907	2.414	-0.494	1833.396	1759.738	-73.658	440.787	440.787	0.000	440.787	440.787	0.000

189909	2.761	2.413	-0.348	2457.455	2383.165	-74.289	649.236	649.236	0.000	649.236	649.236	0.000
189912	2.775	2.413	-0.362	2089.953	2011.928	-78.024	990.940	990.940	0.000	990.940	990.940	0.000
190507	2.536	2.413	-0.123	2430.294	2346.313	-83.981	1605.590	1605.590	0.000	1385.862	1385.862	0.000
186497	2.475	2.413	-0.063	539.832	457.448	-82.384	426.515	426.515	0.000	275.561	275.561	0.000
186501	2.472	2.413	-0.060	138.639	43.201	-95.437	138.639	43.201	-95.437	138.639	43.201	-95.437
187179	2.327	2.413	0.086	737.799	644.269	-93.529	737.799	644.269	-93.529	148.429	148.429	0.000
187183	2.469	2.413	-0.055	250.653	180.084	-70.570	250.653	180.084	-70.570	158.831	158.831	0.000
188273	2.404	2.413	0.009	846.698	756.913	-89.785	846.698	756.913	-89.785	469.174	469.174	0.000
188277	2.410	2.413	0.003	329.988	246.722	-83.266	329.988	246.722	-83.266	60.535	60.535	0.000
187795	2.432	2.413	-0.019	927.797	846.285	-81.511	927.797	846.285	-81.511	679.039	679.039	0.000
187799	2.382	2.413	0.031	466.276	379.659	-86.617	466.276	379.659	-86.617	239.844	239.844	0.000
189253	2.530	2.413	-0.117	1067.859	988.673	-79.186	774.360	774.360	0.000	774.360	774.360	0.000
189257	2.470	2.413	-0.057	598.236	520.811	-77.426	598.236	520.811	-77.426	418.871	418.871	0.000
189829	2.807	2.413	-0.394	1215.668	1132.624	-83.045	827.786	827.786	0.000	827.786	827.786	0.000
189832	2.456	2.413	-0.043	819.845	742.394	-77.450	819.845	742.394	-77.450	638.843	638.843	0.000
189667	2.629	2.413	-0.215	1454.898	1377.161	-77.737	1069.630	1069.630	0.000	1069.630	1069.630	0.000
189672	2.541	2.413	-0.127	1169.016	1089.678	-79.338	1169.016	1089.678	-79.338	913.704	913.704	0.000
189915	2.577	2.413	-0.164	1797.937	1718.826	-79.110	1528.372	1528.372	0.000	1452.390	1452.390	0.000
189918	2.447	2.413	-0.034	1603.446	1516.284	-87.162	1603.446	1516.284	-87.162	918.054	918.054	0.000

190510	2.386	2.413	0.027	2218.354	2123.383	-94.971	2082.313	2082.313	0.000	882.666	882.666	0.000
190514	2.471	2.413	-0.058	2089.985	2001.179	-88.805	1844.008	1844.008	0.000	352.054	352.054	0.000
188281	2.299	2.413	0.114	143.089	80.852	-62.236	143.089	80.852	-62.236	143.089	80.852	-62.236
187804	2.444	2.413	-0.032	15.750	0.000	-15.750	15.750	0.000	-15.750	15.750	0.000	-15.750
189261	2.408	2.413	0.004	184.791	109.300	-75.491	184.791	109.300	-75.491	7.693	7.693	0.000
189265	2.455	2.413	-0.042	73.648	0.000	-73.648	73.648	0.000	-73.648	73.648	0.000	-73.648
189836	2.373	2.413	0.040	542.398	458.999	-83.400	542.398	458.999	-83.400	277.987	277.987	0.000
189840	2.378	2.413	0.035	409.535	324.530	-85.004	409.535	324.530	-85.004	82.893	82.893	0.000
189676	2.554	2.413	-0.141	1000.857	917.891	-82.966	1000.857	917.891	-82.966	537.041	537.041	0.000
189680	2.398	2.413	0.015	933.820	849.077	-84.743	933.820	849.077	-84.743	163.501	163.501	0.000
189921	2.497	2.413	-0.084	1499.822	1416.555	-83.266	1499.822	1416.555	-83.266	368.731	368.731	0.000
189924	2.553	2.413	-0.140	1463.498	1389.339	-74.160	1463.498	1389.339	-74.160	54.192	54.192	0.000
190518	2.707	2.414	-0.294	2034.118	1949.673	-84.446	1654.014	1654.014	0.000	181.158	181.158	0.000
189844	2.227	2.413	0.186	366.627	295.147	-71.480	366.627	295.147	-71.480	366.627	295.147	-71.480
189848	2.303	2.413	0.111	299.889	221.571	-78.318	299.889	221.571	-78.318	299.889	221.571	-78.318
189684	2.414	2.414	0.000	885.000	808.858	-76.141	885.000	808.858	-76.141	143.036	143.036	0.000

Potential Vegetation of the prediction area

Predictions to the baseline and the river regulation scenarios

MPV estimations are identical for the CS and RS scenarios, even though the mean groundwater levels were slightly different for the two scenarios reflecting minor differences in the expected water regime given the two scenarios (Table 3 and 4). This shows that the differences in the water flow do not significantly influence the site conditions from the point of view of vegetation.

19 out of the 47 studied vegetation types potentially occur in one or more of the prediction hexagons (Table 1). The set of the 19 vegetation types is the same for the baseline prediction and for the prediction taking the planned river regulation modifications into account. Three types of marshes (B1a, B5, B6), three of the 'rich fens, wet grasslands and tall-herb vegetation' category (D1, D34, D6), all the four studied halophytic habitats (F1a, F2, F4, F5), two of the category 'dry and semi-dry closed grasslands' (H5a, H5b), three of the 'riverine and swamp woodlands' (J2, J3_J4, J6) and three 'dry deciduous woodlands' (L5, M3, M4) are predicted to potentially occur. Predicted potential occurrence of these 19 vegetation types in the prediction hexagons are summarized in Table 11 and Table 12, and displayed in Pic. 30 and Pic. 31. Difference of the two predictions is summarized in Table 13.

The potential vegetation before interventions shows mixed landscape potential. Potential presence of wetland vegetation appears close to the river, but reeds (B1a) are also prominently potential at the opposite part of the area, likely due to the proximity of an oxbow. Partly due to the narrow strip of actively flooded area along the river within the current dikes, partly due to potentially wetter conditions close to the dike on its other side as well. Here reeds (B1a), gallery forests (J3_J4) and wet grasslands are strongly present in the baseline MPV as well. However, not far from the dike and the river, dry vegetation gains a higher proportion within baseline MPV. Thus steppe vegetation including forest steppe forests (M3, M4), steppe grasslands (particularly H5a) and alkaline grasslands (F1a, F2, F3, F4) present the highest share of potential vegetation at the farthest points from the river (Table 11).

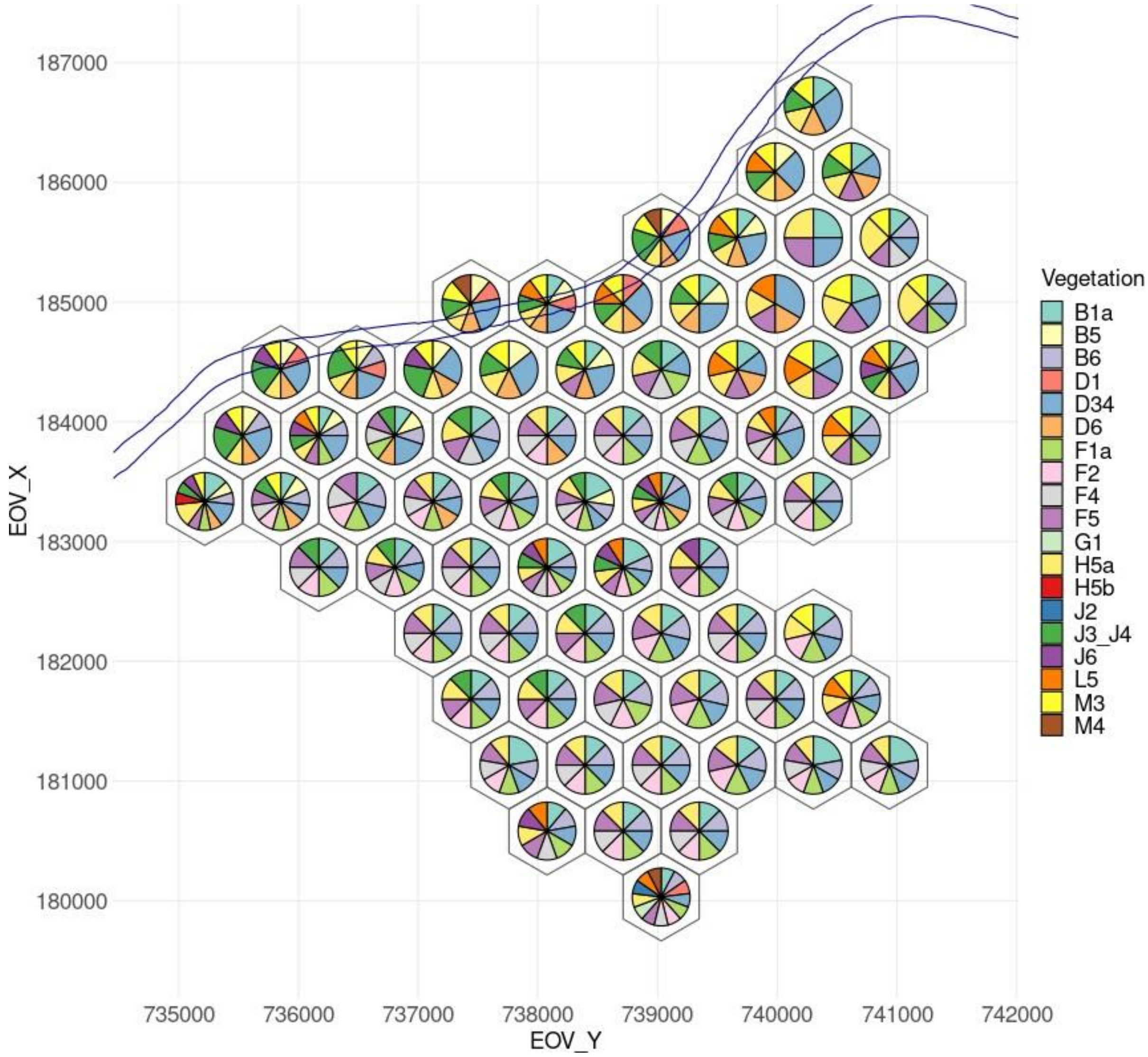
As opposed to this, wetland vegetation has higher ranks in the MPV of the river regulation scenarios. Both gallery forests (J3_J4 and J6) and wet herbaceous vegetation (D6, D34) will be potentially widespread. Reeds (B1a) will be an important part of MPV towards the middle and the South of the study area. The share of alkaline vegetation is also pronounced in the MPV.

Table 11. Predicted potential occurrence of vegetation types according to the baseline. Ranks larger than 1 are highlighted. For the code of vegetation types, please refer to Table 1. The habitat distribution of the hexagons is shown in Fig. 3.

B1a	B5	B6	D1	D34	D6	F1a	F2	F4	F5	G1	H5a	H5b	J2	J3_J4	J6	L5	M3
2	1	2	2	2	1	2	2	2	2	2	2	1	2	1	1	2	1
3	1	2	1	2	1	2	2	2	2	1	2	1	1	1	1	1	1
2	1	2	1	2	1	2	1	2	2	1	2	1	1	1	2	2	1
2	1	2	1	2	1	2	2	2	2	1	2	1	1	1	1	1	1
2	1	2	1	2	1	2	2	2	2	1	2	1	1	1	1	1	1
2	1	2	1	2	1	2	2	2	2	1	2	0	1	1	1	1	1
2	1	2	1	2	1	2	2	2	2	1	2	1	1	1	1	1	1
2	1	2	1	2	1	2	2	1	2	1	2	0	1	1	1	1	1
3	1	2	0	2	1	2	2	2	2	1	2	0	1	1	1	1	1
3	1	2	1	2	1	2	2	2	2	1	2	1	1	1	1	1	1
2	1	2	1	2	1	2	2	2	2	1	2	1	1	1	1	1	1
2	1	2	1	2	1	2	2	1	2	1	2	1	1	2	1	1	1
2	1	2	1	2	1	2	2	2	2	1	2	1	1	1	1	1	1
2	1	2	1	2	1	2	2	1	2	1	2	1	1	2	1	1	1
2	1	2	1	2	1	2	2	1	2	1	2	0	1	2	1	1	1
2	1	2	1	1	1	2	2	2	2	1	2	1	1	1	1	1	1
2	1	2	1	2	1	2	2	1	2	1	2	1	1	1	1	1	1
2	1	2	1	2	1	2	2	1	2	1	2	0	1	1	1	1	1
2	1	2	1	2	1	2	2	2	2	1	2	0	1	1	1	1	1
2	1	2	1	2	1	2	2	2	2	1	2	1	1	1	1	1	1
2	1	2	1	2	1	2	2	1	1	1	2	1	1	1	1	1	2
2	1	2	1	2	1	2	2	1	2	1	2	1	1	1	1	2	2
3	2	2	1	3	2	2	1	1	2	1	3	2	1	2	2	1	2
2	2	2	1	2	2	2	2	2	2	1	1	1	1	2	1	1	2
2	1	2	1	2	1	2	2	2	2	1	1	1	1	2	1	1	1

