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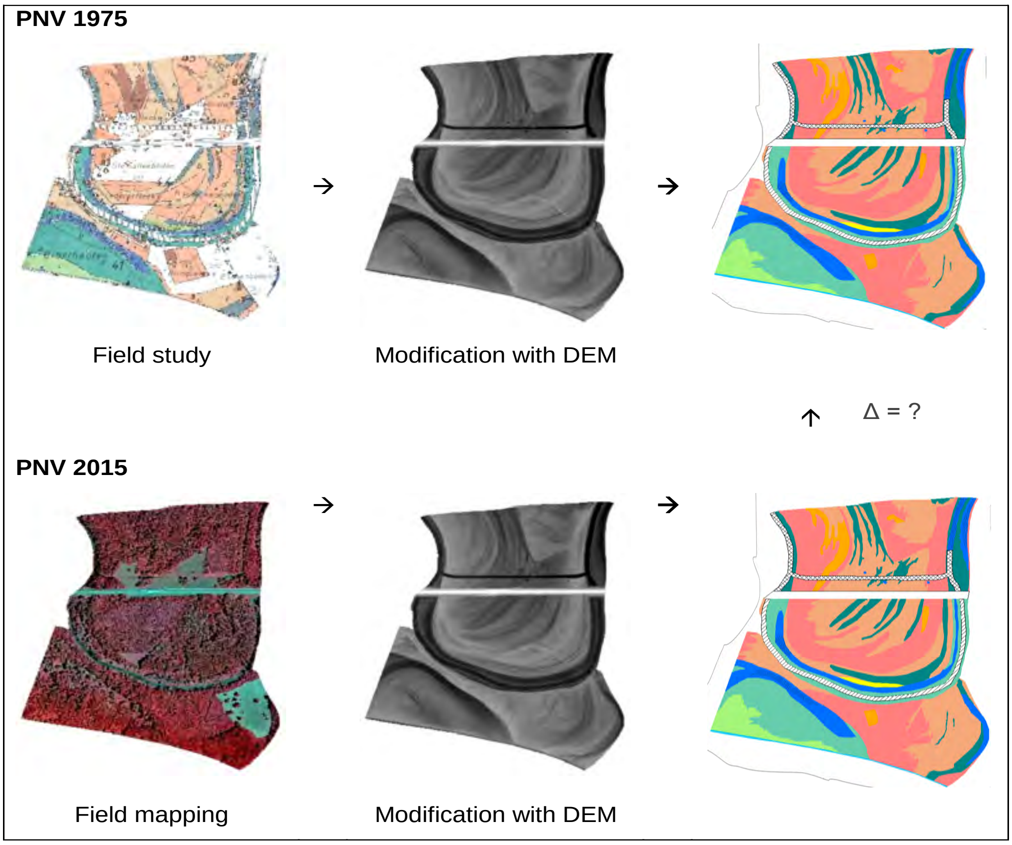
Anna Schöpfer



nationalpark donauauen
KOSTBARE NATUR FÜR GENERATIONEN

Capturing the effects of the Danube River incision on the potential natural vegetation of the Donau-Auen National Park

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Abbreviations

BFW	Austrian Research Centre for Forests (*Bundesvorschungszentrum für Wald*)
DBH	Diameter at breast height
KWD	Characteristic water levels of the Danube (*Kennzeichnende Wasserstände d. Donau*)
m. a. A.	Meters above the Adriatic
MW	Mean flow *(Mittelwasser)*
Öbf	Austrian federal forests (*Österreichische Bundesforste*)
PNV	Potential natural vegetation
RNW	Low flow (*Regulationsniederwasser*)
SMW	Summer mean flow (*Sommermittelwasser*)

Abstract

This study investigates the effects of the incision of the Danube on the floodplain vegetation of a study site in the Donau-Auen National Park. The research questions are: (1) How has the incision of the Danube affected the physical habitat parameters of the floodplain? (2): What is the current state of the potential natural vegetation and how does it differ from the potential natural vegetation mapped in 1975? In order to assess the effect on physical habitat parameters of the floodplain vegetation, the change of groundwater table and flood characteristics over the past decades is modelled in ArcGIS based on a digital elevation model, hydrological data and floodplain aggradation as well as river incision rates. The change of the potential natural vegetation over the past 40 years is captured by mapping the present state of the potential natural vegetation of the study site and comparing it with a map from 1975. The analysis of the physical habitat parameter showed an increase of depth to groundwater of ~ 0.5 m from 1949 to 2010. Depth of inundation and flooded area during flood events decrease over the investigated time. The comparison of the two potential natural vegetation maps shows the shift of a black poplar woodland site to the next successional phase, the rest of the study site has remained in its previously mapped phase of succession. Due to the lack of hydrogemorpological disturbances no new pioneer vegetation has been initiated.

Keywords: *Terrestrialization, Hydrogeomorphology, Floodplain modelling, Vegetation assessment*

Zusammenfassung

Die vorliegende Masterarbeit untersucht die Auswirkung der Flussbetteintiefung der Donau auf die potenziell natürliche Auvegetation anhand einer Versuchsfläche. Die Forschungsfragen lauten: (1) Wie hat sich die Flussbetteintiefung auf die physikalischen Habitatparameter ausgewirkt? (2) Was ist der aktuelle Zustand der potenziell natürlichen Vegetation und wie unterscheidet er sich von der Kartierung der potenziell natürlichen Vegetation von 1975? Der Effekt der Eintiefung auf die physikalischen Habitatparameter wird anhand eines Modells in ArcGIS berechnet, das sich auf ein digitales Höhenmodell, hydrologische Daten, Eintiefungsraten und die Aufsandungsrate stützt. Die Änderung der potenziell natürlichen Vegetation wird durch den Vergleich einer aktuellen Kartierung mit einer in 1975 veröffentlichten erfasst. Die Analyse der Änderung der physikalischen Habitatparameter zeigte ein Absinken des Grundwasserspiegels von ~ 0.5 m von 1949 bis 2010. Auch die Überflutungstiefe und die Überflutete Fläche während Hochwasser Ereignissen nahm stark ab. Der Vergleich der aktuellen und historischen potenziell natürlichen Vegetation zeigte nur einen Wechsel des Sukzessionstyps auf einem 1975 als Schwarzpappel Au kartierten Standorts auf. Die restliche Versuchsfläche verblieb in der gleichen Sukzessionsphase. Auf der Versuchsfläche entstanden keine neuen Pionierstandorte. Dieser Umstand ist auf die Reduktion der hydrogeomorphologischen Störungen zurückzuführen.

Schlüsselbegriffe: *Verlandung, Hydrogeomorphologie, Auwald Modellierung, Vegetationsaufnahme*

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1 Introduction

Floodplains are hotspots of biodiversity, depending on a dynamic disturbance regime (Ward 1998). The flow dynamics of the river and the type and availability of transported sediments and woody debris create a constantly changing mosaic of habitat patches, which provide a broad range of ecological niches (Salo *et al.* 1986, Greenberg et al. 1996, Poff et al. 1997). The damming and regulation of rivers has led to an extensive loss of riverine floodplains worldwide (Tockner et al. 2010). In Austria, only 34% of the Danube's potential floodplain area has remained (Haidvogel et al. 2009). The largest remnant, located along the free-flowing section between Vienna and the Slovakian border, has been declared a National Park in 1996 in order to protect its ecological diversity (Schiemer et al. 2007). The pre-regulated, alluvial Danube was once characterized by a dynamic equilibrium of sediment erosion and deposition (Hohensinner et al. 2009). Historical maps of the Danube document the migrating nature of the river arms that goes hand in hand with the constant regeneration of habitat structures (Jungwirth et al. 2014).

1.1 Problem

The pre-regulated Danube

A reconstruction of the habitat dynamics of the Danube in the Austrian Machland basin in 1812, prior to the channelization of this river section in 1859, shows a river landscape featuring several braided and meandering river arms, islands, gravel and sand banks, oxbow lakes and a floodplain naturally delimited by a terrace (Hohensinner et al. 2011). Hohensinner et al. (2009) classified this pristine state of the Danube at this study section as *gravel-dominated, laterally active anabranching river* following the river typology of Nanson and Knighton (1996). Its associated floodplain corresponds to Nanson and Croke's (1992) class *medium-energy non-cohesive floodplain* (Hohensinner et al. 2009). Floodplains of this class are in dynamic equilibrium with the flow regime and due to the lateral connectivity of the river-floodplain system stream powers typically don't exceed a medium level since the water spreads over a wide-ranging floodplain. New floodplain area generates mainly from point-bar accretion and braided-channel accretion (Nanson and Croke 1992). The dynamic equilibrium of erosion and sedimentation processes in the pre-channelized Danube of 1812 created a certain characteristic distribution of habitats. Even though succession and terrestrialization and the counteracting habitat rejuvenation through morphodynamic disturbances were varying with space and time, over the long term the proportions of habitat types remained more or less the same (Hohensinner et al. 2011). Due to the high percentage of lotic side arms, approximately 97% were connected on both ends (Hohensinner et al. 2004), and the web of vegetated, abandoned channels rising water levels quickly spread over the floodplain (Jungwirth et al. 2014) supplying nutrient rich river water to primary producers to isolated floodplain water bodies. The depth of the groundwater level was lower than later in the channelized state and more sensitive to the river's discharge with rising flows quickly translating to the groundwater table (Hohensinner et al. 2007).

Channelization

Since channelization of the Austrian Danube in the late 19th century the dynamic equilibrium of the river is disturbed. The narrowing of the Danube's main arm to a constrained channel with river banks formed of riprap increased the river's stream power and led to the erosion of the riverbed upstream of Vienna (Schmautz et al. 2002). The eroded sediments were partly aggraded on the floodplain downstream of Vienna, resulting in an increasing distance between the water level of the Danube and the height of the floodplain terrain. Due to the excessive sedimentation side arms were cut-off and oxbow lakes transformed to terrestrial environments (Jungwirth et al. 2014). High levees made of fine-grained sand and silt formed along the riverbanks via overbank deposition (Margl 1973). Additionnally several groynes were built to secure the minimum required depth for navigation in the middle of the channel (Hohensinner et al. 2013). Moreover, a flood protection dyke (*Marchfeldschutzdamm*) was constructed on the left riverbank (Fraissl 1993).

Hydropower

In the early 20th century the river incision relocated downstream of Vienna (Jungwirth et al. 2014) and eroded the sole of the Danube at a rate of 1 cm/a. The construction of hydropower dams accelerated this rate. After the hydropower plant *Aschach* was put in operation in 1964, two other hydropower plants had already been constructed by then, the rate of incision more than doubled to 2.2 cm/a (Gruber 1969). Up to this date eight additional hydropower plants have been constructed in the following years on the Austrian Danube, *Freundenau*, just upstream of the national park, lastly in 1999 (Verbund 2016).

The hydropower plants on the Danube and its tributaries are sediment continuum barriers. Sediments accumulate in the retention reservoirs causing a deficit downstream (Habersack et al. 2012). An excess of flow energy in relation to the sediments load is consumed by riverbed incision where energy goes into the erosion and the subsequent transport of sole material (Fryirs and Brierley 2013). In order to mitigate the riverbed degradation a volume of sediments of about 194 000 m^3/year (average from 1996-2010) are added by *Verbund Hydro Power AG* downstream of the *Freudenau* hydropower plant (Klasz et al 2016).

Nevertheless from 2003 to 2008 the incision of the riverbed downstream of Vienna up to the Slovakian border was in average 1.7 cm/year (Balzhieva 2015). Due to the artificial sediment input the riverbed downstream of the hydropower plant, stream km 1921 to stream km 1915 remains more or less at a constant elevation. Between stream km 1921 and stream km 1890 the riverbed incision continuous at a high rate, which is almost constant along the longitudinal axis. Downstream of stream km 1890 the riverbed erosion rate decreases. Approximately at the confluence with the Morava river/Slovakian border sediments sediment deposition sets in as the velocity decreases with proximity to the retention basin of the hydropower plant of the Slovakian hydropower plant *Gabčikovo* (Klasz et al. 2016).

Lowering of the groundwater table

A study on the future development of the groundwater table conducted on behalf of *viadonau* in 2006 states that the incision of the main channel and consequent lowering of its water levels carries along the lowering of the groundwater table. Lower water levels in the main channel extent the phases of disconnection with side arms. Thus, areas adjacent to side arms are threatened to experience an extensively lower groundwater table. The side arms close-by *Schönau, Orth and Maria Ellend-Haslau-Regelsbrunn* are currently the most sensible to the incision. On the long term also side arms further downstream, up to *Stopfenreuth,* are affected by disconnection, so the prediction of the groundwater model. The proximate floodplain between *Fischamend* and *Petronell-Carnuntum* might experience a lowering of the groundwater table of more than 1 m during low flow. Even areas 5-8 km in the north of this Danube stretch could experience a lowering of 0.2 m (Klasz et al. 2016).

Aggradation on the floodplain

The floodplain of the Donau-Auen National Park features both aquatic and terrestrial habitats, some of them oscillating from one to the other (Margl 1973). Thus, the floodplain features zones of transition between land and water, ecotones, which are characterized by a steep gradient of physic-chemical and environmental conditions providing heterogeneity of habitats (Gibert *et al*. 1997). The flood pulse, the frequency, amplitude and duration of flood events, is the main determinant of the existence, productivity and interactions of a floodplains biota. It regulates the lateral exchange of water, sediments, nutrient and organic matter and drives the nutrients recycling within the floodplain (Junk et al. 1989). The reoccurrence of morphodynamic disturbances, such as floods, on an intermediate supports the widest range of different species, which are able to tolerate the conditions without a few gaining dominance (Connell 1976).

The flood pulse in the free-flowing section downstream of Vienna is relatively unaltered, but the lateral connectivity of the riverscape is reduced by the incision of the main channel and the height of the riverside levees (Tockner et. al 1999). In decoupled river-floodplain systems the conveyance of water and sediments is inhibited, therefore the effects of flood events on the floodplain are reduced (Fryirs and Brierley 2013). Instead of the dynamic equilibrium, which characterized the Danube floodplain in its pre-regulated state, aggradation processes are overbalancing erosional processes. Therefore, the present-day floodplain, following the typology of Nanson and Croke (1992), is no longer a medium energy non-cohesive floodplain but has transformed to a low-energy cohesive floodplain. The aggradation of sediments on the floodplain is by far outweighs erosional processes on the floodplain terrain. In the past 120 years an annual average of about 11 mm was deposited at the levee. At the flood protection dyke (*Marchfeldschutzdamm)* the aggradation rate is about 0.3 mm/a (Klasz et al. 2014).

Responses of the floodplain vegetation

The dynamics of the river create the floodplains mosaic of habitats and they can have destructive as well as nourishing effects on its biota. Close to the river the mechanical force of the water and its sediment load stresses and eventually destructs the vegetation. Thus, the river's sand and gravel bars are vegetated with pioneer species, which can quickly colonize newly formed habitats (Egger et al. 2009). Nowadays this early phase of succession is few and far between therefore renaturation projects in the Donau-Auen National Park aim to give the Danube more room to manoeuvre, for example by the removal of river embankments at designated reaches (Baumgartner 2009). An important step as typical pioneer plants like *Myricaria germanica* and *Typha minima* have already vanished from the floodplain (Adler and Mrkvicka 2003).

In the proximate floodplain (*Offene Au)* the rivers erosive power decreases and deposition overweighs. Nutrients and organic matter carried along with river water fertilise the floodplain vegetation. Mechanical disturbances and especially stress, due to an impacted metabolism due to flood inundation, drive the habitat rejuvenation (Egger et al. 2009). Typical trees of the proximate floodplain in the Donau-Auen National Park are *Salix alba*, *Salix purpurea*, *Alnus incana*, *Populus alba* and *Populus nigra* (Nationalpark Donau-Auen 2010).

With distance to the river the plants are increasingly less affected by flood events and the vegetation develops towards late successional phases. The distal floodplain (*Rezente Au*) has lower nutrient inputs from the river water, but due to the infrequent flooding it is suitable for forestry and agriculture (Egger et al. 2009). *Quercus robus*, *Ulmus minor*, *Fraxinus excelsior* and *Acer campestre* are characteristic for the distal floodplain of the Danube (Margl 1973).

The decline of river dynamics due to the Danube's regulation and hydropower exploitation has caused a trajectory towards terrestrialization (Jungwirth et al. 2014) It can be assumed that the on-going riverbed incision is accelerates a development towards late successional phases. In order to gain comprehensiveness of the impact on the floodplain vegetation, this study aims to quantify the change of floodplain vegetation types and successional phases respectively. Since the floodplain vegetation is modified by human land use (e.g. by tree planting) the potential natural vegetation (PNV) will be identified and mapped. The PNV describes the vegetation potentially present at a certain location if the spatial environmental conditions such as climate, morphology, flooding frequency, flood inundation period, soil saturation and geology remain the same, but human interventions such forestry and agriculture are faded out (Tüxen 1956).

The potential natural vegetation of the present-day Donau-Auen National Park has been studied and mapped in 1950s to 1980s, a research initiated by the *Austrian Research Centre for Forests* (*BFW*) (Jelem 1974). A comparison of the past and present PNV mapping of the Donau-Auen National Park in the context of their respective hydromorphological characteristics (e.g. depth of groundwater table, flood frequency, inundation period) serves to gain comprehensiveness about the development of the floodplain vegetation over the past decades. Via area balances of past and present PNV types and their positions in succession the changes are quantifiable. The outcome of this work can serve as a support for decision-making concerning the management of the Donau-Auen National Park and river renaturation projects. Further it can provide information for modelling and scenario analysis of possible future developments.

1.2 Research questions and hypotheses

This study aims to investigate the effect of the incision of the Danube River on the habitat conditions for floodplain vegetation in the Donau-Auen National Park in order to gain ecosystem comprehensiveness. In 1975 Hermann Margl captured the potential natural vegetation of an ~0.94 km^2 sized study site in the floodplain forest close to Eckertsau, now part of the Donau-Auen National Park. In order to record the development of the potential natural vegetation over the last 40 years, this study studies maps the present-day potential natural vegetation. By comparing the two maps and the specific flood characteristics and depths of groundwater tables at the time of the assessment, this study aims to identify the change of habitat conditions for the floodplain vegetation caused by the river incision.

In order to gain comprehensiveness of how the river incision effects the vegetation the following research questions are stated for this study:

Research question 1: How has the incision of the Danube affected the physical habitat parameters of the floodplain?

Hypothesis 1: The lower the elevation of the riverbed of the Danube at *Orth an der Donau*, the higher the depth to groundwater at the study site.

Hypothesis 2: The lower the elevation of the riverbed of the Danube at *Orth an der Donau*, the smaller the flooded area, the lower the depth of inundation and the shorter the duration of flood events at the study site.

Research question 2: What is the current state of the potential natural vegetation and how does it differ from the potential natural vegetation mapped in 1975?

Hypothesis 3: There is no change of successional phase in the hardwood forest since 1975

Hypothesis 4: The area of softwood forest has decreased from 1975 to 2015 at the study site

Hypothesis 5: No primary succession has been initiated from 1975 to 2015

The outcome of this work can serve as a support for decision-making concerning the management of the Donau-Auen National Park and river renaturation projects. Further it can provide information for modelling and scenario analysis of possible future developments.

2 Potential natural vegetation of the Danube floodplain

Soil, topography and climate determine the water, nutrients and energy resources available to the plants. Also local biotas effect the vegetation, for example through grazing, fungal diseases and concurrence for light exposure (Blume et al*.* 2010). (Fig.1)

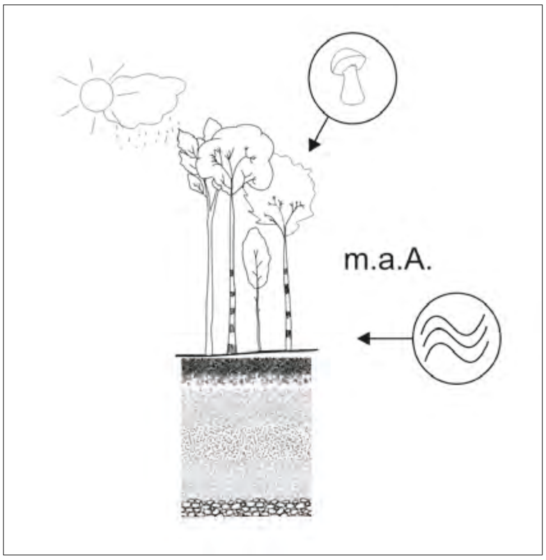


Figure 1 Potential natural vegetation determined by climate, soil, topography and disturbances

Ecological succession

But the potential natural vegetation is not solely a product of the site conditions as structures of plant communities and the structure of the vegetation change over time. In a floodplain, this process of ecological succession is initiated on alluvial deposits. Pioneers, usually annual herbs, colonize the newly formed habitats. They are soon replaced by perennial herbs and subsequently shrubs. As succession continues shrubs are overshadowed by trees, which become the dominating plant life-form and a floodplain forest develops. Succession ends as the forest reaches its climax. During ecological succession the biomass of the vegetation as well as the humus layer of the soil are increasing. Though succession is a unidirectional, disturbances such as floods and erosion, characteristic for floodplains, but also fire, drought and frost can interrupt or reset the process (Egger et al. 2009) (Fig. 2).

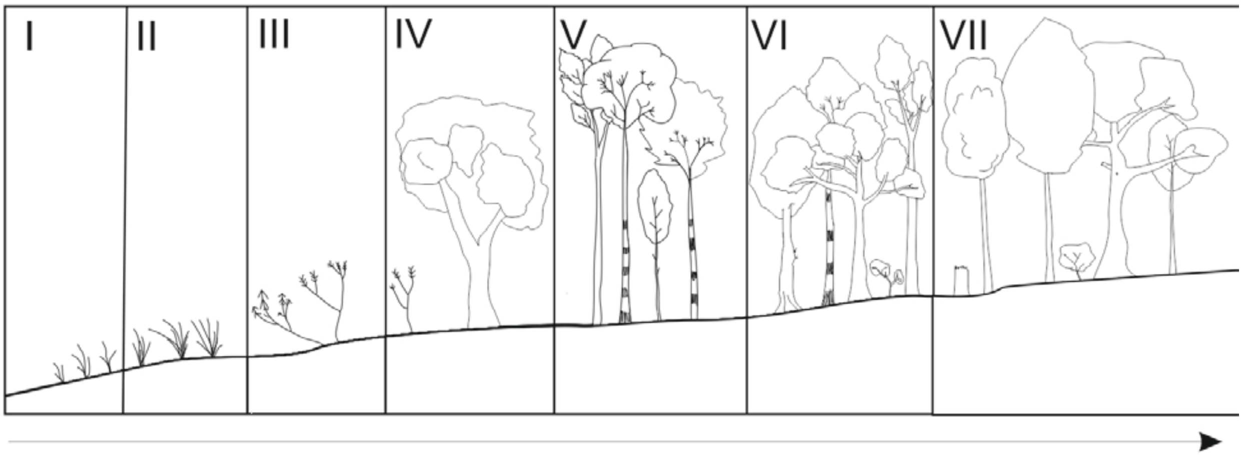


Figure 2 Ecological succession on sand in the Danube floodplain forest. I. Initial phase with annual herbs, II. Pioneer phase with perennial herbs, III. Shrub phase, IV. Early successional woodland phase with softwoods, VI. Late successional woodland: softwood to hardwood transition, V. Established forest phase with hardwoods, VI. Terminal stage: Climax hardwood forest.

Floodplains are located on alluvial deposits. Fluvial dynamics of sediment erosion and deposition create and rework the relief of the floodplain. The pattern of diverse geomorphic units, such as levees, flood pools and crevasse spays, are product of the floodplain forming processes (Fryirs and Brierley 2013). Each geomorphic unit is characterized by specific site conditions and an individual disturbance regime. The combination of site conditions, the disturbance regime and current state of ecological succession leads to the identification of the potential natural vegetation of the geomorphic unit.

Processes of sediment deposition on the floodplain

The Danube transfers sediments of different grain sizes, classified into gravel, sand, silt and clay (Margl 1973). Gravel is transported as bedload. It is deposited at the convex slope of bends, a floodplain formation process referred to as lateral accretion. Sand is transferred as intermittently suspended-load. The particles roll downstream until an increase of velocity lifts them into suspension. Eventually the sediment is dragged down by gravity. Coarse-grained sand is deposited as a thin layer above gravel bars and settles as point bars in slow flowing waters of side arms (lateral accretion). Medium and fine-grained sand is deposited during overbank flow as the floodwater spills sheet-like on the floodplain. Due to the reduced depth of the water column, the flow energy is reduced by the increasing friction loss. The floodplain vegetation additionally slows down the velocity. Medium-grained sand settles at the channel margins, on the proximal floodplain. Fine-grained sand remains longer in suspension and is deposited on the distal floodplain. The deposition of sediments onto the floodplain during overbank flow is called vertical accretion (Fryirs and Brierley 2013). Silt and clay are also deposited during overbank flow. Silt settles at low velocities and clay in standing water. Consequently, these fine-grained sediments are deposited in the depressions of abandoned channels and flood pools, which remain flooded for longer periods (Margl 1972) (Fig. 3). Table 1 states geomorphic units corresponding to dominant grain size deposition processes.

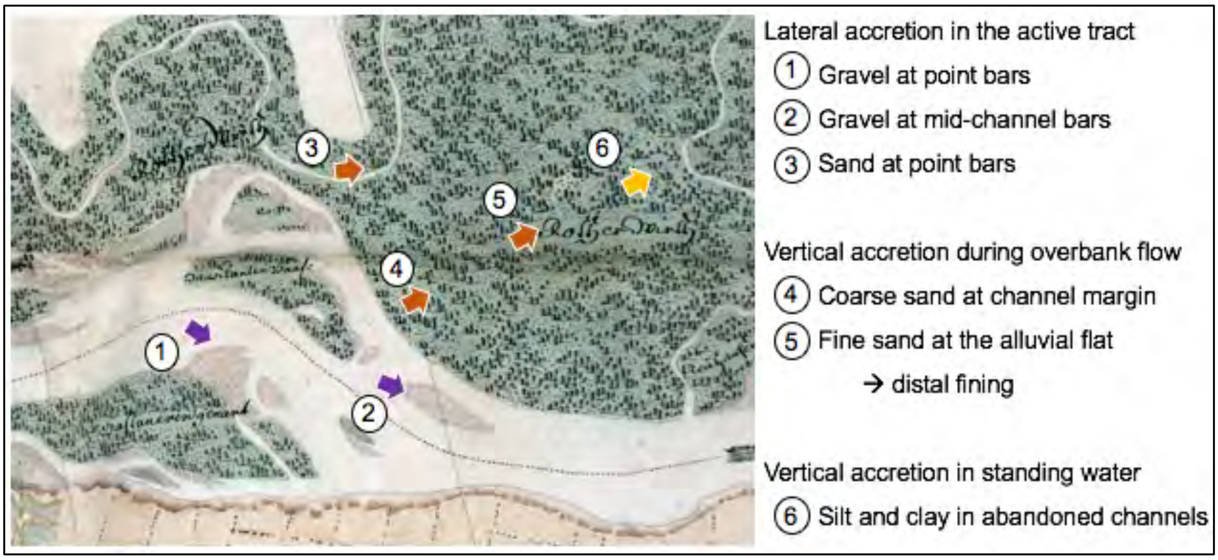


Figure 3 Floodplain Orth 1797-1812 adapted from (Pacassi 1812)

Table 1 Geomorphic unit corresponding to deposition process of sediment grain sizes

Grain size	Deposition process	Geomorphic unit	Spatial location
Gravel	Lateral accretion	Gravel bar	Active tract
Sand	Lateral accretion	Sand bar	Active tract (slow flow)
	Vertical accretion	Levee, ridge, alluvial flat	Proximal Floodplain
Silt	Vertical accretion	Abandoned side arms, flood pool	Floodplain

Grain size as key for ecological succession

Soils featuring coarse grained sediments have higher porosities than soils with predominately fine grained sediments. Thus the water holding capacity and the nutrient availability increase with decreasing grain size (gravel < sand < silt < clay), while the capability of roots to penetrate the soil and the aeration decrease with increasing grain size (clay < silt < sand < gravel) (Blum 2007). Since the grain sizes correlate with processes of sediment deposition and the floodplain relief, the soil texture also indicates the local exposure to fluvial dynamics. Hence the soil texture is a key factor for the development of plant communities. (Egger et al. 2009). Wendelberger-Zelinka (1952) identified three successional trajectories based on the initially predominant sediment grain size and the interrelated deposition process in the floodplains of the Danube in Machland: The successional trajectory on gravel deposited in the active tract of the main channel and fast flowing side arms (lateral accretion), the successional trajectory on sand deposited at the margins of slow flowing side arms (lateral accretion) and the successional trajectory on silt and clay deposited in abandoned side arms (vertical accretion).

Successional pathways in the Donau-Auen National Park

The potential natural vegetation and the succession in the floodplain forest of the Donau-Auen National Park have been characterized by Margl (1972), Margl (1973) and Jelem (1974).

Fig. 4 shows a succession scheme for the Donau-Auen National Park. The scheme is based on Margl and Jelem’s typology. The potential natural vegetation types have been assigned to successional phases following the schematic approach of Egger et al. (2009). In reference to the successional trajectories described by Wendelberger-Zelinka (1952) and their influence on the water budget, the scheme differentiates between a dry, fresh and wet series.

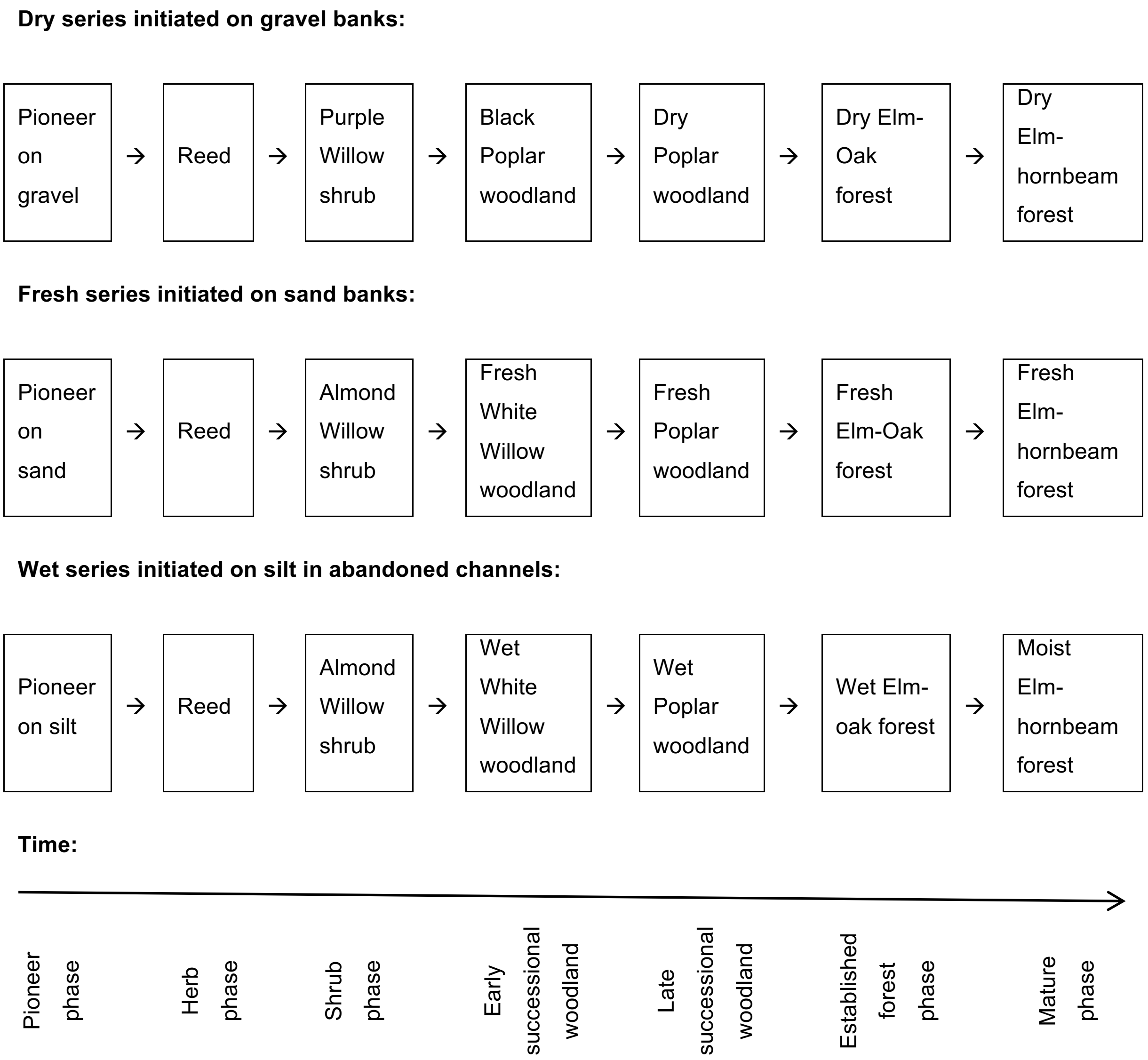


Figure 4 Scheme of ecological succession in the Donau-Auen National Park

Dry series on gravel

As gravel landforms in the active zone of the river they are usually frequently reworked and the succession is counteracted by mechanical destruction. Gravel is highly porous resulting in a very limited capacity to hold water and nutrients. Plants colonizing the gravel must be able to endure periods of extreme dryness and must have resilience to recurring mechanical disturbances (Egger et al. 2009). This early phase (pioneer phase) of succession therefore belongs to a few specialists. Historically *Myrcaria germanica* was a dominant pioneer on the extensive gravel bars in the river-floodplain system of the present-day Donau-Auen National Park (Hübl 1972). *Myrcaria germanica* develops roots able to penetrate the gravel, which allows them to sustain the extreme conditions. But, as it is dependent on high light exposure, they are displaced as soon as other herbs and shrubs overshadow them. After the regulation, which caused a sudden decline of dynamic formation and reformation of its habitats, *Myrcaria germanica* disappeared from the floodplain (Margl 1972).

If sediments continue to settle on the aggraded gravel and the landform rises above the mean summer water level, the succession enters its advanced stage (Drescher et al. 2014). Pioneers are displaced with Reeds and, subsequently, shrubs (Egger et al. 2009). *Salix purpurea* is the dominating shrub due to its ability to root in gravel. Other shrubs occasionally occurring are *Populus nigra*, *Crategus monogyna, Rhamnus frangula* and *Rhamnus cathartica* (Margl 1973). In the following early successional woodland phase *Populus nigra* is the dominating tree as its roots can penetrate the gravel and access groundwater, which is crucial as the soil consisting of gravel and a thin layer of sand has minimal water holding capacity (Jelem 1974, Margl 1973).

Populus nigra remains dominating during the late successional woodland phase. *Alnus incana* emerges but is not able to exploit its full growth potential due the limited availability of water (Margl 1973). The abundance of *Crategus monogyna* increases in the shrub layer (Margl 1972). In the following successional phase, a hardwood forest establishes. *Ulmus minor* and *Quercus robur* are the dominating trees. Further *Populus nigra* and *Populus alba* might remain scatteredly (Jelem 1974). The succession reaches its terminal stage as a mature forest characteristically featuring *Ulmus minor*, *Acer campestre, Quercus robur, Carpinus betulus, Fraxinus excelsior* and *Tilia cordata* (Drescher et al. 2014).

Fresh series on sand

Sand is an intermittently suspended-load deposit. It is transported by saltation. Typically, medium-grained and fine-grained sand sediments settle via vertical accretion above bedload deposits during overbank flow (Fryirs and Brierley 2013). Typical pioneers of this sandy environment are *Agrostis alba, Phalaris arundinacea, Melilotus albus* and *Euphorbia gerardiana (*Drescher et al. 2015*).* In the pre-regulated Danube also *Typha minima,* enlisted in the Austrian Red Data Book as threatened with extinction (Niklfeld 1999)*,* was colonizing the sandy deposits of the floodplain (Drescher et al. 2014). The shrub phase is represented by *Salix alba*, *Salix viminalis*, *Salix triandra* (Jelem 1974) and *Salix purpurea* (Margl 1972). *Salix alba* is dominant in the early successional woodland phase. *Cornus sanguniea* and *Crategus monogyna* join in the course of time (Margl 1973). The soil still has a grey colour but a layer of humic topsoil starts to develop. Although the water holding capacity of the soil remains limited, the high porosity facilitates good access to the groundwater table. Thus the soil can be classified as moist. Characteristically *Salix abla* is preferably found on depressed spots of the relief where the germ buds are able outlast periods where the upper soil layer is dried out (Margl 1972). With ongoing succession *Salix alba* is displaced by *Populus alba* and *Alnus incana*, which develop root sprouts for reproduction. The woodland also features

Prunus padus (Margl 1973). The abundance of *Crategus monogyna* increases in the shrub layer (Margl 1972). Sand and silt are the predominant grain sizes. The layer of humic topsoil is well developed and the soil continuous to be porous. Therefore, the soil has high water holding capacity and is classified as moist (Margl 1973). As a forest establishes, hardwood trees take over. Typically, *Ulmus minor*, *Quercus robur* and *Fraxinus excelsior* in the first tree layer and *Acer campestre* in the second tree layer. The brown coloured soil has a thick layer of humic topsoil and high water holding capacity. (Margl 1972). Succession reaches its terminal stage with *Caprinus betulus* gaining dominance. Other trees of typical for the mature forest are *Populus × canescens*, *Acer pseudoplatanus, Prunus avium, Quercus robur, Ulmus minor* and *Fraxinus excelsior. Tilia cordata* is often found on high ridges (Jelem 1974; Margl 1972).