2	1	2	1	2	1	2	2	2	2	1	1	1	1	1	1	1	1
2	1	2	1	2	1	2	2	2	2	1	2	1	1	2	1	1	1
2	1	2	1	2	2	2	2	2	2	1	2	1	1	1	1	1	1
2	1	2	1	2	1	2	2	2	2	1	2	1	1	1	1	1	1
2	1	2	1	2	1	2	2	2	2	1	2	1	1	2	1	1	1
3	1	2	1	2	1	2	2	2	2	1	2	1	1	2	2	2	1
3	2	2	1	2	1	2	2	2	2	1	2	1	1	2	1	1	1
3	1	2	1	2	1	2	2	1	2	1	2	1	1	2	2	2	1
2	1	2	1	3	2	2	2	2	2	1	2	1	1	2	2	2	1
2	1	2	1	2	1	2	2	1	2	1	2	1	1	1	2	1	1
2	1	2	1	2	1	2	2	2	2	1	2	1	1	2	1	1	1
2	1	2	1	2	1	2	2	2	2	1	2	1	1	1	1	1	1
1	2	2	1	3	2	1	1	1	1	1	2	1	1	3	2	1	2
1	2	1	2	3	2	1	1	1	1	1	2	1	1	3	2	1	2
2	2	2	1	3	1	2	1	1	2	1	2	1	1	2	2	2	2
1	2	2	2	3	2	1	1	1	1	1	2	1	1	3	1	1	2
2	2	2	1	3	2	2	1	2	2	1	1	1	1	2	1	1	1
1	2	1	1	3	2	1	1	1	1	1	2	1	1	3	2	1	2
2	1	2	1	2	1	1	1	2	2	1	2	0	1	2	1	1	1
1	2	1	1	3	2	1	1	1	1	1	2	1	1	2	1	1	2
2	1	2	1	2	2	1	2	2	2	1	2	1	1	1	1	1	1
2	2	1	1	3	2	1	1	1	2	1	2	1	1	2	1	1	2
2	1	2	1	2	1	2	2	2	2	1	2	1	1	1	1	1	1
2	1	1	1	2	1	2	1	2	2	1	2	0	1	2	1	1	1
2	1	2	1	2	1	2	1	2	2	1	2	1	1	1	1	1	1
2	1	1	1	2	2	1	1	1	2	1	2	0	1	1	1	2	2
2	1	2	1	3	1	2	2	2	2	1	2	0	1	1	1	2	1
2	1	1	1	2	1	1	1	1	2	1	2	0	1	1	1	2	2
2	1	2	1	2	1	2	1	1	2	1	2	0	1	1	1	2	2
2	1	2	1	3	1	1	1	1	2	1	2	0	1	2	2	2	2

1	2	1	2	3	2	1	1	1	1	1	2	1	1	2	1	1	2
2	2	1	2	3	2	1	1	1	1	1	2	1	1	2	1	2	2
1	1	1	2	3	2	1	1	1	1	1	2	1	1	2	1	2	2
1	2	1	2	3	2	1	1	1	1	1	2	1	1	3	1	1	2
2	2	1	1	3	2	1	1	1	1	1	2	0	1	2	1	1	2
2	2	1	1	3	2	1	1	1	1	1	2	1	1	2	1	2	2
1	1	1	1	3	2	1	1	1	2	1	2	0	1	1	1	2	1
2	1	1	1	2	1	1	1	1	2	1	2	0	1	1	1	1	1
2	1	1	1	2	1	1	1	1	2	1	2	0	1	1	1	1	2
2	1	2	1	2	1	1	1	2	2	1	3	0	1	1	1	1	2
2	1	2	1	2	1	2	1	1	2	1	3	1	1	1	1	1	2
1	2	1	1	3	2	1	1	1	1	1	2	1	1	2	1	2	2
2	1	1	1	3	2	1	1	1	1	1	2	1	1	2	1	1	2
2	1	1	1	2	2	1	1	1	2	1	2	0	1	2	1	1	2



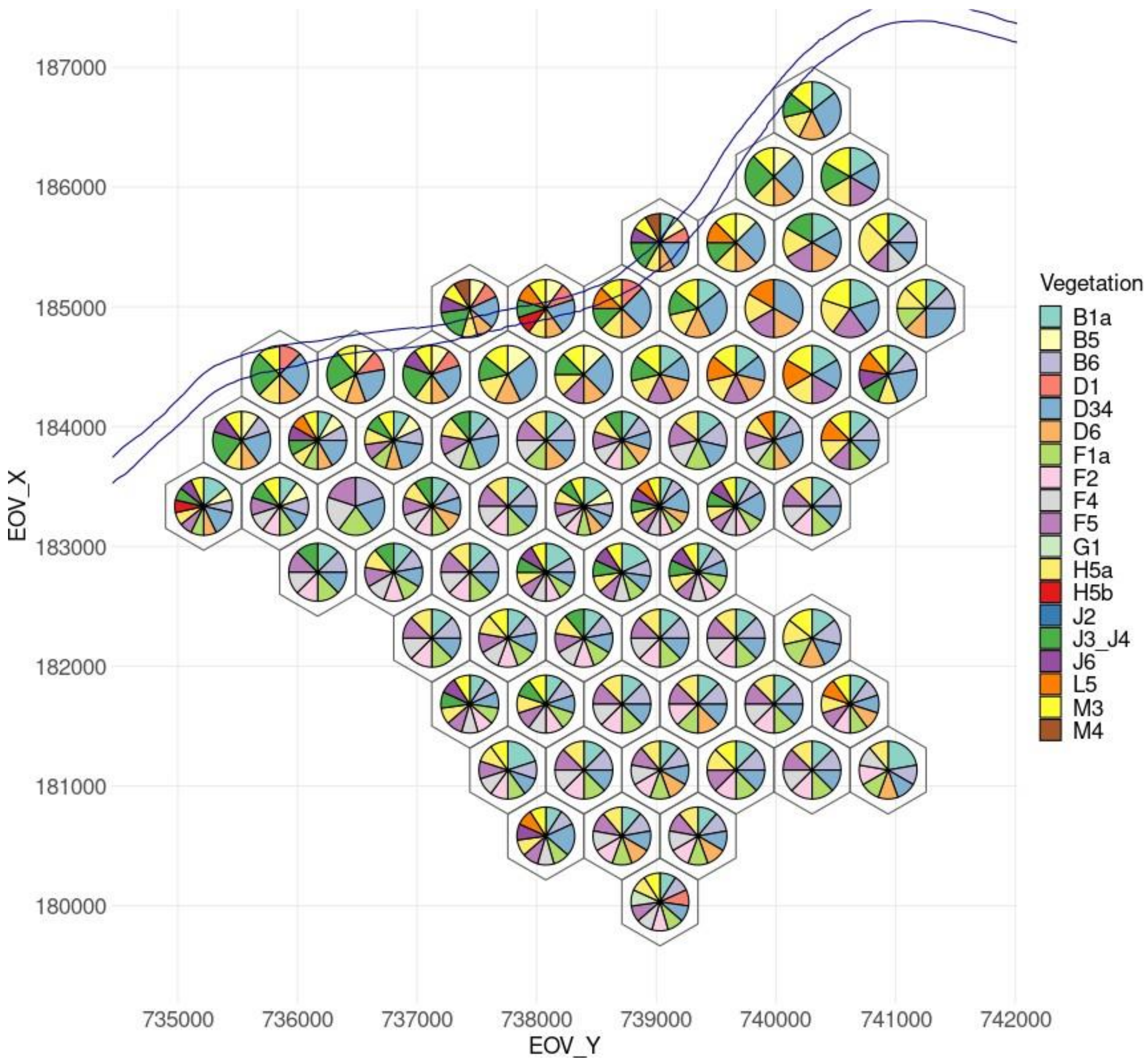
Pic. 30 Predicted potential occurrence of vegetation types according to the baseline. Ratios within the pie charts are relative to the rank within MPV (2, 3 or 4) minus 1 (1, 2 or 3). The subtraction serves better visualisation in the pie charts. Within a hexagon, the larger the slice a vegetation type has, the more probable it potentially occurs. The data underlying the figure are detailed in Table 5. *Habitat codes stand for: B1a: Eu- and mesotrophic reed and Typha beds; B5: Non-tussock tall-sedge beds; B6: Salt marshes; D1: Rich fens; D34: Mesotrophic wet meadows; D6: Tall-herb vegetation of floodplains, marshes and mesic shadowed forest fringes; F1a: Artemisia salt steppes; F2: Salt meadows; F4: Dense and tall Puccinellia swards (alkaline vegetation); F5: Annual salt pioneer swards of steppes and lakes; G1: Open sand steppes; H5a: Closed steppes on loess, clay, tufa; H5b: Closed sand steppes; J2: Alder and ash swamp woodlands; J3_J4: Riverine willow shrubs and willow-poplar woodlands; J6: Riverine oak-elm-ash woodlands; L5: Closed lowland steppe oak woodlands; M3: Open salt steppe oak woodlands with openings; M4: Open sand steppe oak woodlands with openings.*

Table 12. Predicted potential occurrence of vegetation types according to the prediction taking the planned river regulation modifications into account. Ranks larger than 1 are highlighted. For the code of vegetation types, please refer to Table 1. The habitat distribution of the hexagons is shown in Fig. 4.

hexagon ID	B1a	B5	B6	D1	D34	D6	F1a	F2	F4	F5	G1	H5a	H5b	J2	J3_J4	J6	L5	M3	M4
191471	2	1	2	2	2	1	2	2	2	2	2	2	1	1	1	1	1	2	1
189647	3	1	2	1	2	1	2	2	2	2	1	2	1	1	1	1	1	2	0
189898	2	1	2	1	3	1	2	1	2	2	1	2	1	1	1	2	2	2	0
189901	2	1	2	1	2	1	2	2	2	2	1	2	1	1	1	1	1	1	0
190488	2	1	2	1	2	2	2	2	2	2	1	2	1	1	1	1	1	1	0
190492	2	1	2	1	2	2	2	2	2	2	1	2	0	1	1	1	1	1	0
191475	2	1	2	1	2	2	2	2	2	2	1	2	1	1	1	1	1	1	0
191478	2	1	2	1	2	1	2	2	1	2	1	2	0	1	1	1	1	2	0
192239	2	1	2	0	2	1	2	2	2	2	1	2	0	1	1	1	1	1	0
192383	3	1	2	1	2	2	2	2	2	1	1	2	1	1	1	1	1	1	0
189242	2	1	2	1	2	1	2	2	2	2	1	2	1	1	1	1	1	1	0
189815	2	1	2	1	2	1	2	2	2	2	1	2	1	1	2	2	1	2	0
189818	2	1	2	1	2	1	2	2	2	2	1	2	1	1	1	1	1	2	0
189651	2	1	2	1	2	1	2	2	2	2	1	2	0	1	2	1	1	2	0
189655	2	1	2	1	2	1	2	2	2	2	1	2	0	1	2	1	1	1	0
189904	2	1	2	1	2	1	2	2	2	2	1	2	0	1	1	1	1	1	0
189907	2	1	2	1	2	1	2	2	2	2	1	2	0	1	1	1	1	1	0
190496	2	1	2	1	2	2	2	2	1	2	1	2	0	1	1	1	1	1	0
190499	2	1	2	1	2	1	2	2	2	2	1	2	0	1	1	1	1	1	0
191481	2	1	2	1	2	1	2	2	2	2	1	2	0	1	1	1	1	1	0
191485	2	1	2	1	2	2	2	1	1	1	1	2	1	1	1	1	1	2	0
192243	2	1	2	1	2	2	2	2	1	2	1	2	1	1	1	1	2	2	0
186493	3	2	2	1	3	2	2	1	1	2	1	2	2	1	2	2	1	2	0
187175	2	2	2	1	2	1	2	2	2	2	1	1	1	1	2	1	1	2	0
188266	2	1	2	1	2	1	2	2	2	2	1	1	1	1	2	1	1	1	0

188270	1	1	2	1	2	1	2	1	2	2	1	1	0	1	1	1	1	1	0
187787	2	1	2	1	2	1	2	2	2	2	1	2	1	1	2	1	1	1	0
187791	2	1	2	1	2	2	2	2	2	2	1	2	0	1	2	1	1	1	0
189246	2	1	2	1	2	1	2	2	2	2	1	2	0	1	1	1	1	1	0
189250	2	1	2	1	2	1	2	2	2	2	1	2	1	1	1	1	1	1	0
189822	3	1	2	1	2	1	2	2	2	2	1	2	1	1	2	2	1	2	0
189825	3	2	2	1	2	2	2	2	2	2	1	2	1	1	2	1	1	2	0
189659	3	1	2	1	2	1	2	1	2	2	1	2	1	1	2	2	1	2	0
189663	2	1	2	1	3	2	2	2	2	2	1	2	1	1	2	2	2	2	0
189909	2	1	2	1	2	1	2	2	2	2	1	2	1	1	2	2	1	2	0
189912	2	1	2	1	3	1	2	2	2	2	1	2	1	1	2	2	1	2	0
190507	2	1	2	1	2	1	2	2	2	2	1	2	1	1	1	1	1	1	0
186497	1	2	2	1	3	2	1	1	1	1	1	2	1	1	3	2	1	2	0
186501	1	1	1	2	3	2	1	1	1	1	1	2	1	1	3	1	1	2	0
187179	2	2	2	1	3	2	2	1	1	1	1	2	1	1	2	2	2	2	0
187183	1	2	1	2	3	2	1	1	1	1	1	2	1	1	3	1	1	2	0
188273	2	2	2	1	3	2	2	1	1	2	1	2	1	1	2	1	1	2	0
188277	1	2	1	2	3	2	1	1	1	1	1	2	1	1	3	2	1	2	0
187795	2	1	2	1	3	1	2	1	2	2	1	2	0	1	2	1	1	1	0
187799	1	2	1	1	3	2	1	1	1	1	1	2	1	1	2	1	1	2	0
189253	2	1	2	1	2	2	2	1	2	2	1	2	1	1	1	1	1	1	0
189257	1	2	1	1	3	2	1	1	1	2	1	2	0	1	2	1	1	2	0
189829	2	1	2	1	2	2	2	2	2	2	1	2	1	1	2	1	1	1	0
189832	2	1	1	1	2	2	1	1	1	2	1	2	0	1	2	1	1	2	0
189667	2	1	2	1	2	1	2	1	2	2	1	2	1	1	1	1	1	1	0
189672	2	1	1	1	2	2	1	1	1	2	1	2	0	1	1	1	2	2	0
189915	2	1	2	1	3	2	2	1	2	2	1	2	0	1	1	1	2	1	0
189918	2	1	1	1	2	1	1	1	1	2	1	2	0	1	1	1	2	2	0
190510	2	1	2	1	2	1	2	1	1	2	1	2	0	1	1	1	2	2	0
190514	2	1	2	1	3	1	1	1	1	1	1	2	0	1	2	2	2	2	0