Wet series on silt

Silt settles at low velocities and clay in standing water. Consequently, these fine-grained sediments vertically accrete in the depressions of abandoned channels and flood pools, which remain flooded for longer periods. Moreover, the water column is higher than in surrounding more elevated spots. This increases the amount of silt and clay settling in concave landforms. Over time their relief rises to the point where it equalizes with its surroundings creating a plain (Margl 1972). Typical pioneer plants in eutrophic standing water bodies of the Danube floodplain are *Nuphar lutea* and *Nymphaea alba*. Their presence indicates a trajectory towards terrestralization (Schratt-Ehrendorfer 1999). The shores of oxbow lakes and ponds silt up and are only intermittently underwater. Reeds featuring *Phragmites australis* and *Phalaris arundinacea* are typical for these semiaquatic habitats. During flood events the reeds of the herb phase are sometimes buried under fluvial deposits. Several willow species such as *Salix alba*, *Salix viminalis*, *Salix triandra* and *Salix purpurea* can germ on the bare sediment banks. Their woolly-haired seeds are easily transported by the wind (Hübl 1972). With time *Salix abla* outgrows the other willow shrubs and becomes predominat in the early successional woodland (Margl 1973). In the late successional woodland *Populus alba* gains dominance. *Prunus padus*, *Fraxinus excelsior* and *Alnus incana* are also featured in the tree layer (Margl 1972). The brown soil is moist, compact and coloured by rust stains (Jelem 1974). As the established forest phase is reached a thick layer of slit and clay has developed. Depressions in the relief remain as evidence of the former oxbow lakes and flood pools. The elm-oak hardwood forest resembles the one of the fresh series and reaches its climax with *Caprinus betulus* (Margl 1972, Jelem 1974).

3 Study site

Location

The study site is located on the left river bank between river-km1899.0 and river-km 1898 of the Danube in the Donau-Auen National Park in Lower Austria. It has an area of 0.95 km^2.

A side arm of the Danube, *Faden*, characterizes the study site. A meander bend was cut off during the construction of the inundation dam and a channel on the northern side of the dam was built to re-connect the two ends of the *Faden* (Fig. 5).

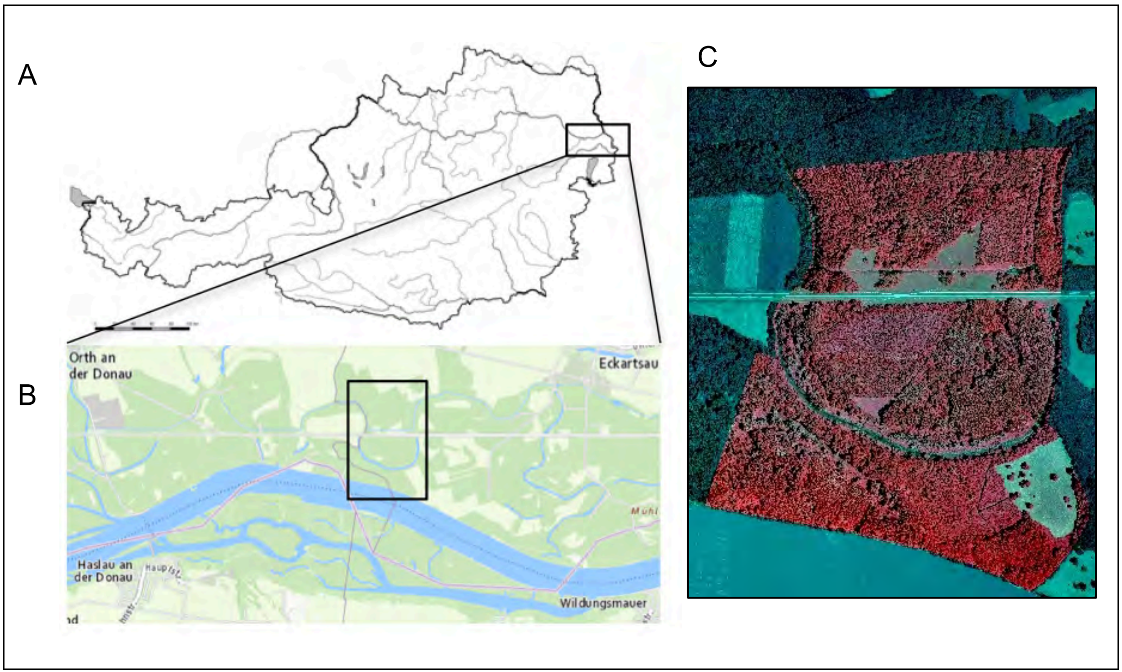


Figure 5 A: Location of the study site in Austria (Öbv – Freytag und Berndt 2016), B: the Danube segment (Geoland 2016) and C: orthophoto of study site (ÖBf 2011)

Background

The area was selected because of the near natural state of the forest. It is owned by the Republic of Austria and managed by Öbf. In 1973 the area was chosen as experimental site for a beaver resettlement study conducted by the Konrad Lorenz Institute of Ethology and future logging was renounced (Fraissl 1993). In 1996 the National Park Donau-Auen was established, which urges a land use management supporting the natural environment and the conservation of site-specific biota and habitats (Nationalpark Donau-Auen 2016).

Hydrology

Table 2 gives an overview of the hydrological characteristics of the Danube at the study site. The mean flow is 1930 m^3/s. If the discharge exceeds 1939 m^3/s it is classified as 1-year flood.

Table 2 Hydrological characteristics of the Danube at *Wildungsmauer* (via donau 2014)

Low flow (RNW) (m^3/s)	≈ 980
Mean flow (MW) (m^3/s)	≈ 1930
1-year flood (m^3/s)	≈ 5300
2-year flood (m^3/s)	≈ 5890
5-year flood (m^3/s)	≈ 6620
10-year flood (m^3/s)	≈ 7280
20-year flood (m^3/s)	≈ 8750
30- year flood (m^3/s)	≈ 9290
50-year flood (m^3/s)	≈ 9730
100-year flood (m^3/s)	≈ 10350

At study site the Danube has a drainage area of ~ 102,000 km^2 (Klasz 2010) and its river regime is nivo-glacial (Lászlóffy 1967). The hydrograph of the year 2010 (Fig. 6) shows a maximum discharge between May and July, which is characteristic for nivo-glacial regimes of the norther hemisphere according to Luna et al. (1995).

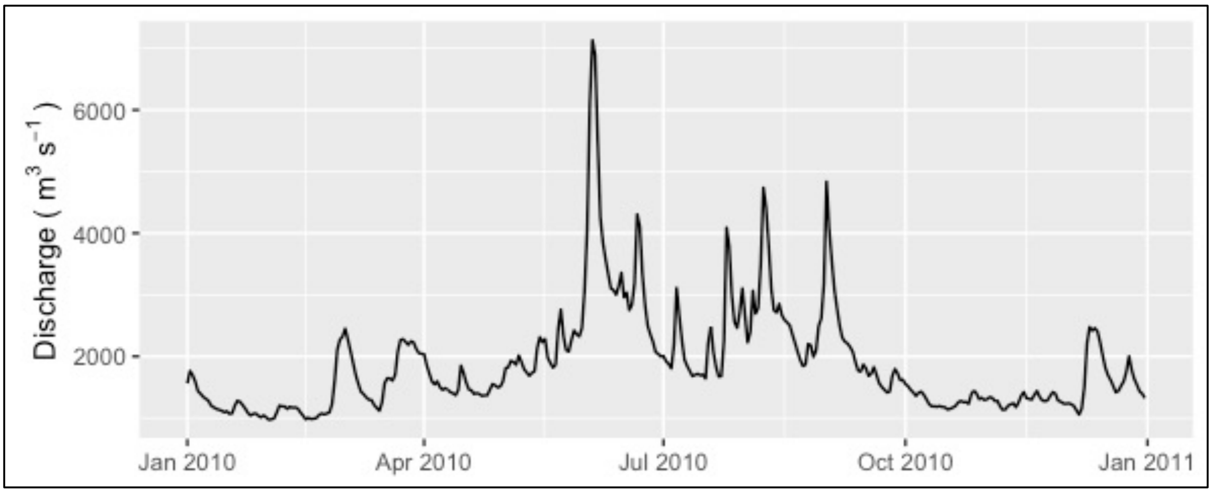


Figure 6 Hydrograph with daily discharge values of 2010 at *Wildungsmauer* (raw data: via donau)

The left riverbank of the national park is located on the *Marchfeld* aquifer. Under current climate the mean annual precipitation and evaporation are almost in balance. The groundwater level's main defining factor is the Danube's water level as the aquifer is recharged via seepage from the river (Blascke 2006). A comparison of the mean daily water level at *Wildungsmauer* and groundwater level at its closest gauging station, *Eckertsau, BI 1894.5*, shows the groundwater table rising and falling with the Danube level (Fig. 7).

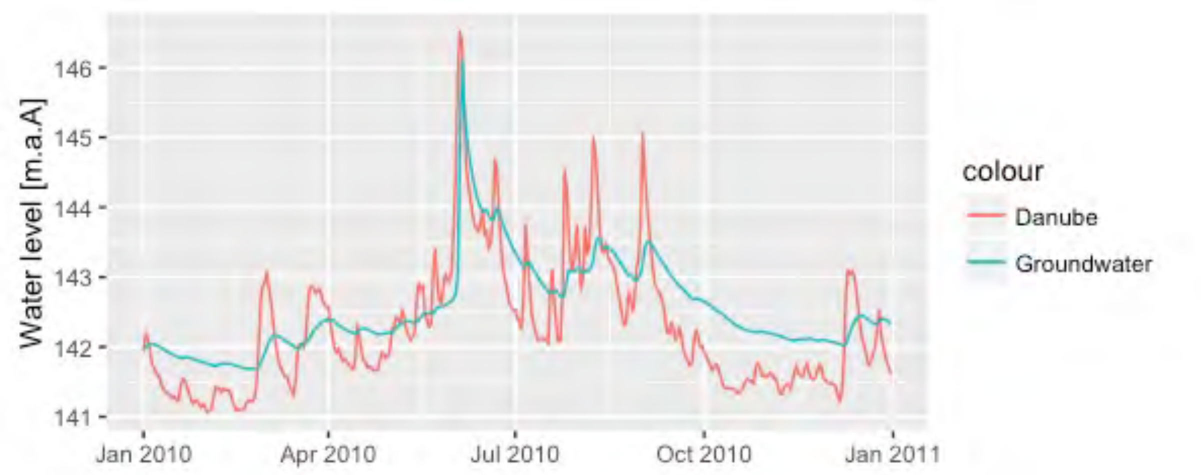


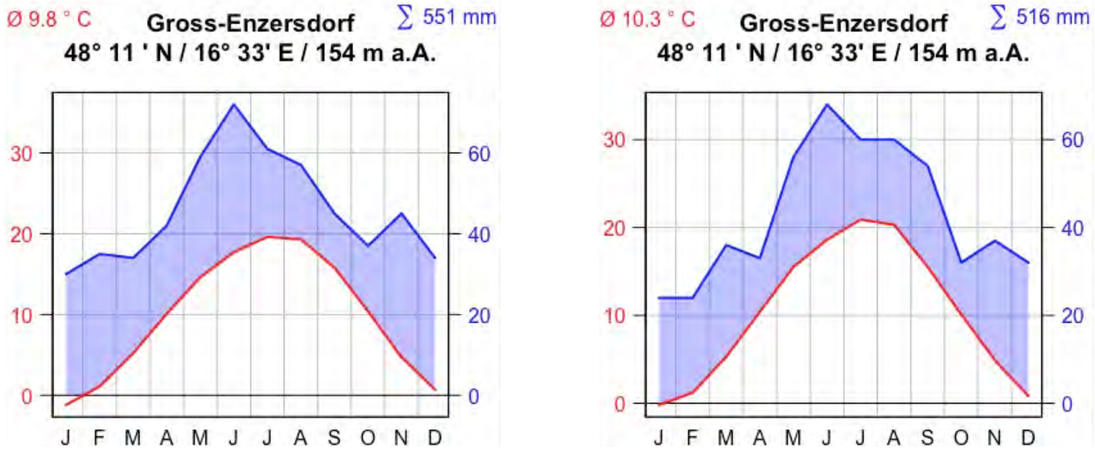
Figure 7 Water levels of Danube at *Wildungsmauer* and groundwater (Eckartsau, BI 1894.5) in 2010 (raw data: via donau)

Sediment load

An annual sediment load of 3.0 to 3.5 ∗ 106 tonnes is transported in suspension (Nachtnebel et al. 1998). The transport capacity of bedload is 300 000 to 400 000 m^3 per year (Habersack and Nachtnebel 1995, Klasz et al. 2009).

Climate

For the period 1981-2010, the mean temperature at the closest meteorological station *Groß-Enzersdorf* is 10.3°C and the annual precipitation is 516 mm. Compared to the period 1961-1981 the temperature has increased by 5°C and the precipitation decreased by 35 mm (data source: ZAMG). The Walter-Lieth diagram generated for *Groß-Enzersdorf* illustrates that the climate is humid and the vegetation period starts ~ 1st April and ends ~ 31st October (Fig. 8).



1961-1990 1981-2010

Figure 8 Walter-Lieth diagram *Groß-Enzersdorf* (raw data: ZAMG)

Potential natural vegetation 1975

The potential natural vegetation of the Danube floodplain mapped in 1975 is shown Fig. 9. The study site, indicated with the red square, was mapped by Hermann Margl and Müller (1975) .

Figure 9 Potential natural vegetation of 1975 (Margl und Müller 1975)

Fig. 10 shows the mapping of the study site by Margl and Müller (1975) with legend of the PNV types (German)..

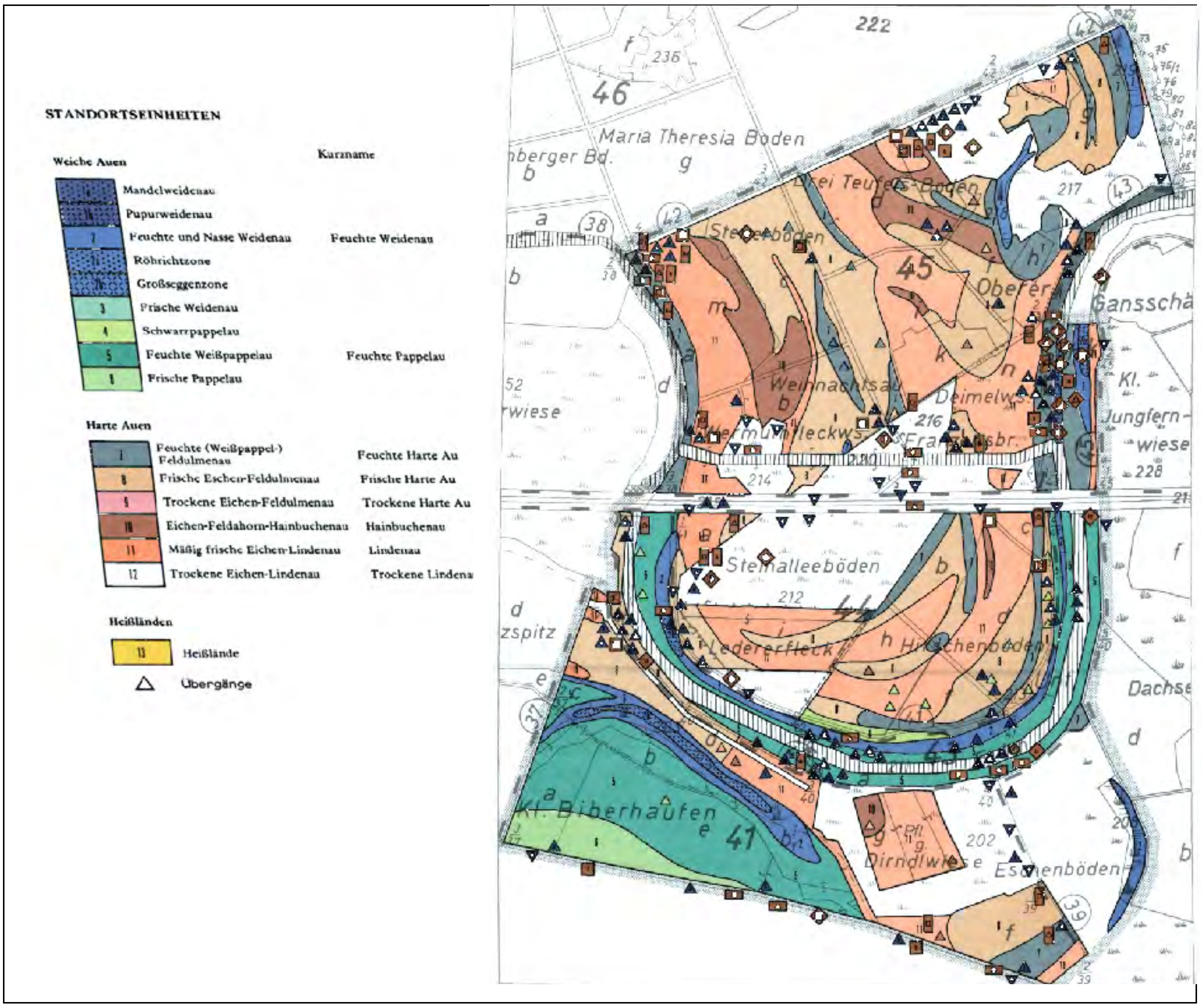


Figure 10 Potential natural vegetation 1975 with legend in German (Margl and Müller 1975)

4 Material and Methods

The study design includes field work as well as its processing and analysis in ArcGIS, R and Excel. Information about the investigation of the research questions (→ 1.2) is stated in the following subchapters.

4.1 Modelling of physical habitat parameters

This chapter describes methods and material used to investigate the first research question dealing with the effects of the incision of the Danube on the physical habitat parameters of the study site. To implement the effect of the floodplain aggradation (→ 1.1) the digital elevation model (DEM) of the floodplain of 1999 was modified for specific years (4.1.1). The investigated physical habitat parameters are depth to groundwater (4.1.2), depth and area of inundation during flood events as well as the frequency of flood events (4.1.3) and the duration of flood events (4.1.4)

4.1.1 Modification of the digital elevation model

The study of the aggradation of the floodplain terrain over the past 120 years by Klasz et al. (2014) estimates an average annual sedimentation rate of ~ 11 mm for the area of the present day levee on the left river bank in the Donau-Auen National Park. An annual sedimentation rate of 7.5 mm was calculated specifically for the levee section of the study site using site specific data provided by the study of Klasz et al. (2014) for Dyke-km 30 and following the approach of calculation stated in the paper. With a calculated annual aggradation rate of 7.5 mm the elevation of study site's levee as given in the DEM from 1999 was modified to for the years 1949, 1956, 1970. 1976, 1985, 1996 and 2010. The levee, characterized by a site specific width of 36.2 m by Klasz et al. (2014), was identified in ArcGIS and adapted using the tool Raster Calculator.

4.1.2 Generation of depths to groundwater

A simple linear regression was calculated in order to predict the elevation of the groundwater table at based on the water level of the Danube. The linear regression was preformed using the mean monthly water level of the groundwater gauging station *Eckartsau, Bl 1897.3*, located close to the study site, and the Danube gauging station *Hainburg* (data source: via donau). The monthly means were calculated for the months from April to October for the period from 1989 to 2013. A significant regression equation was found (F(1, 109) = 285.64, $p < 2.2\ e^{-16}$) with a R^2 of 0.7238. The predicted elevation of the groundwater table equals to 67.06562+0.55336 (groundwater) meters above the Adriatic, when groundwater is measured in meters above the Adriatic. The SMWs for the years 1949, 1956, 1970. 1976, 1985, 1996 and 2010 were calculated as the arithmetic mean of the daily water levels from 1st of April to 31st of October of the 30 years previous to each of the seven investigated years. Based on the SMWs historic groundwater levels were predicted using the regression equation. The depth to groundwater was calculated in ArcGIS, whereby the elevation of the groundwater for each of the years chosen to investigate were subtracted from the terrain elevation of the corresponding year in the raster cells of the DEM.

4.1.3 Generation flooded areas and depth of inundation

Flooded area and depth of inundation for 1-year, 2-year, 5-year, 10-year, 20-year, 30-year, 50-year and 100-year flood were generated for the seven time steps based on the modified DEMs of the study site and the annual incision rates of the Danube at the closest gauging station *Orth an der Donau*. Annual incision rates were calculated based on historic RNW values as stated by Bundesstrombauamt (1951), Bundesstrombauamt (1959), Bundesstrombauamt (1970), Bundesstrombauamt (1978) Wasserstrassendirektion (1986), Wasserstrassendirektion (1998) and via donau (2010). The area and depth of inundation during a flood event was generated in ArcGIS using the DEM. The water column height during a specific flood event was projected onto the floodplain terrain separating the area of the study site in sites flooded at various depths and sites not flooded. Consecutively areas which appeared to be flooded due to their elevation but had no linkage to the Danube, being separated by not flooded areas, where redefined as not flooded. Flood maps for 1949, 1956, 1970, 1976, 1985, 1996 and 2010 were generated using the corresponding modified DEMs and lowering or increasing the height of the water column according to the calculated incision rates of the Danube.

4.1.4 Investigation of flood durations

The flood durations were calculated with discharge data from the gauging station *Hainburg* (data source: via donau). Days of flood events were identified based on the mean daily discharge and categorized. The number of flood days during periods of 6 or 7 years as well as the number of flood days of different annuities per year was calculated using the maximal daily discharge from 1996 to 2013 of *Hainburg* (data source: via donau).

4.2 Assessment of the potential natural vegetation

In order to investigate the second research question asking about the current state of the potential natural vegetation of the study site and how it differs from the one mapped in 1975 a modification of Margl’s PNV of 1975 to carried out using the DEM in ArcGIS (→4.2.1). A new vegetation map for 2015 was mapped with field assessments (→4.2.2) and digitized in ArcGIS (→ 4.2.3). In order to gain information about the age of the PNV polygons a floodplain age map based on the analysis of historical maps of the study site was created using ArcGIS (→ 4.2.34).

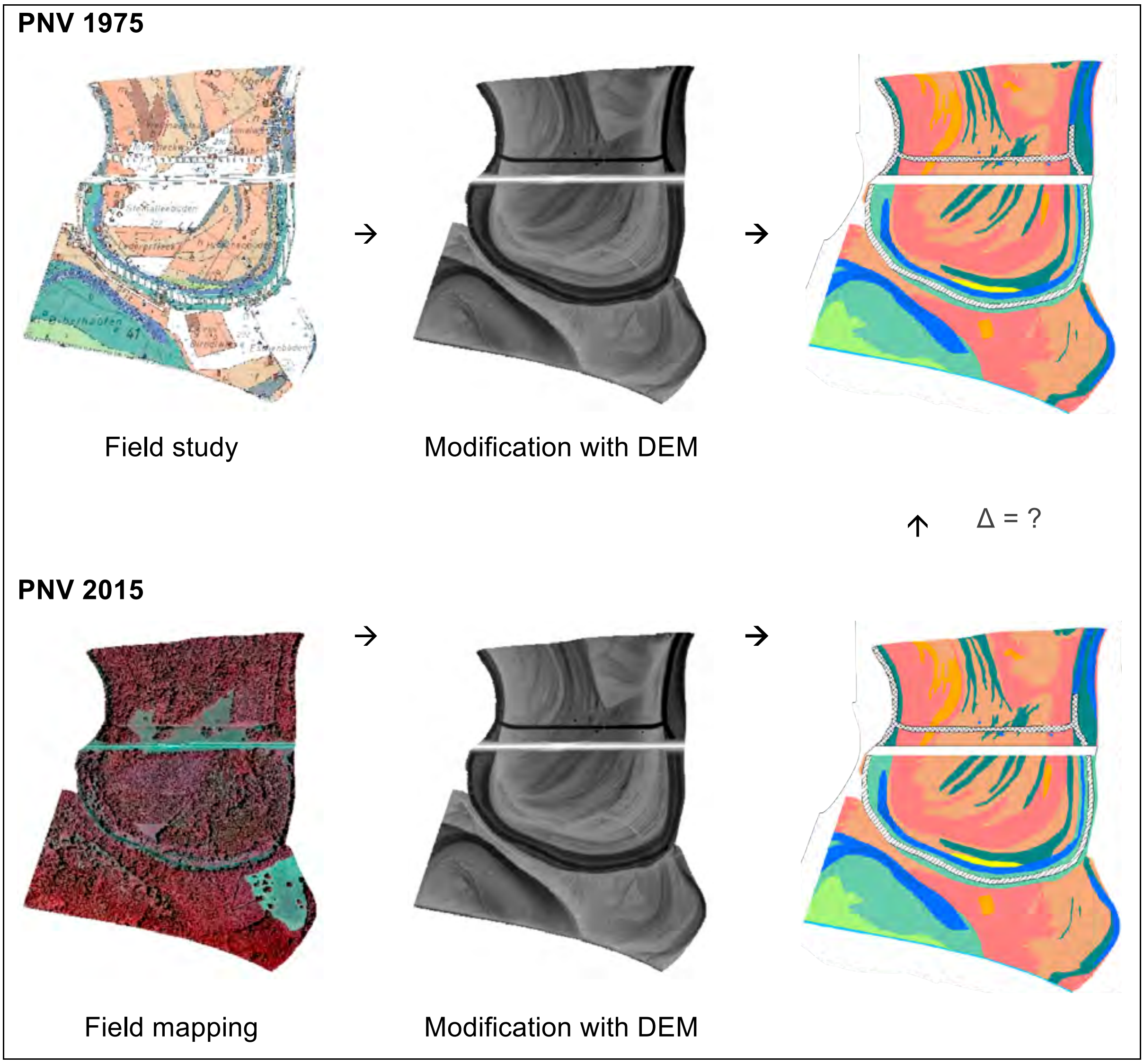


Figure 11 Study design PNV

The study design for the assessment of the change of potential natural vegetation from 1975 to 2015 is schematized in Fig. 11.

4.2.1 Modification of PNV 1975

With field visits and literature research (→ 2) the potential natural vegetation mapping of Margl from 1975 was analysed regarding the association of PNV type with topography, soil and vegetation of the mapped unit (→ Appendix). Following Margl's descriptions of topographic characteristics of the PNV types the polygons mapped by Margl were digitized in ArcGIS and their shape modified using isolines generated in ArcGIS. This resulted in a modified map of Margl's PNV more precisely reflecting the geomorphic setting of the study site.

4.2.2 Field mapping PNV

Homogenous polygons were identified based on topography, soil and vegetation in the field and mapped on an orthophoto of 2011 (Fig.12). Characteristics of topography, soil and vegetation were recorded in standardized field assessment forms. Plant species were identified and the cover of tree, shrub and herb layer determined.

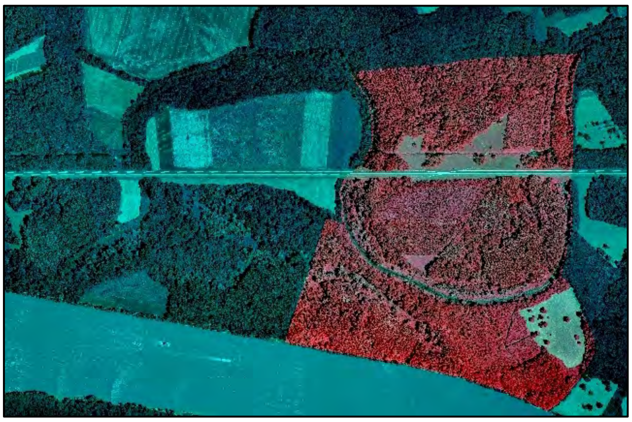


Figure 12 Orthophoto 2011 (data source: Öbf)

The thickness of the topsoil layer (up to 20 cm) was recorded and the share of sand, silt and clay in the upper 10 cm of the soil estimated According to the shares of the grain sizes the soil texture type was identified as stated in Blum *et al.* (1996). The soil moisture was determined following the scheme of *Guidelines for Forest Site Mapping in Austria* (Englisch and Kilian 1998). Additionally, the flood inundation class and the morphodynamic disturbance class according to the scheme in Egger et al. (2015) was estimated. Based on the flied assessment the polygons were assigned to PNV types according to the classification of Margl (1973) as well as to a natural habitat type listed in the Habitats Directive of the European Union and a plant association (European Commission 2013).)

4.2.3 Digitization PNV

The mapped polygons were digitized in ArcGIS and the boundaries were adapted to the isolines generated from the DEM in order to increase the accuracy of the topographic distinctions.

4.2.4 Generation of flood plain age

In order to estimate the age of the floodplain landscape units were identified on historic maps of the study site from 1775 (*Josephinische Landaufnahme*), 1816 (*Lorenzo-Karte*) and 1873 (*Franzisko-Joesphinische Landesaufnahme)* and digitized in ArcGIS. A map of the floodplain age was generated by intersection of the digitized landscape units.

5 Results

Results concerning the effects of the incision on groundwater table and the characteristics of flood events are stated in chapter 5.1, whereas chapter 5.2 presents the map of the potential natural vegetation of the study site and the change of physical habitat parameters from 1970 to 2010 for each PNV type. Floodplain age, the successional phases of the study and the change of successional phases from 1975 to 2015 are stated in chapter 5.3.

5.1 Effects of the incision on physical habitat parameters

Continuously decreasing RNW values indicate the ongoing incision process at the gauging station *Orth an der Donau* (Fig. 11). Over the period from 1949 to 2010 the annual incision rate ranges from an averaged reduction of elevation of -0.57 cm per year (1949 – 1956) to an average of -2.27 cm/a (1985 – 1996) (Table 3).

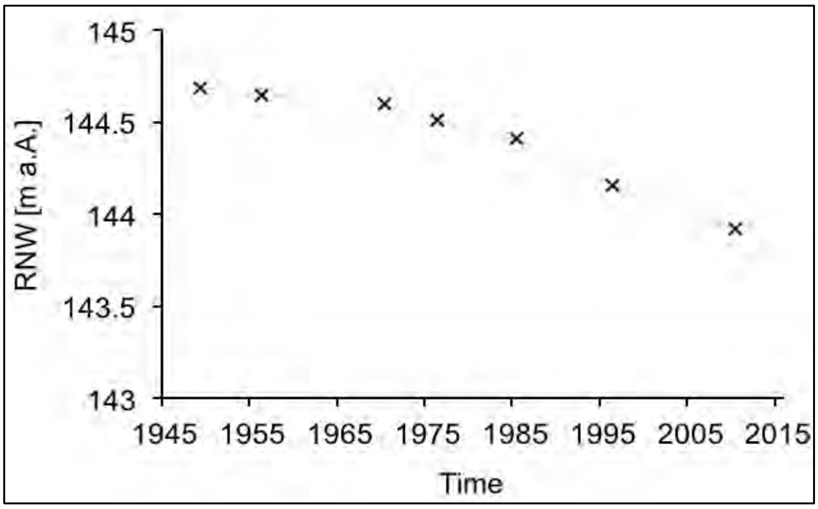


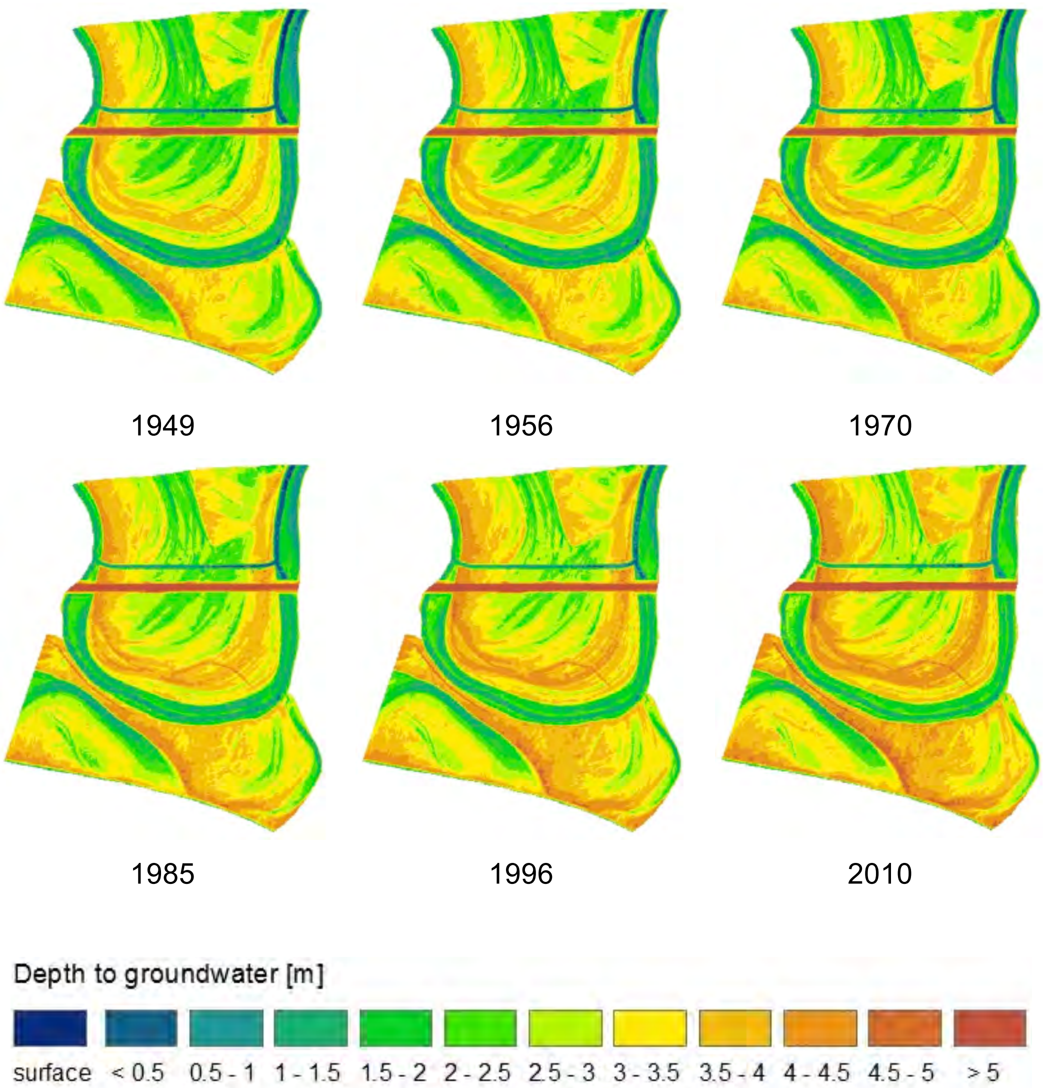
Figure 13 Incision at gauging station Orth an der Donau (raw data: KWD)

Table 3 Incision rate Orth a. d. Donau (raw data: KWD)

Period	Incision [cm/a]
1949 - 1956	- 0.57
1956 - 1970	- 0.71
1970 - 1976	- 1.5
1976 - 1985	- 1.11
1985 - 1996	- 2.27
1996 - 2010	- 1.71

Depth to groundwater

The groundwater table of the floodplain rises and falls with the water level of the Danube. Fig. 14 illustrates maps stating the depth to groundwater at the study site as modelled for the SMW of each investigated year.



1949 1956 1970

1985 1996 2010

Figure 14 Map of modelled mean depth to groundwater in meters at the study site between April and October in 1949, 1956, 1970, 1985 and 2010 (raw data: via donau)

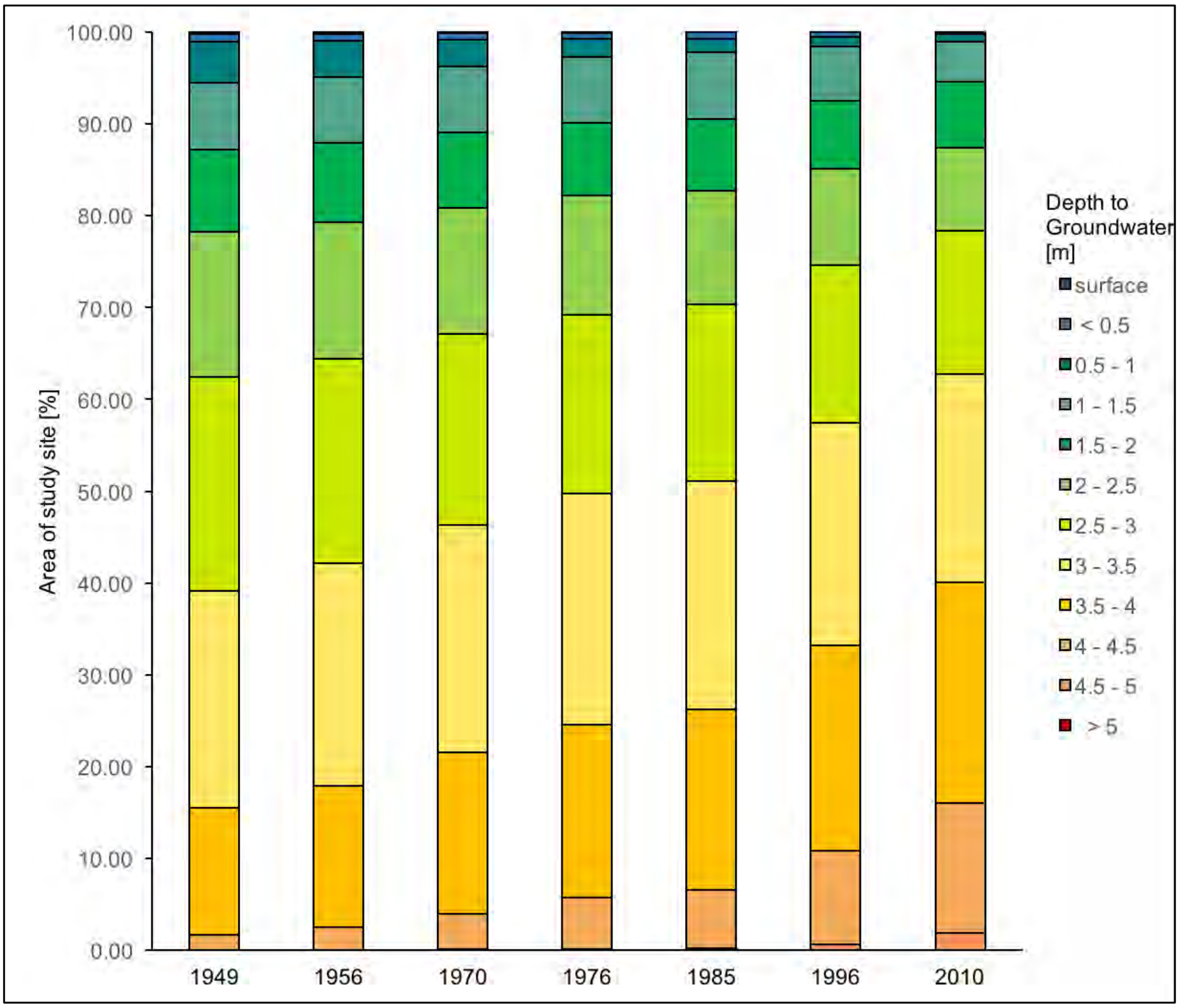


Figure 15 Percentage (%) of depth to groundwater categories of the total area of the study site (exclusive of the area of the flood protection dam) for the years 1949, 1956, 1970. 1985, 1996 and 2010. Groundwater categories based on modelled mean depth to groundwater between April and July (raw data: via donau)

Table 4 Depth to groundwater in percentage of total study area

Depth to Groundwater	**1949**	**1956**	**1970**	**1976**	**1985**	**1996**	**2010**
Water at the surface	0.22	0.17	0.12	0.08	0.05	0.01	0.00
< 0.5 m	0.84	0.78	0.73	0.69	0.68	0.47	0.21
0.5 m – 1 m	4.51	3.92	2.93	1.90	1.50	1.07	0.83
1 m - 1.5 m	7.25	7.21	7.14	7.20	7.22	5.89	4.42
1.5 m – 2 m	8.98	8.64	8.19	7.96	7.84	7.42	7.18
2 m - 2.5 m	15.80	14.88	13.79	12.99	12.41	10.49	9.04
2.5 m – 3 m	23.27	22.28	20.80	19.47	19.20	17.16	15.57
3 m - 3.5 m	23.63	24.22	24.75	25.13	24.83	24.31	22.64
3.5 m – 4 m	13.79	15.35	17.59	18.82	19.73	22.34	24.10
4 m - 4.5 m	1.67	2.49	3.89	5.61	6.35	10.18	14.11
4.5 m – 5 m	0.03	0.05	0.08	0.14	0.19	0.63	1.86
> 5 m	0.00	0.00	0.00	0.00	0.00	0.01	0.04

Throughout the investigated years only a very small fraction has a mean depth to groundwater exceeding 4.5 m. Most of the area has a depth to groundwater ranging between 2 m to 4 m (Table 4). The mean depth to groundwater in period between April and October decreased by almost half a meter from 1949 to 2010 at the study site. In 1949 the mean depth is 2.19 m, whereas in 2010 it is 2.7 m (Fig. 15). Fig. 16 shows the mean depth to groundwater of the otal study site with standard deviation.

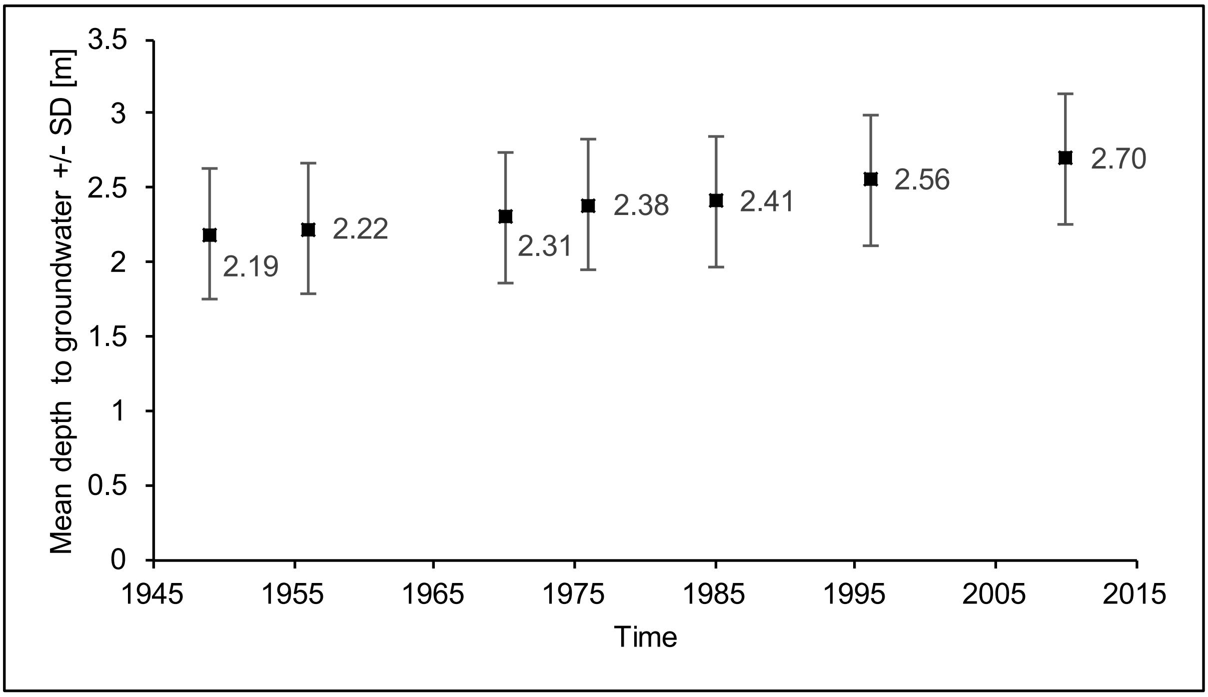
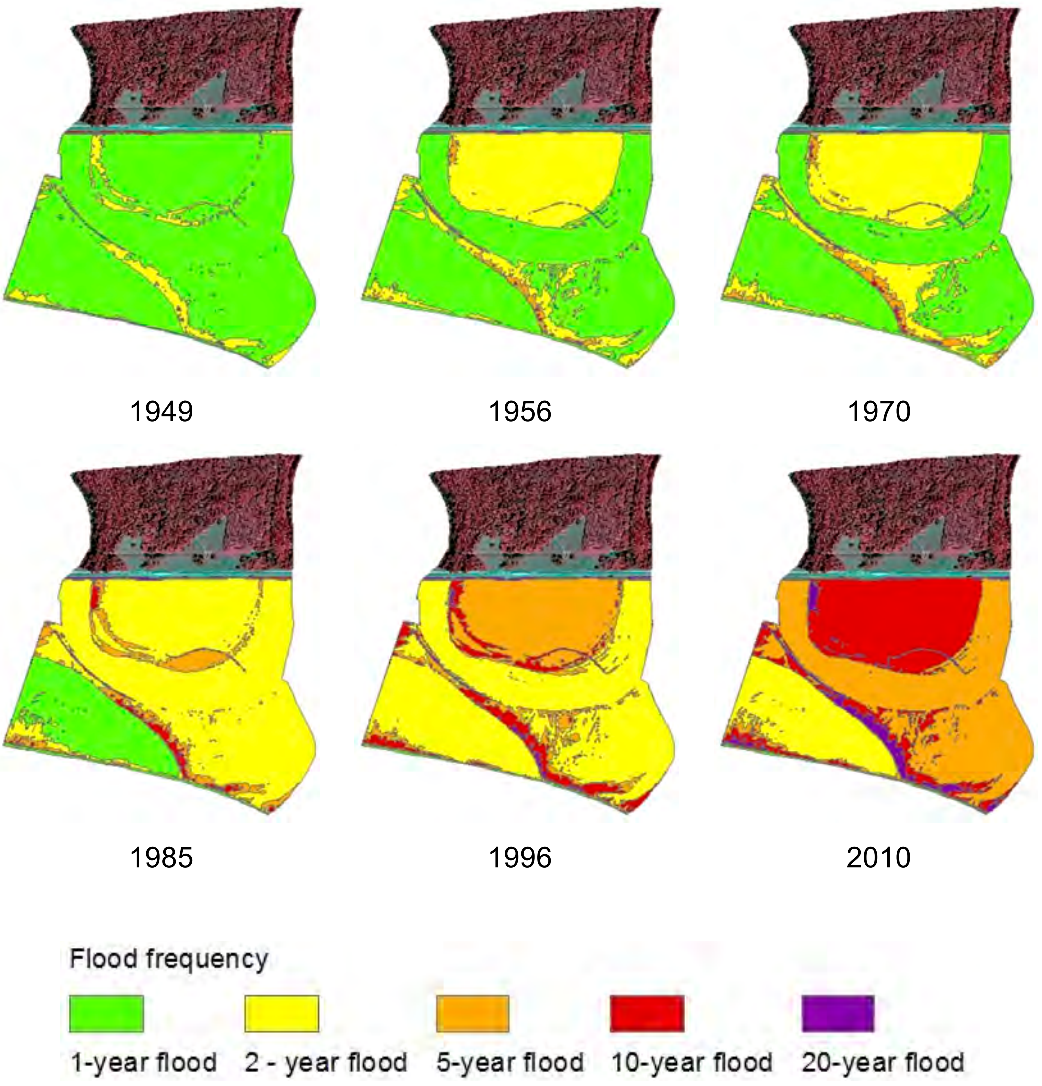


Figure 16 Modelled mean depth to groundwater (April to October) in meters and standard deviation for the years 1949, 1956, 1970, 1985, 1996 and 2010 (raw data: via donau)

Flood frequency

Due to the aggradation of the levee and the incision of the Danube the flood frequency of the area of the study site located between river and dam decreases from 1949 to 2010. The maps in Fig.17 illustrate the spatial extent of 1-year, 2-year, 5-year, 10-year and 20-year flood events at different years. In 1949 over 90% of the area of the study site located between river and dam are flooded during a 1-year flood and there are only small differences concerning the aerial extent of 5-year, 10-year and 20-year floods. In the following years the differences concerning the aerial extent of the different flood events are more characteristic (Fig. 18). In 2010 only 0.66% of the area is flooded during a 1-year flood, compared to 91.1% in 1949. The 2-year flood covers 98.66% in 1949 and 18.16% in 2010 (Table 5).


1949 1956 1970

1985 1996 2010

Figure 17 Map of modelled flood frequency of the study site. The colours indicate which flood event of a given probability (1-year flood, 2-year flood, 5-year flood, 10-year flood, 20-

year flood) inundates the study site in 1949, 1956, 1970, 1985, 1996, 2010. The map is coloured by the lowest magnitude flood event reaching a certain area (raw data: via donau)

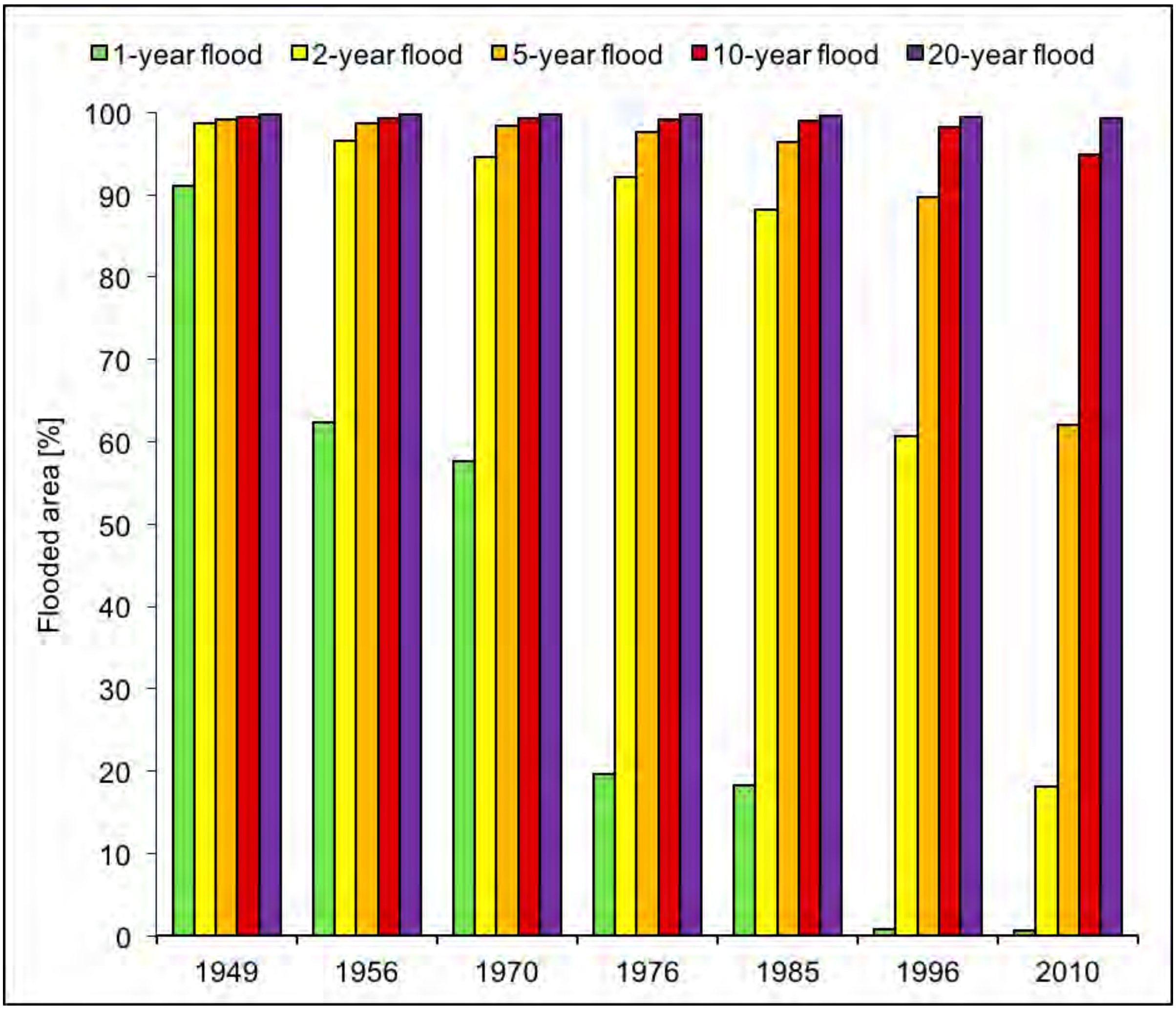


Figure 18 Modelled flooded area of the study site in m^2 for the 1-year flood, 2-year flood, 5-year flood, 10-year flood and 20-year flood in 1949, 1956, 1970, 1976, 1985, 1996 and 2010 (raw data: via donau)

Table 5 Flooded area as percentage of proximate floodplain area (*Offene Au*)

Year	1-year flood	2-year flood	5-year flood	10-year flood	20-year flood	50-year flood	100-year flood
1949	91.10	98.66	99.10	99.50	99.76	99.93	100.00
1956	62.30	96.61	98.75	99.35	99.76	99.93	100.00
1970	57.68	94.60	98.36	99.23	99.73	99.90	99.97
1976	19.68	92.12	97.65	99.12	99.70	99.87	99.96
1985	18.24	88.15	96.49	99.00	99.66	99.84	99.92
1996	0.78	60.65	89.76	98.18	99.53	99.76	99.85
2010	0.66	18.16	62.12	94.91	99.28	99.67	99.78

Flood depth

1-year flood

The maps in figure 19 illustrate the flood depth during a 1-year flood event modelled for six investigated years. The shares of low depths of inundation increases over the years and high depths of inundation are less frequent 1949 than 2010 (Fig. 20). For example, the inundation depth 2 m to 3 m has a share of 16.86% in 1949, only 0.05& in 2010 (Table 6).

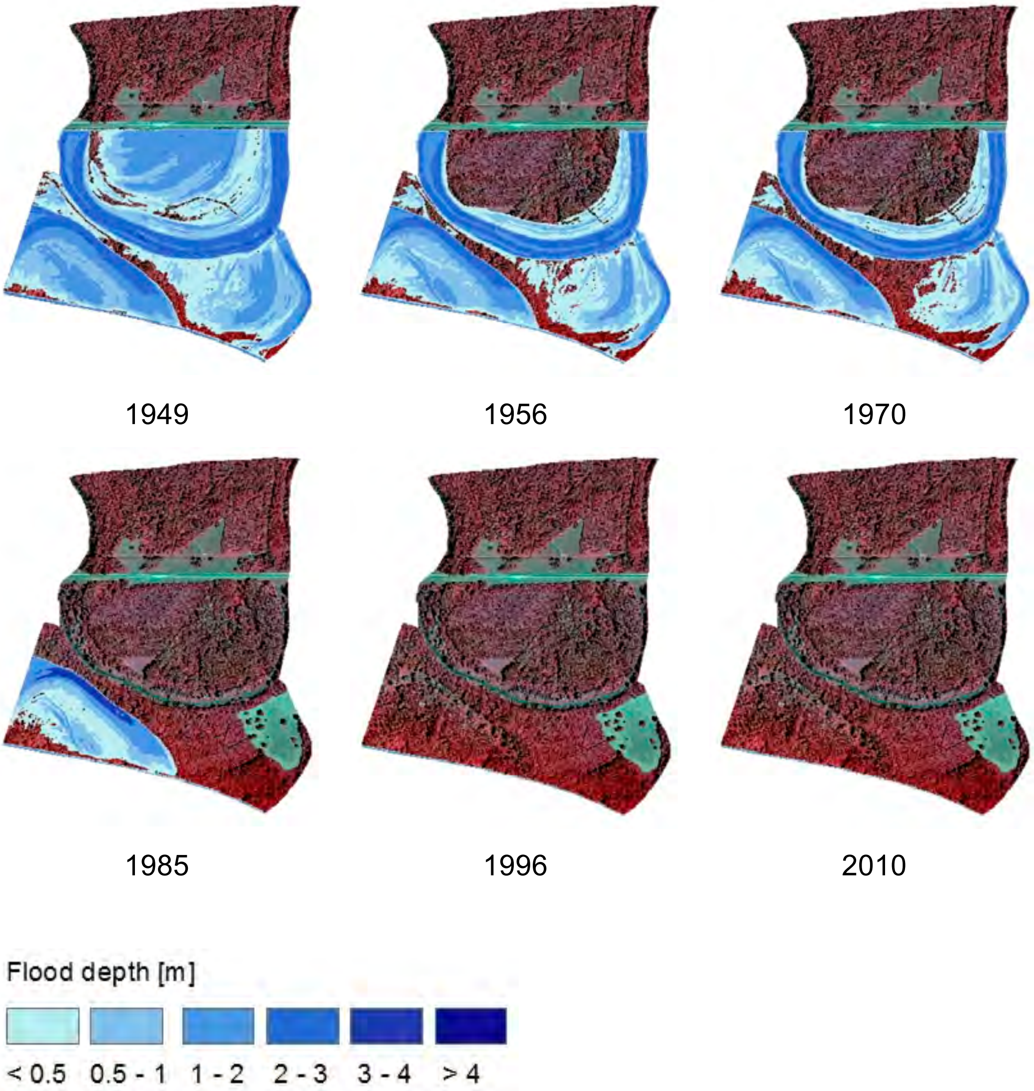


Figure 19 Modelled flood depth (inundation) in meters during a 1-year flood at the study site in 1949, 1956, 1970, 1985, 1996, 2010 (raw data: via donau)

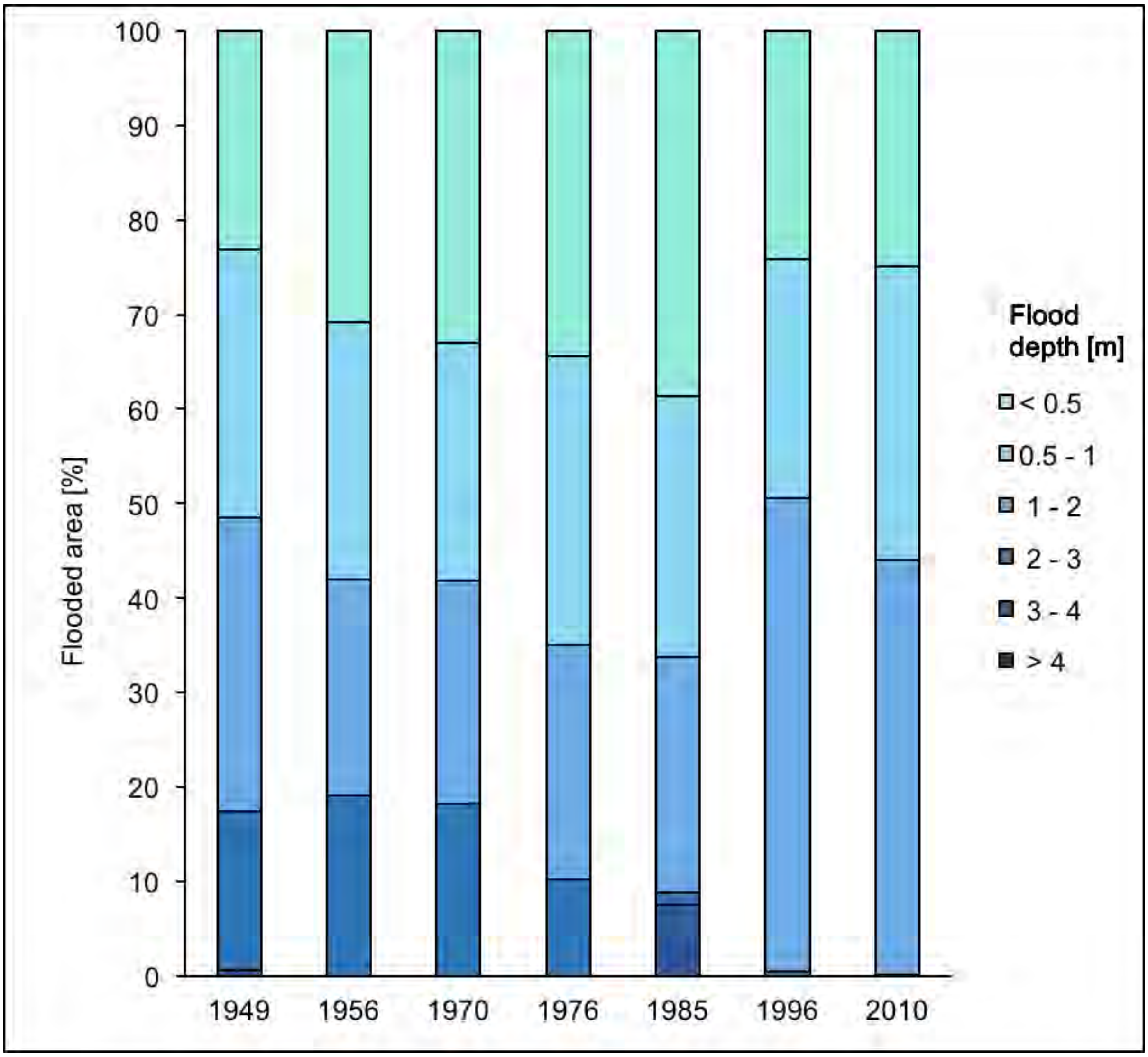


Figure 20 Modelled area (in m^2) of the study site flooded by the 1-year flood in 1949, 1956, 1970, 1976, 1985, 1996 and 2010. Colours indicate the depth of the water column. The categories are: > 4 m,3 – 4 m, 2 – 3 m, 1 – 2 m, 0.5 – 1 m and < 0.5 m (raw data: via donau)

Table 6 Percentage 1-year flood as percentage of proximate floodplain

			Depth of inundation (m)			
Year	**> 4**	**3 - 4**	**2 - 3**	**1 - 2**	**0.5 - 1**	**< 0.5**
1949	0.00	0.58	16.86	31.02	28.46	23.08
1956	0.00	0.04	19.08	22.88	27.12	30.88
1970	0.00	0.03	18.14	23.64	25.21	32.98
1976	0.00	0.00	10.19	24.86	30.59	34.36
1985	0.00	7.58	1.23	24.91	27.67	38.60
1996	0.02	0.00	0.51	50.05	25.22	24.20
2010	0.02	0.00	0.05	43.99	30.99	24.95

2-year flood

The characteristics of 2-year floods concerning area and inundation depth also changed over the year (Fig.21). The share of each depth class on the area between inundation dam und river are presented in Fig. 22. While in 1949 8.62% were flooded at a depth ranging from 3 m to 4 m, the share decreased to 2.98% in 1970. In 2010 no area is flooded at this depth range. The flood depth range, which has the largest fraction in 1949 is 1 m to 2 m and occupies 44.82% in 1949, 34.36% in 1970 and 25.18% in 2010 (Table 7).

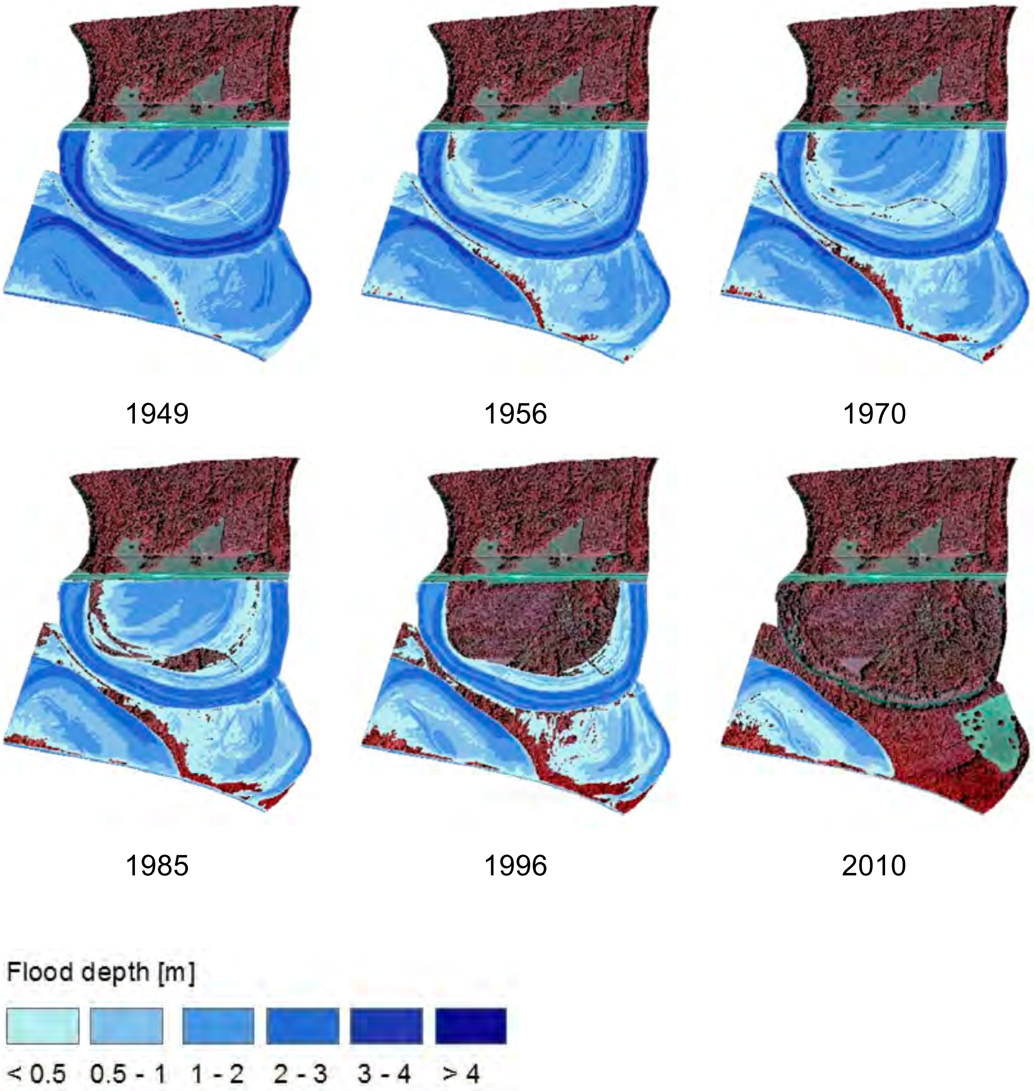


Figure 21 Modelled flood depth (inundation) in meters during a 2-year flood at the study site in 1949, 1956, 1970, 1985, 1996,2010 (raw data waterlevel, discharge: viadonau 2013, raw data: flood events: via donau 2014, raw data elevation: Donau-Auen National Park)

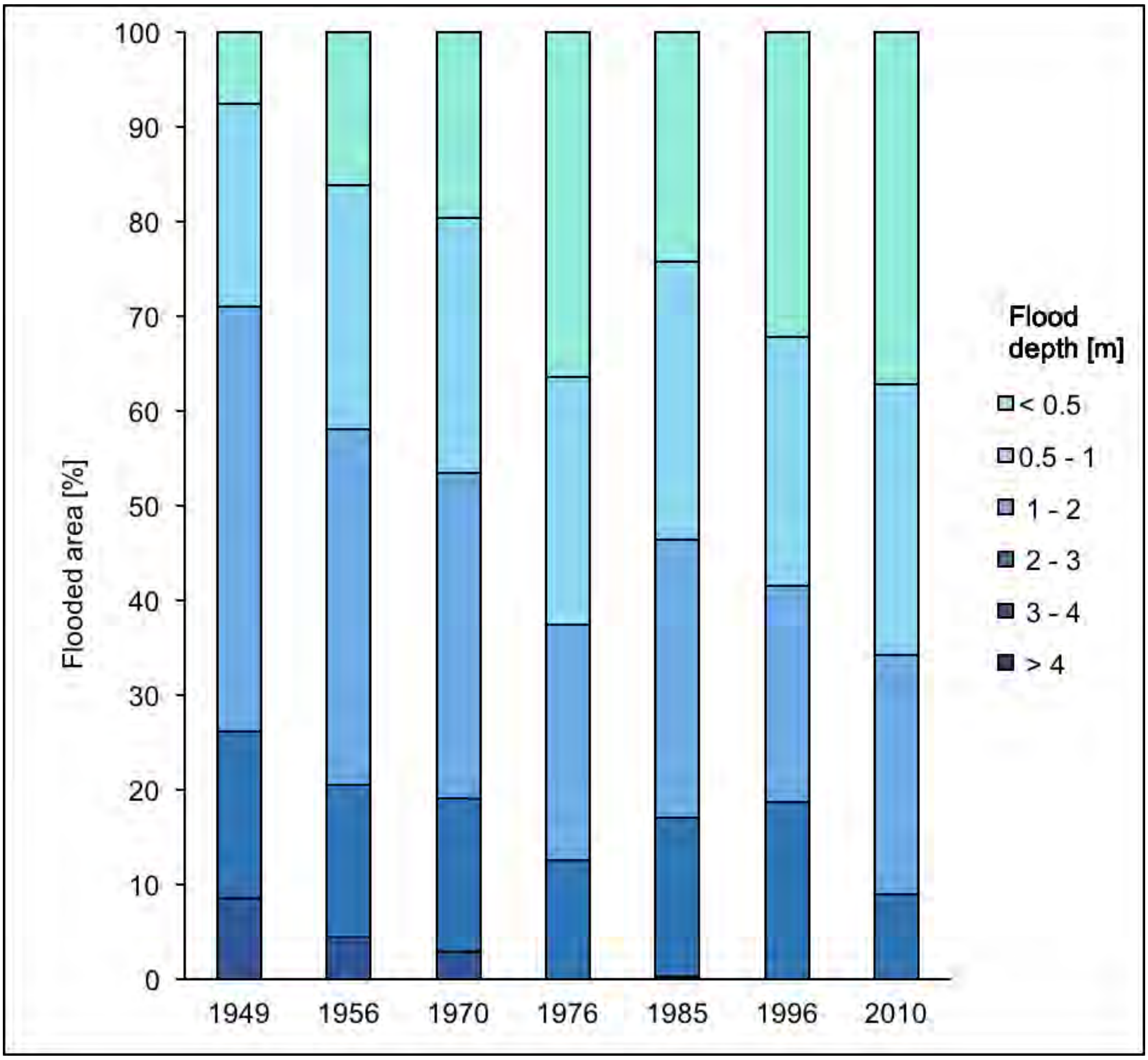


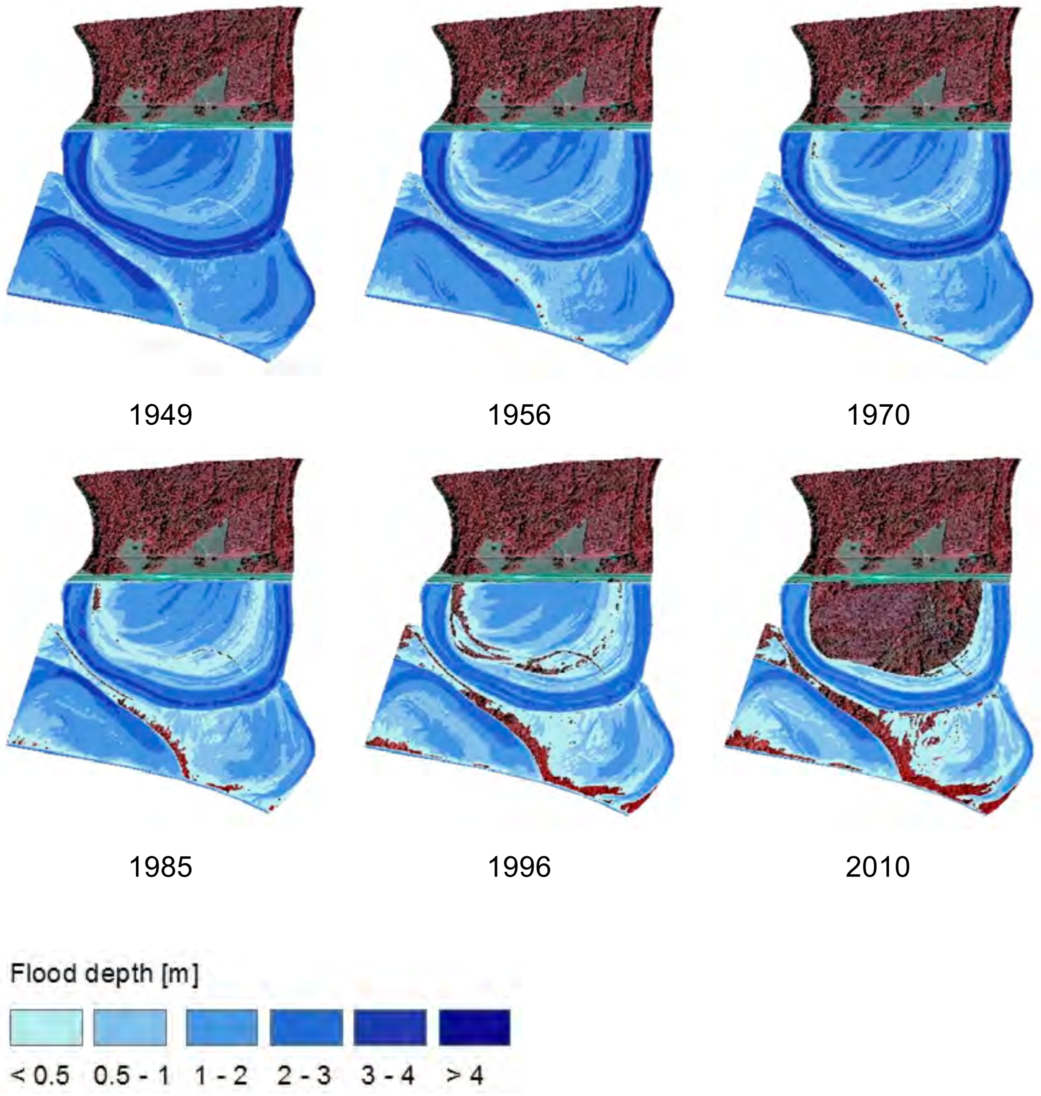
Figure 22 Modelled area (in m^2) of the study site flooded by the 2-year flood in 1949, 1956, 1970, 1976, 1985, 1996 and 2010. Colours indicate the depth of the water column. The categories are: > 4 m,3 – 4 m, 2 – 3 m, 1 – 2 m, 0.5 – 1 m and < 0.5 m (raw data: via donau)

Table 7 Inundation depth of 2-year flood as percentage of proximate floodplain

			Depth of inundation (m)			
Year	**> 4**	**3 - 4**	**2 - 3**	**1 - 2**	**0.5 - 1**	**< 0.5**
1949	0.01	8.62	17.57	44.82	21.38	7.59
1956	0.01	4.50	16.04	37.54	25.69	16.22
1970	0.00	2.98	16.06	34.36	27.00	19.59
1976	0.00	0.02	12.53	24.82	26.17	36.45
1985	0.00	0.21	16.79	29.32	29.37	24.30
1996	0.00	0.04	18.67	22.86	26.18	32.25
2010	0.00	0.00	9.02	25.18	28.63	37.16

5-year flood

The maps in Fig. 23 show the depth of inundation during a 5-year flood events as modelled for the investigated years. The area balances show a shift towards lower flood depths over the years (Fig. 24). In 1949 the highest share of the area falls into the range 1m – 2 m (49.11%), whereas in 2010 this category is reduced to 22.88% and the category > 0.5 m has the highest share with 31.13% (compared to 1.84% in 1949) (Table 8).