188281	1	2	1	2	3	2	1	1	1	1	1	2	1	1	3	2	1	2	2
187804	1	2	1	2	3	2	1	1	1	1	1	2	2	1	2	1	2	2	0
189261	1	1	1	2	3	2	1	1	1	1	1	2	1	1	2	1	2	2	0
189265	2	2	1	2	3	2	1	1	1	1	1	2	1	1	3	2	1	2	2
189836	2	1	1	1	3	2	1	1	1	1	1	2	0	1	2	1	1	2	0
189840	1	2	1	1	3	2	1	1	1	1	1	2	1	1	2	1	2	2	0
189676	1	1	1	1	3	2	1	1	1	2	1	2	0	1	1	1	2	1	0
189680	2	1	1	1	2	2	1	1	1	2	1	2	0	1	2	1	1	1	0
189921	2	1	1	1	2	1	1	1	1	2	1	2	0	1	1	1	1	2	0
189924	2	1	2	1	2	1	1	1	2	2	1	3	0	1	1	1	1	2	0
190518	2	1	2	1	3	2	2	1	1	1	1	2	1	1	1	1	1	2	0
189844	1	2	1	1	3	2	1	1	1	1	1	2	1	1	3	1	1	2	0
189848	2	1	1	1	3	2	1	1	1	1	1	2	1	1	2	1	1	2	0
189684	2	1	1	1	2	1	1	1	1	2	1	2	0	1	2	1	1	2	0



Pic. 31 Predicted potential occurrence of vegetation types according to the prediction taking the planned river regulation modifications into account. Ratios within the pie charts are relative to the rank within MPNV (2, 3 or 4) minus 1 (1, 2 or 3). The subtraction serves better visualisation in the pie charts. Within a hexagon, the larger the slice a vegetation type has, the more probable it potentially occurs. The data underlying the figure are detailed in Table 6. *Habitat codes stand for: B1a: Eu- and mesotrophic reed and Typha beds; B5: Non-tussock tall-sedge beds; B6: Salt marshes; D1: Rich fens; D34: Mesotrophic wet meadows; D6: Tall-herb vegetation of floodplains, marshes and mesic shadowed forest fringes; F1a: Artemisia salt steppes; F2: Salt meadows; F4: Dense and tall Puccinellia swards (alkaline vegetation); F5: Annual salt pioneer swards of steppes and lakes; G1: Open sand steppes; H5b: Closed sand steppes; J2: Alder and ash swamp woodlands; H5a: Closed steppes on loess, clay, tufa; J3_J4: Riverine willow shrubs and willow-poplar woodlands; J6: Riverine oak-elm-ash woodlands; L5: Closed lowland steppe oak woodlands; M3: Open salt steppe oak woodlands with openings; M4: Open sand steppe oak woodlands with openings.*

Change of the Potential Natural Vegetation

The potential vegetation of the area after the intervention has a distinctly different character than the baseline. After the proposed river regulation modifications, the majority (n=52) of the hexagons are expected to experience some form of MPV change. Changes are in accordance with expectations regarding vegetation change after allowing more natural river dynamics. Changes to dry vegetation and particularly dry grassland vegetation potential are the most severe. The potential of dry herbaceous vegetation even drops by two categories in several hexagons (Pic. 32). Some alkaline grassland types (alkaline meadows: F2, annual vegetation: F5) are affected the most, however, other alkaline grasslands (alkaline steppes: F1a, F4) will even increase their share in the MPV distribution.

Changes to dry wooded vegetation is more balanced. Decreases and increases are equally estimated for this group of habitats (Pic. 33). There will be a very marked increase in the representation of alkaline oak steppe woodlands (M3) in the MPV of the region. This can be explained by the presence of alkaline conditions that already were ideal for alkaline grasslands demonstrated by their share in the original MPV. With increasing water availability the environment appears to become suitable for the corresponding woodland vegetation as well. Furthermore, existing stands of M3 are known to be in contact with gallery forests, which would also be the case here regarding potentiality. On the other hand other oak dominated woodland types (M4, L5) become less potential, leaving M3 the dominant dry wooded type in the MPV of the area.

Changes in the potentiality of wet herbaceous vegetation are as expected when allowing more water to reach the area (Pic 34). The most marked increase belongs to the tall-herb vegetation (D6), which is predicted to be potential with higher rank in 12 hexagons. Mesotrophic wet meadows (D34) also appear to greatly benefit from the interventions. There are hexagons close to the river, where decrease is predicted (mostly for reeds and sedge communities; B1a and B5 respectively), however, here the decrease is in the favour of wet woodland vegetation.

Wet woodland vegetation suitability is predicted to increase partly in a few hexagons along the river, besides other hexagons, where it is potential already currently and thus it does not appear as an increase (Pic. 35). Altogether, gallery forests (J3_J4, J6) are highly potential and will become even more so, where not already such along the river. Similar increase is observed in a few scattered hexagons elsewhere. On the other hand, alder and ash woodlands (J2) will become less potential, which is in good accordance with ecological knowledge since these prefer moor conditions, while the interventions will carry oxygenated water with regular floods.

Table 13. Difference of the two predictions summarized in Table 5 and Table 6. Changes are highlighted. The bottom row summarizes the changes. For the code of vegetation types, please refer to Table 1. The amount of changes are also displayed in maps (Fig. 5-8) with habitats grouped according to wetness and life forms. Group membership per habitat is indicated in the 'Habitat category' column of Table 1.

B1a	B5	B6	D1	D34	D6	F1a	F2	F4	F5	G1	H5a	H5b	J2	J3_J4	J6	L5	M3
0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	-1	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1	0	0	0	-1	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	0	1	0	0	0	-1	0	0	0	0	1
0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	0	0	0	0	0	0	-1	0	0	0	0	0
0	0	0	0	0	0	0	0	1	0	0	0	-1	0	0	0	0	0
0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0
0	0	0	0	0	1	0	-1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0
0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-1	0	0	0	0	0	0	-1	0	0	0	0	-1	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	-1	0	1	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	1
0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	-1	1	0	0	0	0	0	0	0	-1	1
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0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1
0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1
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0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0
0	0	0	0	0	1	0	0	0	-1	0	0	0	0	0	0	0	0
0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	-1	0	0	1	0	0	0	0	0	1
0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
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0	0	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	0	0
-1	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0
0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	1	-1	0	-1	0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1	0	-1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
-1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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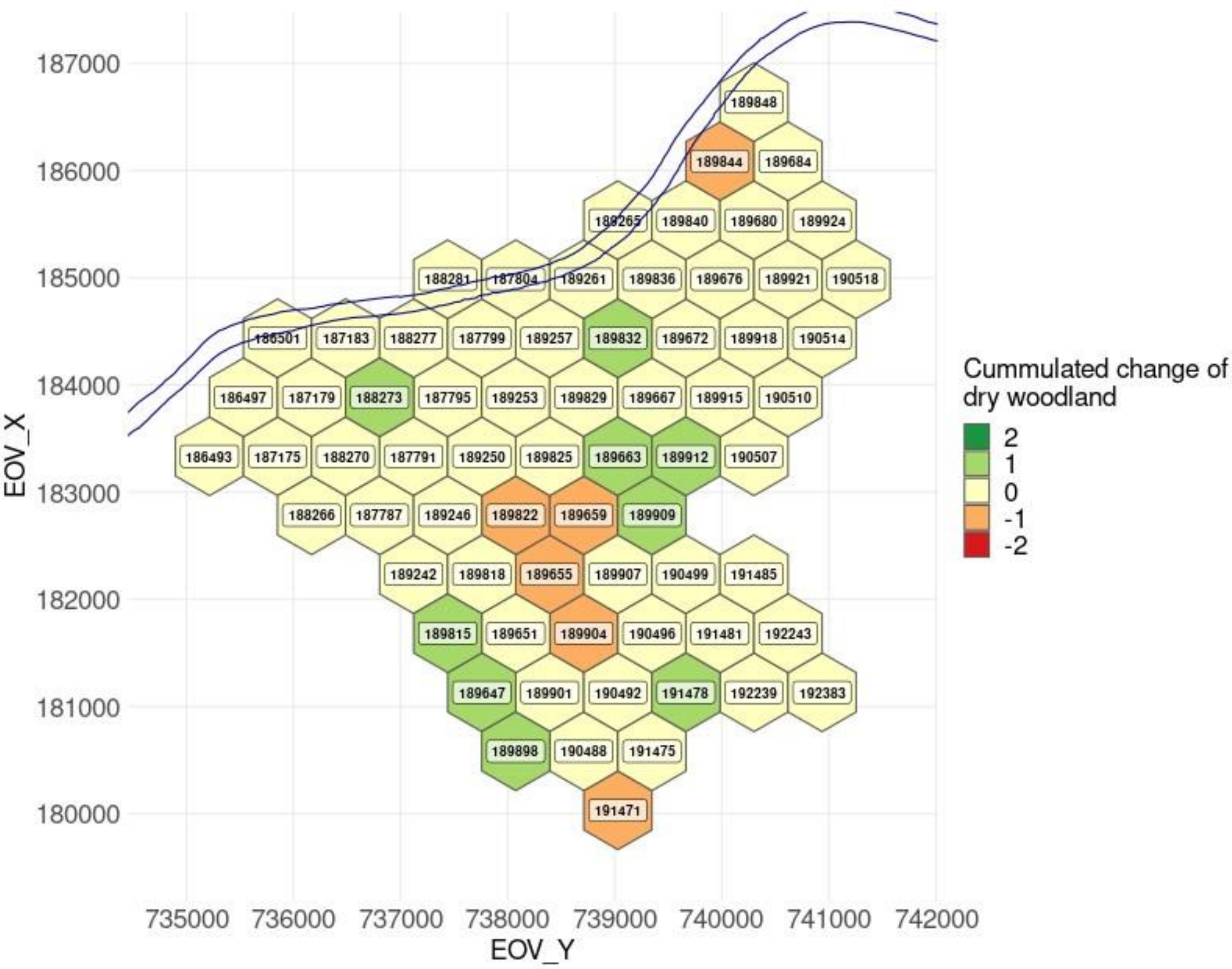
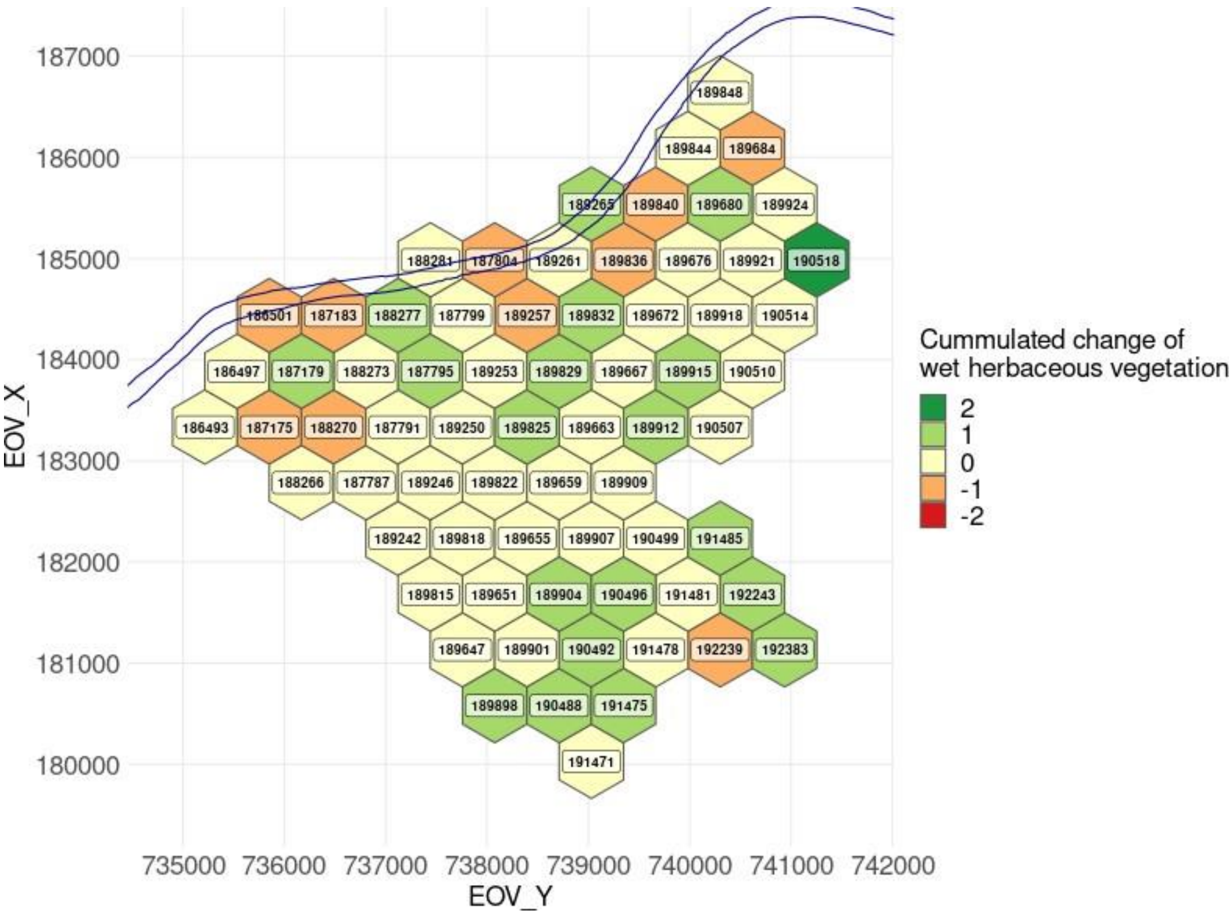
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	1	0	0	0	-1	0	-1	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0
-4	-2	-1	1	5	12	1	-5	4	-4	0	-1	-7	-1	5	3	-4	15



Pic. 32 Predicted cumulated change in the potential occurrence rank of dry herbaceous vegetation. For the habitats belonging to the category please refer to Table 1.