1949 1956 1970

1985 1996 2010

Figure 23 Modelled flood depth (inundation) in meters during a 5-year flood at the study site in 1949, 1956, 1970, 1985, 1996, 2010 (raw data: via donau)

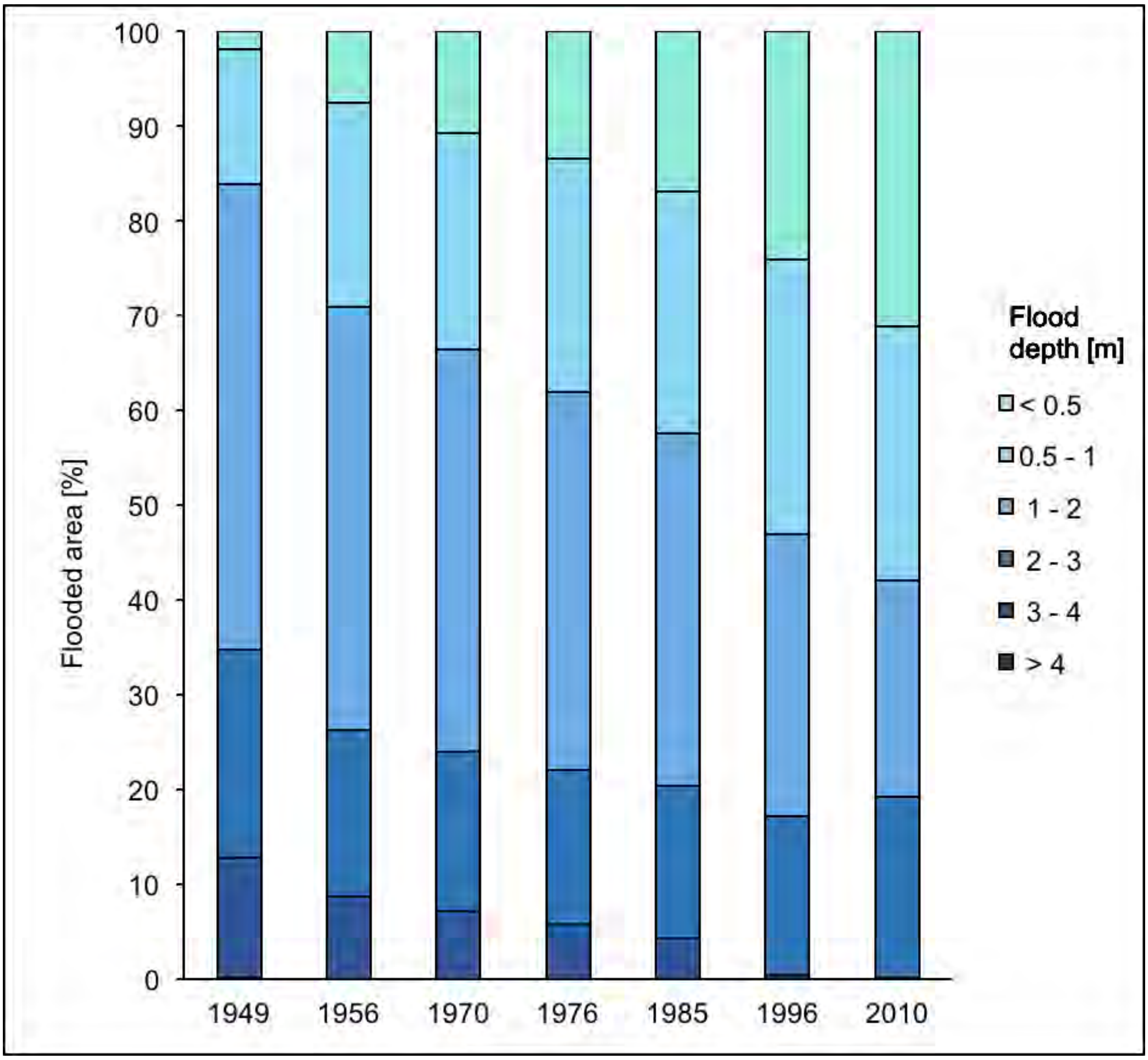


Figure 24 Modelled area (in m^2) of the study site flooded by the 5-year flood in 1949, 1956, 1970, 1976, 1985, 1996 and 2010. Colours indicate the depth of the water column. The categories are: > 4 m,3 – 4 m, 2 – 3 m, 1 – 2 m, 0.5 – 1 m and < 0.5 m (raw data: via donau)

Table 8 Inundation depth of 5-year flood as percentage of proximate floodplain

			Depth of inundation (m)			
Year	**> 4**	**3 - 4**	**2 - 3**	**1 - 2**	**0.5 - 1**	**< 0.5**
1949	0.04	12.77	21.90	49.11	14.34	1.84
1956	0.01	8.66	17.59	44.71	21.46	7.56
1970	0.01	7.09	16.82	42.44	22.93	10.70
1976	0.01	5.76	16.32	39.79	24.75	13.38
1985	0.01	4.29	16.01	37.30	25.53	16.87
1996	0.00	0.32	16.83	29.75	29.06	24.04
2010	0.00	0.04	19.11	22.88	26.83	31.13

10-year flood

The 10-year flood experiences a small decrease of spatial extent from 1949 to 2010. The depth of inundation for the investigated years is presented in the Fig. 25. A comparison of the shares of the categories of depth of inundation shows a shift to lower depths (Fig. 26). In 1949, 0.52% were flooded by a water column less than half a meter high. In 1970 this category holds a share of 1.55%. By 2010 the share has increased to 19.72% (Table 9).

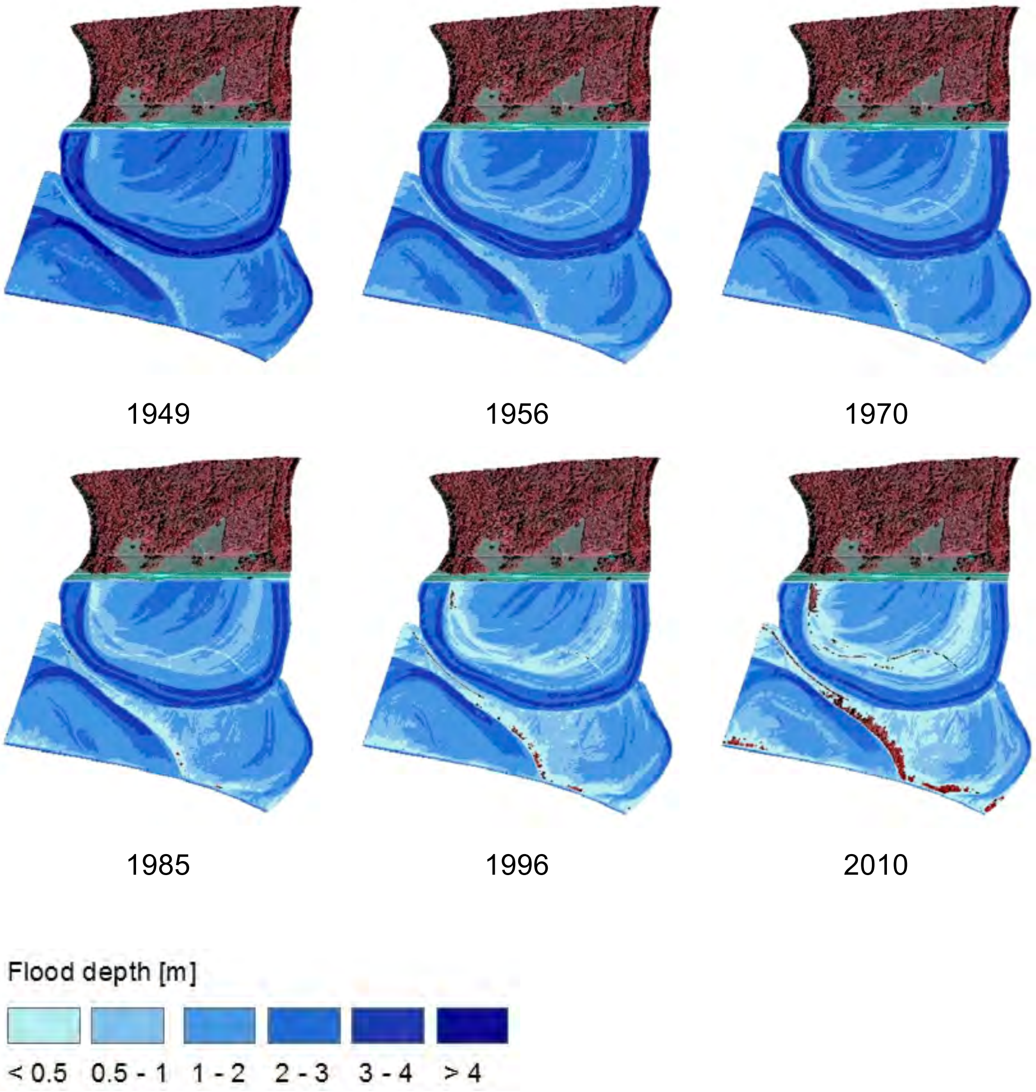


Figure 25 Modelled flood depth (inundation) in meters during a 10-year flood at the study site in 1949, 1956, 1970, 1985, 1996, 2010 (raw data waterlevel, discharge: viadonau 2013, raw data: flood events: via donau 2014, raw data elevation: Donau-Auen National Park)

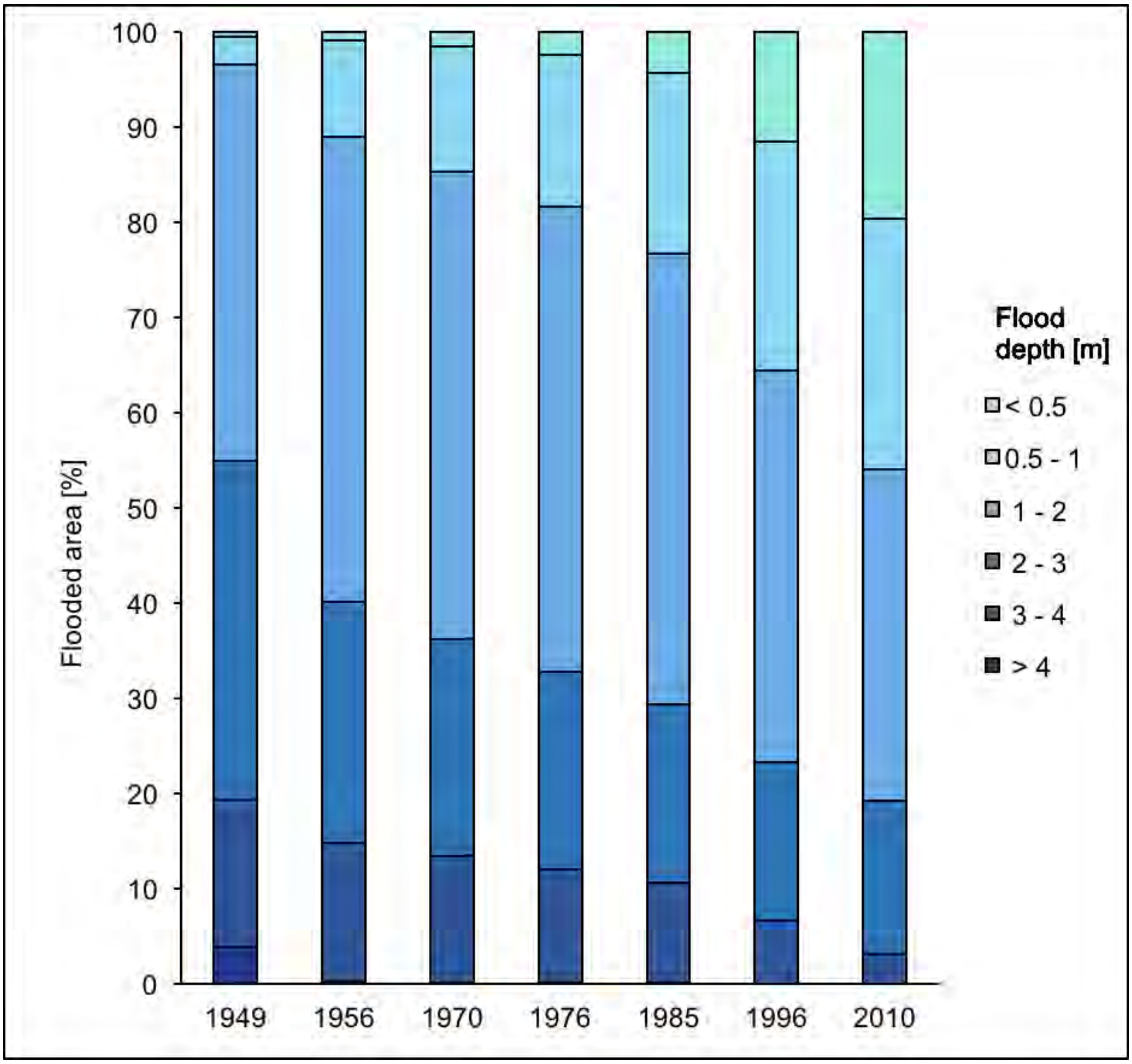


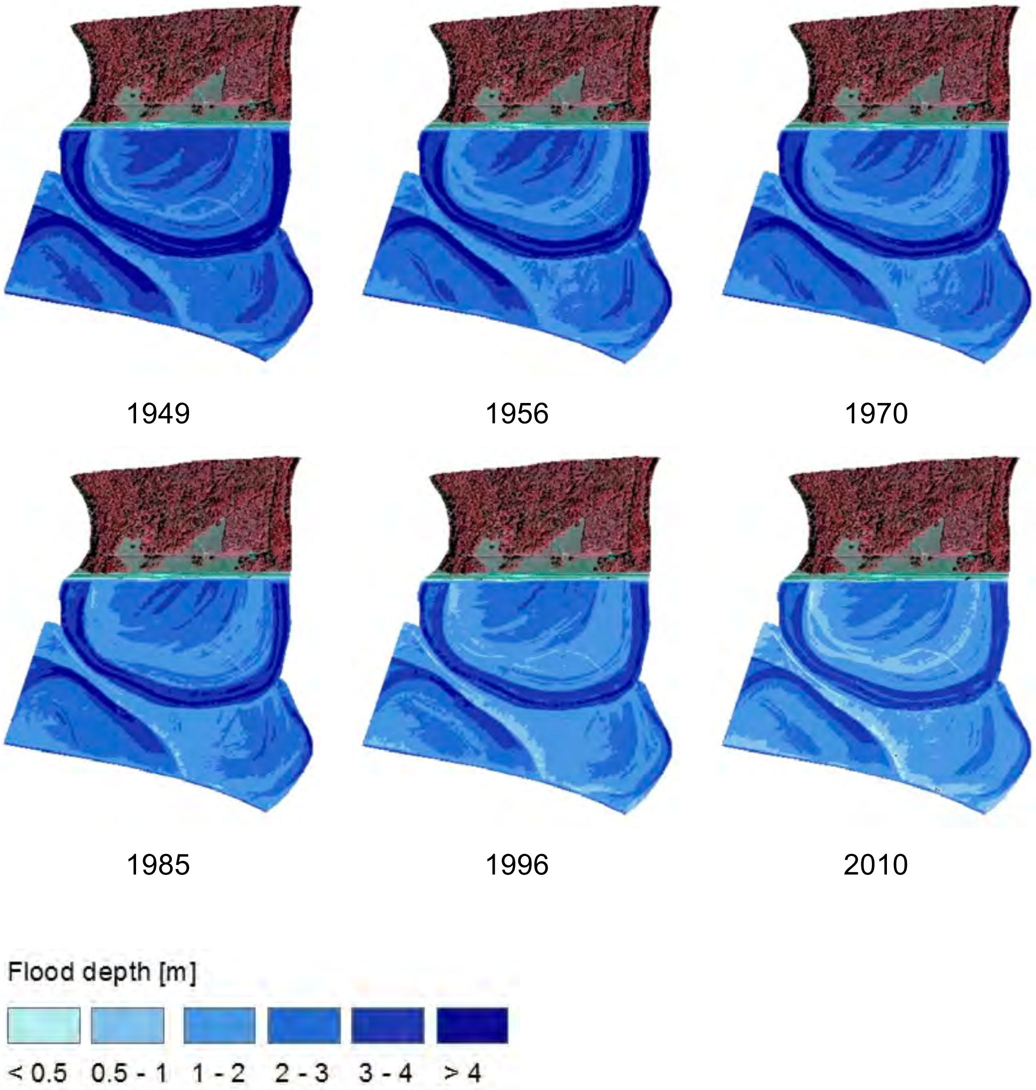
Figure 26 Modelled area (in m^2) of the study site flooded by the 10-year flood in 1949, 1956, 1970, 1976, 1985, 1996 and 2010. Colours indicate the depth of the water column. The categories are: > 4 m,3 – 4 m, 2 – 3 m, 1 – 2 m, 0.5 – 1 m and < 0.5 m (raw data: via donau)

Table 9 Inundation depth of 10-year flood percentage of proximate floodplain

			Depth of inundation (m)			
Year	**> 4**	**3 - 4**	**2 - 3**	**1 - 2**	**0.5 - 1**	**< 0.5**
1949	3.87	15.42	35.54	41.68	2.98	0.52
1956	0.15	14.59	25.36	48.83	10.16	0.91
1970	0.05	13.36	22.69	49.12	13.23	1.55
1976	0.03	11.98	20.70	48.87	15.91	2.51
1985	0.02	10.56	18.74	47.37	18.92	4.39
1996	0.01	6.64	16.65	41.15	23.94	11.62
2010	0.00	3.09	16.14	34.73	26.31	19.72

20-year flood

The maps in Fig 27 show the flood depth during a 20-year flood event for the investigated years. Fig. 28 illustrates the shift towards lower depths of inundation. The shares of depth classes of the study area for the investigates years are stated in Table 10.



1949 1956 1970

1985 1996 2010

Figure 27 Modelled flood depth (inundation) in meters during a 20-year flood at the study site in 1949, 1956, 1970, 1985, 1996, 2010 (raw data: via donau)

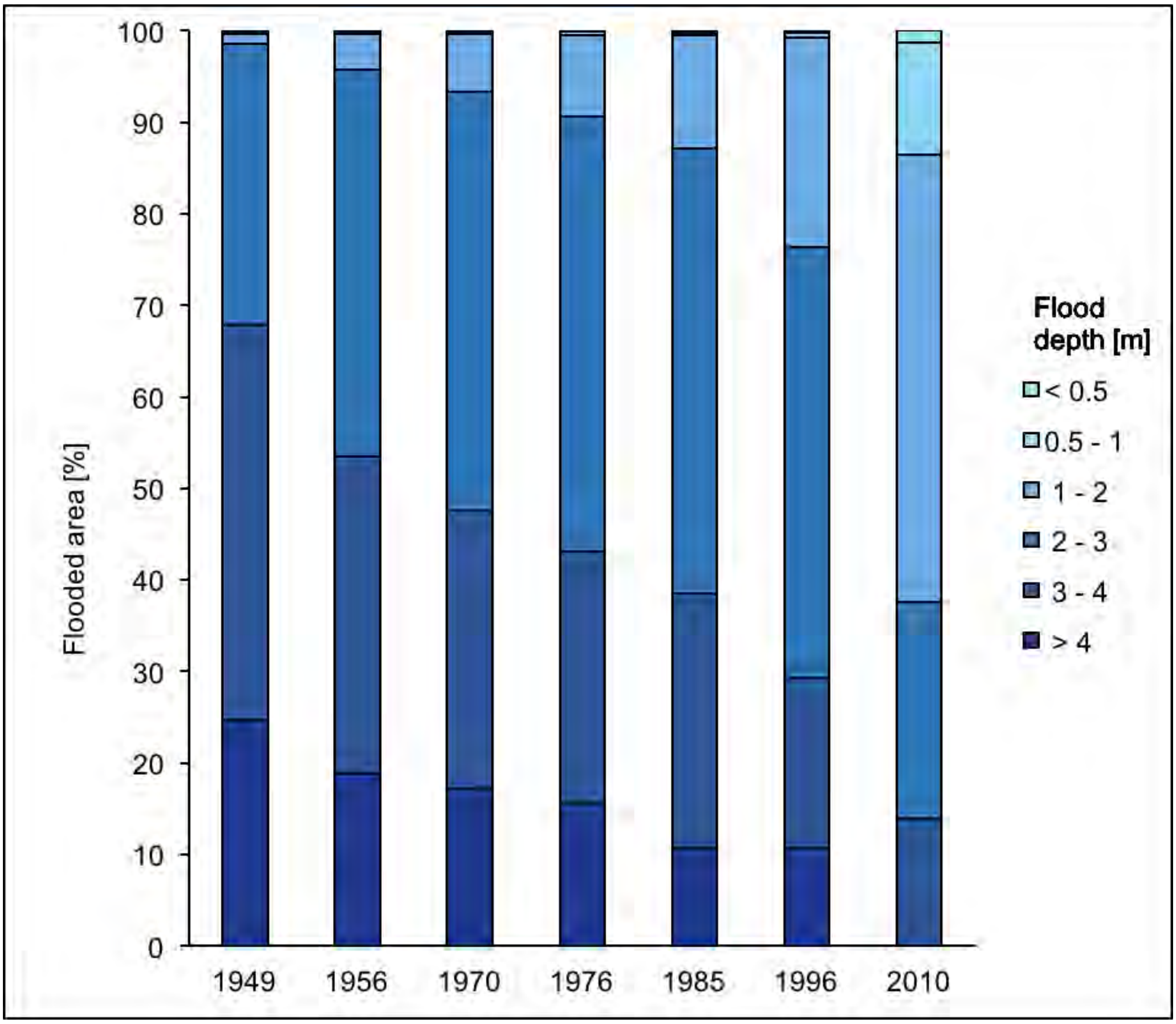


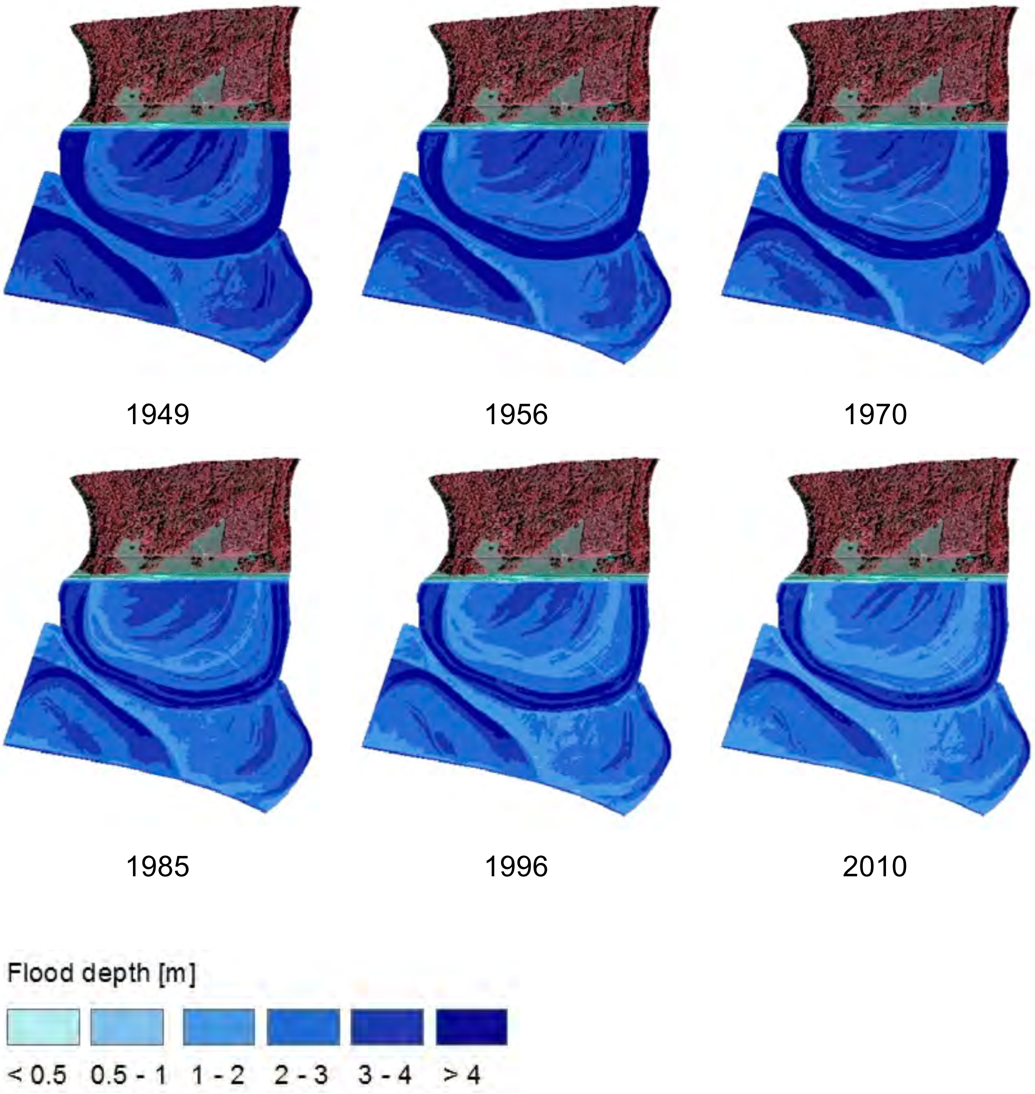
Figure 28 Modelled area (in m^2) of the study site flooded by the 20-year flood in 1949, 1956, 1970, 1976, 1985, 1996 and 2010. Colours indicate the depth of the water column. The categories are: > 4 m,3 – 4 m, 2 – 3 m, 1 – 2 m, 0.5 – 1 m and < 0.5 m (raw data: via donau)

Table 10 Inundation depth of 20-year flood percentage of proximate floodplain

	Depth of inundation (m)					
Year	**> 4**	**3 - 4**	**2 - 3**	**1 - 2**	**0.5 - 1**	**< 0.5**
1949	14.57	25.32	48.58	11.02	0.35	0.16
1956	10.61	18.70	47.24	22.73	0.55	0.17
1970	9.02	17.85	45.07	27.19	0.65	0.22
1976	7.71	16.89	42.69	31.60	0.82	0.30
1985	6.09	16.21	40.09	35.94	1.31	0.37
1996	2.29	15.28	31.37	45.37	5.15	0.55
2010	0.07	13.83	23.65	48.94	12.27	1.23

50-year flood

Fig. 29 illustrates how a 50-year flood event inundates the study area at specific years. Comparing the shares of different flood depths shows again a shift to lower depths of inundation (Fig. 30). In 1949, 24.63% are flooded with a depth of more than 4m and 43.32% are flooded 3 m – 4 m. The percentages are decreased to 17.12 % (> 4 m) and 30.47% (3 m – 4m) in 1970. In 2010 the area flooded with more than 4m has 6.89% and the area with an inundation depth of 3m – 4m 16.54% (Table 11).


1949 1956 1970

1985 1996 2010

Figure 29 Modelled flood depth (inundation) in meters during a 50-year flood at the study site in 1949, 1956, 1970, 1985, 1996, 2010 (raw data: via donau)

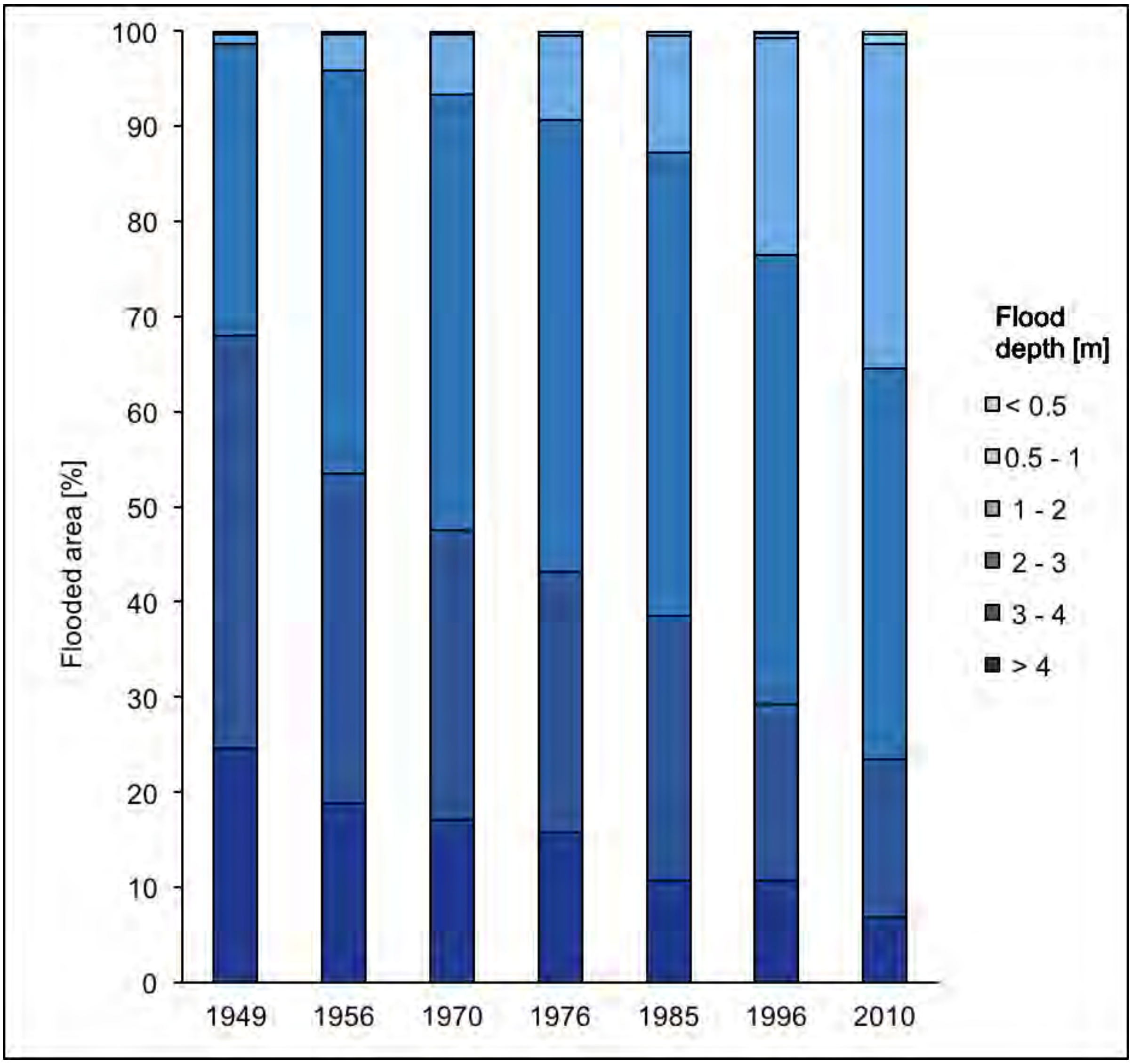


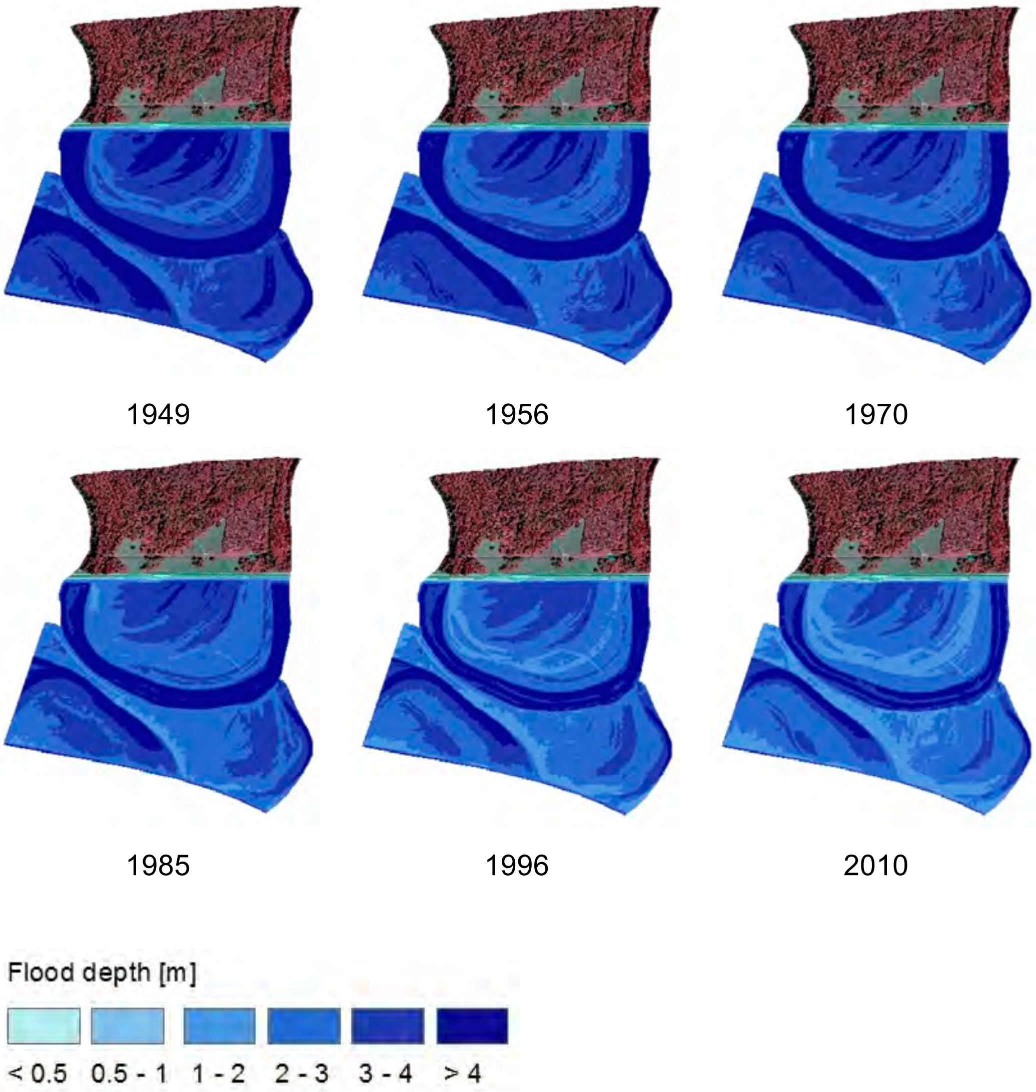
Figure 30 Modelled area (in m^2) of the study site flooded by the 50-year flood in 1949, 1956, 1970, 1976, 1985, 1996 and 2010. Colours indicate the depth of the water column. The categories are: > 4 m,3 – 4 m, 2 – 3 m, 1 – 2 m, 0.5 – 1 m and < 0.5 m (raw data: via donau)

Table 11 Inundation depth of 50-year flood percentage of proximate floodplain

	Depth of inundation (m)					
Year	**> 4**	**3 - 4**	**2 - 3**	**1 - 2**	**0.5 - 1**	**< 0.5**
1949	24.63	43.32	30.63	1.11	0.15	0.15
1956	18.92	34.52	42.38	3.86	0.20	0.12
1970	17.12	30.47	45.77	6.29	0.22	0.13
1976	15.69	27.44	47.55	8.91	0.29	0.13
1985	10.70	27.86	48.61	12.32	0.37	0.14
1996	10.61	18.69	47.09	22.89	0.55	0.17
2010	6.89	16.54	41.09	34.12	1.04	0.32

100-year flood

The maps of Fig. 31 show the depth of inundation during a 100-year flood event for the years 1949, 1956, 1970, 1985, 1996 and 2010. The percentage of areas with lower flood depths increases over time (Fig. 32). 1949, 32.38% were inundated more than 4 m. 2010, it is decreased to 11.05 m (Table 12).



1949 1956 1970

1985 1996 2010

Figure 31 Modelled flood depth (inundation) in meters during a 100-year flood at the study site in 1949, 1956, 1970, 1985, 1996, 2010 (raw data: via donau).

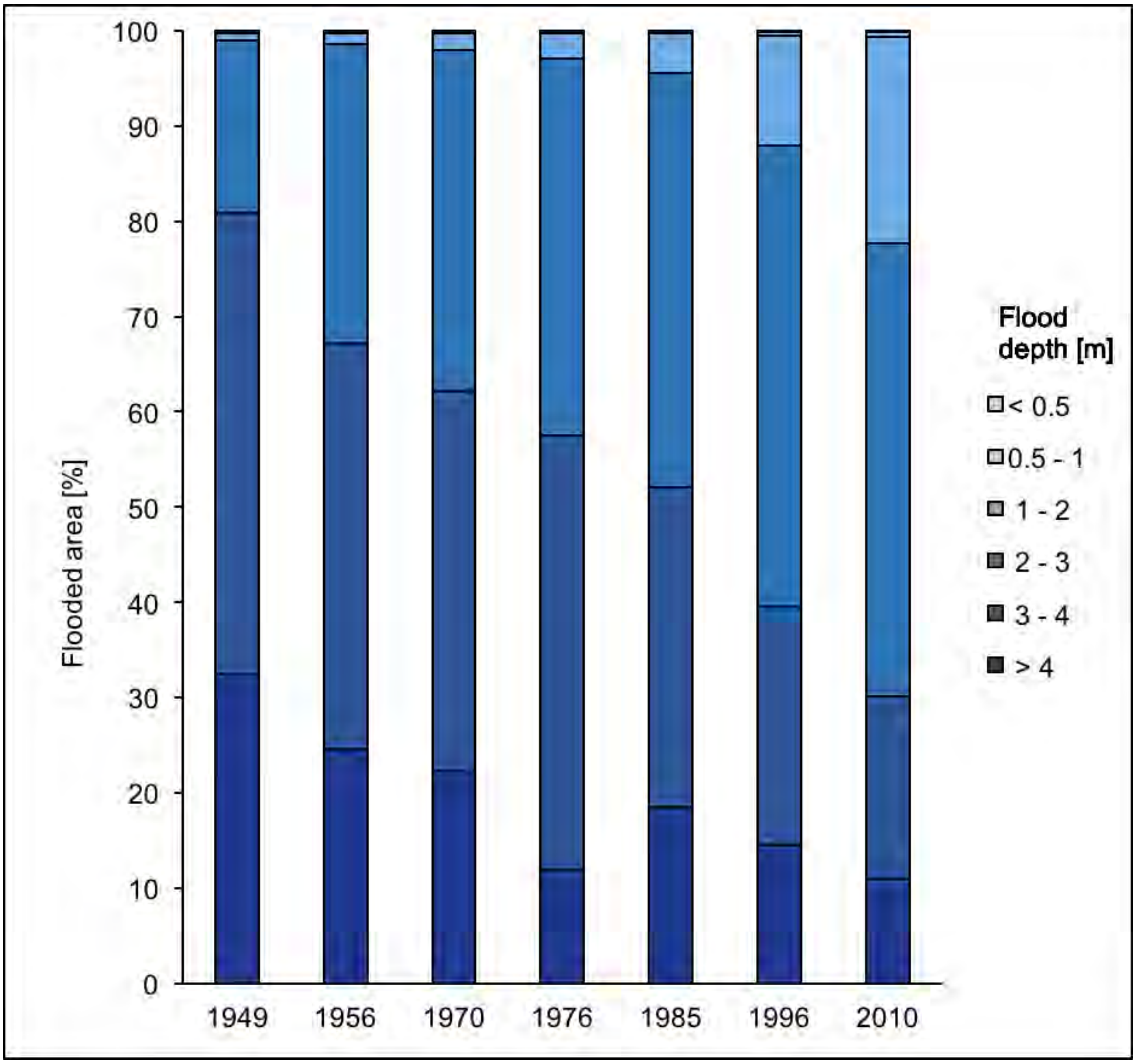


Figure 32 Modelled area (in m^2) of the study site flooded by the 100-year flood in 1949, 1956, 1970, 1976, 1985, 1996 and 2010. Colours indicate the depth of the water column. The categories are: > 4 m,3 – 4 m, 2 – 3 m, 1 – 2 m, 0.5 – 1 m and < 0.5 m (raw data: via donau)

Table 12 Percentage 100-year flood

			Depth of inundation (m)			
Year	**> 4**	**3 - 4**	**2 - 3**	**1 - 2**	**0.5 - 1**	**< 0.5**
1949	32.38	48.45	18.19	0.68	0.15	0.15
1956	24.53	42.66	31.39	1.14	0.15	0.13
1970	22.22	40.05	35.74	1.70	0.18	0.11
1976	11.91	45.56	39.63	2.59	0.19	0.12
1985	18.53	33.59	43.41	4.15	0.19	0.12
1996	14.56	24.94	48.44	11.57	0.36	0.14
2010	11.05	19.13	47.54	21.58	0.53	0.17

Flooded area

As a result of the incision of the Danube and the aggradation of the floodplain the area of the study site flooded during flood events decreases over time. The 1-year flood shows distinct changes. In 1949 a 1-year flood inundates 64.76% of the total area of the study site. In 1970 its 40.92% and 2010 only 0.47% of the area are flooded. The 2-year flood reaches 70.13% of the study site, almost the whole area between river and dam are flooded. In 2010 only 12.89% are flooded during a 2-year flood. From the 10-year flood upwards almost the whole area between river and dam remains flooded through the years (Table 13). Fig. 33 illustrates the percentage of the study site flooded during a 1-year, 2-year, 5-year and 10-year flood for the investigated years. It shows two general trends: The flooded area increases with annuity and it decreases with time.

Table 13 Percentage flooded area of total area study site

	Flooded area (%)						
Year	**1-year flood**	**2-year flood**	**5-year flood**	**10-year flood**	**20-year flood**	**50-year flood**	**100-year flood**
1949	64.76	70.13	70.44	70.73	70.91	71.03	71.08
1956	44.20	68.54	70.07	70.49	70.78	70.90	70.96
1970	40.92	67.12	69.79	70.40	70.76	70.88	70.93
1976	13.96	65.36	69.28	70.33	70.74	70.86	70.92
1985	12.94	62.55	68.46	70.24	70.71	70.84	70.90
1996	0.55	43.03	63.69	69.66	70.62	70.78	70.84
2010	0.47	12.89	44.08	67.34	70.44	70.72	70.79

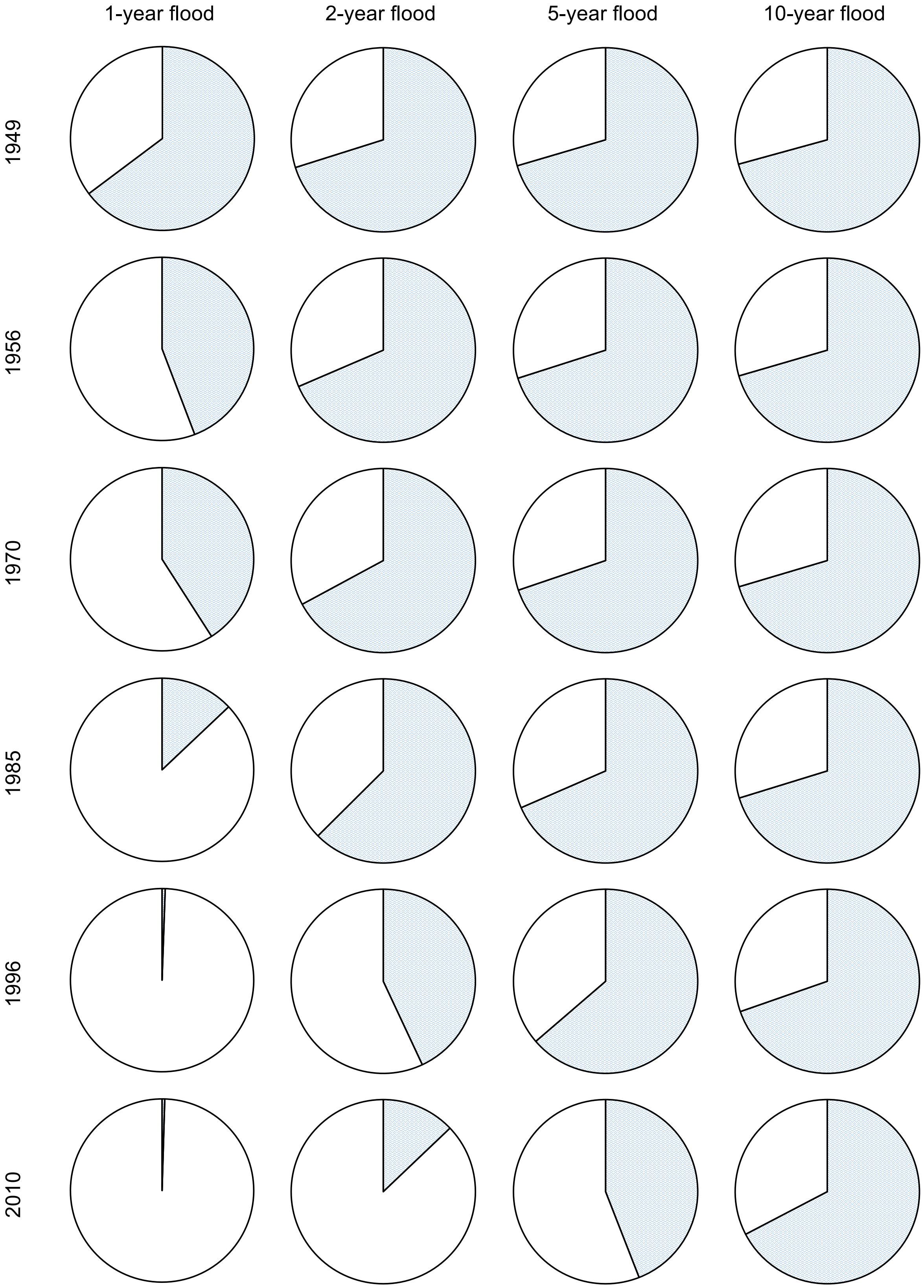


Figure 33 Percentage flooded area of total study site. 1-year, 2-year, 5-year, 10-year flood (raw data: via donau)

Flood duration

The hydrograph from 1977 to 2013 shows a number of major flood events during the last decade (Fig 34).

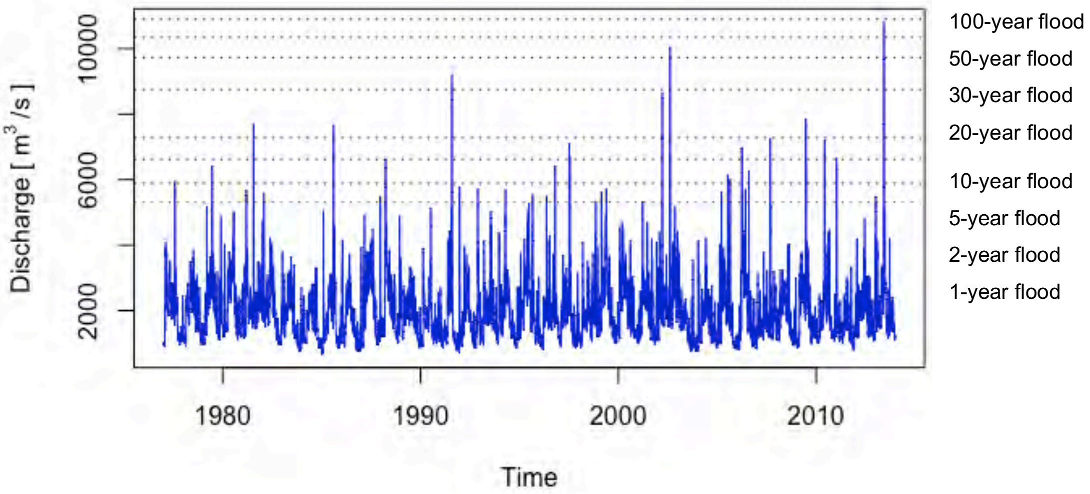


Figure 34 Discharge of the Danube in m3/s measured at Hainburg for the period 1977-2013. Dotted lines indicate flood events (raw data: via donau)

Table 14 states the number of days, flood events of different magnitudes were happening for periods of six or seven years. It shows a higher number of days of flood events in recent years. Remarkably is the 100-year flood in 2013. During this period also a day with 20-year flood, 30-year flood and 50-year flood is recorded, but they are part of the 100-year flood event in 2013.

Table 14 Number of days of flood events for periods of 6 years, alternatively 7 years, between 1977 and 2013 at *Wildungsmauer* (raw data: via donau)

	Period					
Flood event	**77 - 82** *6 a*	**83 - 88** *6 a*	**89 - 94** *6 a*	**95 - 00** *6 a*	**01 - 06** *6 a*	**07 - 13** *7 a*
1-year flood	8	3	4	15	10	6
2-year flood	4	3	1	3	7	7
5-year flood	1	1	0	2	7	4
10-year flood	2	1	2	0	4	3
20-year flood	0	0	1	0	1	1
30-year flood	0	0	0	0	1	1
50-year flood	0	0	0	0	0	1
100-year flood	0	0	0	0	0	1
Total	*15*	*8*	*8*	*20*	*30*	*24*

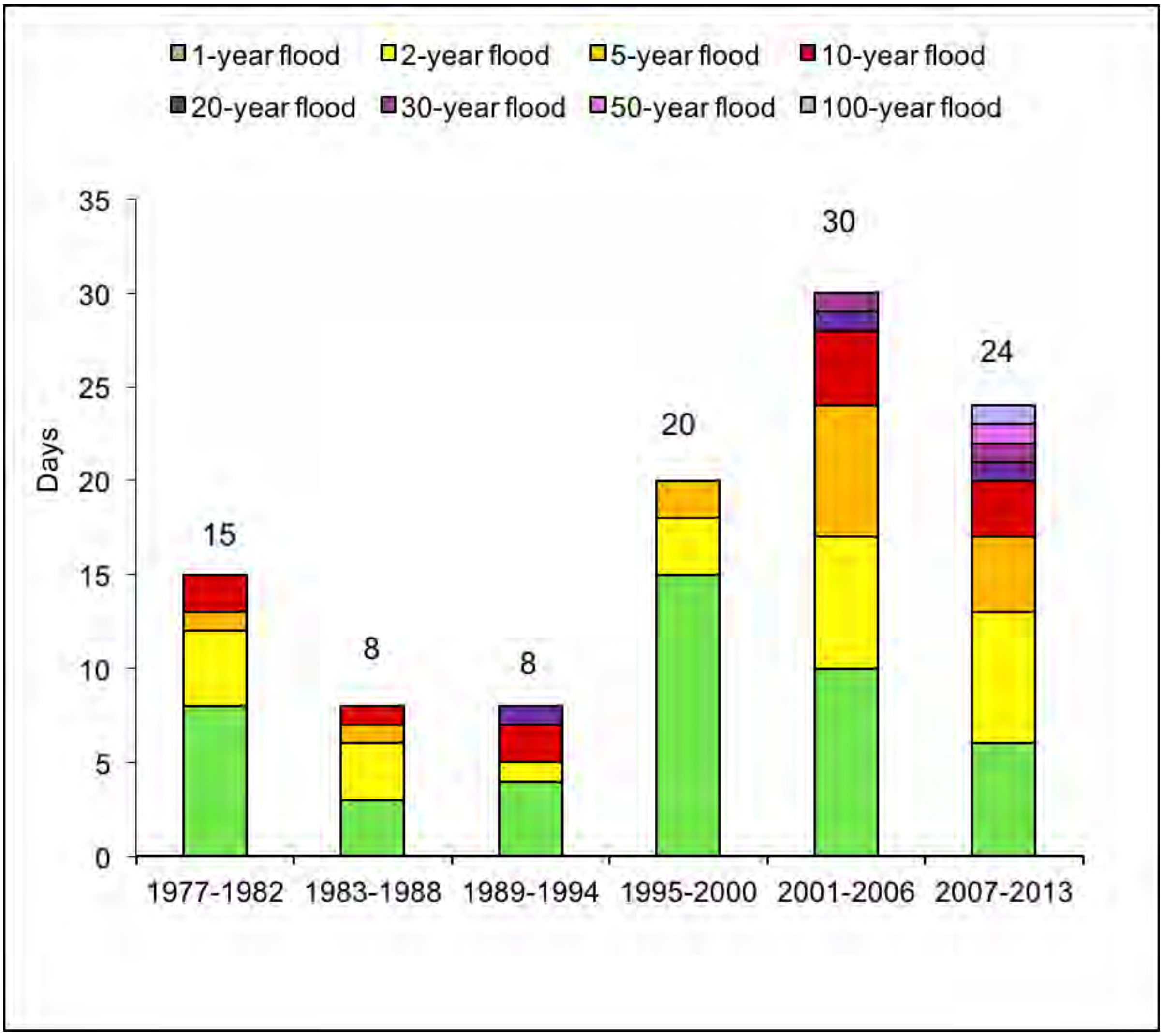


Figure 35 Number of days of flood for periods of 6 years, alternatively 7 years, between 1977 and 2013 (raw data discharge: viadonau 2013, raw data: flood events: via donau 2014)

Fig. 35 compares the number days of flood from 1997 to 2013 in six or seven year periods. The periods 1995-2000, 2001-2006 and 2007-2013 have comparatively high numbers of flood days: 20 days, 30 days and 24 days respectively Earlier periods have lower number. 1977-1882 features 15 days of flood. 8 days of flood are features in the period 1983-1988 and 8 days again in 1989-1994. An overview of flood events from 1997 to 2013 is given in Table 15.

Table 15 Flood events between 1977 and 2013 with date of beginning, duration in total days, mean discharge over total days of flood event (Q_{mean}) and maximum discharge (Qmax). Q_{max} from 1977 and 1995 as maximum daily mean discharge during duration of flood. Q_{max} from 1996 to 2013 as maximum hourly discharge during duration of flood event. (raw data: via donau)

Year	**Flood event**	**Beginning**	**Duration [days]**	**Q_{mean} [m^3/s]**	**Q_{max} [m^3/s]**
1977	2-year flood	3.August	2	5795.5	5951
1979	2-year flood	20.May	4	6115.5	6427
1981	1-year flood	14.March	2	5585.5	5674
1981	10-year flood	21.July	6	6576.8	7697
1982	1-year flood	1.February	1	5598	5598
1985	10-year flood	8.August	3	6923	7674
1987	1-year flood	20.December	1	5492	5492
1988	5-year flood	25.March	6	6127.5	6628
1991	20-year flood	3.August	5	7657.8	9214
	1-year flood	24.December	1	5788	5788
1992	1-year flood	24.November	1	5723	5723
1994	1-year flood	19.April	1	5706	5706
1995	1-year flood	3.September	1	5559	5559
1996	1-year flood	15.May	1	5501	5501
	2-year flood	22.October	2	5935	6418
1997	5-year flood	7.July	3	6419	7075
	5-year flood	20.July	3	6175	6803
1998	1-year flood	12.November	1	5348	5748
	1-year flood	22.February	2	5593.5	5916
1999	1-year flood	22.May	7	5567.9	5821
2001	1-year flood	25.March	1	5330	5515
2002	10-year flood	21.March	5	7452.6	8820
	5-year flood	8.August	2	6130.5	6985
	30-year flood	13.August	5	8672.8	10249
2005	1-year flood	20.March	1	5642	6030
	2-year flood	12.July	2	5734	6265
	2-year flood	25.August	3	5677	6210
2006	5-year flood	28.March	9	6261.1	7241
	1-year flood	4.June	1	5703	5953
	2-year flood	8.August	2	6102	7039
2007	5-year flood	7.September	3	6520.3	7478
2009	10-year flood	24.June	7	6526.1	8071
2010	5-year flood	3.June	4	6406.5	7494
2011	5-year flood	15.January	2	6490.5	6963
2013	1-year flood	6.January	1	5486	5632
	100-year flood	2.June	8	8166.1	10980

5.2 Potential natural vegetation of the study site

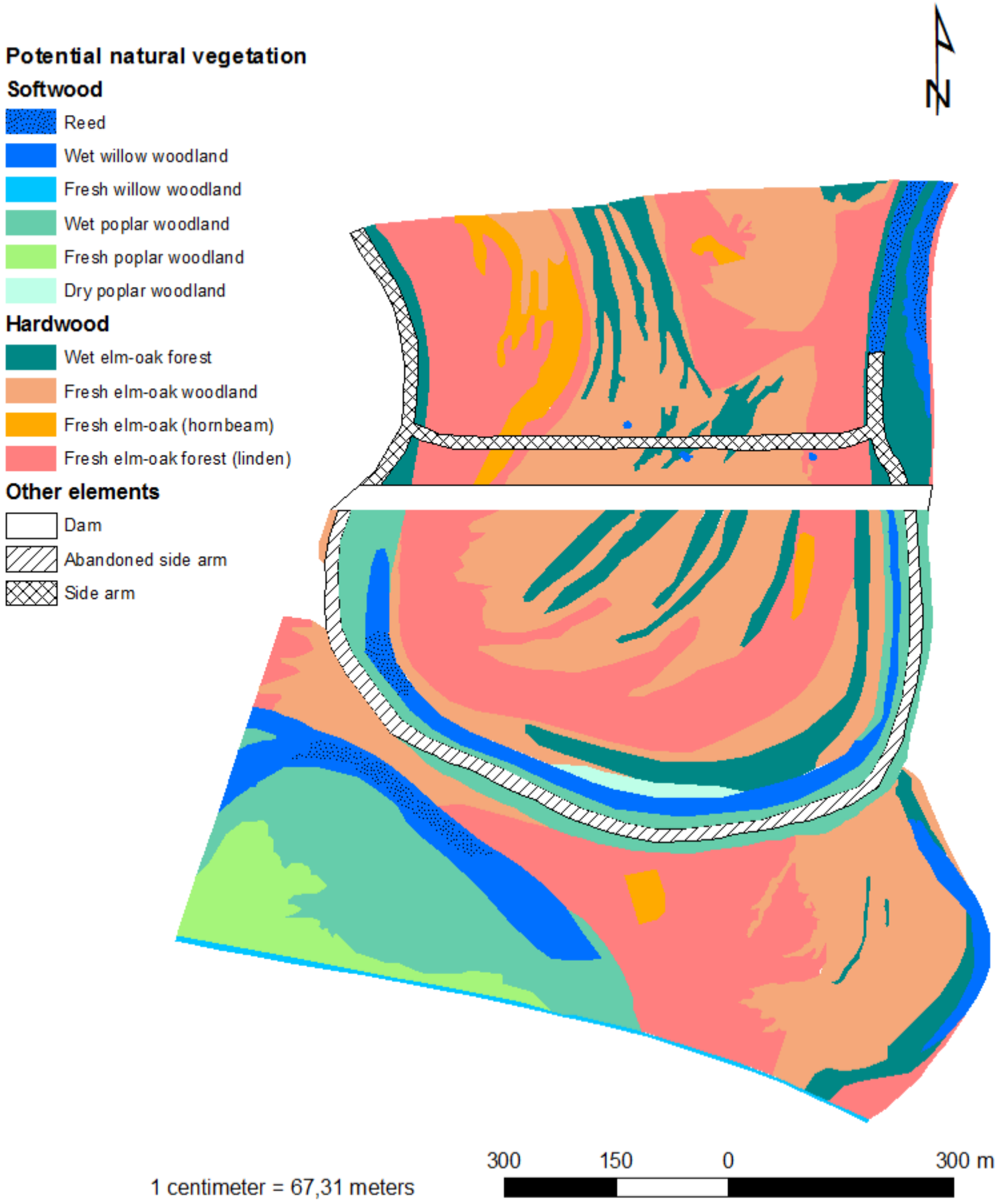


Figure 36 Potential natural vegetation of the study site mapped in 2015

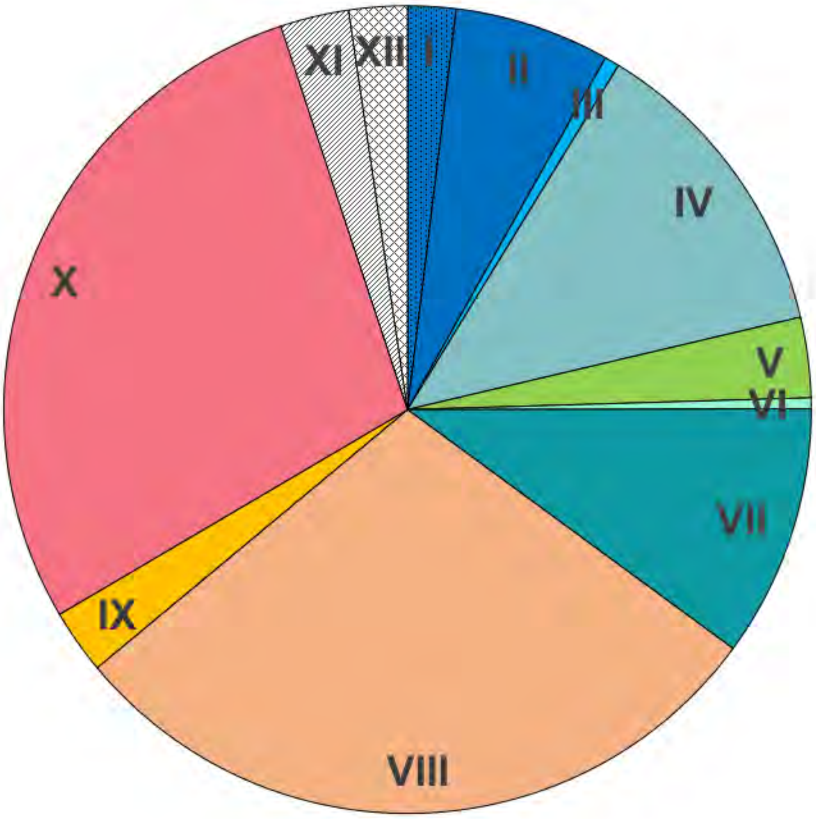


Figure 37 Area fractions (%) of PNV types

Table 16 Area fraction (%) and area (m^2) of PNV types

Type ID	PNV type	Fraction (%)	Area [m^2]
I	Reed	1.93	17800
II	Wet willow woodland	6.23	57548
III	Fresh willow woodland	0.60	5496
IV	Wet poplar woodland	12.57	116040
V	Fresh poplar woodland	3.21	29674
VI	Dry poplar woodland	0.44	4067
VII	Wet elm-oak forest	10.10	93282
VIII	Fresh elm-oak forest	28.89	266738
IX	Fresh elm-oak forest (hornbeam)	2.58	23822
X	Fresh elm-oak forest (linden)	28.37	262010
XI	Abandoned side arm	2.75	25370
XII	Side arm	2.34	21597
Total	All types (minus Dam)	100	923444

The map generated from 2015 is shown in Fig. 36. Fig. 37 presents the shares of each PNV type- The shares and their area are states in Table 16. Table 17 presents the mean depth to groundwater of each PNV type in 1970 and 2010 and the difference in depth between the years..

Table 17 Mean depth to groundwater of PNV types in 1970 and 2010 and change (Δ) from 1970 to 2010

	1970				2010				Δ
PNV type	Mean (m)	STD (m)	Min (m)	Max (m)	Mean (m)	STD (m)	Min (m)	Max (m)	Mean (m)
Reed	0.82	0.49	0.00	3.48	1.21	0.49	0.03	3.87	0.38
Wet willow woodland	1.56	0.44	0.33	3.62	1.94	0.44	0.72	4.01	0.38
Wet poplar woodland	2.43	0.57	0.90	3.93	2.81	0.57	1.29	4.32	0.38
Wet elm-oak forest	2.29	0.57	0.58	4.18	2.67	0.57	0.97	4.57	0.38
Fresh willow woodland	2.19	0.58	0.76	3.53	2.63	0.65	1.15	4.22	0.44
Fresh poplar woodland	3.49	0.31	2.59	4.32	3.89	0.31	3.06	4.71	0.40
Fresh elm-oak forest	2.87	0.45	0.85	4.76	3.25	0.45	1.24	5.15	0.38
Fresh elm-oak forest (hornbeam)	2.98	0.28	2.06	3.78	3.37	0.28	2.45	4.17	0.38
Fresh elm-oak forest (linden)	3.58	0.36	0.73	5.03	3.96	0.36	1.12	5.42	0.39
Dry poplar woodland	3.15	0.33	1.70	3.63	3.54	0.33	2.09	4.02	0.38

5.2.1 Wet willow woodland

Topography and soil

Wet willow woodland is located in depressed areas of former meander bends of the side arm *Faden* and in flood pools. The topsoil layer has a thickness of more than 20 cm and the moderately moist to moist. Due to rust spots the top layer the soil is categorized as *Gley* (Table 18). The average the soil consists of 18.5% sand, 54% silt and 27.38% clay, which corresponds to the soil texture type *Silty Clay Loam*. Silt is the most abundant grain size class at all assessment sites (Fig. 33).

Vegetation

The vegetation of *wet willow woodland* is dominated by *Salix alba* in the tree layer and *Phragmites australis* and *Rubus caesius* in the herb layer. In sites comparison with other PNV types the tree coverage is low. The mean cover in the 1st tree layer is in 22.5%, the maximal tree coverage 50%. Two assessment feature no trees. On the contrary the herb coverage is comparatively high with an average of 72.5%. The highest *Salix alba* trees are ~ 25 m high and have a DBH of ~1 m. Many willow trees are old and the bark is often split and branches disjoined (Table 19).

Classification of PNV type

The sites of *wet willow woodland* are classified as European natural habitat type *91E0 *Alluvial forests with Alnus glutinosa and Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae)*. *Salicetum albae Issler 1926* is identified as the plant association corresponding to the PNV type *wet willow woodland*. It can also be categorized as softwood forest.

Groundwater

During the vegetation period *wet willow woodland* has a mean depth to groundwater of 1.94 m with a standard deviation is 0.44 m. The highest depth to groundwater is 4.01 m and the lowest 0.72 m. The only PNV type with a lower mean depth to groundwater is *reed* (Table 17)

Floods

The wet willow woodland site in the southwest of the study site is flooded at a 2-year flood, the rest of the wet willow woodland located between river and dam is flooded at a 5-year flood. In a year with typical fluvial dynamic it is flooded for 1 to 3 days. The average inundation depth during a 2-year flood is 1.64 m (only one site flooded). During the 5-year flood mean flood depth is 2.04 m. A 10-year flood results in an inundation depth of 2.45 m

Table 18 Soil and topography characteristics (Geomorphology: d=depression, l=levee, f=alluvial flat, r=ridge, t=terrace) in 2015/2016

Assessment N°	2	12	26	27	44	54	77	97
Topsoil [cm]	> 20	> 20	> 20	> 20	> 20	> 20	> 20	> 20
Soil type	G	G	G	G	G	G	G	G
Soil moisture	m	m	m	m	mw	m	mw	mm
Sand %	20	25	14	16	20	18	15	20
Silt %	60	47	56	47	55	55	52	60
Clay %	20	28	30	37	25	27	32	20

Table 19 Vegetation assessment of wet willow woodland at the study site in 2015/2016

Assessment N°		2	12	26	27	44	54	77	97
Tree cover (1st layer)	4	30	40	0	20	25	15	0	50
Tree cover (2nd layer)	3	0	0	0	0	20	0	0	0
Shrub cover	2	0	0	10	15	40	5	0	70
Herb cover	1	40	40	95	90	60	95	90	70
Tree height (1st layer)		25	25	0	23	50	25	0	25
Tree height (2nd layer)		0	0	0	0	20	0	0	0
Shrub height		0	0	1	1	5	1.5	0	2
Herb height		1	0.8	1	1	1	1	2	2
Cornus sanguinea	2	.	.	10	15	20	5	.	60
Crataegus monogyna	2	.	.	.	.	20	.	.	.
Fagus sylvatica	4	.	.	.	.	7	.	.	.
Phalaris arundinacea	1	.	.	.	.	.	.	20	.
Phragmites australis	1	80	20	80	75	10	90	70	10
Populus alba	3	.	.	.	.	20	.	.	.
Populus nigra	4	.	.	.	.	.	.	.	10
Quercus robur	4	.	.	.	.	15	.	.	.
Rubus caesius	1	20	20	15	15	50	5	.	70
Salix alba	4	30	40	.	20	.	15	.	40
Ulmus laevis	3	.	.	.	.	3	.	.	.

Changes of physical habitat parameters 1970 to 2010

A comparison of the modelled depths to groundwater of wet willow woodland in 1970 and 2010 shows that the area with low depths of groundwater decreased during the vegetation period decreased in favour of higher depths to the groundwater table (Fig. 39). 1970, 47.28% of the wet willow woodland area has a mean depth to groundwater between 0.5 m and 1m. The depth category with the second highest share is 1.5 m to 2 m with 31.80%. 40 years later, in 2010, the share of the latter category has increased by 15.48% to 48.76%, making it the highest share. The category with the formerly highest share, 0.5 m to 1 m, has decreased by 35.3% to a share of 11.98% of the total area of wet willow woodland at the study site (Table 20). The mean depth to groundwater changes from 1.56 m in 1970 to 1.94 in 2010 (Table 17).

Table 20 Percentages of area of wet willow woodland in depth to groundwater classes

		Depth to groundwater [m]										
Year	**s.**	**< 0.5**	**0.5 - 1**	**1 - 1.5**	**1.5 - 2**	**2 - 2.5**	**2.5 - 3**	**3 - 3.5**	**3.5 - 4**	**4 - 4.5**	**4.5 - 5**	**> 5**
1997	0.00	0.01	4.88	47.28	31.80	12.81	2.42	0.78	0.02	0.00	0.00	0.00
2010	0.00	0.00	0.22	11.98	48.76	29.75	6.78	2.10	0.41	0.00	0.00	0.00

The change of mean flood depth of each wet willow woodland polygon of the study site during a 2-year, 5-year, 10-year and 50-year flood is illustrated in figure 39.

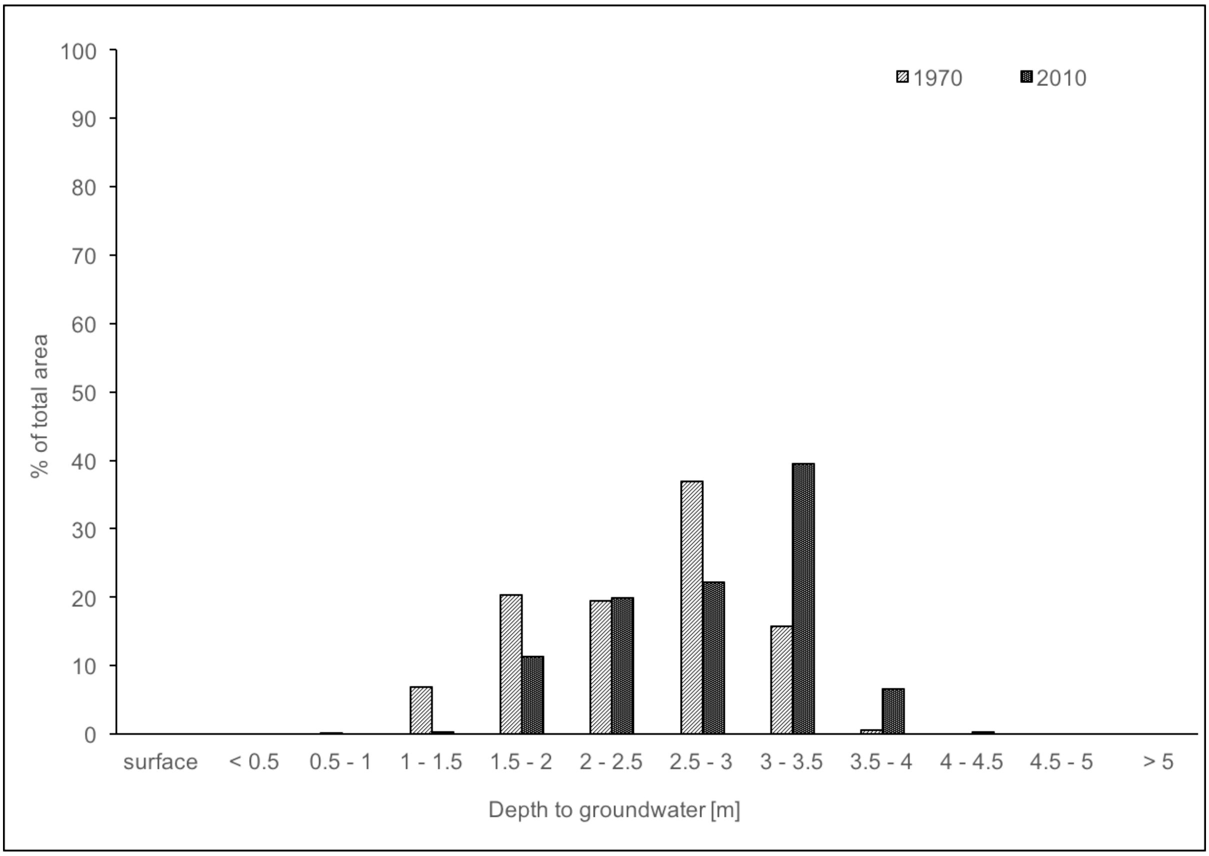
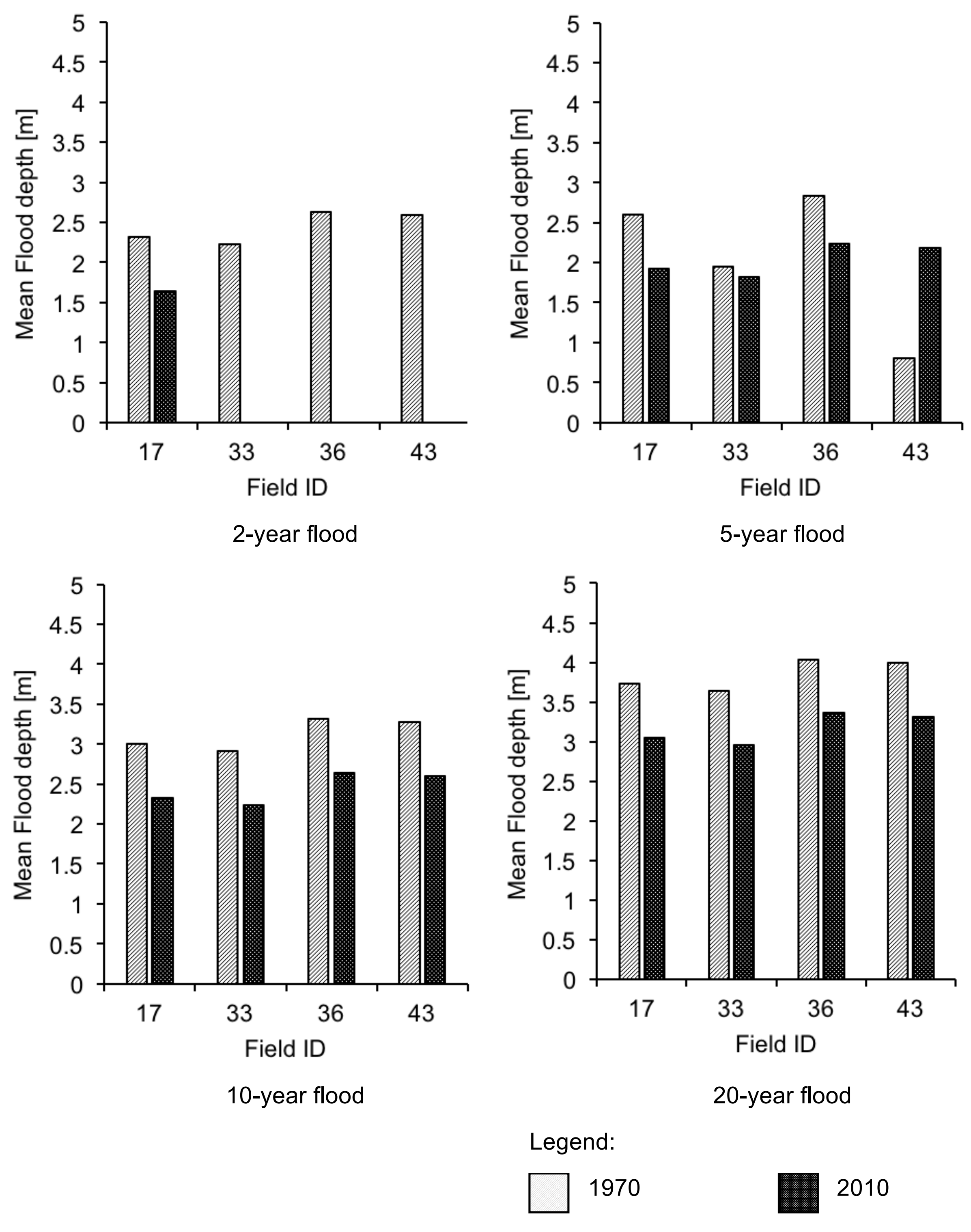


Figure 38 Shares of depth to groundwater classes of area of wet willow woodland



2-year flood

5-year flood

10-year flood

20-year flood

Figure 39 Mean depth of wet willow woodland polygons of the study site (Field IDs)

5.2.2 Fresh willow woodland

Topography and soil

On the study site *Fresh willow woodland* is only found on the levee. The topsoil layer has a thickness of about 3 cm and the soil moisture is moist. The floodplain soil is categorized as grey floodplain soil (Table 21). The upper layer of the soil features 55% sand, 40% silt and 5% clay. Thus, the soil texture type is *Sandy Loam* (Fig. 40).

Vegetation

The fresh willow woodland of the study site features *Salix alba* in the tree layer and in the shrub layer. The tree cover is ~40% and the maximum tree height is 20 m (Tab. 20).

Classification of PNV type

The fresh *willow woodland* site is classified as European natural habitat type *91E0 *Alluvial forests with Alnus glutinosa and Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae)*. The plant association corresponding to the PNV type is *Salicetum albae Issler 1926*. It can also be categorized as softwood forest.

Groundwater

Fresh willow woodland has a mean depth to groundwater of 2.63 m during SMW in 2010. The standard deviation is 0.57 m and the depth ranges between 0.97 m and 4.57 m.

Floods

This PNV type is inundated during 1-year flood events as it is located on the levee. During a 2-year flood event the depth of inundation is almost to 2 m (Fig. 42).