Pic. 33 Predicted cumulated change in the potential occurrence rank of dry woodland. For the habitats belonging to the category please refer to Table 1.

Pic 34. Predicted cumulated change in the potential occurrence rank of wet herbaceous vegetation. For the habitats belonging to the category please refer to Table 1.

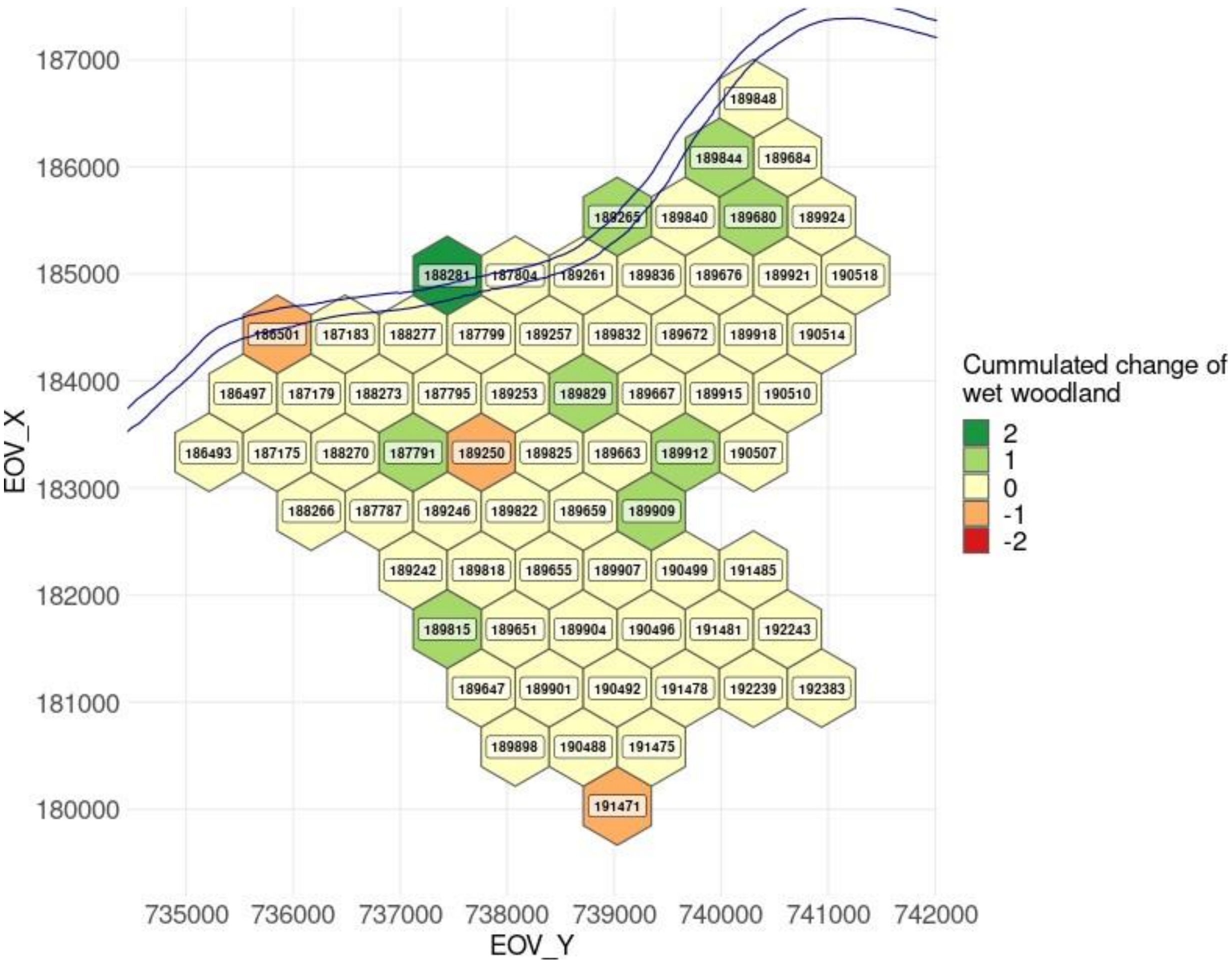


Figure 8. Predicted cumulated change in the potential occurrence rank of wet woodland. For the habitats belonging to the category please refer to Table 1.

Conclusions

Predictions obtained for the study area are in good accordance with expectations. However, individual details will be useful in supporting the planning of habitat restoration and sustainable land use. It is a very strong result, that the two land use scenarios did not differ in the expected MPV distribution. This shows that the waterflow in the two cases is similar from the point of view of the vegetation. The planned water regulation interventions create a similar environment to plants, whether calculated with unchanged or modified land use. It also means that the more eco-friendly modified land use does not significantly change the site potential here. Please note that we speak of potential and not actual vegetation. Land use clearly limit the realisation of potential vegetation into actual vegetation, but that was not a target in our investigations.

The direction of changes in the expected potential vegetation distribution can be well explained with the increasing water availability and with the regular income of fresh water. Dry vegetation types are predicted to be less potential with the exception of alkaline vegetation. Here water incoming in the spring is expected to evaporate or be lost by transpiration through the summer, which brings up the ions towards the soil surface resulting in alkaline conditions in the case of the local soil conditions. From a nature conservation point of view, this is acceptable. Near-natural land cover consists of alkaline grasslands here, which will still find their environmental requirements after the river regulation interventions and thus no natural value is threatened by the interventions. To the contrary potentiality of these types will further increase, which will make the conservation of these stands even easier.

Again, in accordance with expectations, wet herbaceous and wooded vegetation will become more potential. This will increase potential area for wet meadows and marsh vegetation as well as make poplar-willow and hardwood gallery forests to be site-adapted vegetation in a wider belt along the river and in selected locations elsewhere in the area. Thus extending the cover of woody vegetation will be easier, which is a possible measure to mitigate climate change. However, when the target vegetation type of afforestation is selected, it is crucial to select from the MPV distribution. In this case, gallery forests and alkaline oak steppe woodland can be self-sustainable targets and thus long-term carbon sinks. There are hexagons, however, in the middle of the study area, where forests are not potential. Forcing forest cover would be harmful for the ecological status of the area and also not sustainable, thus could not serve carbon sequestration on the long run either.

In conclusion, expected changes due to river regulation interventions largely mean the increase of potentiality for wetland vegetation types. Additionally, alkaline vegetation that is already present in undisturbed patches will also benefit from the interventions, thus changes will support the natural capital as well. The expected MPV provides ample opportunities for ecological climate change mitigation as well as for ecological restoration of further stands of habitats, which are already present in patches and thus can support new stands by propagule availability.

IX. Cost-benefit analysis

The analysis applies the methodology - *ESS-CBA DECISION SUPPORT MODEL AND METHODOLOGY (2020)* that was developed in the 4th work package. The CBA calculations of the Cibakháza-Tiszaföldvár floodplain case are supported by an MS Excel based tool, The Danube Floodplain ESS extended Cost Benefit calculation and impact structure Module.

The analysis describes the economic calculations of REKK based on the inputs of experts from KÖTIVIZIG, WWF Hungary and the HNPI, albeit the economic analysis uses and interprets these inputs to fit to a coherent calculation methodology.

Key aspects of the analysed scenarios

Our analysis covers the combination of 2 land use and 4 hydrological scenarios, in total 8 versions, as portrayed in 04.

The analysed scenario combinations

Land use	Tisza dyke along the Cibakháza-Tiszaföldvár floodplain			
	No modification	Demolished dyke	Sluiceway	Flood gate
Current land use (CS)	BAU	CS_all	CS_sluiceway	CS_gate
Future, modified land use (RS)	RS_none	RS_all	RS_sluiceway	RS_gate

In case of the BAU scenario current conditions will continue, same land use and the area will stay protected from floods by the main defense lines along the river.

As detailed in chapter 0, current land use (CS) is cropland dominated, while the intended future land use (RS) has a lower share of croplands, and more grassland and forests.

Under the “no modification” option the Cibakháza-Tiszaföldvár floodplain is not reconnected to the river. Under the „demolished dyke” scenario it is reconnected and high waters can enter the floodplain area without obstacle. In case of the “sluiceway” version only floods exceeding the 30 year return period will be able to enter the floodplain area, while the “flood gate” scenario relies on a flood gate to cut the peak of the flood and release only the peak into the floodplain area. With the exception of the “no modification” scenario all measures require local defense lines on the border of the floodplain, to avoid flooding external areas unintentionally.

In all scenarios we calculate the following costs and benefits (when applicable):

- Costs of infrastructure development (estimated by the dyke around the case study floodplain area)
- Farm income from land use in the Cibakháza-Tiszaföldvár floodplain (net income from agricultural and forestry activities, with special considerations on CAP support), adjusted for inundation damages due to floods released into the floodplain
- Flood related costs along the Tisza, including defense costs and catastrophe damage (excluding damages that take place in the Cibakháza-Tiszaföldvár floodplain)
- Land use based carbon emissions / sequestration

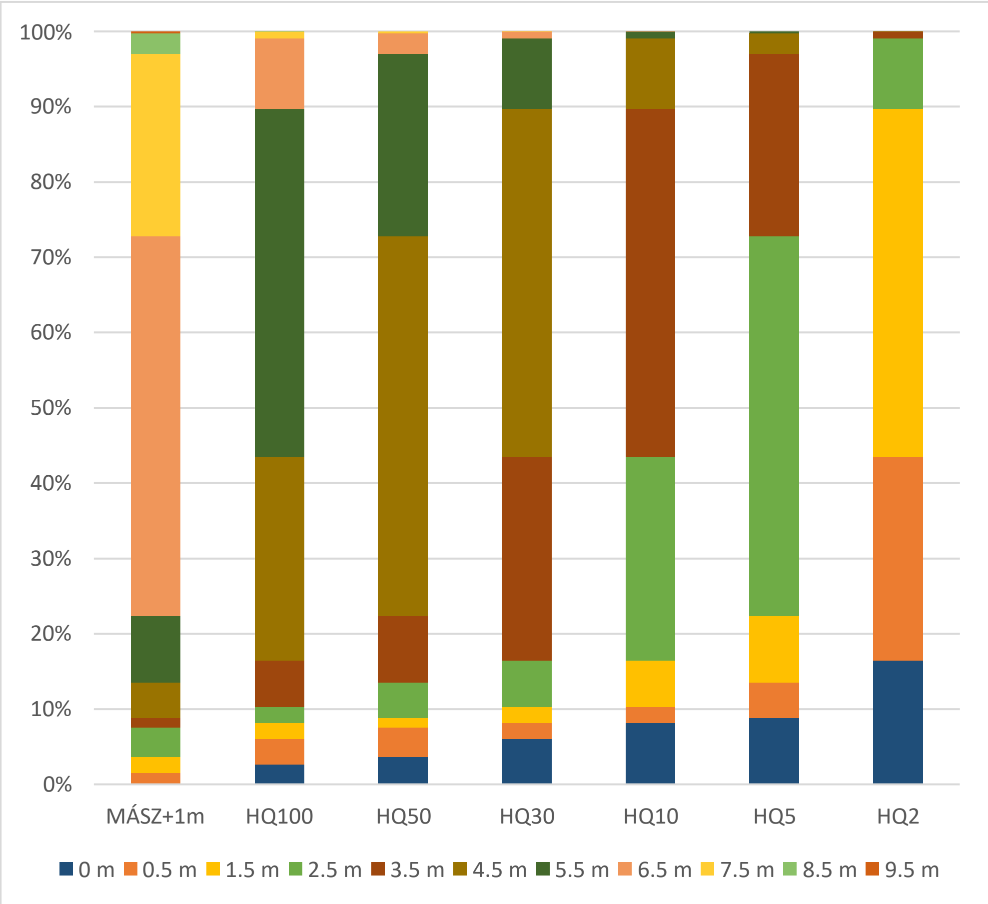
All financial values are calculated in present value to ensure comparability among the scenarios. A 2% real discount rate is applied for the calculation of present values, and the analysed period covers the next 50 years. There are some costs and benefits the economic value of which was not possible to express, these are described in chapter 0 as non-monetised items.

Costs of local defense line development

Depending on the flood levels (from HQ2 to HQ100) at which inundation of the Cibakháza-Tiszaföldvár floodplain area is intended in an orderly way, different scale of levee development is necessary to protect the territories that lie further behind the presumed case study site.

The length of the borderline around the presumed study area is 19.5 km. The below figure shows the distribution of the necessary levee heights to keep flood water inside the area.

Distribution of necessary levee heights around the case study site at different flood heights



Levee development costs are proportional to the volume of the necessary soil/building material. According to actual levee developments in the area two types of levee cross-section were utilized: for the containment of the HQ30-HQ100 water levels the slope ratio of the embankments is 1:3 with 5 meters of levee-top width and for the HQ2-HQ10 water levels the slope ratio is 1:2 and the top-levee width is 3 meters.

The necessary volume of soil grows exponentially with the height increase. This is reflected in the estimated cost of the different construction scenarios. These numbers are broad estimates for theoretical comparison and they do not contain specific elements that would be associated with the actual locality of the area.

The volume based cost of levee development scenarios on the border of the delineated area

Inundation scenario	MÁSZ+ 1m	HQ100	HQ50	HQ30	HQ10	HQ5	HQ2
Estimated costs, million HUF	6 580	5 067	4 573	4 084	1 962	1 670	823

Levees need land to be built on that may incur costs as well. The cost of land purchase is calculated separately because this element is necessary only if there was no agreement on future land use with current land owners. Levee slopes can be utilized as pasture further on as it was the deal for example in an Austrian case of flood polder development at Mittersill. Consequently, the land purchase cost is an upper estimate of this potential cost element. Land prices are discussed in the Fokorúpuszta study (REKK, 2020), where an average value of 1.66 million HUF/hectare was used.