Table 21 Soil assessment fresh willow woodland

Assessment N°	47
Topsoil [cm]	3
Soil moisture	m
Sand %	55
Silt %	40
Clay %	5

Table 22 Vegetation assessment fresh willow woodland

Assessment N°		47
Tree cover (1st layer)	4	40
Tree cover (2nd layer)	3	0
Shrub cover	2	20
Herb cover	1	20
Tree height (1st layer)		20
Tree height (2nd layer)		0
Shrub height		5
Herb height		0.5
Salix alba	4	40
Salix alba	2	20

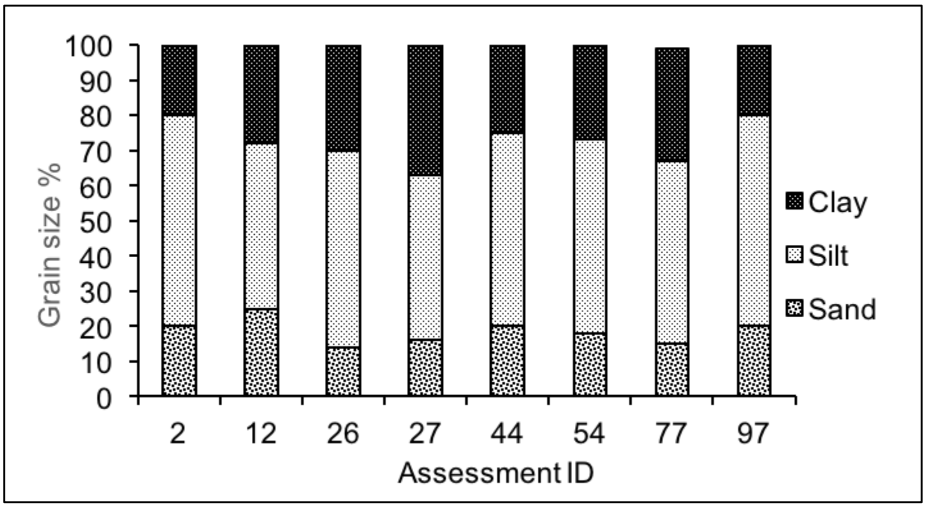


Figure 40 Grain size distribution at assessment sites

Changes of physical habitat parameters 1970 to 2010

Table 23 shows the change of depth to groundwater from 1970 to 2010 as percentages of the area in depth to groundwater classes. In 1970 0.04% of the fresh willow woodland have a depth to groundwater of 3.5 m – 4 m. 2010 it is 11.66%. This shift towards higher depths is illustrated in Fig. 41.

Table 23 Percentages of area of fresh willow woodland in depth to groundwater classes

		Depth to groundwater [m]										
Year	**s.**	**< 0.5**	**0.5 - 1**	**1 - 1.5**	**1.5 - 2**	**2 - 2.5**	**2.5 - 3**	**3 - 3.5**	**3.5 - 4**	**4 - 4.5**	**4.5 - 5**	**> 5**
1970	0.00	0.00	0.27	14.26	26.67	22.49	28.93	7.33	0.04	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.66	20.41	26.02	21.96	18.70	11.66	0.58	0.00	0.00

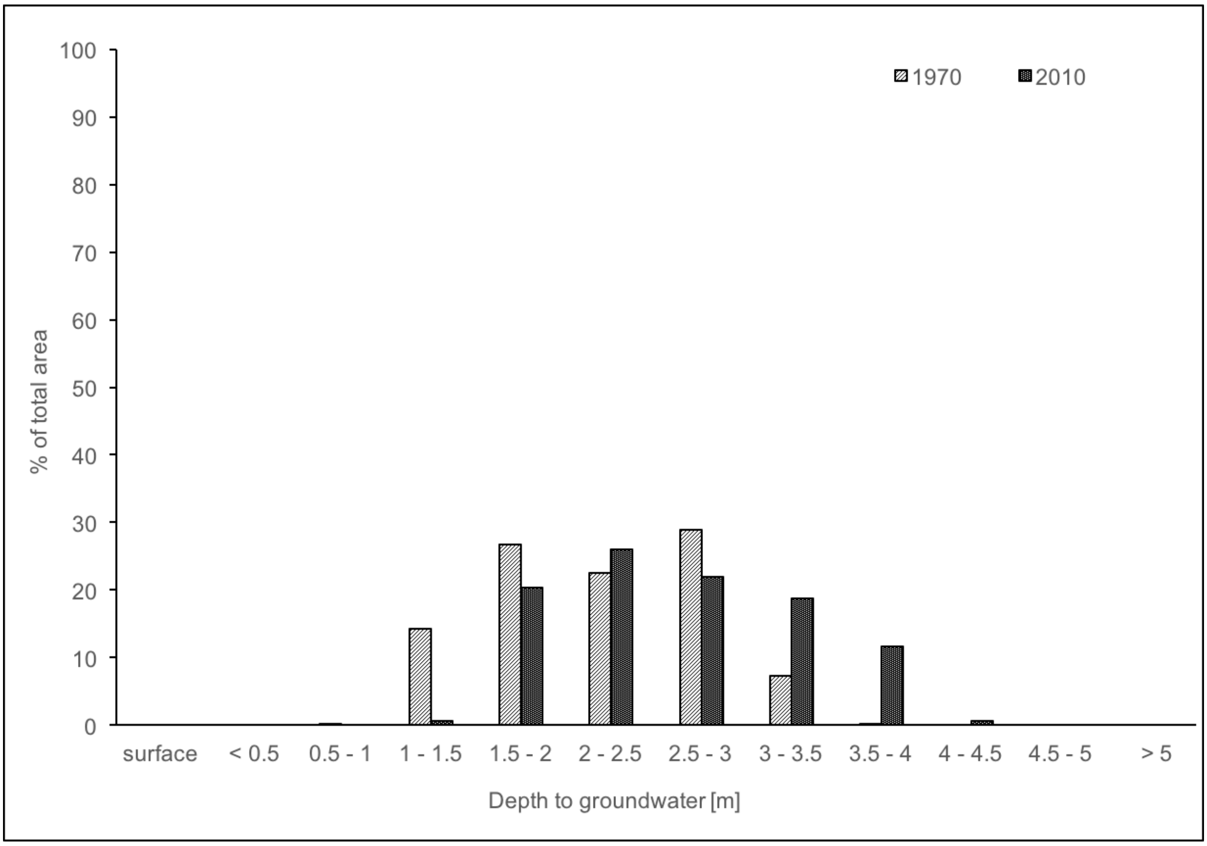
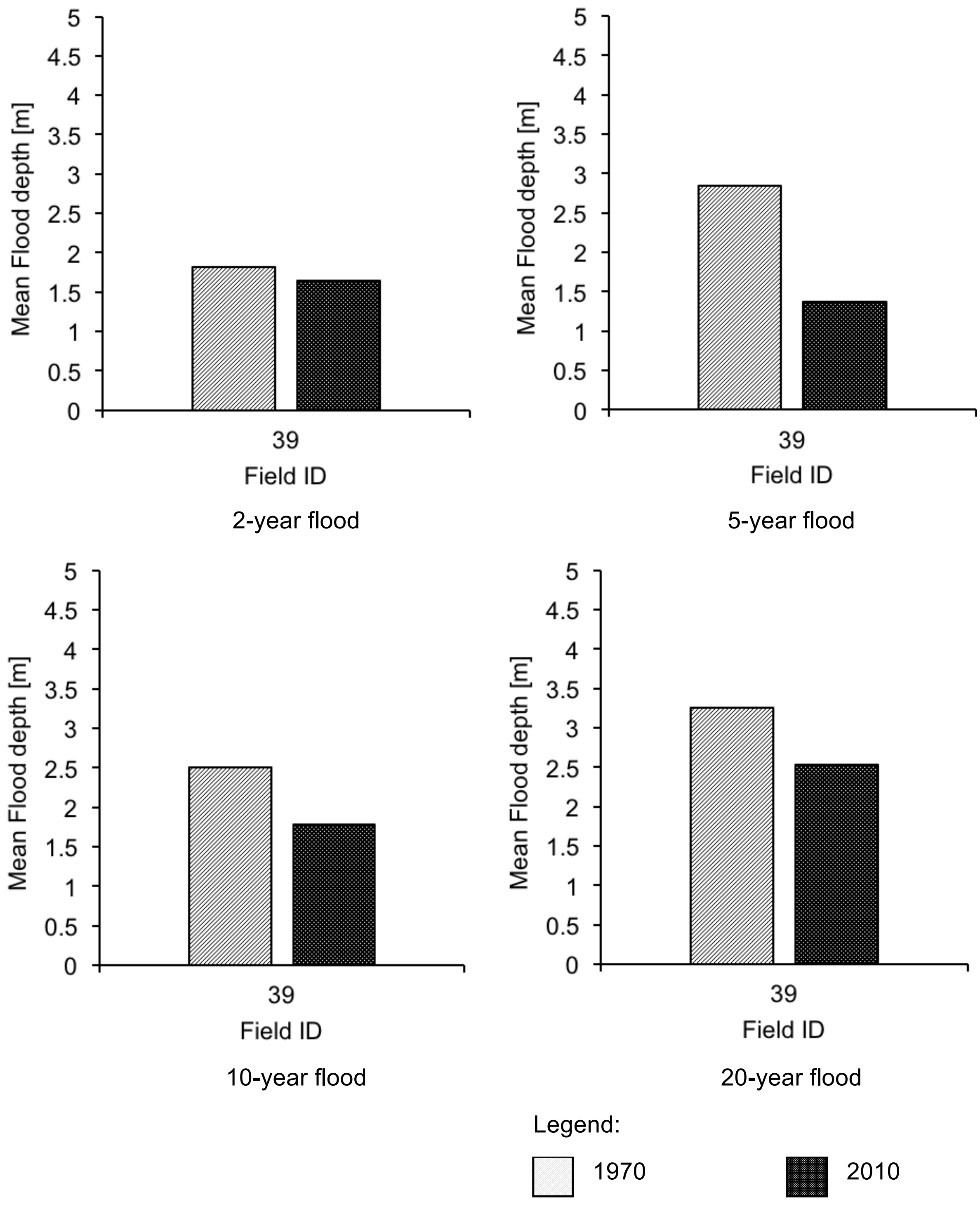


Figure 41 Shares of depth to groundwater classes of area of fresh willow woodland



2-year flood

5-year flood

10-year flood

20-year flood

Figure 42 Mean depth of fresh willow woodland polygons of the study site (Field IDs)

5.2.3 Dry poplar woodland

Topography and soil

There is only one dry poplar woodland site. It is located on a ridge by the bend of the cut-off meander. In the mapping of 1975 the site is classified as black poplar woodland, but due to the topsoil layer of ~10 cm it is classified as dry poplar woodland in 2015. The grain size shares are: 55% sand, 35% silt and 10% clay, which corresponds to the soil texture class of *Sandy loam*. The soil is moderately moist (Table 24)

Vegetation

The tree layer features *Populus nigra*, *P. canescens* and *Quercus robur*, *Crategus monogyna* and *Rubus caesius* are found in the shrub layer (Table 25).

Classification of PNV type

The f*resh willow woodland* site is classified as European natural habitat type *91E0 *Alluvial forests with Alnus glutinosa and Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae)*. The plant association corresponding to the PNV type is *Fraxino-Populetum Jurko 1958*. It is considered as softwood forest.

Groundwater

The mean depth to groundwater is 3.54 m. The standard deviation is 0.33 m (Table 17).

Floods

The dry poplar woodland site is flooded during a 5-year flood event with a water column of ~0.5 m (Fig.43).

Table 24 Soil assessment dry poplar woodland

Assessment N°	96
Sand %	55
Silt %	35
Clay %	10
Topsoil [cm]	10
Soil moisture	mm

Table 25 Vegetation assessment dry poplar woodland

		96
Tree Cover	4	70
Tree 2 Cover	3	50
Shrub cover	2	20
Herb cover	1	30
Tree Height		25
Tree 2 Height		20
Shrub Height		5
Herb Height		0.5
Cornus sanguinea	2	5
Corylus avellana	2	10
Crataegus monogyna	2	10
Populus canescens	4	70
Populus nigra	4	30
Quercus robur	4	20
Rubus caesius	1	30

Changes of physical habitat parameters

Figure 42 illustrates the shift towards higher depths to groundwater on dry poplar woodland sites.

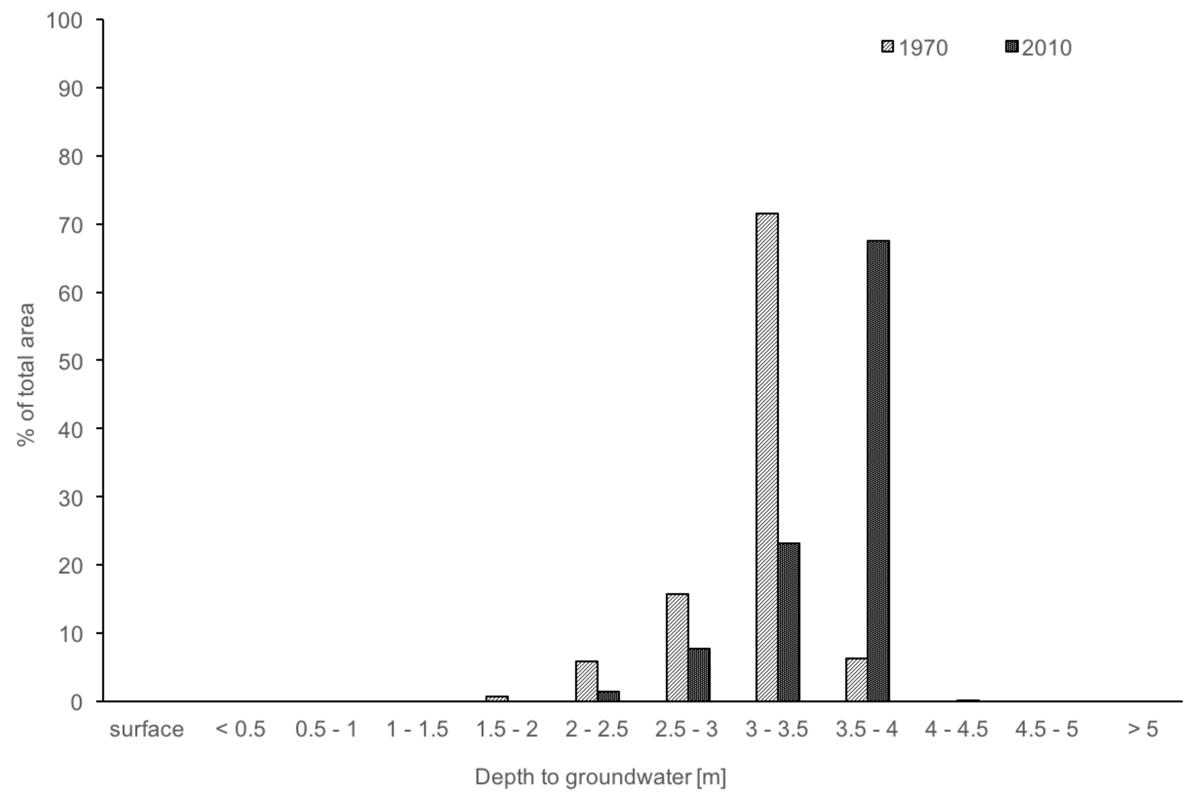


Figure 43 Shares of depth to groundwater classes of area of wet willow woodland

The area balance comparing the flood depths of dry poplar woodland in 1970 and 2010 is presented in Fig. 43. It shows that the site of dry poplar woodland was likely to be flooded during 2-year floods in 1970.

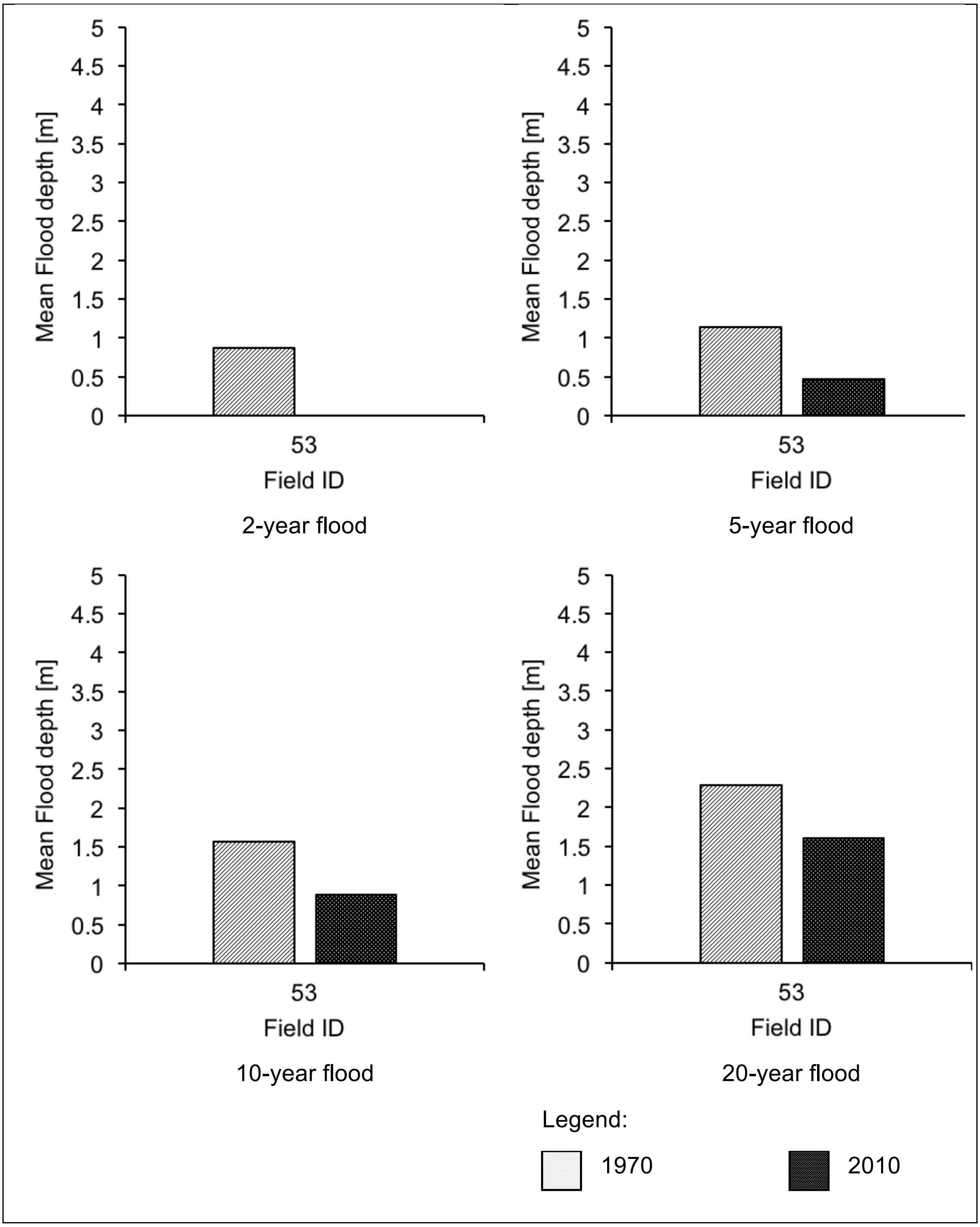


Figure 44 Mean depth of dry poplar woodland polygons of the study site (Field IDs)

5.2.4 Wet poplar woodland

Topography and soil

Wet poplar woodland succeeds wet willow woodland and is also located in depressions of the floodplain relief, which constitute former side arms or flood pools. The grain size shares estimated at the study site are presented in Table 26 and visualized in Fig. 44. All sites have more than 15% silt. The soil is moist or moist-wet.

Vegetation

The vegetation features *Populus canescens*, *Rubus caesius*, *Phragmites australis* and *Cornus sanguina* with high coverages (Table 27).

Classification of PNV type

The *wet poplar woodland* site is classified as European natural habitat type *91E0 *Alluvial forests with Alnus glutinosa and Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae)*. The plant association corresponding to the PNV type is *Fraxino-Populetum Jurko 1958*. It is also referred to as softwood forest.

Groundwater

The mean depth to groundwater at SMW is 2.81 m (Table 17).

Floods

The sites are flooded during 5-year floods by a water column of about 0.5m to 2 m (Fig. 45).

Table 26 Soil assessment wet poplar woodland

Assessment N°	3	7	11	21	23	42	49	56	98	99
Sand %	15	20	14	15	18	20	30	15	20	20
Silt %	60	60	56	60	52	55	55	55	60	50
Clay %	25	20	30	25	30	25	15	30	20	30
Topsoil [cm]	10	5	20	20	20	20	3	0	1	3
Soil moisture	m	m	m	m	m	mw	m	m	m	m

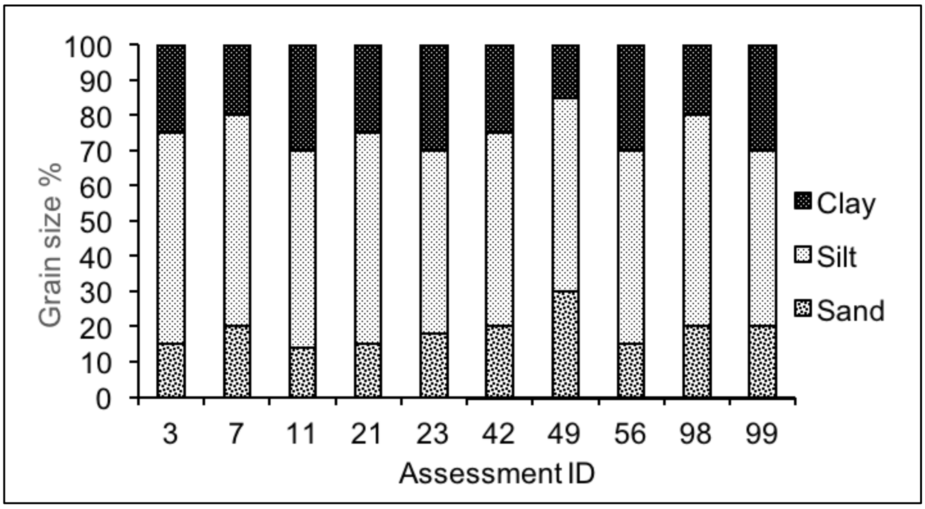


Figure 45 Soil texture of wet poplar woodland

Table 27 Vegetation assessment wet poplar woodland

Assessment N°		3	7	11	21	23	42	49	56	98	99
Tree Cover	4	70	60	60	25	62	20	40	60	10	90
Tree Height		25	20	23	23	23	18	27	27	23	23
Tree 2 Cover	3	0	10	0	0	30	20	30	0	0	0
Tree 2 Height		0	18	0	0	20	15	20	0	0	0
Shrub cover	2	10	10	15	0	10	30	50	0	15	20
Shrub Height		5	5	2	0	5	5	5	0	5	1
Herb cover	1	50	30	70	80	40	50	40	80	90	60
Herb Height		0.5	1	1	1	1	1	0.5	1	2	1
Alnus glutinosa	4	.	.	.	.	.	.	15	.	.	.
Carex sylvatica	1	.	5	.							.
Cornus sanguinea	2	.	5	10	.	10	15	40	.	10	.
Cornus sanguinea	1	.	.	.	.	.	.	.	.	.	10
Crataegus monogyna	2	.	5	.	.	.	15	.	.	10	.
Hedera helix	1	.	.	.	.	.	.	10	.	.	.
Juglans regia	4	.	.	.	.	.	.	15	.	.	.
Phragmites australis	1	.	.	30	70	20	20	.	70	80	50
Poa trivialis	1	.	5	.	.	.	.	.	.	.	.
Populus alba	2	5	.	.	.	.	.	15	.	.	.
Populus alba	4	.	10	.	.	.	.	.	60	.	.
Populus canadensis	4	40	.	.	.	.	.	.	.	.	.
Populus canescens	4	40	5	10	.	30	.	.	.	.	90
Populus nigra	4	.	5	.	.	.	.	.	.	.	.
Quercus robur	4	.	.	10	.	.	.	.	.	.	.
Rubus caesius	1	.	20	10	10	20	20	30	10	.	.
Salix alba	4	20	.	40	25	60	.	.	.	10	.
Tilia codata	4	.	.	.	.	.	.	5	.	.	.
Ulmus laevis	3	.	50	.	.	2	10	10	.	.	.

Table 28 Wet poplar woodland

		Depth to groundwater [m]										
Year	**s.**	**< 0.5**	**0.5 - 1**	**1 - 1.5**	**1.5 - 2**	**2 - 2.5**	**2.5 - 3**	**3 - 3.5**	**3.5 - 4**	**4 - 4.5**	**4.5 - 5**	**> 5**
1997	0.00	0.00	0.05	6.89	20.27	19.48	36.99	15.71	0.61	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.30	11.25	19.93	22.22	39.54	6.53	0.23	0.00	0.00

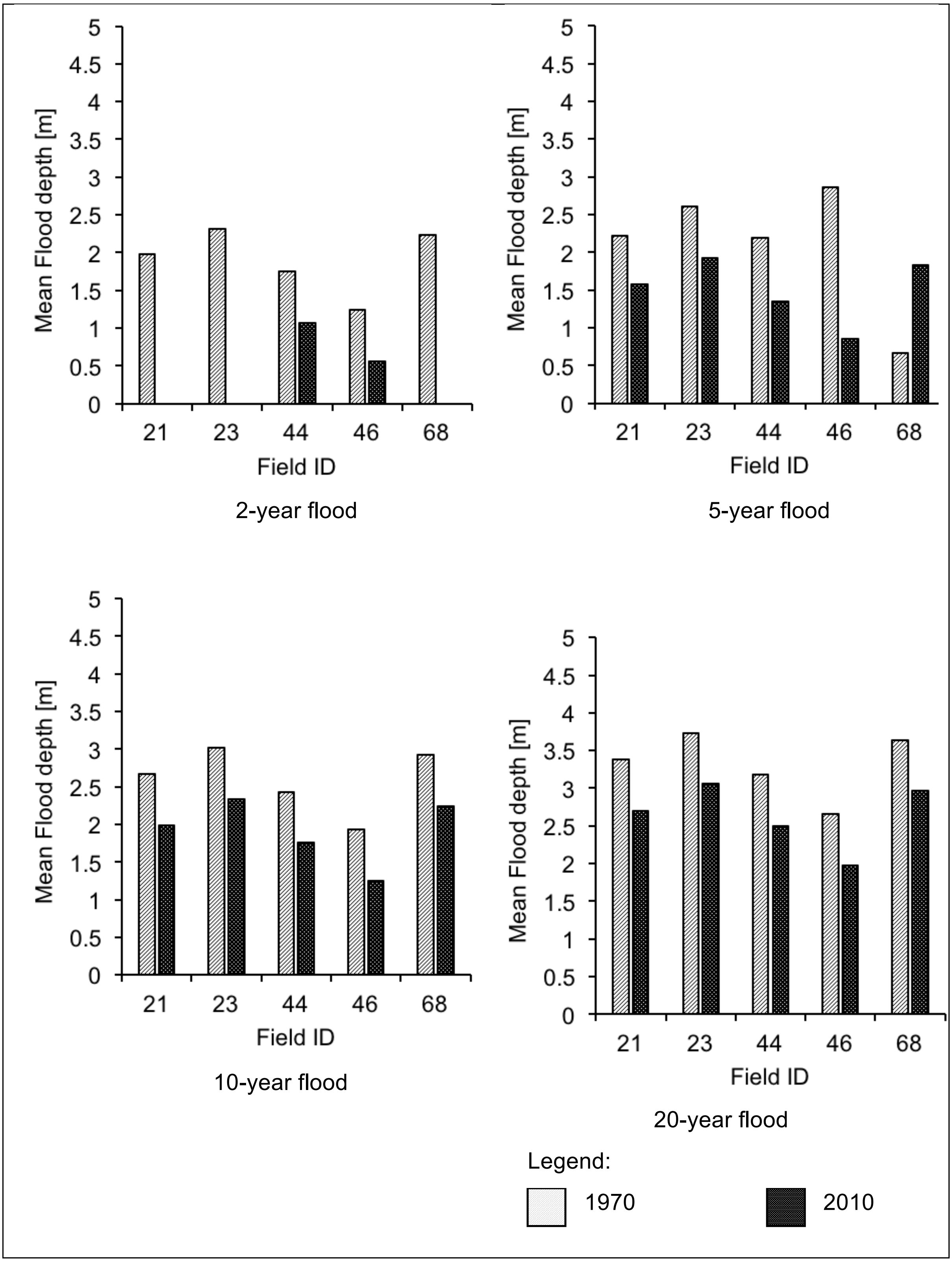


Figure 46 Mean flood depth wet poplar woodland

5.2.5 Fresh poplar woodland

Topography and soil

Fresh poplar woodland is located on the levee in the southwest of the study site. It features high shares of sand (45% and 60%) (Fig. 47). One assessment site features about 60 %, the other 45% (Tabe 29).

Vegetation

The vegetation features *Populus alba*, *P. nigra*, *P. canescens*, *Ulmus laevis* and *Sambucus nigra* (Fig. 31),

Classification of PNV type

The *fresh poplar woodland* site is classified as European natural habitat type *91E0 *Alluvial forests with Alnus glutinosa and Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae)*. The plant association corresponding to the PNV type is *Fraxino-Populetum Jurko 1958*. It is also referred to as softwood forest.

Groundwater

The mean depth to groundwater during the months of April to October is 3.89 m (Table 17).

Floods

Figure 48 illustrates that fresh willow woodland has relatively low flood depths. At the 20-year flood event the assessment sites have a water column of about 1.25 m

Table 29 Soil assessment fresh poplar woodland

Assessment N°	8	9
Sand %	45	60
Silt %	50	35
Clay %	5	5
Topsoil [cm]	5	5
Soil moisture	mm	mm

Table 30 Vegetation assessment fresh poplar woodland

Assessment N		8	9
Tree Cover	4	95	60
Tree Height		27	23
Tree 2 Cover	3	10	10
Tree 2 Height	20	18	.
Shrub cover	2	5	20
Shrub Height	2	5	.
Herb cover	1	20	20
Herb Height		0.5	0.5
Populus alba	4	90	50
Populus canescens	4	5	.
Ulmus laevis	3	5	10
Prunus padus	3	5	.
Cornus sanguinea	2	5	.
Populus nigra	4	.	5
Fraxinus excelsior	4	.	5
Sambucus nigra	2	.	5

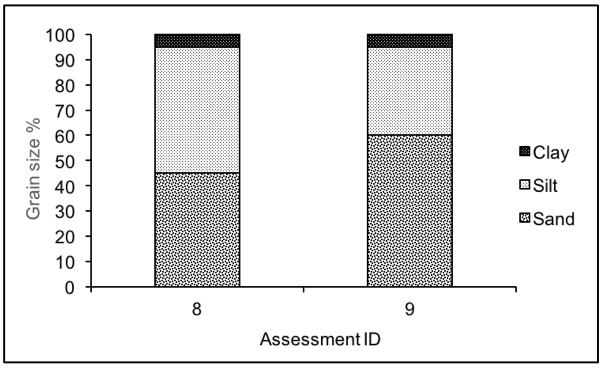


Figure 47 Soil texture fresh poplar woodland

Change of physical habitat parameters from1970 to 2010

Fig. 47 shows the change of depth to groundwater. The shares of the depth classes are stated in Table 30. Flood inundation depths are presented in Fig. 48.

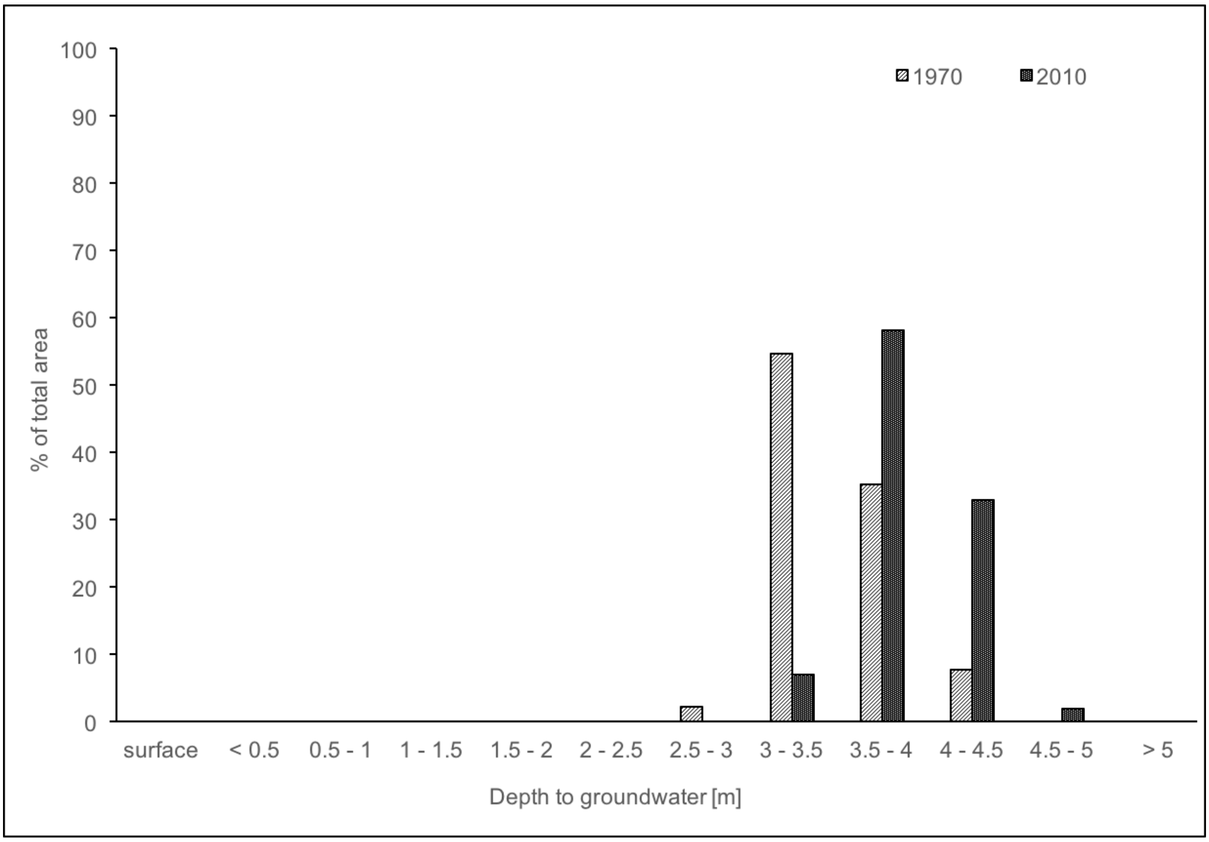
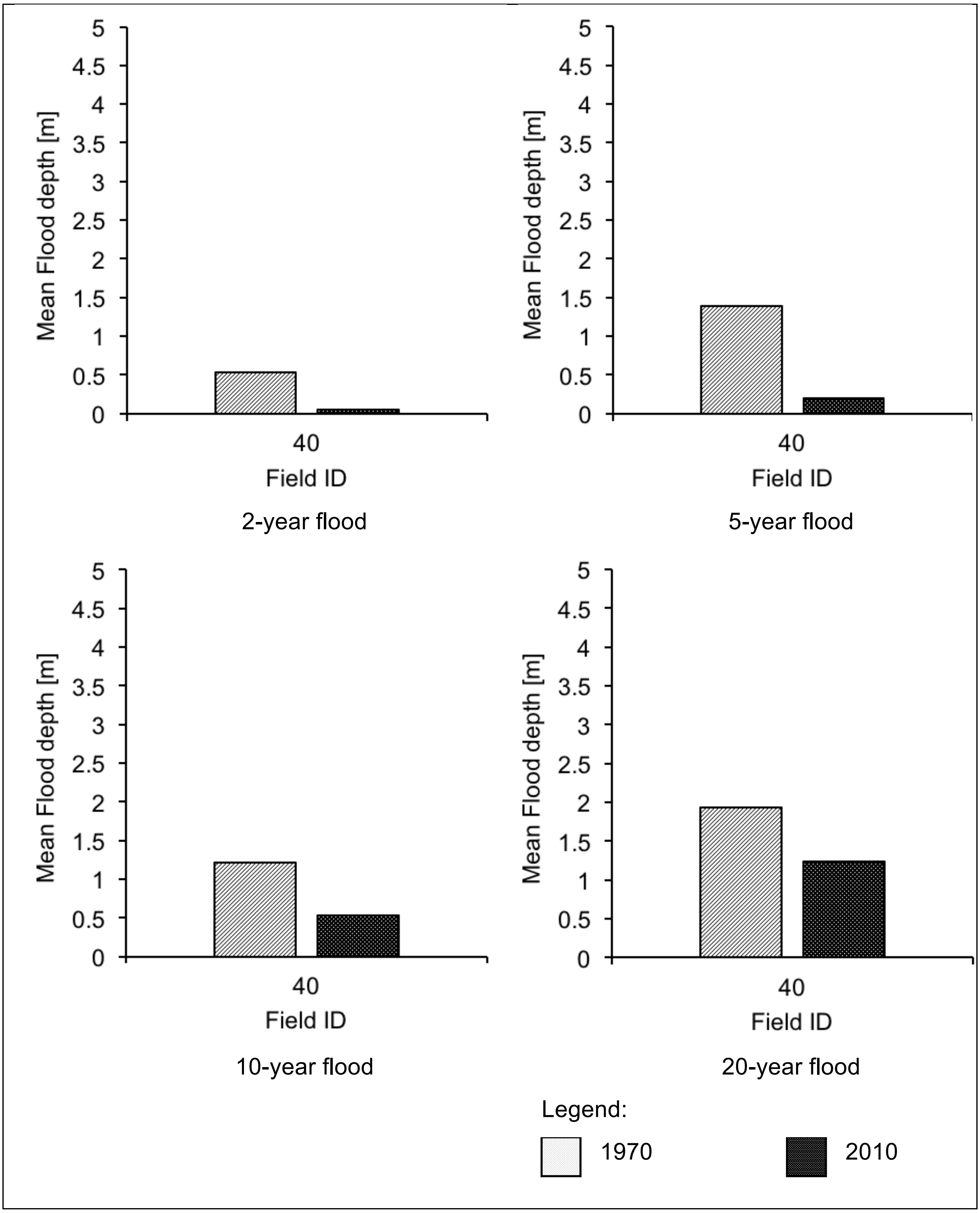


Figure 48 Fresh poplar woodland

Table 31 Fresh poplar woodland

Year	s.	< 0.5	0.5 - 1	1 - 1.5	1.5 - 2	2 - 2.5	2.5 - 3	3 - 3.5	3.5 - 4	4 - 4.5	4.5 - 5	> 5
		Depth to groundwater [m]										
1997	0.00	0.00	0.00	0.00	0.00	0.00	2.28	54.63	35.31	7.77	0.00	0.00
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.97	58.17	32.94	1.92	0.00



2-year flood

5-year flood

10-year flood

20-year flood

Figure 49 Fresh poplar woodland

5.2.6 Wet elm-oak forest

Topography and soil

This PNV type is located in depressions of the terrain. The soil has high shares of silt and is moist-wet to moist (Table 32, Table 33).