The cost of land acquisition for the levees

	MÁSZ+1 m	HQ100	HQ50	HQ30	HQ10	HQ5
Land size, hectare	86	68	62	56	30	26
Aquisition cost, million HUF	142	113	103	94	49	43

Farming and forestry

The structure of land use

The definition of the land use scenarios analysed was a two-stage process. A floodplain elevation driven delineation was created by the project partners that were analysed by the previously applied methodology. Based on the initial results a streamlined version was created by the REKK staff. At the initial stage two land use scenarios have been compared: current land use (CS scenario) and expected future land use (RS-intermediate scenario). The surface cover of the various land use categories are summarised in 0. The shift between CS and RS-intermediate indicates reduced crop production, substantially more grassland and forest, and the introduction of orchards and large scale vegetable production.

Land cover of the two land use scenarios (hectare)

Land use	CS	RS-intermediate
Arable land (crops)	1939.6	1230.3
Grassland	103.8	609.5
Deciduous forest	23.6	249.0
Orchards		40.3
Large scale vegetable production		48.3
Total	2067.0	2177.3

From an economic perspective neither intensive orchards nor vegetable production would make sense in the pilot floodplain area. The respective areas would be under water in every other year on average. The corresponding damage would be much higher than the net income that can be attained with these farming activities. Moreover, as these cultivation methods have high production value their increased territory dragged the overall balance into negative that make the adaptation scenario less resilient than the current one.

This contradictory modelling result has two main reasons. The floodplain elevation based delineation can't take into consideration that the planned embankment along the study site overwrite the perceived inundation conditions. On the other hand, damage calculations are based on the ÁKK methodology, where intensive orchards are considered as the widely maintained form. The initial land use plan considers "floodplain orchards", which are more resistant to regular inundation, but they also delivers lower yields that currently doesn't make it as a cultivation choice for land owners at places with similar hydrological conditions. These floodplain orchards have very special local characteristics that make the yield/loss relationship too uncertain to apply it in the calculation model. This is more realistic to assume that these orchards are maintained as a supplementary benefit at the most suitable places in areas dominated and calculated by other cultivation types. In our analysis therefore we assume that these floodplain orchards offer the same economic profile as deciduous forests, therefore their area has been reallocated to the forest category (0). Similarly, instead of large scale vegetable production we apply the arable land (crops) category to this area.

As due to some technicalities the total area under RS is larger than under CS, under the modified RS land cover we also reduced the area of each land use category proportionately, in order to enable comparison between the results of the CS and RS scenarios (0).

Modified land cover of the two land use scenarios (hectare)

Land use	CS	RS
Arable land (crops)	1939.6	1213.8
Grassland	103.8	578.6
Deciduous forest	23.6	274.6
Orchards		---
Large scale vegetable production		---
Total	2067.0	2067.0

Net income from farming and forestry

We have estimated the net income (revenues minus costs) for all three land use categories. Our calculations reflect average years, without inundation damages. The latter will be covered in the next subchapter (0).

The majority of the area is used for crop production in both land use scenarios. As discussed in REKK (2020), based on the 2014-16 years of the FADN (2018) report the post tax result of wheat/sunflower rotation, typical for this region, is about 330 EUR/year. This is an average value with significant annual variation, and approximately 70% of it is generated by agricultural subsidies. In the analysis we assume the same annual net income, and we use the current EUR/HUF exchange rate of 360 to calculate its value in HUF. Thus our assumption is that the subsidy makes up 75 thousand HUF/hectare/year and net income from crop production is equal to 45 thousand HUF/hectare/year.

Farmers on grassland are also eligible to agricultural subsidies, and similarly to crop production, those subsidies amount to about 75 thousand HUF/hectare. Within the FADN (2018) system the net income from grassland is not included on its own, only together with crop production and/or animal husbandry. We know from REKK (2020) that grassland management without subsidies is barely profitable, if at all. This is indicated by the lack of interest (or very modest interest) in renting such areas. Therefore for this land use category we assume a small nominal net income of 5 thousand HUF/hectare/year.

When calculating the income for forestry activities we relied on the interim results of the BIOSCREEN project (2021). Within the project a bio-economic model has been developed for Hungary, supported by data on forest growth and forest economics, the latter encompassing various costs of forest management activities and prices of different timber selections (fire wood, pulp wood, logs for industrial use). When calculating the net income from forestry for the Cibakháza-Tiszaföldvár floodplain, we made the following assumptions:

- We consider all forests (both the existing 23.6 hectares and the envisioned 274.6 hectares) as new forests, planted at present.
- All planting costs are covered by government subsidies, therefore we assumed 0 costs for the land owner for this activity.
- We assumed a mix of oak and poplar forests, with a 50:50 ratio of land cover.
    - There is no harvesting (final cut) during the analysed 50 year period, but we take account of the timber value of the forest at the end of the period. There is, however, thinning in each decade, according to timber growth tables.

The net income generated from forest management (excluding the income supplement provided by the state) at the end of each decade is summarised in 0. The last row includes the annualised net income. If this net income was available for each year of the analysed 50 year period then the present value of this stream of cash flow would be equal to the present value of the sum of the thinning revenues and the final value of the timber stand. 2% real discount rate was used for the present value calculation.

Net income (revenues minus cost) of forestry activites, mixed forest

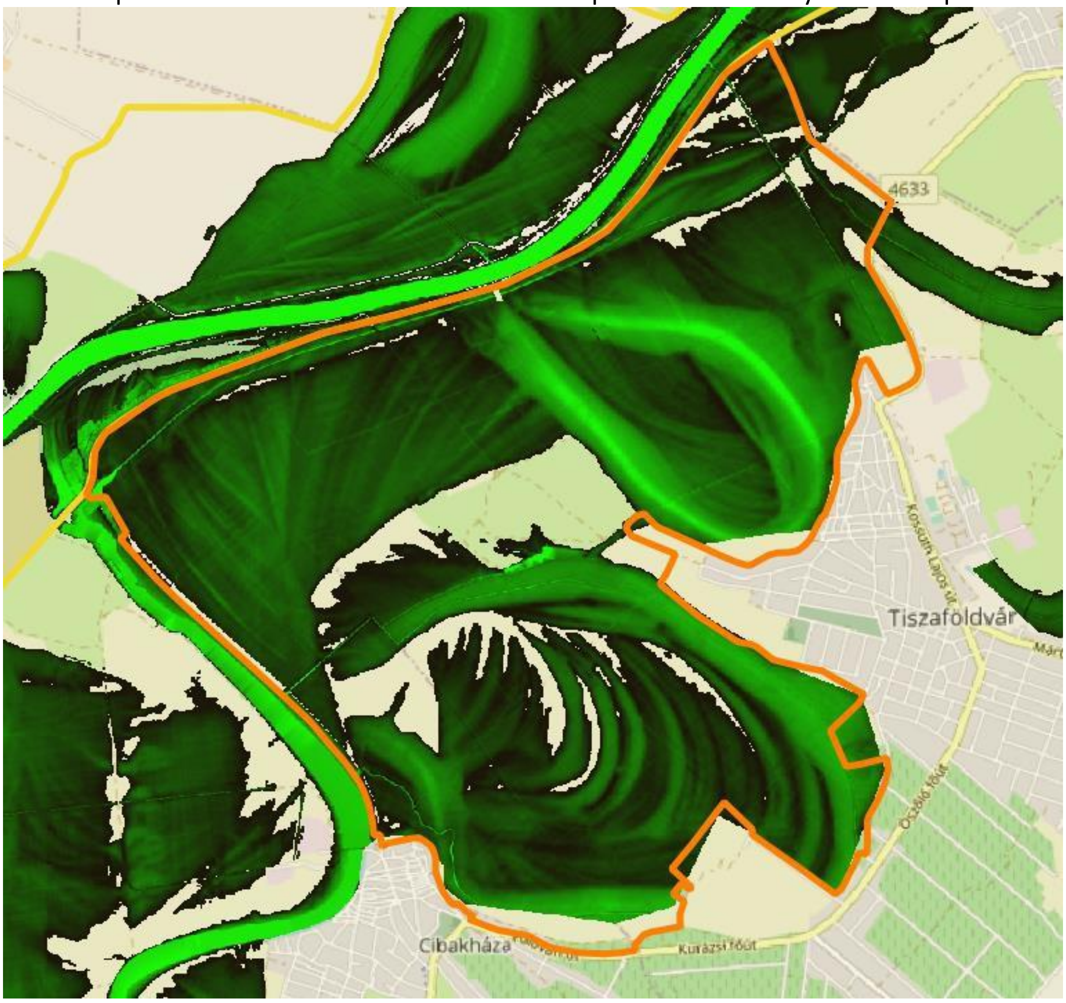
Income generating activity	Net income per hectare (thousand HUF/hectare)	Net income for the 23.6 hectares of the CS scenario (million HUF)	Net income for the 274.6 hectares of the RS scenario (million HUF)
Thinning, year 10	178	4.2	48.9
Thinning, year 20	615	14.5	168.8
Thinning, year 30	1000	23.6	274.7
Thinning, year 40	830	19.6	227.8
Thinning, year 50	892	21.0	244.9
Value of the standing timber	4699	110.9	1290.2
Annualised net income for the 50 year period	113	2.7	31.1

In addition, income supplement is available to farmers that decide to pursue afforestation, to make up for the lost income from discontinued agricultural activities. This income is available for up to 12 years and its value is 432 EUR/hectare/year (source: Magyarország Kormánya (2016)). We take account of this income stream within the CBA.

Inundation losses

The Cibakháza-Tiszaföldvár floodplain area is planned to be regularly inundated, and this generates damage to farming activities (cropland and grassland). In case of forests we assume that water resistant species are planted which can cope with regular temporary inundation, therefore no forest damage is expected. The level of agricultural damage is different in each location within the area, and its value can be calculated based on the value at risk (potential maximum damage), the water depth specific fractional flood damage curve, and the actual water depth. Therefore a combination of land use data, the economic value of each land use category, flood damage curves and inundation maps was required to calculate the damage of a given inundation event. The economic value of both land use category (cropland, grassland) as well as the fractional damage curves were obtained from the ÁKK methodology. Inundation maps were generated by Dávid Béla Vizi of KÖTIVIZIG, and he also provided valuable assistance by computing the surface area covered by a specific water depth for each land use category and each inundation event, the latter corresponding to a specific flood return period. 0 provides an illustration of the water depths in the floodplain area associated with a 2-year return period flood.

Water depths at the Cibakháza-Tiszaföldvár floodplain related to 2 year return period floods

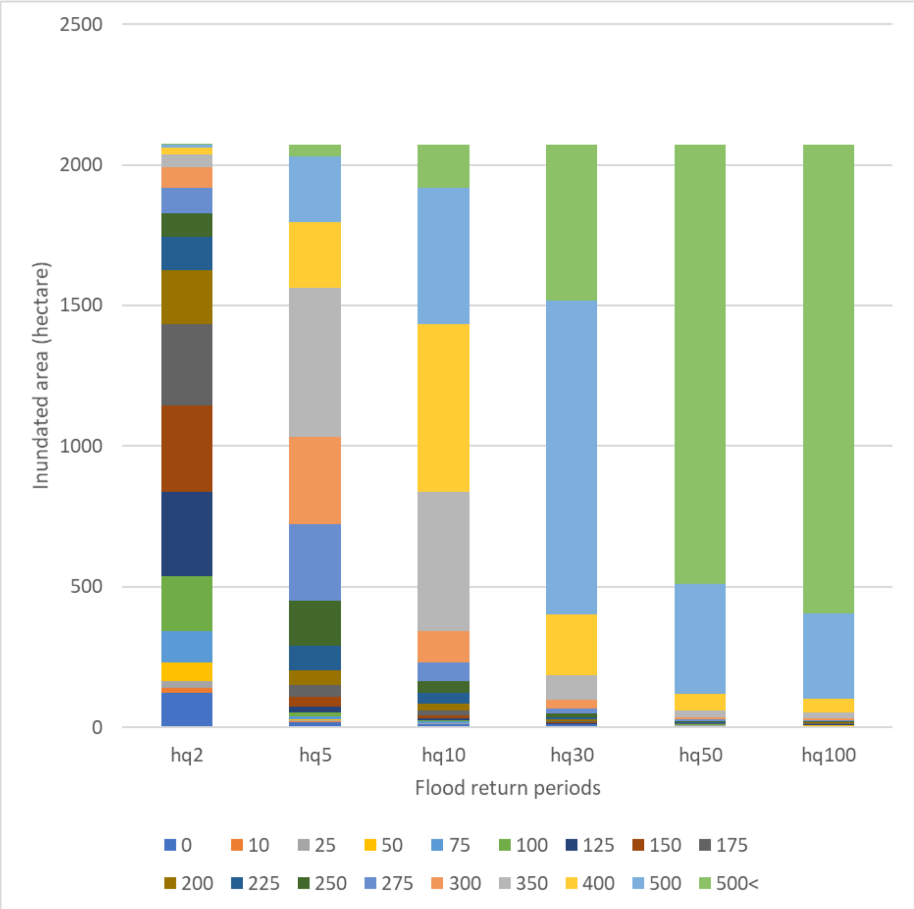


Legend: The orange line delineates the case study area, no inundation outside it is perceived. The colouring shows the water depth differences from zero to 3.5 meters at the bottom of once functional river bends.

0 gives an example of how many hectares of the Cibakháza-Tiszaföldvár floodplain belong to given inundation depths under various flood return periods. In case of a 2 year return period flood, for example, about 500 hectares have a water depth of less than 100 cms, while the rest of the area is

covered by deeper water. In case of a 100 year flood, over 90% of the floodplain area has water cover of at least 400 cms.

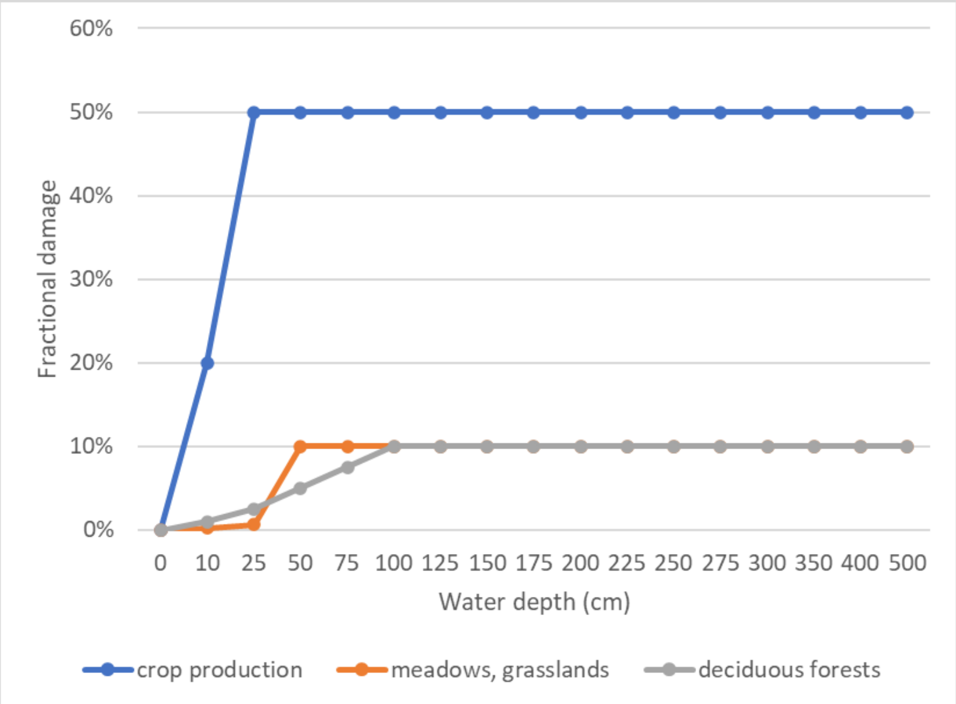
Share of the Cibakháza-Tiszaföldvár floodplain area according to water depth (in cm) at given flood return periods



Note: different colours represent different inundation water depths, in cm.

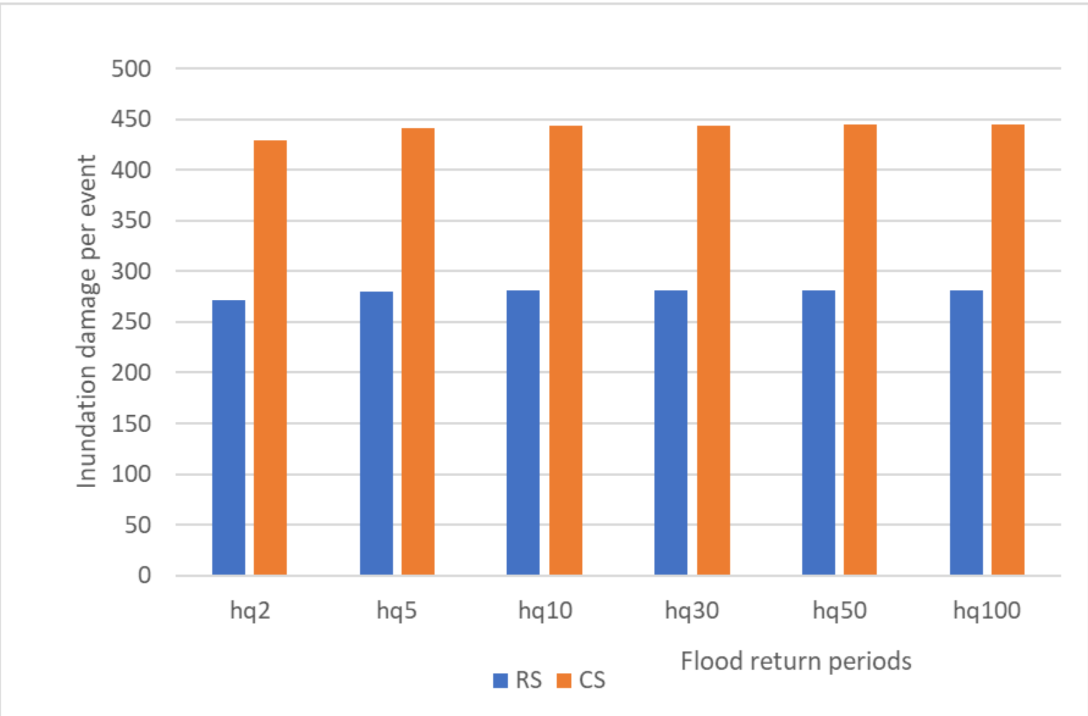
The fractional flood damage curves in 0 show that crop production reaches its peak damage ratio of 50% at a water depth of 25 cm, while for grassland the peak value is 10%, and it is attained at water depths of 50 cm. For forests the peak damage value would also be 10%, but as we explained, we assume no damage for forests.

Fractional flood damage curves



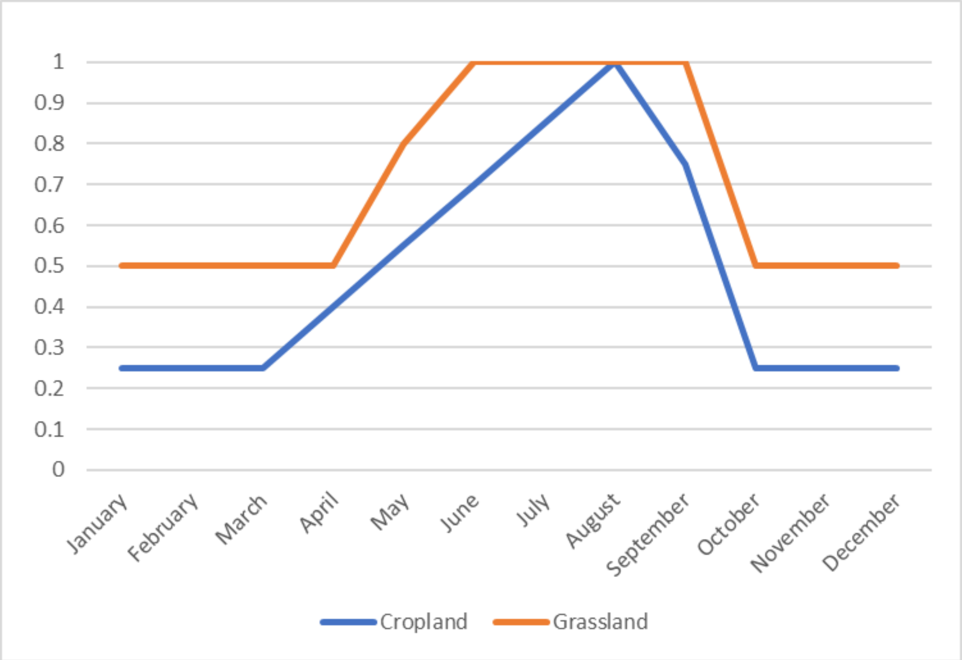
Since already for a 2 year flood event much of the area is covered by water that is at least 1 meter deep, a lot of cropland related damage takes place at a high frequency. Larger floods generate only modestly higher damages, as depicted by 0. Over 98% of the damage takes place on cropland, and less than 2% on grassland, even though grasslands make up 28% of the total floodplain area.

Inundation damages in the Cibakháza-Tiszaföldvár floodplain for selected flood events (million HUF/flood)



Agricultural inundation damages are highly seasonal. The previous figure represents the maximum potential damage which, according to Ungvári and Kis (2018), would take place in August before some of the major crops are harvested. Inundation damages in other months can be significantly lower, as displayed in 0. In the absence of a detailed statistical analysis (or future forecasts) of the seasonality of floods with different return periods, we assume an even distribution of all types of floods thorugh the year. This results in a multiplier of 0.48 for cropland and 0.69 for grassland, implying inundation damages of 408.9-426.3 million HUF for the CS, and 256.9-269.0 million HUF for the RS scenario, depending on the flood return period.

Seasonal damage as a ratio of the maximum inundation damage



Using the seasonality adjusted inundation damage data we can calculate the annualised level of inundation damages. This calculation depends on which return period floods are allowed to enter the floodplain area (which depends on the level of the Tisza dyke or the sluiceway, or the operation of the floodgate). 0 shows the results accordingly. As expected, under the land use structure of the RS scenario damage is already lower than in case of the CS scenario, due to having converted some of the cropland into meadows and forests. For frequent inundations, however, these values are still substantial. In case there is only forest and grassland in the RS scenario (all remaining cropland is turned into grassland) then the annualised damage drops to much lower levels. If only forests are present, then the damage is zero.

Annualised damage in the floodplain area as a function of which floods are released (million HUF/year)

Which return period floods appear in the Cibakháza-Tiszaföldvár floodplain	CS	RS
hq2-hq100	209.6	132.3

hq5-hq100	148.3	93.8
hq10-hq100	63.7	40.3
hq30-hq100	28.4	17.9
hq50-hq100	11.4	7.2
hq100	6.4	4.0

Net income of land use from the farmer's perspective

Looking at the net income of crop production vs. afforestation from the perspective of farmers (0), calculated as present value, forest management has a considerable advantage on average land[2]. On a 50 year time horizon the value of timber is expected to be higher than the net income from cropland, and this is not fully compensated by the difference between the long term agricultural subsidies and the short term income supplement for afforestation. We can assume that many farmers are not aware of the current favourable economics of afforestation and they keep cultivating land with average of below average productivity, even though afforestation would provide better economic prospects.

Comparison of the net income of crop production and forest management, current subsidies

Name	Annual benefit value (HUF/ hectare/ year)	First year	Last year	Present value (HUF/hectare)
Crop production				
Annual CAP support	75,000	1	50	2,403,906
Annual net income from cropland	45,000	1	50	1,442,344
Total				**3,846,249**
Forest management				
Afforestation (after subsidies)				0
Annualised net income from forests	113,438	1	50	3,635,924
Income supplement for new afforestation	155,520	1	12	1,677,571
Total				**5,313,494**

Note: 2% real discount rate has been applied

The current favourable subsidies for afforestation, with 432 EUR/hectare/year of income supplement for the first 12 years, are available until 31 December 2022. Whether, and how they would change from 2023, is not known at this time. Therefore, as a point of reference, we also make a calculation with the previous level of income supplement for afforestation, 172 EUR/hectare/year. The results are displayed in 0. In present value terms forest management continues to be more attractive than crop production, but since the majority of the actual revenue takes place decades from today, many farmers would choose a stable current income as opposed to a higher, but less certain future income.

Comparison of the net income of crop production and forest management, previous subsidies

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[2] The same would apply to low quality land, while the best pieces of cropland would probably favour crop production as opposed to forest management.

Name	Annual benefit value (HUF/ hectare/ year)	First year	Last year	Present value (HUF/hectare)
Crop production				
Annual CAP support	75,000	1	50	2,403,906
Annual net income from cropland	45,000	1	50	1,442,344
Total				**3,846,249**
Forest management				
Afforestation (after subsidies)				0
Annualised net income from forests	113,438	1	50	3,635,924
Income supplement for new afforestation	155,520	1	12	667,922
Total				**4,303,845**

Net income after inundation losses

By multiplying the size of the area covered by the three different land uses with the net income per hectare (chapter 0) we arrive at the annual average net income provided by all land use categories of the Cibakháza-Tiszaföldvár floodplain, as depicted in 0.

Annual(ised) net income without flood damage (million HUF)

	CS	RS
Cropland	87.3	54.6
Grassland	0.5	2.9
Forest	2.7	31.1
Total	90.5	88.7

While the annualised net income is almost the same in the two scenarios, once the annualised inundation damage (0) is subtracted, the attractiveness of the RS scenario becomes obvious (0). If only 50-100 year floods are released into the floodplain area, then the two scenarios are more or less equivalent, but in case of more frequent inundations, RS prevails.

Annualised net income of land use activities after inundation losses for the Cibakháza-Tiszaföldvár floodplain area (million HUF)

Which return period floods appear in the Cibakháza-Tiszaföldvár floodplain	CS	RS
hq2-hq100	-119.2	-43.7
hq5-hq100	-57.8	-5.1
hq10-hq100	26.7	48.3
hq30-hq100	62.1	70.7
hq50-hq100	79.1	81.5
hq100	84.1	84.6

Monetised flood risk along the Tisza

The same methodology has been applied to calculate the economic value of flood risk (reduction) as for the Middle Tisza Pilot case study at Fokorúpuszta (REKK, 2020). The methodology is presented in detail in the Annex of the report.

We know from Ungvári and Kis (2018) that in case of the Tisza, floods with return periods of at least 30 years pose substantial risk to properties. Therefore we did hydraulic and economic modelling of 9 relevant scenarios: three flood return periods (30, 50, 100 years) and three variations on the dyke along the Cibakháza-Tiszaföldvár floodplain (no modification, sluiceway, flood gate). Under the sluiceway scenario the floods would freely enter the floodplain area, moderately reducing the water level in the river bed. Under the flood gate scenario the opening of a flood gate would be timed to cut the peak of the flood. The total cost of each scenario is displayed in 0. Evidently, the flood gate has a more beneficial impact than the sluiceway. In case there is no dyke at all between the floodplain and the river, the flood related benefits are expected to be the same as in the case of the sluiceway scenario.

Summed cost of flood defense and catastrophe damage for specific flood events for sections of the Tisza impacted by the Cibakháza-Tiszaföldvár floodplain (million HUF)

Return frequency	No modification of the dyke	Sluiceway	Flood gate
hq30	2,711	2,708	2,686
hq50	12,542	11,533	10,217
hq100	42,003	41,451	37,525
Annualised value of all floods together	885	865	789

Land use based carbon emissions and sequestration

In this chapter we look at changes in greenhouse gas emissions (GHG) and carbon sequestration, as an ecosystem service generated by the floodplain restoration. We assess the GHG impacts of land use change, but disregard the emissions arising from any construction activities, such as demolishing existing dyke sections, building new dykes, or constructing a flood gate. The same methodology is applied as in REKK (2020).