Vegetation

Ulmus laevis, Populus alba, Populus canescens, Cornus sangunia and Rubus caesis are frequently present in this PNV type (Table 34, Table 35).

Classification of PNV type

The habitats directive type is ‘91F0 Riparian mixed forests of *Quercus robur*, *Ulmus laevis* and *Ulmus minor*, *Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*)’. The plant association is *Querco-Ulmetum Issler 1926.*It is further classified as hardwood forest.

Groundwater

The mean depth to groundwater is 2.67 m (Table 17).

Table 32 Soil assessment of wet elm-oak forest part 1

	13	25	29	34	37	41	43	48	57
Sand	20	30	20	15	15	10	10	25	10
Silt	60	55	60	70	60	70	70	60	65
Clay	20	15	20	15	25	20	20	15	25
Topsoil [cm]	20	20	20	20	20	20	20	20	20
Soil moisture	mm	mm	mm	m	mm	m	mw	m	m

Table 33 Soil assessment of wet elm-oak forest part 2

	58	69	78	80	82	92	93	101	102
Sand	15	5	18	15	20	15	15	18	15
Silt	75	80	60	70	65	70	70	70	70
Clay	10	15	22	15	15	15	15	12	15
Topsoil [cm]	20	20	20	20	20	20	20	20	20
Soil moisture	m	m	mm	mm	m	m	m	m	m

Table 34 Vegetation assessment wet elm-oak forest part 1

Assessment N°		13	25	29	34	37	41	43	48	57
Tree Cover	4	95	50	75	80	80	80	60	20	90
Tree 2 Cover	3	0	0	0	0	0	30	30	40	10
Shrub cover	2	10	30	40	40	25	20	40	10	10
Herb cover	1	10	60	20	30	30	30	60	80	10
Tree Height		23	23	25	20	20	24	23	25	25
Tree 2 Height		0	0	0	0	0	20	18	20	20
Shrub Height		4	5	5	2	5	5	5	5	5
Herb Height		0.5	0.5	0.5	0.5	0.5	0.5	1	1	0.4
Aegopodium podagraria	1	2	.	.	.	.	.	.	.	.
Alnus glutinosa	4	.	.	.	.	.	.	.	.	.
Carpinus betulus	3	.	.	.	.	.	.	.	.	.
Clematis vitalba	2	.	.	.	.	5	.	.	.	.
Cornus sanguinea	2	5	10	20	40	.	.	10	10	.
Corylus avellana	2	5	20	20		20	15	.	.	10
Crataegus monogyna	2	.	.	.	.	.	5	30	.	.
Fagus sylvatica	4	.	.	.	.	35	.	5	.	.
Hedera helix	1	2	.	.	.	.	.	.	.	.
Juglans regia	4	.	.	.	.	35	.	5	.	.
Populus alba	4	95	.	.	.	.	.	.	45	80
Populus canadensis	4	.	.	.	.	.	.	.	.	.
Populus canescens	4	.	10	60	40	.	90	.	.	.
Populus nigra	4	.	.	.	.	.	.	.	.	.
Quercus robur	4	.	.	.	30	.	.	.	.	10
Rubus caesius	1	2	20	20		20	.	.	40	
Salix alba	4	.	20	.	10	.	.	.	.	.
Sorbus aucuparia	2	.	.	.	.	5	.	.	.	.
Tilia codata	4	.	.	.	.	.	.	.	5	.
Ulmus laevis	3	.	10	15	.	.	.	50	15	10
Ulmus minor	3	.	10	.	.	.	.	.	.	.

Table 35 Vegetation assessment wet elm-oak forest part 2

Assessment N°		58	69	78	80	82	92	93	101	102
Tree Cover	4	80	80	75	70	40	80	70	10	10
Tree 2 Cover	3	25	20	23	21	20	24	26	24	24
Shrub cover	2	0	30	10	10	20	20	20	90	80
Herb cover	1	0	15	16	15	12	18	20	20	20
Tree Height		40	40	15	60	40	30	30	20	10
Tree 2 Height		4	5	5	20	5	5	5	2	1
Shrub Height		30	60	40	40	60	30	30	70	20
Herb Height		1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Aegopodium podagraria	1	.	.	.	.	.	.	.	.	.
Alnus glutinosa	4	20	15	.	.	.	.	.	.	.
Carpinus betulus	3	.	.	.	5	.	.	.	.	.
Clematis vitalba	2	5	5	.		15	.	.	.	.
Cornus sanguinea	2	.	20	2	40	5	15	30	20	10
Corylus avellana	2	20	.	10	.	.	.	.	.	.
Crataegus monogyna	2	15	20	3		20	15	.	.	.
Fagus sylvatica	4	.	15	25	20	20	.	.	.	.
Hedera helix	1	.	.	.	.	.	.	.	.	.
Juglans regia	4	.	20	25	20	40	.	.	.	.
Populus alba	4	.	.	.	.	.	.	.	.	.
Populus canadensis	4	.	.	.	.	.			90	10
Populus canescens	4	.	20	.	.	.	24	30	10	80
Populus nigra	4	.	.	.	.	.	.	.	.	.
Quercus robur	4	60	30	20	.	.	.	20	.	.
Rubus caesius	1	.	.	.	.	.	.	.	.	.
Salix alba	4	20	40	20	20	.	15	20	70	.
Sorbus aucuparia	2	.	.	.	.	.	.	.	.	.
Tilia codata	4	.	.	.	.	.	.	20	.	.
Ulmus laevis	3	.	.	.	.	.	.	.	.	.
Ulmus minor	3	.	.	5	10	.	.	.	.	.

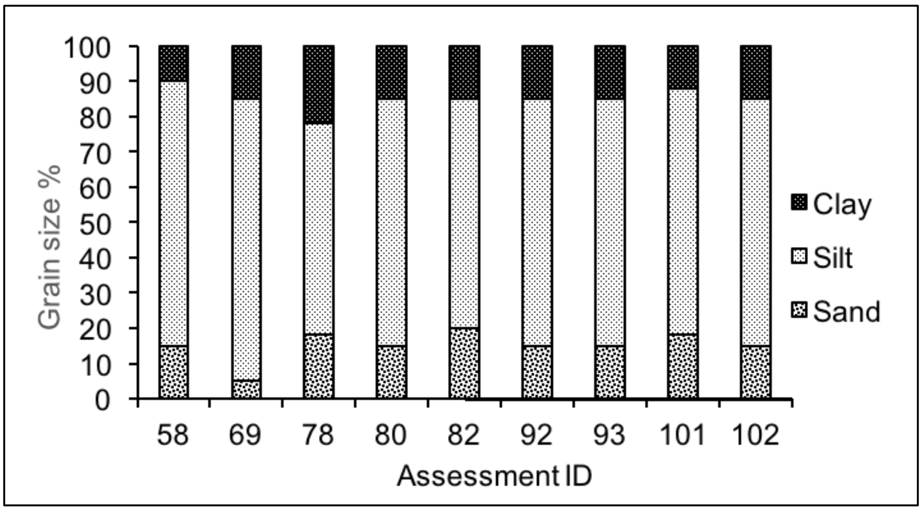


Figure 50 Soil assessment wet elm-oak forest part 1

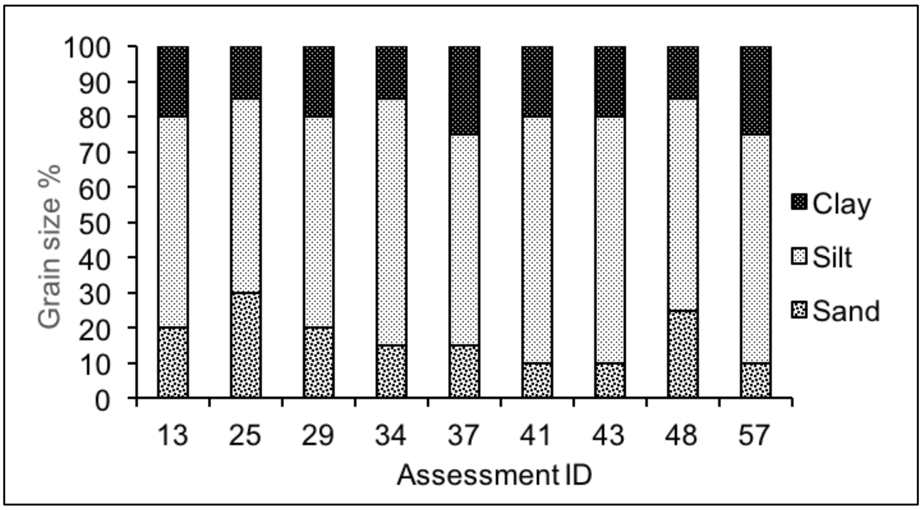


Figure 51 Soil assessment wet elm-oak forest part 1

Changes of physical habitat parameters 1970 to 2010

Changes are illustrated in Fig. 51 (groundwater) and Fig. 52 (floods). The fractions of depth to groundwater classes are states in Table 34.

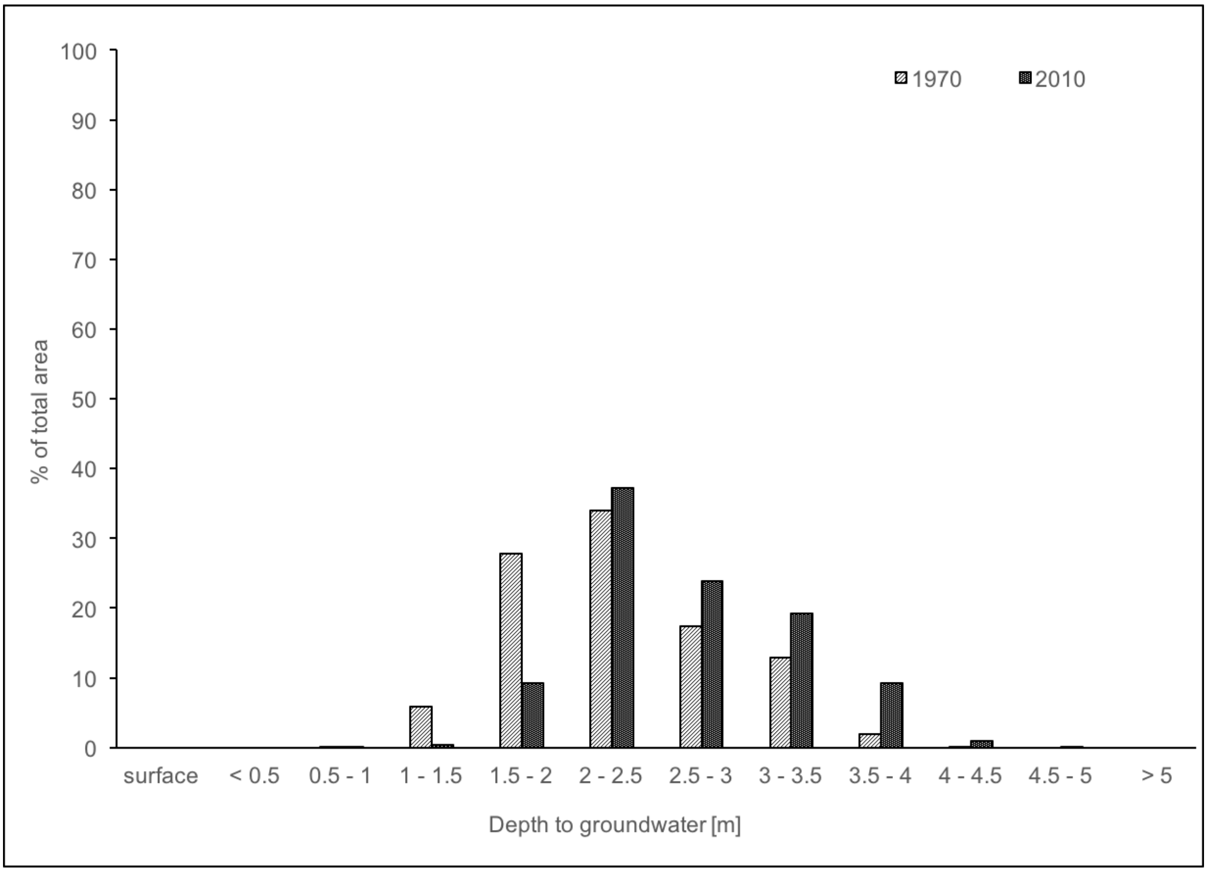


Figure 52 Wet elm-oak forest

Table 36 Wet elm-oak forest

						Depth to groundwater [m]						
Year	**s.**	**< 0.5**	**0.5 - 1**	**1 - 1.5**	**1.5 - 2**	**2 - 2.5**	**2.5 - 3**	**3 - 3.5**	**3.5 - 4**	**4 - 4.5**	**4.5 - 5**	**> 5**
1997	0.00	0.00	0.10	5.86	27.82	33.96	17.34	12.91	1.91	0.10	0.00	0.00
2010	0.00	0.00	0.00	0.33	9.19	37.24	23.84	19.14	9.28	0.96	0.01	0.00

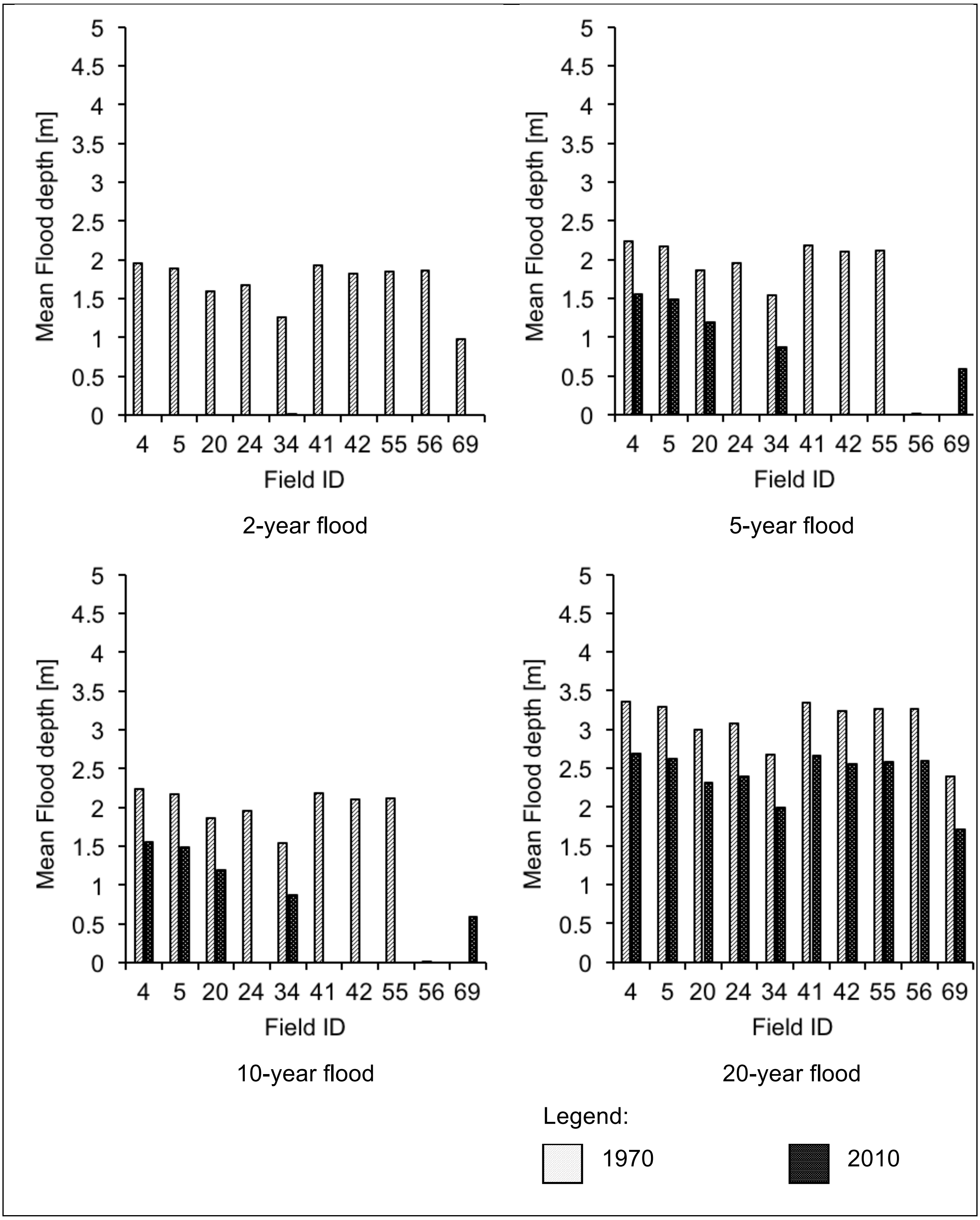


Figure 53 Mean depth wet elm-oak forest

5.2.7 Fresh elm-oak forest

Topography and soil

Fresh elm-oak forest occurs on ridges, terraces and alluvial flats. Soil characteristics of the assessment sites are stated in Table 37 and Table 38 and visualized in Fig. 53 and Fig 54.

Vegetation

Corylus avellana, *Populus alba* and *Populus canescens* as well as Quercus roburs are frequently occurring (Table 39, Table 40).

Classification of PNV type

The habitats directive type is ‘91F0 Riparian mixed forests of *Quercus robur*, *Ulmus laevis* and *Ulmus minor*, *Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*)’. The plant association is *Querco-Ulmetum Issler 1926.*It is further classified as hardwood forest.

Groundwater

The mean depth to groundwater is 3.25m (Table 17).

Table 37 Soil assessment of fresh elm-oak forest part 1

	5	19	20	22	31	46	84	5	19
Sand	30	35	30	40	30	20	30	30	35
Silt	50	50	45	40	50	60	45	50	50
Clay	20	15	25	20	20	20	25	20	15
Topsoil [cm]	20	20	20	20	20	20	20	20	20
Soil moisture	mm	mm	mm	m	mm	m	mw	m	m

Table 38 Soil assessment of fresh elm-oak forest part 2

	85	86	88	89	100	103	85	86
Sand	25	25	20	25	40	30	25	25
Silt	50	55	60	50	50	55	50	55
Clay	25	20	20	25	10	15	25	20
Topsoil [cm]	20	20	20	20	20	20	20	20
Soil moisture	m	m	mm	mm	m	m	m	m

Table 39 Vegetation assessment fresh elm-oak forest part 1

		5	19	20	22	31	46	84
Tree Cover	4	70	70	70	60	60	80	90
Tree 2 Cover	3	30	0	0	0	60	0	0
Shrub cover	2	10	20	10	30	20	15	10
Herb cover	1	10	15	12	30	10	30	10
Tree Height		23	25	23	20	25	26	17
Tree 2 Height		18	0	0	0	18	0	0
Shrub Height		5	5	5	5	5	4	1
Herb Height		0.5	0.4	0.4	0.4	0.5	0.5	0.5
Acer campestre	4	10	.	.	30	.	.	.
Acer pseudoplatanus	4	10	.	.	.	.	.	.
Aegopodium podagraria	1	.	20	.	.	.	.	.
Betula pendula	4	10	.	.	.	10	.	5
Carpinus betulus	4	.	.	.	.	10	.	.
Carpinus betulus	3	.	.	.	.	.	.	43
Clematis vitalba	2	.	.	.	.	.	5	8
Cornus sanguinea	2	5	50	.	.	10	10	2
Corylus avellana	2	5	50	60	10	10	10	.
Crataegus monogyna	2	.	.	20	.	.	.	.
Fagus sylvatica	4	.	.	.	.	.	5	.
Fraxinus excelsior	4	20	.	.	.	.	.	.
Juglans regia	4	.	.	.	.	.	15	.
Populus alba	4	.	.	.	.	.	65	.
Populus canadensis	4	.	.	.	.	.	.	.
Populus canescens	4	.	.	70	.	40	.	.
Populus nigra	4	.	.	.	.	.	.	.
Prunus avium	3	.	.	.	.	15	.	.
Prunus padus	4	.	.	.	30	.	.	.
Quercus robur	4	20	.	.	.	10	.	42
Rubus caesius	1	.	.	.	.	10	.	.
Salix alba	4	.	.	.	5	5	.	.
Sorbus aucuparia	2	.	.	.	.	10	.	.
Ulmus laevis	3	.	.	.	.	20	.	.
Ulmus minor	3	.	.	20	.	.	.	.

Table 40 Vegetation assessment fresh elm-oak forest part 2

		85	86	88	89	100	103
Tree Cover	4	85	60	95	70	60	90
Tree 2 Cover	3	10	0	0	0	40	0
Shrub cover	2	10	60	15	70	50	40
Herb cover	1	30	20	20	20	50	10
Tree Height		24	23	22	23	23	19
Tree 2 Height		9	0	0	0	19	0
Shrub Height		5	5	5	5	5	5
Herb Height		0.5	0.5	0.5	0.5	0.5	0.5
Acer campestre	4	.	.	.	.	.	.
Acer pseudoplatanus	4	.	.	.	.	.	.
Aegopodium podagraria	1	.	.	.	.	.	.
Betula pendula	4	.	.	.	10	20	5
Carpinus betulus	4	.	.	.	.	.	40
Carpinus betulus	3	.	.	.	.	.	.
Clematis vitalba	2	.	.	2	.	.	.
Cornus sanguinea	2	2	.	.	10	40	10
Corylus avellana	2	.	50	5	40	10	.
Crataegus monogyna	2	8	10	5	20	.	.
Fagus sylvatica	4	5	.	3	.	.	.
Fraxinus excelsior	4	.	.	.	.	.	.
Juglans regia	4	.	.	20	.	.	.
Populus alba	4	.	.	.	.	.	.
Populus canadensis	4	.	.	.	.	20	.
Populus canescens	4	40	30	.	40	60	.
Populus nigra	4	.	.	.	.	.	.
Prunus avium	4	5	.	.	.	.	.
Prunus padus	3	.	.	.	.	.	.
Quercus robur	4	40	30	70	20	.	50
Rubus caesius	1	.	15	.	.	30	.
Salix alba	4	.	.	.	.	.	.
Sorbus aucuparia	2	.	.	.	.	.	.
Ulmus laevis	3	.	.	.	.	.	.
Ulmus minor	3	5	.	5	.	.	.

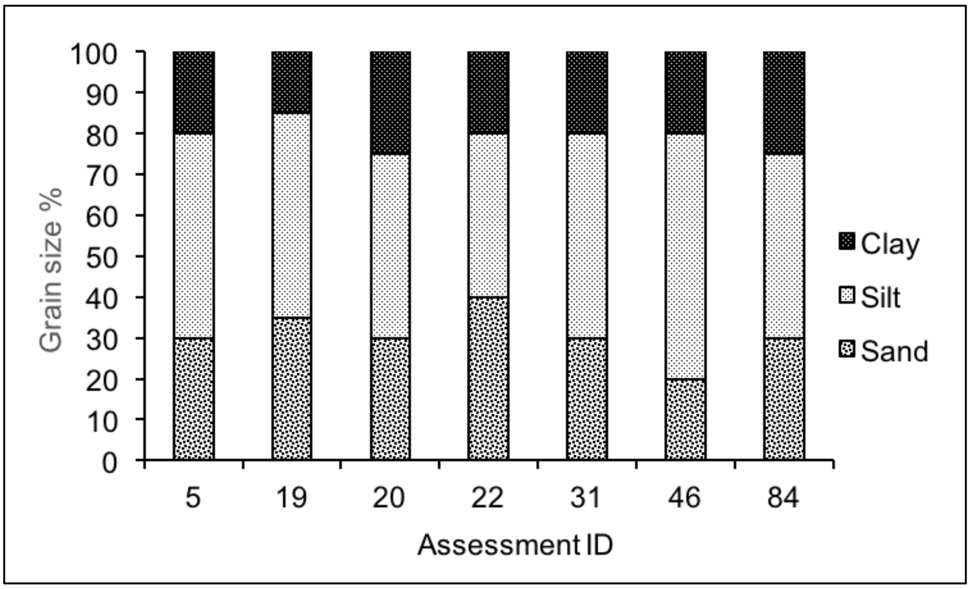


Figure 54 Fresh elm-oak forest soil part 1

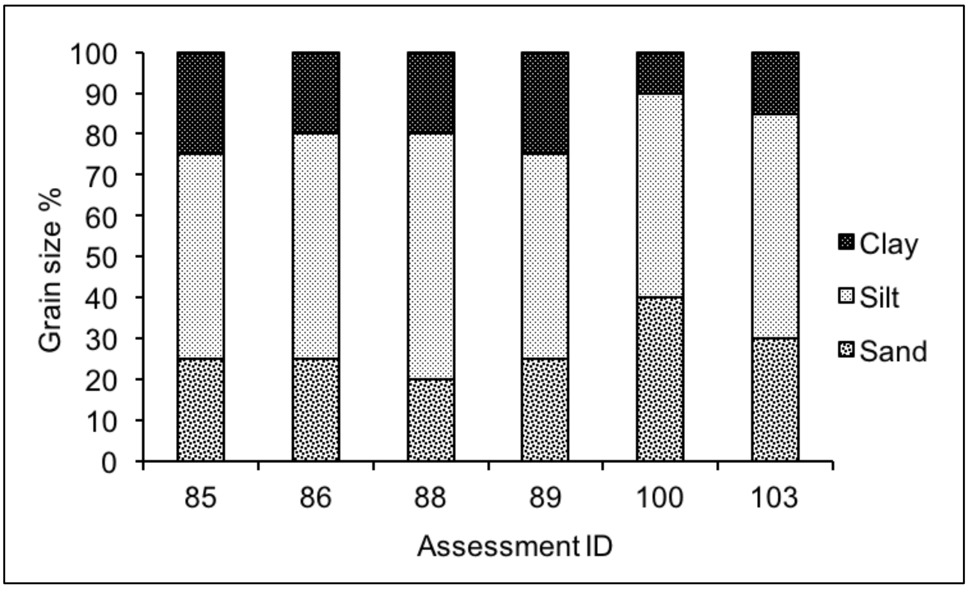


Figure 55 Fresh elm-oak soil part 2

Changes of physical habitat parameters 1970 to 2010

Changes of depth to groundwater are visualized in Fig. 55 and stated in Table 41.

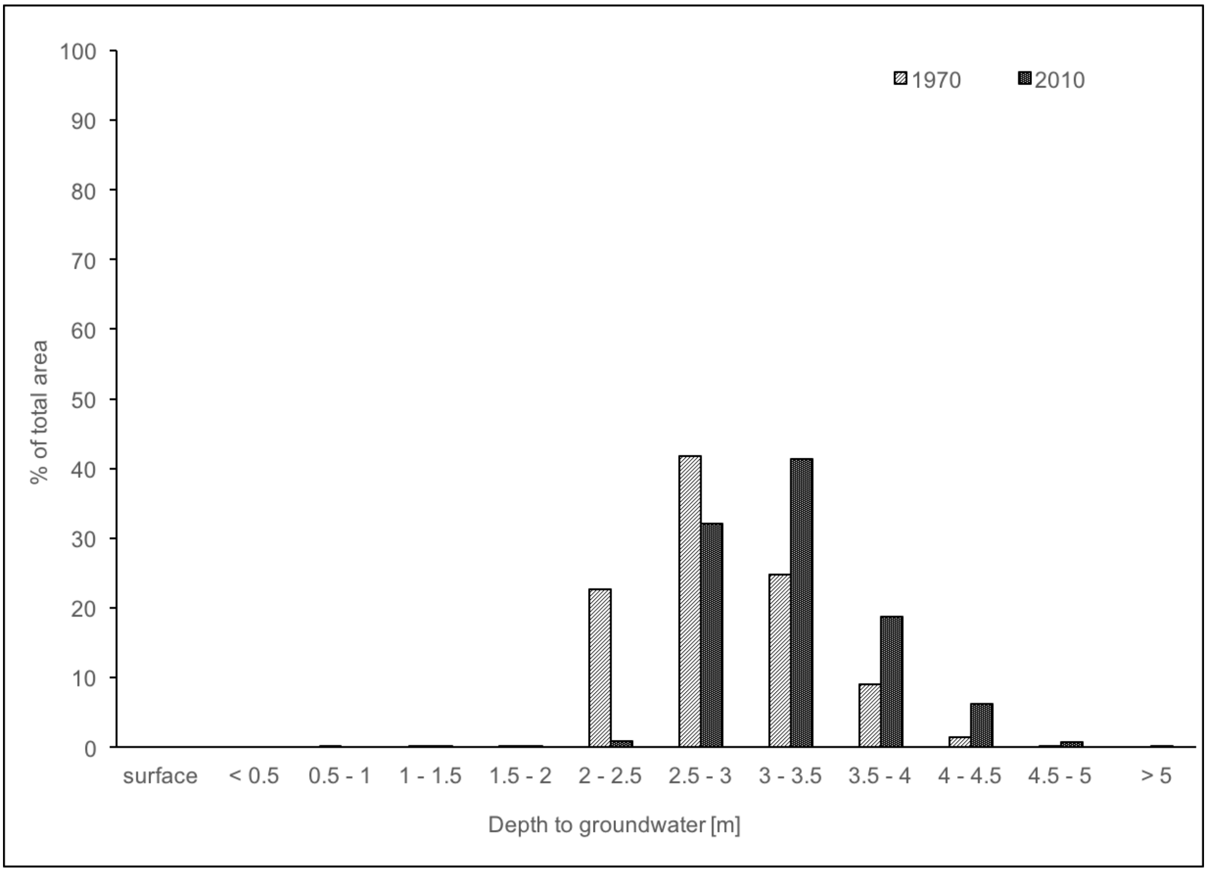


Figure 56 Fresh elm-oak forest

Table 41 Fresh elm-oak forest

Year	s.	Depth to groundwater [m]									
		< 0.5	0.5 - 1	1 - 1.5	1.5 - 2	2 - 2.5	2.5 - 3	3 - 3.5	3.5 - 4	4 - 4.5	4.5 - 5	> 5
1997	0.00	0.00	0.00	0.01	0.23	22.65	41.83	24.71	9.03	1.44	0.11	0.00
2010	0.00	0.00	0.00	0.00	0.02	0.84	32.05	41.37	18.73	6.17	0.78	0.03

5.2.9 Fresh elm-oak forest (hornbeam)

Topography and soil

Fresh elm-oak forest (hornbeam) is located on spots with high elevation, typically ridges. The topsoil is well developed and moist or moderately moist (Table 42).

Vegetation

The vegetation features for example Acer campestre, Quercus robur, Crategus monogyna (Table 42).

Classification of PNV type

The habitats directive type is ‘91F0 Riparian mixed forests of *Quercus robur*, *Ulmus laevis* and *Ulmus minor*, *Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*)’. The plant association is *Querco-Ulmetum Issler 1926.*It is further classified as hardwood forest.

Groundwater

The mean depth to groundwater is 3.37 m (Table 17).

Floods

This PNV type is flooded at a 10-year flood with almost 1.5 m (Fig.58).

Table 42 Soil assessment of fresh elm-oak forest (hornbeam)

	52	60	87	91
Sand	20	10	20	15
Silt	55	55	60	60
Clay	25	35	20	25
Topsoil [cm]	20	20	20	20
Soil moisture	mm	mm	mm	m

Table 43 Fresh elm-oak forest (hornbeam)

Assessment N°		52	60	87	87	91
Tree Cover	4	40	85	80	80	50
Tree 2 Cover	3	20	25	23	23	25
Shrub cover	2	0	0	0	0	20
Herb cover	1	0	0	0	0	19
Tree Height		70	20	20	20	70
Tree 2 Height		5	3	5	5	5
Shrub Height		20	20	20	20	30
Herb Height		0.5	0.5	0.5	0.5	0.5
Acer campestre	4	.	40	.	.	.
Ailanthus altissima	4	.	.	.	.	5
Carpinus betulus	4	.	.	5	.	.
Clematis vitalba	2	.	.	.	.	10
Cornus sanguinea	2	10	.	5	.	40
Corylus avellana	2	.	.	.	.	20
Crataegus monogyna	2	60	20	18	.	.
Fagus sylvatica	4	5	40	10	.	.
Juglans regia	4	.	.	5	.	15
Populus alba	4	.	.	.	.	30
Populus canescens	4	.	.	40	.	.
Populus nigra	4	.	.	.	.	20
Prunus avium	3	5	.	.	.	.
Quercus robur	4	20	25	10	.	.
Rubus caesius	2	.	20	.	.	20
Salix alba	4	5	.	.	.	.
Ulmus laevis	3	5	.	.	.	.
Ulmus minor	3	.	.	10	.	.

Changes of physical habitat parameters 1970 to 2010

Fig. 57 illustrates the change of depth to groundwater at the study site. Table 44 states the shares of depth to groundwater classes in 1970 and 2010. The flood depths are illustrated in Fig. 58.

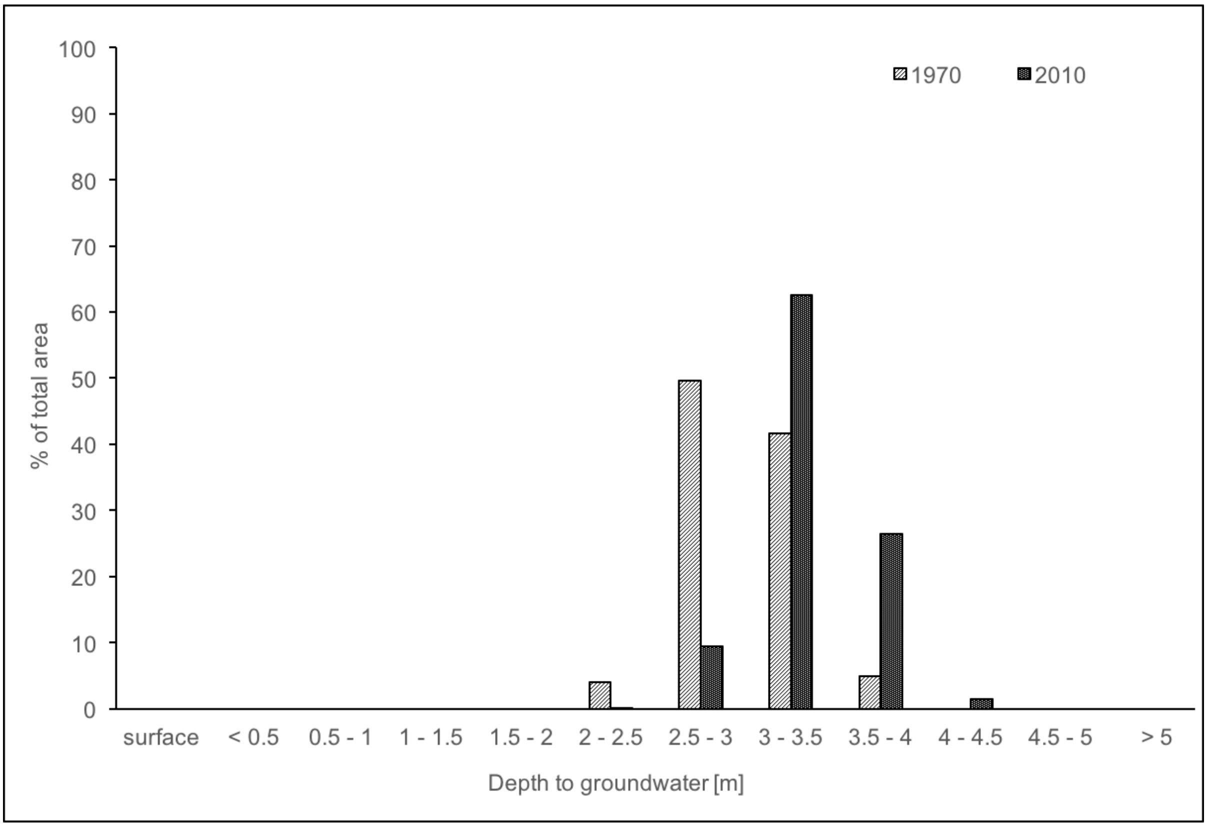
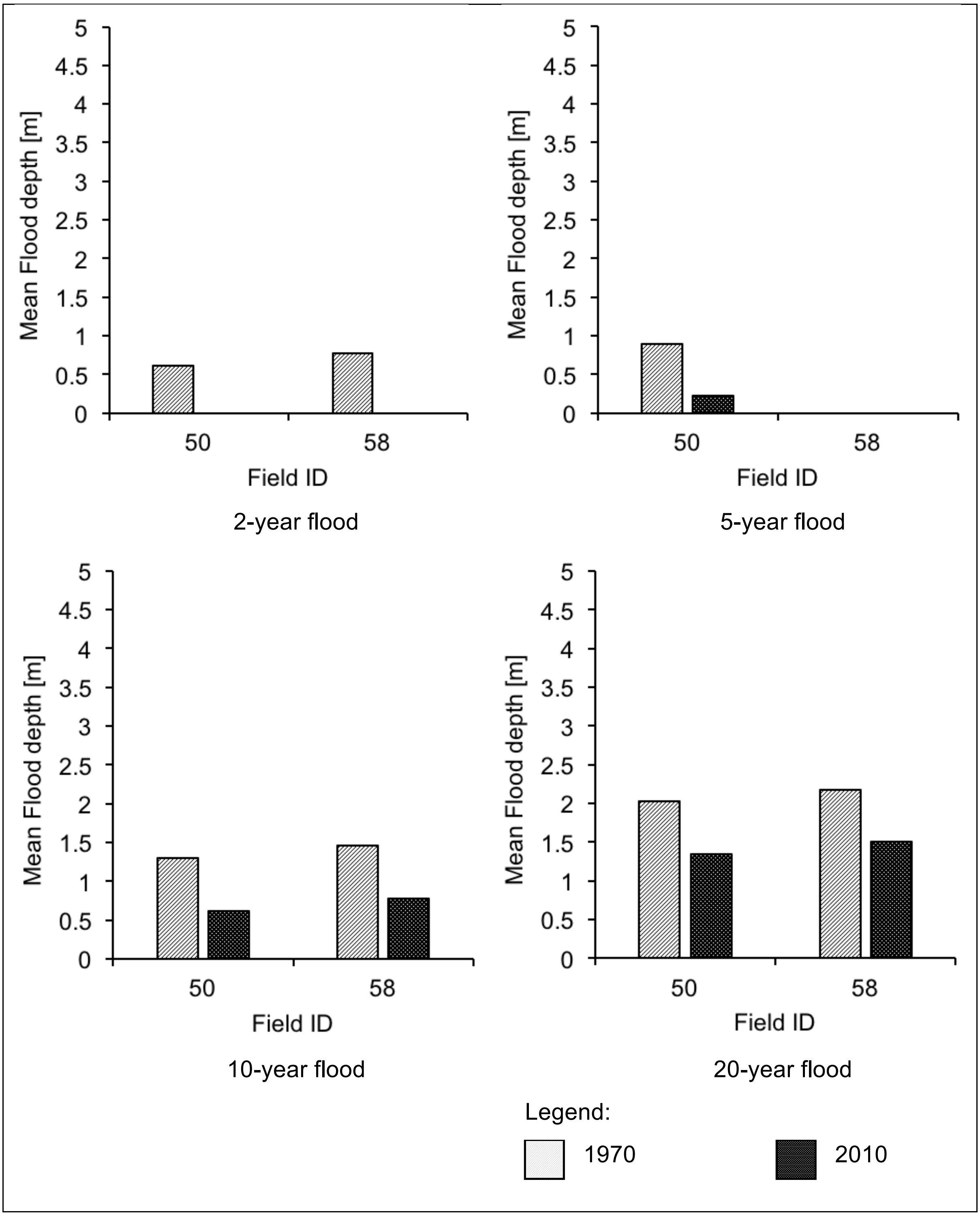


Figure 57 Fresh elm-oak forest (hornbeam)

Table 44 Fresh elm-oak forest (hornbeam)

						Depth to groundwater [m]						
Year	**s.**	**< 0.5**	**0.5 – 1**	**1 – 1.5**	**1.5 – 2**	**2 – 2.5**	**2.5 – 3**	**3 – 3.5**	**3.5 – 4**	**4 – 4.5**	**4.5 – 5**	**> 5**
1997	0.00	0.00	0.00	0.00	0.00	3.94	49.62	41.58	4.87	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.00	0.00	0.05	9.45	62.52	26.51	1.48	0.00	0.00



2-year flood

5-year flood

10-year flood

20-year flood

Figure 58 Food depth fresh-elm oak (hornbeam)

5.2.10 Fresh elm-oak forest (linden)

Topography and soil

Fresh elm-oak forest (linden) is located on the highest spots of the floodplain, usually on ridges. The soil features high shares of sand and is moderately moist or moist. The topsoil is well developed (Table 45, Table 46).