For the purpose of Danube Floodplain climate analysis the TESSA toolkit has been recommended. The TESSA toolkit makes further reference to the Tier 1 methods of the Intergovernmental Panel on Climate Change (IPCC). However, even those methods require data that is not readily available, therefore we relied on other, even further simplified calculations, which, on the other hand, are also based on the IPCC methods.

We made use of the National Inventory Report for 1985-2016 (NIR, 2018) and its Annexes submitted by Hungary to the UNFCCC. We divided the total sector and land use specific GHG figures by the corresponding land area published by the Central Statistical Office of Hungary. We received average GHG figures per hectare. These results are Hungary specific, though there is some variation of the carbon balance of different land use locations even within the same land use category, which makes our results less precise compared to strictly following the IPCC Tier 1 methods.

According to NIR (2018) croplands sequestered 379 kt of CO_2 in 2016. This figure, however, is misleading since activities on cropland (e.g. cultivation with machines, application of fertilisers, pesticides, manure) represent an important source of emissions. Total agricultural emissions, in 2016 reached 6878 kt of CO2e (CO_2 equivalent), the most important components of which include enteric fermentation, manure management and agricultural soils, the latter is related to the use of fertilisers. If we add emissions from agricultural soils (3472 CO_2e in 2016) to the sequestered CO_2 then we receive 3093 kt CO_2e of net emissions. Dividing this figure with the 2016 croplands of 4,332,400 hectares, a unit emission figure of 0.714 ton/hectare/year appears. This is the figure that we will continue to use.

In 2016 there was 783,200 hectares of grassland in Hungary, while the corresponding net emission figure from NIR (2018) is 14 kt of CO_2e. Therefore there is a unit emission of 0.018 ton/hectare/year.

Concerning forests, 3141 kt of carbon-dioxide was sequestered in 2016 on 1,940,700 hecares, resulting in a unit figure of 1.618 ton of CO_2 removal per year per hectare. However, this is an average figure, which corresponds to mature forests. For new afforestation reaching this level of sequestration takes 10-15 years, after that it will surpass this benchmark. For the sake of simplicity, we assume constant CO_2 sequestration.

Pairing actual land use figures (hectares) with unit emission / sequestration figures we arrive at the annual carbon balance of the area (0). Land use change from arable land toward meadows and forests generates substantial CO2e emission savings, of about 915 tons/year.

Annual CO2e emissions of the current and planned land use

	Land cover (hectare)			Annual CO2e emissions (ton/year)		
	CS	RS	CO2e emisson / removal (ton/ hectare/ year)	CS	RS	Difference
Arable land (crops)	1939.6	1213.8	0.714	1384.9	866.6	-518.3
Meadows	103.8	578.6	0.018	1.9	10.4	8.5
Deciduous forest	23.6	274.6	-1.618	-38.1	-444.3	-406.2
Total	2067.0	2067.0		1348.6	432.7	-915.9

When determining the economic value associated with CO2 emissions, we continue to follow the approach developed and applied by the EBRD, just like in REKK (2020), as we believe that this is a methodologically sound approach that well approximates the true cost of carbon emissions (and vice versa, the actual benefit of carbon sequestration).

The EBRD (2019) has adopted a carbon pricing approach under which the carbon impact of all projects is assessed using a “shadow price”. The shadow price considers all socials costs as opposed to market based CO_2 emission allowance prices which reflect the operation of a carbon market that is to a large extent driven by the number of carbon allowances made available to market participants by regulation. The latter price fluctuates, it’s movement driven by supply and demand, independently of the true cost that the release of CO_2 into the atmosphere generates. The shadow carbon price is incorporated into decision making, when the costs and benefits of a new investment are assessed, it puts a value on greenhouse gas emissions, thus correcting for the market failure of not fully considering the externalities caused by the emission.

Regarding the actual cost level, the EBRD follows the recommendations of the High-Level Commission on Carbon Prices (https://www.carbonpricingleadership.org/). This commission was created in 2016 with the explicit purpose of benchmarking the cost of pollution. The recommended carbon price range is 40-80 USD/ton of CO_2 for the year 2020, rising to 50-100 USD/ton of CO_2 by 2030. Beyond 2030 carbon prices are increased by 2.25% per year. All of these values are in real terms, in 2017 prices. Thus any inflation of the US dollar would result in further increase of the nominal value of the shadow price. The EBRD carries out a sensitivity analysis by applying both the lower and the upper edge of the price range during its CBA calculations. We checked EBRD resources to see if the shadow carbon prices have been updated for the last two years, but EBRD continues to use these same figures as in 2019.

An important recent development, however, is that in the most relevant greenhouse gas market, the EU ETS market, prices for CO2 allowances have more than doubled for the last two years, rising from about EUR 25 to an average price of around EUR 60 for September and October 2021. These prices are in line with the above described EBRD benchmarks.

The RS scenarios have lower net carbon emissions than the CS scenarios, due to the increasing carbon sequestration of forests and lower emissions from croplands, as the size of the latter declined. The value of land use change related CO2 emission reduction is calculated by multiplying the difference between the two scenarios with the year specific CO2 shadow price. The results are displayed in 0. This monetised value of emission reduction is between 12 and 24 million HUF initially, rising to about 40-80 million HUF by the end of the examined 50 year period. For the purpose of scenarios calculations we use the mid point of the range for each year.

The economic value of land use change triggered CO2e emission reduction

Year	Net CO_2 reduction due to land use change	Minimum carbon shadow price (EUR/ton)	Maximum carbon shadow price (EUR/ton)	Minimum CO_2 benefit of land use change (million HUF)	Maximum CO_2 benefit of land use change (million HUF)
2020	915.9	36.0	72.0	11.87	23.74
2021	915.9	36.9	73.8	12.17	24.33
2022	915.9	37.8	75.6	12.46	24.93
2023	915.9	38.7	77.4	12.76	25.52
2024	915.9	39.6	79.2	13.06	26.11
2025	915.9	40.5	81.0	13.35	26.71
2026	915.9	41.4	82.8	13.65	27.30
2027	915.9	42.3	84.6	13.95	27.89
2028	915.9	43.2	86.4	14.24	28.49
2029	915.9	44.1	88.2	14.54	29.08
2030	915.9	45.0	90.0	14.84	29.67
2031	915.9	46.1	92.3	15.21	30.42
2032	915.9	47.3	94.6	15.59	31.18
2033	915.9	48.5	96.9	15.98	31.96
2034	915.9	49.7	99.3	16.38	32.76
2035	915.9	50.9	101.8	16.79	33.57
2036	915.9	52.2	104.4	17.21	34.41
2037	915.9	53.5	107.0	17.64	35.27
2038	915.9	54.8	109.7	18.08	36.16
2039	915.9	56.2	112.4	18.53	37.06
2040	915.9	57.6	115.2	18.99	37.99
2041	915.9	59.0	118.1	19.47	38.94

2042	915.9	60.5	121.0	19.95	39.91
2043	915.9	62.0	124.1	20.45	40.91
2044	915.9	63.6	127.2	20.96	41.93
2045	915.9	65.2	130.3	21.49	42.98
2046	915.9	66.8	133.6	22.03	44.05
2047	915.9	68.5	136.9	22.58	45.15
2048	915.9	70.2	140.4	23.14	46.28
2049	915.9	71.9	143.9	23.72	47.44
2050	915.9	73.7	147.5	24.31	48.63
2051	915.9	75.6	151.2	24.92	49.84
2052	915.9	77.5	154.9	25.54	51.09
2053	915.9	79.4	158.8	26.18	52.36
2054	915.9	81.4	162.8	26.84	53.67
2055	915.9	83.4	166.9	27.51	55.01
2056	915.9	85.5	171.0	28.20	56.39
2057	915.9	87.7	175.3	28.90	57.80
2058	915.9	89.8	179.7	29.62	59.24
2059	915.9	92.1	184.2	30.36	60.73
2060	915.9	94.4	188.8	31.12	62.24
2061	915.9	96.8	193.5	31.90	63.80
2062	915.9	99.2	198.3	32.70	65.40
2063	915.9	101.6	203.3	33.52	67.03
2064	915.9	104.2	208.4	34.35	68.71
2065	915.9	106.8	213.6	35.21	70.42
2066	915.9	109.5	218.9	36.09	72.18
2067	915.9	112.2	224.4	36.99	73.99
2068	915.9	115.0	230.0	37.92	75.84
2069	915.9	117.9	235.8	38.87	77.73
2070	915.9	120.8	241.7	39.84	79.68

Note: EUR/HUF exchange rate of 360 is used during the calculations.

Non-monetised aspects

While it has been possible to quantify the economic value of a lot of the key cost and benefit components of the Cibakháza-Tiszaföldvár floodplain scheme, there are some items where lack of available data did not allow quantification. These items are introduced in the current chapter.

Based on the experiences of the workshop focusing on the Fokorúpuszta area the ecosystem-service elements that are not monetized in the study are listed below:

Ecosystem service change that is not monetized
• Biodiversity • Habitat for various species, more robust fauna and flora • Lower pollution • More hunting and more game meet

- Increased water infiltration into the soil, ground water recharge
- Micro-climate regulation
- Increasing recreational, sport, hobby and educational activities
- Beekeeping

These benefits also appear in the Cibakháza-Tiszaföldvár floodplain area, as land use is transformed from the currently dominant crop production to a more balanced mix of cropland, grassland and deciduous forest. Some of the more important benefit items are detailed below, together with those non-monetised cost items which are necessary to enable land use change and water retention schemes.

Beekeeping

More bee families can be sustained in the additional natural area. As over 700 hectares of land would be transformed from cropland to more natural vegetation, this would enable 4-5 beekeepers to make a livelihood, if there is enough interest. Beekeeping, from the perspective of the available area, has been an underutilised opportunity recently, therefore the value that can be assigned to this activity is rather uncertain. We do not make attempts to monetise it. We should also keep in mind that bees not only produce honey, but they also contribute to the productivity of agricultural activities and to a healthy ecosystem.

Hunting

As the size of the natural area increases, more wild animals will be present. In the Fokorúpuszta case water fowl was more likely to thrive than wild mammals, and we think this would also apply here. Altogether, the value of hunting may increase, but the extent of this change is difficult to predict.

Recreational, sport, hobby and educational activities

More natural areas may entice more people to spend increasing time in nature pursuing different activities. The area is close enough to Cibakháza and Tiszaföldvár to attract people to jogging, leisure walking, biking. The natural area in the proximity of the river may become an attractive spot for bird watching, but we do not have a basis to estimate the actual number of such visitors. The natural area provides educational potential as well, such as nature trails and on-site biology and ecology classes, school trips and camps.

Ecosystem improvements

As approximately 700 hectares of cropland is converted into more natural land use, habitat will sustain an increased fauna and flora, it is supposed to exhibit increased biodiversity and more resilience to external disturbances. These are all important, but unquantified improvements.

Increasing groundwater recharge

Due to the regular inundation of the area more groundwater recharge is expected, contributing to the healthy water balance of the region. Higher groundwater levels are beneficiary both for nearby farmers and the ecology.

Triggering land use change

Farmers need to be incentivised to give up farming their croplands and switch to grassland, forests or other nature-friendly land uses. There are many different ways of doing this: upfront payments, regular payments, exchange of their land to parcels outside the floodplain area, assistance in adjustment to regular inundation on their land etc. No specific method has been defined for the current analysis, thus we cannot estimate the corresponding cost. It is quite certain, however, that resources would be needed to achieve land use change (both as incentives, and also to cover the costs of initial adjustment). One may reckon the level of these costs by comparing the net income from different land uses, since lost profit would somehow have to be covered, in order to ensure that the financial position of farmers does not worsen.

Technical measures to connect the floodplain to the river

Various technical measures are needed to ensure the release of water from the river to the floodplain at given flood heights:

- Demolishing a section of the dyke reconnects the floodplain, high waters would enter its area.
- Developing a sluiceway creates a section in the dyke where a given level of water can cut through toward the floodplain.
- Building a flood gate enables the cutting of the peak of the flood without allowing the unrestricted flow of water to the floodplain area.

Any of these engineering solutions can be designed and implemented in multiple ways and at different cost levels, thus they would need to be defined quite precisely before tyring to estimate their costs.

Conclusions

0 provides a summary of the costs and benefits of all eight analysed scenarios. Only the monetised items are included. In the case of flood related costs, we do not display the full costs (as those would fall in a different magnitude, and that value has not much to do with the pilot floodplain area), but the difference compared to the BAU.

The yellow rows in the bottom of the table show the total figures (all cost items for all stakeholders added together). The first total row includes transfer payments, the second does not. A transfer payment "is a one-way payment to a person or organization which has given or exchanged no goods or services for it"[3]. As such, a transfer does not represent an actual economic cost or benefit (it can have indirect economic consequences, but those are not nearly as powerful as payments for services or goods). Total benefits / costs including transfer payments are important for individuals and market players, such as farmers, because their financial position is directly influenced by the transfers. Therefore these are important variables if we would like to understand how they view the outcome of given scenarios. From the perspective of the whole economy it is better to consider total benefits / costs without transfers, thus the latter should guide a social cost benefit analysis.

The following conclusions can be drawn based on 0:

- The BAU scenario with the current land use and without any hydrological change represents substantial benefits to farmers, although much of it originates from agricultural subsidies (which are transfers). All other scenarios would reduce the benefits enjoyed by farmers, thus a compensation would be necessary.

[3] https://www.investopedia.com/terms/t/transferpayment.asp

- Under the RS_none scenario, also without any change in hydrology, the economic position of farmers declines, but only moderately, as they change crop production to less productive meadow management, which is only partly counterbalanced by the shift to more productive forest management. Declining carbon emissions, however, generate substantial (global) social benefits. From the perspective of society this is the most attractive scenario.
- Under CS_all and RS_all the floodplain area is frequently inundated which generates land use specific inundation damages and just as importantly requires the development local defense lines (levees) which turned out to be very expensive. At the same time, the flood related benefits are moderate, they do not compenate the costs related to the local defense line. These are the economically least attractive scenarios.
- Under the sluiceway scenarios (CS_sluiceway, RS_sluiceway) inundation losses are much lower since only floods with a return frequency of at least 30 years are allowed to enter the floodplain area.
- The inundation losses are similar in case of the CS_gate and RS_gate scenarios, but the flood related benefits are much higher, since the peak of the floods are cut. Still, these benefits are not enough to counterbalance the quantified costs of local defense line devepment. Moreover, there are substantial, yet unquantified costs of flood gate construction and maintenance, which further deteriorate the economic position of these scenarios.

In conclusion, compared to the current state (the BAU scenario) only the new land use without any inundation (RS_none) would generate supplemental benefits. All other scenarios are more costly, and neither the flood related benefits or CO_2 emission reductions would be sufficient to compensate the loss of farming income and the flood defense infrastructure investment costs. Whether the non-monetised benefits of land use change coupled with frequent inundation would justfify the monetised costs, requires further analysis.

Costs and benefits of the inspected scenarios, net present value (million HUF)

				BAU	CS_all	CS_sluiceway	CS_gate	RS_none	RS_all	RS_sluiceway	RS_gate
Stakeholder	**Costs / Benefits**	**Name**	**Description**	**Present value**	**Present value**	**Present value**	**Present value**	**Present value**	**Present value**	**Present value**	**Present value**
State (flood)	Benefits	Reduction of flood related costs	Based on catastrophe damage and flood defense costs together	0	646	646	3,055	0	646	646	3,055
State (flood)	Costs	Local defense line	Along the floodplain area	0	-6,580	-6,580	-6,580	0	-6,580	-6,580	-6,580
State (flood)	Costs	Land purchase for local defense line	Along the floodplain area	0	-142	-142	-142	0	-142	-142	-142
State (flood)	**Net monetised benefit (+) or cost (-)**			**0**	**-6,075**	**-6,075**	**-3,667**	**0**	**-6,075**	**-6,075**	**-3,667**
Farmers	Costs	Inundation losses	Related to agricultural activities in the Cibakháza-Tiszaföldvár floodplain	0	-6,719	-364	-364	0	-4,242	-230	-230
Farmers	Benefits	Annual CAP support	Only cropland and grassland are eligible, forestry is not	4,912	4,912	4,912	4,912	4,309	4,309	4,309	4,309
Farmers	Benefits	Annual net income from cropland		2,798	2,798	2,798	2,798	1,751	1,751	1,751	1,751
Farmers	Benefits	Annual net income from grassland		17	17	17	17	93	93	93	93
Farmers	Benefits	Annualised net income from forests		86	86	86	86	998	998	998	998
Farmers	Benefits	Income supplement for new afforestation	Available for farmers to replace the lost income of discontinued agricultural activities for up to 12 years	0	0	0	0	421	421	421	421
Farmers	**Net monetised benefit (+) or cost (-)**			**7,812**	**1,093**	**7,448**	**7,448**	**7,572**	**3,330**	**7,342**	**7,342**
Global society	Costs	Carbon emissions	Based on shadow price of carbon. Positive value indicates net emisssions, negative value net sequestration.	-1,513	-1,513	-1,513	-1,513	-486	-486	-486	-486
Global society	**Net monetised benefit (+) or cost (-)**			**-1,513**	**-1,513**	**-1,513**	**-1,513**	**-486**	**-486**	**-486**	**-486**
All stakeholders together	***Net monetised benefit (+) or cost (-)***			***6,299***	***-6,496***	***-141***	***2,267***	***7,086***	***-3,231***	***781***	***3,189***
	Net monetised benefit (+) or cost (-) without transfers			***1,387***	***-11,408***	***-5,053***	***-2,645***	***2,356***	***-7,961***	***-3,949***	***-1,541***

Based on our analysis, the current land use is not the most advantageous one from a long term perspective, neither for the public nor, the landowners.

From an annualized perspective the net income of the CS and RS scenarios are very close to each other (0), but the table reveals that in case of the RS scenario the still relatively lower forest cover share provides a significant part of the benefits. Path dependency is a strong force maintaining the status-quo. Meanwhile planting forest among the recent circumstances on an average or below average quality land is more beneficial than sticking to crop production during the same 50-year period. This result is true in both cases if CAP subsidies are taken into consideration or not (0, 0). Landowners may not be aware of the changing conditions, or don't have the financial background for managing the necessary change or lack the necessary knowledge or trust in the predictability of the regulation or have long term cultivation contracts.

Also, at the same time there are non-realized benefits attached to forestry as public benefit derived from the value of the carbon sequestration of the forest (0 and 0). This potential benefit is in the range of 11-24 million HUF annually, or about 1 billion HUF of present value, based on the shadow price of carbon.

The recent incentive policy on land use could trigger an afforestation process without further considerations. The expansion of a previous table, see (**Fehler! Verweisquelle konnte nicht gefunden werden.**) that such a land use transformation will reduce the damage exposure, that might open up space for other land management arrangements.

Annualised damage in the floodplain area as a function of which floods are released (million HUF/year)

Which return period floods appear in the Cibakháza-Tiszaföldvár floodplain	CS	RS
hq2-hq100	209.6	132.3
hq5-hq100	148.3	93.8
hq10-hq100	63.7	40.3
hq30-hq100	28.4	17.9
hq50-hq100	11.4	7.2

hq100	6.4	4.0

From this perspective the provision of further non-monetized benefits hang on the difference between the benefits of carbon sequestration and the cost of installing the necessary infrastructure that protect other areas from the detrimental effect of inundations. 0 and 0 show that there is a wide range of infrastructure development costs in relation to the level of the perceived flood risk reduction service. Further details must be clarified whether there is a low-levee-height equilibrium when only the most frequent floods are allowed to a mostly forested area.

The listed topics are recommended for additional research:

- The viability of floodplain cropland use
- Average national net income figures were used for the cropland of the Cibakháza-Tiszaföldvár floodplain, but further research uncovering the profitability of this area would help to finetune the conclusions. Net income in different parts of the floodplain is crucial when the ideal land use is determined.
- We suspect that floodplain forests are economically more attractive than croplands or grasslands, especially when inundation damages are also considered. This notion should be validated with further research.

The structur

Stakeholder meetings

Two stakeholder meetings were organized in Hungary. The first part aimed farmers and land owners, while the second part aimed authorities and regional asset managers. Results of the Danube Floopdplain project were presented to the stakeholders with special focus on the pilot area located near Tiszaföldvár, Martfű and Cibakháza.

On 5 October 2021 stakeholder meeting in Szolnok, Hungary was organised aiming at involving farmers to give inputs about their needs and experiences about the lack of water on the area. Participants first listened to presentations which showed various possibilities of water supply on this former deep floodplain area. It could improve long drought conditions of the area. As no infrastructure is present on the area, it would be technically possible to make the floodplain active again.

In case of floodplain activation the area could serve the mitigation of catastrophic flood events and with setting up a water supply system smaller floods could serve as water supply in drought periods.

Various possibilities of advantageus land use change were also presented – from a possibility of conservation of current land use structure but with an adaptation of hygrophilous crops through applying plants and trees or wetland which break up monotonity of intensive cultures, improving biodiversity and water balance.

In the second part of the event a very active discussion followed where the present farmers spoke about their problems which are in connection with area payments: EU CAP doesn't support those areas wich are inundated, they need to irrigate but irrigation channels don't work. They would not do any agricultural activity there if the area would be an active floodplain again because they can't report a vis maior in that case.

Summarizing the outcome of the event, people would like the idea of any water supply but Common Agriculture Policy (CAP) must serve the new land use system.

On 14 October 2021, participants first listened to presentations which showed various possibilities of water supply on this former deep floodplain area. It could improve long drought conditions of the area. As no infrastructure is present on the area, it would be technically possible to make the floodplain active again.

In case of floodplain activation the area could serve the mitigation of catastrophic flood events and with setting up a water supply system smaller floods could serve as water supply in drought periods.

Various possibilities of advantageous land use change were also presented – from a possibility of conservation of current land use structure but with an adaptation of hygrophilous crops through applying plants and trees or wetland which break up monotonity of intensive cultures, improving biodiversity and water balance.

Hereinafter, role of cost-benefit analysis with an integration of certain, monetizable ecosystem services was presented.

Modelling results of potential natural vegetation of the area could be helpful in planning of new land use system and also in showing location of new xerophytic or hygrophilous associations since after the alterations and the restorations the water surplus is not obvious on the whole area.

At the end representative of the chamber of agriculture in Hungary gave an insight about new possibilities in financial support of outlined water retention activities.

In the second part of the event a very active discussion followed and this focused on verifying the feasibility of the technical solutions from water directorate land ownership and nature conservation perspective. All authorities are working under current legal conditions and could not change the whole structure at once. A step by step solution is needed where the first step would be to make this land use type to be supportable.

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Annex: Methodology for flood risk calculation

The areas along the Hungarian section of the river Tisza are protected by dykes. Dykes alone, however, are not always sufficient to ensure perfect protection. Large floods require additional defense operations, and a catastrophe may also occur in case a dyke fails or its height is not sufficient to hold the water, and areas are flooded outside the floodplain. These are the two main types of costs associated with large flood events: the costs of defense operations and catastrophe damage in case a catastrophe takes place.

In order to reduce the risk of a flood catastrophe, flood defense development projects are regularly implemented by governments. These projects may consist, for example, of strengthening and raising the dykes, investing into peak flood polders, ensuring smoother water flow in the river bed or giving more room to the river via the relocation of dykes.

To judge the cost effectiveness of investing into and operating peak flood polders, a hydrologic simulation based economic decision support model was developed within the "Coordinated peak-flood polder management on the river Tisza" project (Tisza Üzemirányítási projekt, 2017-19). While the original model was designed to assess the economic viability of peak flood polders, it was now amended to be able to inspect the economic benefits of the Cibakháza-Tiszaföldvár floodplain restoration idea.

The core idea behind our analysis is that the changed river regime (floodplain restoration through different solutions) will alter the behaviour of flood waves, thereby requiring a different level of defense operation and altering the risk of a catastrophe. The economic model is based on the relationship between water levels, defense costs and the probability of dyke failure. For any given flood wave we are comparing several scenarios: how the flood would move along the river under the original and the new, altered river regime, when more space is available for the water (through various engineering solutions). These scenarios are hydrologically simulated in HECRAS and the hydrological results are converted to an input for the economic model: hourly time series of water levels in various river sections.

Even relatively benign floods require some flood defense preparations, such as the daily inspection of the condition of the dykes, while higher floods tend to demand growing efforts, such as reinforcing the side of the dykes or piling sand bags on top of the embankment. Within the economic model the relationship between flood characteristics and defense operation costs along the dykes was derived from a regression analysis of historic flood defense data from the river Tisza and its tributaries between the 2000-2013 period. The input data of the cost estimation comprised the physical characteristics of the flood waves (peak water level of the flood, the number of days under stage three defense alert, the length of the defended dike section) and the flood defense activities taking place during the analyzed period officially characterized as “extreme level” defense. The resulting statistical relationship was reliable, with a relatively large standard deviation.

The economic model also depicts the connection between flood events and catastrophe damages. This relationship was to a large extent formulated based on the ÁKK (Árvíz Kockázat Kezelési projekt – Flood Risk Management project) database, created by the flood risk mapping project triggered by the EU Flood Directive. The ÁKK project surveyed all dykes to identify the most vulnerable dyke sections, which were called „rupture sections”. For all these sections the water level was determined at which static problems may start occuring. Within the economic model – based on consultations with the engineers of the ÁKK project – a water level based dyke failure probability function was generated for all rupture sections. Higher water levels thus translate into a higher probability of catastrophe. If high water levels stay for an extended period, then the value of this probability further increases. The ÁKK project also assessed the areas that would be flooded if the dyke at a given rupture section fails, and how much damage would register in this case. All of this information is incorporated into the economic model.

The economic model is a Monte Carlo simulation based probabilistic model. The main reason for applying the Monte Carlo approach in this case is that the dyke rupture and the resulting flood catastrophe is a small probability event, but one that comes with a huge economic loss. Simply looking at the average case – in which no catasrophe takes place – is misleading. A flood wave is better depicted by the expected value of the full event horizon, which also includes the probability of a catastrophe. The full event horizon can be rather complex. Even a short river stretch may contain multiple rupture sections, and once a section breaks the water level within the river bed drops, thus a second dyke rupture cannot happen. Moreover, a dyke breach may happen at different water levels (with increasing probability at higher levels), implying that the flooded area is also different, and so is the corresponding damage. To be sure that the majority of the event horizon is captured, each model scenario needs to be run at least 10,000 times.

The models need to be run for both the baseline scenario and the altered river regime reflecting the changes of the dyke section along the Cibakháza-Tiszaföldvár floodplain. By comparing the expected total cost of the two scenarios it becomes possible to conclude if the floodplain restoration has generated net benefits in terms of lower overall flood related costs.

The above process is applicable to a specific flood, and the results will show the flood related benefits of dyke relocation for that one specific flood event. However, the dyke relocation is supposed to generate benefits not only for a single flood event, but for an extended time horizon. Therefore it makes sense to look at a long time horizon (e.g. 100 years) and consider all the possible floods that can take place during the period. Alternatively, we can look at the annual probability that specific floods will occur. Floods are defined by their "return period", which is the estimated average time between events. A 10 year flood, for example, is a flood with a peak water level that has a 1/10=10% chance of being exceeded in any given year. In a similar vein, a 50 year flood has a 1/50=2% chance of being exceeded in any given year.

We can compute the annual expected cost of floods if we simulate floods with different return periods, compute the cost associated with each flood, calculate the annual expected value of each flood by multiplying its cost and the probability that the flood would occur in any given year, and finally sum all of the annual expected values to arrive at the cost of the full event horizon (all possible floods).