Vegetation

The tree layer occasionally features *Tilia cordata. Quercus robur, Fraxinus excelsior* and *Crategus monagyna* are occurring at many assessment sites with high coverages as stated in Table 45 and Table 46.

Classification of PNV type

The habitats directive type is '91F0 Riparian mixed forests of *Quercus robur*, *Ulmus laevis* and *Ulmus minor*, *Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*)'. The plant association is *Querco-Ulmetum Issler 1926.*It is further classified as hardwood forest.

Groundwater

With a mean of 3.96 m *Fresh elm-oak forest (linden)* has the highest depth to groundwater of all PNV types on the study site (Table 17).

Floods

Flooded during 10-year floods by less than half a meter (Fig 60).

Table 45 Soil assessment fresh elm-oak forest (linden) part 1

	1	10	14	24	30	35	38	39	40	45
Sand %	30	25	40	35	35	40	40	40	45	55
Silt %	60	60	50	45	50	50	45	45	45	35
Clay %	10	15	10	20	15	10	15	15	10	10
Topsoil [cm]	20	20	20	20	20	20	20	20	20	20
Soil moisture	mm	mm	mm	mm	mm	mm	m	m	m	mm

Table 46 Soil assessment fresh elm-oak forest (linden) part 2

	47	50	51	53	59	75	81	83	90	94	95
Sand %	30	45	40	45	45	50	40	50	50	45	40
Silt %	50	50	45	50	45	45	55	40	45	50	50
Clay %	20	5	15	5	10	15	15	10	5	5	10
Topsoil [cm]	20	20	20	20	20	20	20	20	20	20	20
Soil moisture	m	m	m	m	mm	m	mm	m	mm	m	mm

Table 47 Vegetation assessment fresh elm-oak forest (linden) part 1

Assessment N°		1	10	14	24	30	35	38	39	40	45
Tree Cover	4	70	60	80	80	75	75	70	80	75	50
Tree 2 Cover	3	15	15	23	23	25	23	27	27	27	27
Shrub cover	2	30	0	0	0	0	0	40	10	20	40
Herb cover		40	2	30	20	30	30	30	60	40	70
Tree Height		15	30	20	30	40	40	20	30	20	20
Tree 2 Height		1	10	0	0	0	0	0	20	17	17
Shrub Height		4	5	5	4	5	5	5	5	5	5
Herb Height		0.5	0.2	0.5	0.5	0.5	0.5	0.7	0.7	0.5	1
Acer campestre	4	.	.	4	.	.	.	30	30	5	.
Carpinus betulus	4	20	.	.	30	.	.	.	.	.	.
Clematis vitalba	2	3	.	.	.	.	.	.	.	.	.
Cornus sanguinea	2	5	15	.	5	5	20	.	10	5	.
Corylus avellana	2	.	.	4	25	30	20	.	20	10	.
Crataegus monogyna	2	5	15	.	.	.	.	20	.	10	10
Fagus sylvatica	4	.	.	.	.	.	.	.	.	.	20
Fraxinus excelsior	4	.	60	4	.	.	.	.	.	.	.
Hedera helix	2	.	.	.	.	.	.	.	.	.	.
Juglans regia	4	.	.	4	.	.	25	.	5	.	.
Ligustrum vulgare	2	5	.	.	.	5	.	.	.	.	.
Populus alba	4	.	.	4	.	.	.	30	.	50	40
Populus canescens	4	.	.	.	.	50	.	.	30	.	.
Populus nigra	4	.	.	.	.	.	.	.	.	.	.
Prunus avium	3	.	.	.	.	.	.	.	.	.	.
Quercus robur	4	70	.	.	50	10	25	30	10	20	.
Rubus caesius	1	.	.	.	20	.	20	.	.	.	50
Salix alba	4	.	.	.	.	.	25	.	.	.	.
Sorbus aucuparia	2	.	.	.	.	.	.	.	.	.	.
Tilia codata	4	.	.	.	.	.	.	.	.	.	10
Ulmus laevis	3	5	.	.	.	15	.	.	5	.	20
Ulmus minor	3	.	.	.	.	.	.	10	.	5	.

Table 48 Vegetation assessment fresh elm-oak forest (linden) part 2

Assessment N°		47	50	51	53	59	75	81	83	90	94	95
Tree Cover	4	40	50	10	25	90	20	30	90	70	40	20
Tree 2 Cover	3	20	20	23	70	25	20	16	17	25	25	26
Shrub cover	2	0	0	20	20	0	0	0	0	20	40	80
Herb cover		20	30	40	40	20	40	20	10	30	30	20
Tree Height		20	40	60	40	30	90	70	10	50	30	20
Tree 2 Height		20	0	0	20	40	0	0	0	0	20	20
Shrub Height		5	5	5	5	5	5	5	1	5	5	5
Herb Height		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Acer campestre	4	.	.	.	.	.	.	.	.	.	.	.
Carpinus betulus	4	.	.	.	.	.	.	.	45	.	.	.
Clematis vitalba	2	.	5	5	.	.	10	10	8	.	.	.
Cornus sanguinea	2	.	10	20	20	.	10	10	2	5	5	20
Corylus avellana	2	.	5	.	20	25	60	.	.	40	20	.
Crataegus monogyna	2	.	30	55	.	5	10	50	.	2	5	.
Fagus sylvatica	4	.	.	.	.	5	15	.	.	.	.	.
Fraxinus excelsior	4	.	.	.	.	.	.	.	.	.	.	.
Hedera helix	2	.	.	.	.	.	.	.	.	3	.	.
Juglans regia	4	.	15	.	.	.	5	25	.	20	10	.
Ligustrum vulgare	2	.	.	.	.	.	.	.	.	.	.	.
Populus alba	4	.	30	18	5	.	.	.	.	.	.	.
Populus canescens	4	.	.	.	.	.	.	.	.	70	40	20
Populus nigra	4	.	.	.	.	.	.	.	.	.	20	20
Prunus avium	3	.	5	2	.	.	.	.	.	.	.	.
Quercus robur	4	.	.	5	20	75	.	.	45	.	10	40
Rubus caesius	1	.	.	.	40	.	.	.	.	.	20	15
Salix alba	4	40	.	5	.	.	.	.	.	.	.	.
Sorbus aucuparia	2	.	.	.	.	.	.	.	.	.	.	.
Tilia codata	4	.	.	.	.	.	.	.	.	.	.	.
Ulmus laevis	3	.	.	.	20	10	.	.	.	.	.	.
Ulmus minor	3	.	.	.	.	.	.	5	.	.	.	20

Changes of physical habitat parameters 1970 to 2010

Fig. 59 illustrates the change of depth to groundwater from 1970 to 2010. The shares of the depth classes are stated in Table 29.

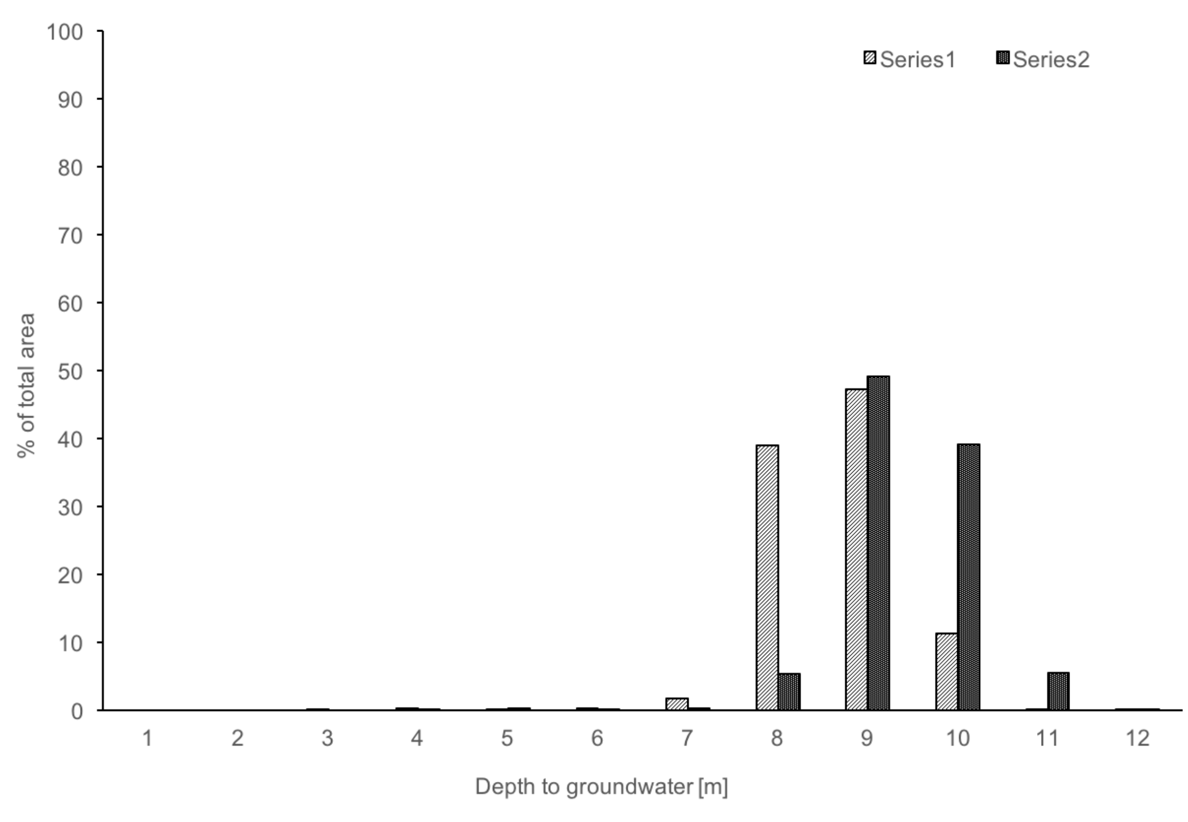
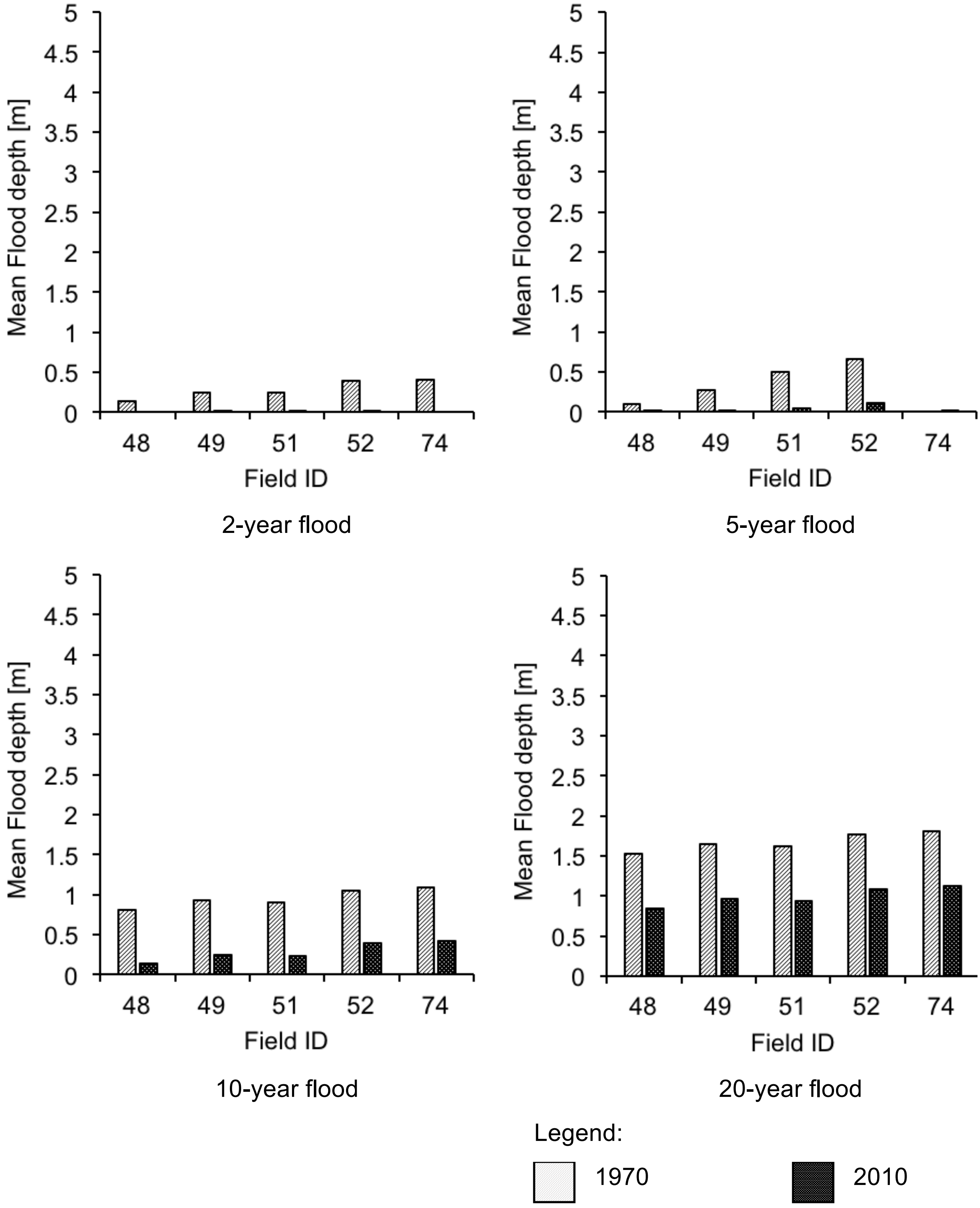


Figure 59 Fresh elm-oak forest (linden)

Table 49 Fresh elm-oak forest (linden)

		Depth to groundwater [m]										
Year	**s.**	**< 0.5**	**0.5 - 1**	**1 - 1.5**	**1.5 - 2**	**2 - 2.5**	**2.5 - 3**	**3 - 3.5**	**3.5 - 4**	**4 - 4.5**	**4.5 - 5**	**> 5**
1997	0.00	0.00	0.02	0.21	0.19	0.23	1.66	38.93	47.26	11.31	0.19	0.00
2010	0.00	0.00	0.00	0.06	0.22	0.18	0.30	5.35	49.16	39.10	5.55	0.10



2-year flood

5-year flood

10-year flood

20-year flood

Figure 60 Fresh elm-oak forest (hornbeam)

5.3 Succession at the study site

Historic maps

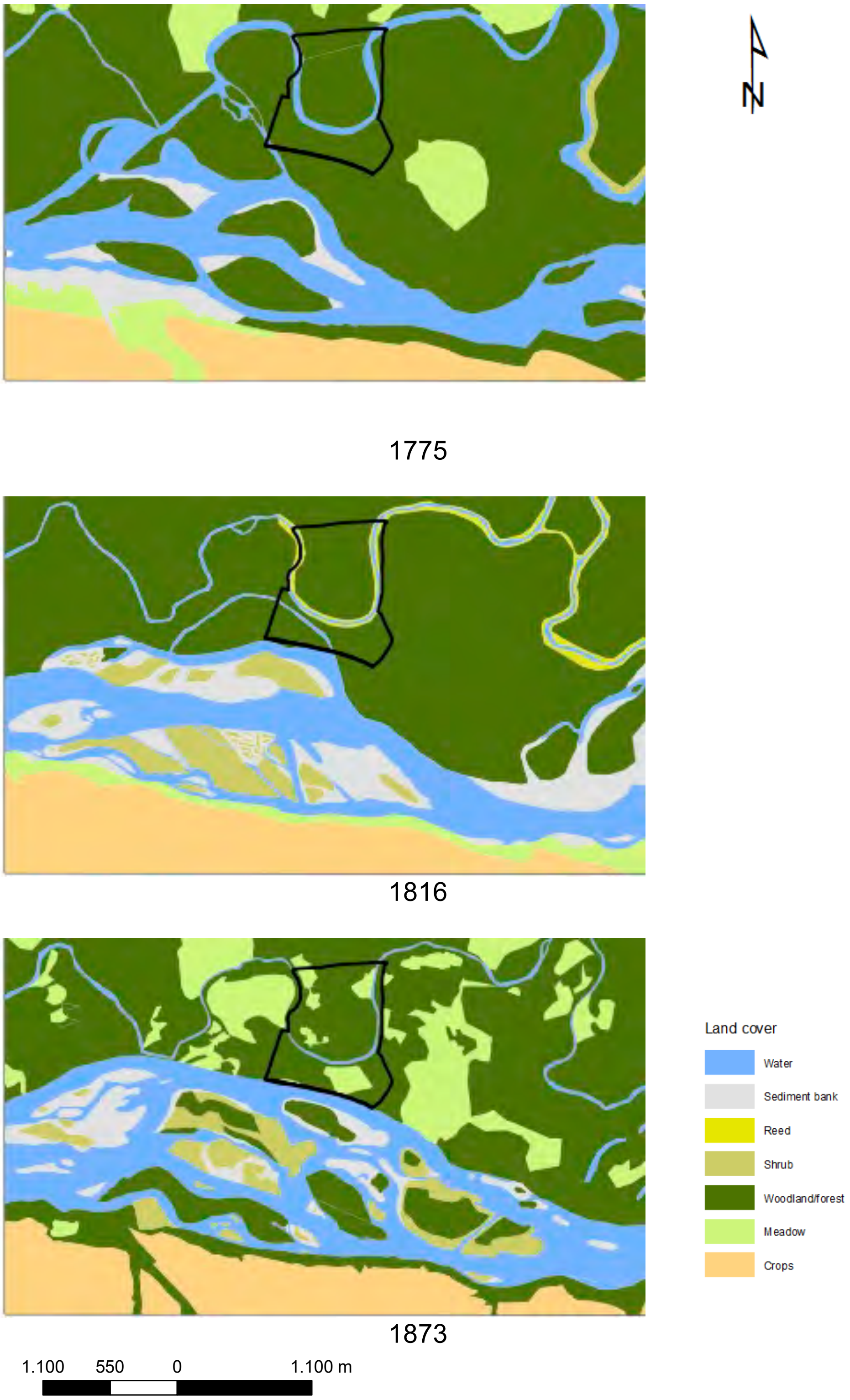


Figure 61 Historic maps of the study site from 1778, 1816 and 1873

The historic maps (Fig. 61) show dynamic habitat shift in the pre-regulated Danube. The study site is remains relatively stable, except for a side arm in the southwest of the site. In 1873 the side arm has transformed to a paleochannel as it is disconnected from the river.

Floodplain Age

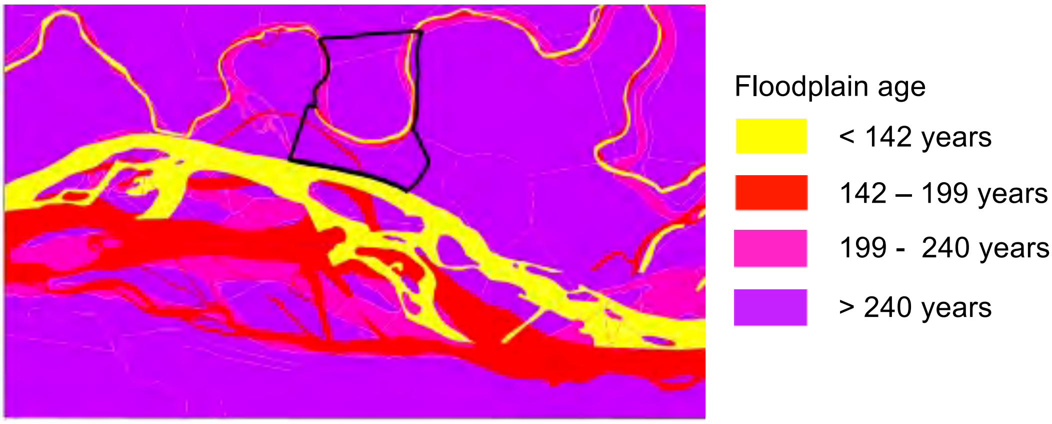


Figure 62 Map of the floodplain age

The map in figure 62 shows the age of the floodplain. The study site is predominantly at least over 240 years old, with the exception of a former side arm in the southwest and small areas where the meander of the *Faden* has migrated. These areas are about 142 to 240 years old.

Successional phases

The comparison of the PNV map of 1975 and the map of 2015 shows that no shift of successional phase happened during the past 40 years at the study site with the exception of the black poplar woodland site at the cut-off meander, which has progressed to dry poplar woodland. Thus, the site has moved from the early successional woodland phase to the late successional woodland phase (Table 50)

Table 50 area balance of PNV type shares the study site 1975 and 215

PNV type	1975 (%)	2015 (%)
Reed	1.93	1.93
Wet willow woodland	6.23	6.23
Fresh willow woodland	0.60	0.60
Wet poplar woodland	12.57	12.57
Black poplar woodland	3.21	0
Fresh poplar woodland	0.44	0.44
Dry poplar woodland	0	3.21
Wet elm-oak forest	10.10	10.10
Fresh elm-oak forest	28.89	28.89
Fresh elm-oak forest (hornbeam)	2.58	2.58
Fresh elm-oak forest (linden)	28.37	28.37
Abandoned side arm	2.75	2.75
Side arm	2.34	2.34

6 Discussion

Discussion of Research question 1

How has the incision of the Danube affected the physical habitat parameters of the floodplain?

The incision of the Danube affected the physical habitat parameters of the study site. The depth to groundwater increased by 51 cm from 1949 to 2010. Since the mapping by of the PNV in 1975 the depth has increased by ~ 40 cm. The soil of this floodplain area has good water holding capacities due to its high share of silt and the thickness of the topsoil layer, which exceeds at almost at all investigated sites 20 cm. These characteristics of the soil are able to buffer the impact of the lowering of the groundwater table, as long as the groundwater table pulse during flood events reaches the upper layer of the soil. During the field work no impact of the lowering of the groundwater table on the vegetation has been identified. The first hypothesis, stating that the lower the elevation of the riverbed of the Danube at *Orth an der Donau*, the higher the depth to groundwater at the study site could be verified.

The characteristics of flood events were also distinctly changed by the river incision and the aggradation of the floodplain. In 1949 a 1-year flood event would inundate almost the total area of the study site situated between Danube and dam. In 2010 it floods only the levee with fresh willow woodland and an inundation of the majority of the proximate floodplain occurs at a 10-year flood. Also the depth of inundation of various flood events has been reduced due to the incision of the Danube. In the case of wet willow woodland sites the flood depths during 10-year floods have decreased by about half a meter from 1970 to 2010. Due to the lower spatial extent of flood events it can be assumed that the days of inundation per year have also decreased since 1949. But since this study has no records of the discharge before 1977 no this assumption neither be verified nor falsified. So with the exception of flood duration the second hypothesis stating, the lower the elevation of the riverbed of the Danube at *Orth an der Donau*, the smaller the flooded area, the lower the depth of inundation and the shorter the duration of flood events at the study site could be verified.

Discussion of research question 2

What is the current state of the potential natural vegetation and how does it differ from the potential natural vegetation mapped in 1975?

The area balance between PNV types in 2015 and 1975 shows that each PNV type except of black poplar woodland and dry poplar woodland is exactly the same. This is due to the fact that the map by Margl and Müller (1975) as well as the field mapping of 2015 were modified based on the topography in the DEM. Since the floodplain has low levels hydrogreomorphic disturbances the terrain from 1975 can be assumed to most closely approximate the terrain of 2015 with the exception of the floodplain aggradation at the levee. The floodplain age map (Fig. 62) shows that the majority of the floodplain of the study site is at least over 240 years old. Thus, the floodplain vegetation is in predominately in the *established forest phase* and in a relatively stable state. The comparison of 2015 and 1975 shows that there has been no shift of successional phase in the hardwood forest over the past 40 years. According to Schratt-Ehrendorfer (2011) a hardwood site of 1500 years is documented in the Danube floodplain. Also Margl (1973) states that hardwood forest can remain for hundreds of years of the Danube floodplain. Also Drescher et al. (2014) state, that elm-oak forest stand can sustain more than 300 years. Thus, the third hypothesis stating that there has been no change of successional phase since 1975 in the floodplain forest is verified.

Area balances of the two maps (PNV of 1975 and 2010) show that there has been no shift from softwood forest to hardwood forest over the past 40 years. The site which featured black poplar woodland in 1975 has been identified as dry poplar woodland due to the developed topsoil layer, which is well developed. The site also features *Quercus robur*, which indicates that it might transition towards dry elm-oak woodland. Fresh Poplar woodland) has a longevity of approximately 500 years (Margl 1973). The initial black poplar woodland mapped by Margl and Müller (1975) at the meander bend of the *Faden* might have resulted from the deposition of thick layers of sand. The soil assessment of the site shows a high share of sand. As dry poplar woodland belongs to the softwood stages, the fourth hypothesis stating a shift from softwood to hardwood is falsified.

Based on the field assessment of the study site the fifth hypothesis stating that no new primary succession has been initiated at the study site is verified as no new pioneer stands have been recorded. This lack of habitat rejuvenation is connected the channelization and damming of the Danube. The ongoing incision disconnects the river from the floodplain and decreases hydrogeomorphic disturbances as flood frequency and depth decreases. The aggradation at levee supports this trajectory towards terrestrialization as it acts as a barrier during flood events.

7 Conclusion

The river incision of the Danube has reduced flood frequency and depth of inundation. The groundwater table has lowered due to the lowering of the riverbed. Thus, the incision of the Danube has led to a change of physical habitat parameters of the Danube. Due to the lack of hydrogeomorphic disturbances no primary succession has been initiated on the study site during the past 40 years. There has been no shift from softwood forest to hardwood forest. The high share of silt in the soil leads to a high water holding capacity which makes the vegetation more resilient to drought. The floodplain vegetation is predominately in advanced successional phases, which are characterized by a high longevity. This might explain why the effect of the incision on the physical habitat parameters has not distinctly translated to the state of the potential natural vegetation.

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Appendix

List of Figures

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RNW at Orth an der Donau (data source: KWD)

Year	RNW [m a.A.]	Data source
1949	144.69	Bundesstrombauamt (1951)
1956	144.65	Bundesstrombauamt (1959)
1970	144.6	Bundesstrombauamt (1970)
1976	144.51	Bundesstrombauamt (1978)
1986	144.41	Wasserstrassendirektion (1986)
1996	144.16	Wasserstrassendirektion (1998)
2010	143.92	Via donau (2010)

Groundwater table model (raw data: via donau)

Year	**SMW [m a.A.]**	**GW [m a.A.]** GW = 67.06562+0.55336*SMW
1949	138.99462	143.9796829
1956	138.9007097	143.9277167
1970	138.7562038	143.8477529
1976	138.6180673	143.7713137
1985	138.574479	143.7471937
1996	138.3114941	143.6016684
2010	138.0616944	143.4634392

Austrian standard for soil texture classification in habitat mapping after Blum et al. (1996)

Soil texture type	Sand 2.000 – 0.060 mm	Silt 0.060 – 0.002 mm	Clay > 0.002 mm
	%		
Sand	65 – 100	0 – 30	0 – 10
Silty sand	40 – 70	30 – 55	0 – 5
Loamy sand	30 – 80	10 – 55	5 – 15
Sandy silt	10 – 45	55 – 75	0 – 15
Silt	0 – 25	75 – 100	0 – 25
Clay sand	65 – 90	0 – 10	10 – 25
Sandy loam	20 – 75	10 – 55	15 – 25
Clay silt	0 – 30	55 – 75	15 – 25
Sandy clay	50 – 75	0 – 10	25 – 40
Loam	5 - 65	10 – 55	25 – 40
Silty loam	0 – 20	55 – 75	25 – 40
Loamy clay	0 – 60	0 - 55	40 – 50
Clay	0 – 50	0 - 50	50 – 100

Scales of morphodynamics and flood inundation duration by Egger et al. (2015)

Scales	Morphodynamics	Flood inundation duration
5	Very high: swift flows several times yearly, extensive erosion and sedimentation, sand or gravel with no organic horizon or litter layer; non-vegetated surfaces, may be pioneer vegetation	Very high: repeatedly flooded annually; frequently with flooding indicators of woody debris, sparse vegetation or sporadic flood-tolerant plants
4	High: annual moderate erosion and sedimentation, sand or gravel with no organic horizon and a thin litter layer, pioneer vegetation with reeds and flow-resistant woody plants, often with damage including sheared branches and a braided trunks	High: flooded once or a few times annually by discharges from Q_1 to bank-full flow, some flooding indicators and flood-tolerant plant species
3	Moderate: morphodynamic processes generally limited to slight sedimentation of sand and local erosion; weak organic layer and distinct litter layer; dense reed or intermediate flow-resistant woody plants	Moderate: stage range from bank-full to medium floods, flooding indicators only after major floods; some moderately flood-sensitive species, mostly perennials, trees and shrubs
2	Low: low level morphodynamic processes with weak intensity, limited local erosion and sedimentation of fine sand and silt; distinct organic and litter layer; young or intermediate deciduous forest	Low: only inundated with moderate to major floods, flooding plays a minor role, low effect on tree layer, understory with maturity indicator species
1	Very low: morphodynamic processes are confined to rare major floods; only local sedimentation of fine material; distinct organic and litter layer; mature hardwood forest or mixed deciduous-coniferous forest	Very low: achieved only by rare floods, flooding plays minimal role; vegetation approaches the surrounding upland vegetation

Plant associations in correspondence to successional phase and PNV type based on Egger at al. (2009), Margl (1973), Margl (1972), Jelem (1974), Wendelberger (1952) and Wallnöfer et al. (1993, Grass (1993), Balátová-Tuláčová et al. (1993) and Schratt (1992)

Dry series: Potential natural vegetation and corresponding association with flagship species

Phase	PNV type	Plant community	Flagship species
Pioneer phase	Pioneers on gravel	Creeping bentgrass stadium (Wendelberger-Zelinka 1952)	*Agrostis stolonifera*
Herb phase	Reeds	*Salici incanae-Hippophaetum Br.-Bl. in Volk 1939*	*Hippophae rhamnoides subsp. Fluviatilis, Salix daphnoidis, S. eleagnos, S. purpurea Achillea millefolium, Centaurea jacea, Euphorbia cyparissas, Melilotus albus, Calamagrostis epigejos*
Shrub phase	Purple willow shrub	*Salicetum purpureae Wendelberger-Zelinka 1952*	*Salix purpurea*, *Agrostis stolonifera*, *Phalaris arundinaceae*
Early successional woodland phase	Black poplar woodland	*Salici-Populetum Meijer-Drees 1936*	*Populus nigra, Salix alba*, *S. eleangos*
Late successional woodland phase	Dry poplar woodland	*Fraxino-Populetum Jurko 1958*	*Populus alba*, *P. nigra*, *Salix alba*, *Alnus incana*, *Prunus padus*, *Acer pseudoplatanus*, *Fraxinus excelsior*, *Cornus sanguinea*
Established forest	Dry elm-oak forest	*Querco-Ulmetum Issler 1926*	*Quercus robur*, *Acer campestre*, *A. pseudoplatanus*, *Fraxinus excelsior*, *Ulmus minor*, *Betula pendula*, *Conrnus sanguinea*, *Crategus monogyna*, *Vibrium opulus*
Mature forest	Dry Oak-Hornbeam forest	*Primulo veris-Carpinetum Neuhäusl et Neuhäuslová-Novotná 1964*	*Acer campestre*, *Caprinus betulus*, *Prunus avium*, *Quercus robur, Ligustrum vulgare, Quercus petraea, Conus sanguniea*

Fresh series: Potential natural vegetation and corresponding association with flagship species

Phase	PNV type	Association	Flagship species
Pioneer phase	Pioneers on sand	No specific association (Bernhard et al.)	*Amaranthus albus, Anthemis arvensis, Astragalus glycyphyllo, Atriplex oblongifolia, Bidens tripartitus, Centaurea jacea, Chenopodium strictu, Cyperus eragrostis, Eragrostis minor, Festuca arundinacea, Galeopsis pubescens, Juncus articulatus, Malva neglecta, Persicaria hydropiper, Poa annua, Setaria decipiens, Solanum nigrum, Verbascum speciosum*
Herb phase	Reeds	*Rorippo-Phalaridetum Kopecky 1961*	*Rhorippa palustris, R. amphibian, R. obtusifolius, Phalaris arundinacea, Mentha aquatic, Poa palustris, Urtica dioica Calystegia sepium, Persicaria hydropiper, Rumex conglomeratus*
Shrub phase	Almond willow shrub	*Salicetum tiandra en Malcuit ex Noirfalise in Lebrun et al. 1955*	*Salix tiandra*, *S.viminalis*
Early successional woodland phase	Fresh white willow woodland	*Salicetum albae Issler 1926*	*Salix alba*, *Populus alba*
Late successional woodland phase	Fresh white poplar woodland	*Fraxino-Populetum Jurko 1958*	*Populus alba*, *P. nigra*, *Salix alba*, *Alnus incana*, *Prunus padus*, *Acer pseudoplatanus*, *Fraxinus excelsior*, *Cornus sanguinea*
Established forest	Fresh elm-oak forest	*Querco-Ulmetum Issler 1926*	*Quercus robur*, *Acer campestre*, *A. pseudoplatanus*, *Fraxinus excelsior*, *Ulmus minor*, *Betula pendula*, *Conrnus sanguinea*, *Crategus monogyna*, *Vibrium opulus*
Mature forest	Fresh Oak-Hornbeam forest	*Primulo veris-Carpinetum Neuhäusl et Neuhäuslová-Novotná 1964*	*Acer campestre*, *Caprinus betulus*, *Prunus avium*, *Quercus robur, Ligustrum vulgare, Quercus petraea, Conus sanguniea*

Wet series: Potential natural vegetation and corresponding association with flagship species

Phase	PNV type	Association	Flagship species
Pioneer phase	Pioneers on silt	*Hydrocharitetum morsus-ranae van Langendonck 1935;* *Nymphaeetum albo-luteae Nowinski 1928;*	*Hydrocharis morsus-ranae, Lemna minor, L. triscula; Spirodela polyrhiza;* *Nuphar lutea*, *Nymphea alba var. alba;*
Herb phase	Reeds	*Phragmitetum vulgaris von Soó;* *Caricetum elatae Koch 1926;* *Glycerietum aquatica Hueck 1931*	*Phragmites australis; Carex elata, Equisetum fluviatile, Galium palustre, Schoenoplectus lacustris, Typha angustifolia;* *Carex elata, Galium palustre, Lysimachia vulgaris, Lythrum salicaria, Mentha aquatica, Phragmites australis;* *Glyceria maxima, Alisma plantago-aquatcia, Carex acuta*
Shrub phase	Almond Willow shrub	*Salicetum tiandra en Malcuit ex Noirfalise in Lebrun et al. 1955*	*Salix tiandra*, *S.viminalis*
Early successional woodland phase	Wet White Willow woodland	*Salicetum albae Issler 1926*	*Salix alba*, *Populus alba*
Late successional woodland phase	Wet Poplar woodland	*Fraxino-Populetum Jurko 1958*	*Populus alba*, *P. nigra*, *Salix alba*, *Alnus incana*, *Prunus padus*, *Acer pseudoplatanus*, *Fraxinus excelsior*, *Cornus sanguinea*
Established forest	Wet Elm-Oak forest	*Querco-Ulmetum Issler 1926*	*Quercus robur*, *Acer campestre*, *A. pseudoplatanus*, *Fraxinus excelsior*, *Ulmus minor*, *Betula pendula*, *Cornus sanguinea*, *Crategus monogyna*
Mature forest	Wet Oak-Hornbeam forest	*Primulo veris-Carpinetum Neuhäusl et Neuhäuslová-Novotná 1964*	*Acer campestre*, *Caprinus betulus*, *Prunus avium*, *Quercus robur, Ligustrum vulgare, Quercus petraea, Conus sanguniea*

Side arm *Faden* with deadwood in 2016

Reed in the channel of the side arm *Faden* in 2016

Meander cutoff of *Faden* is fed by groundwater pulse during flood event 2016

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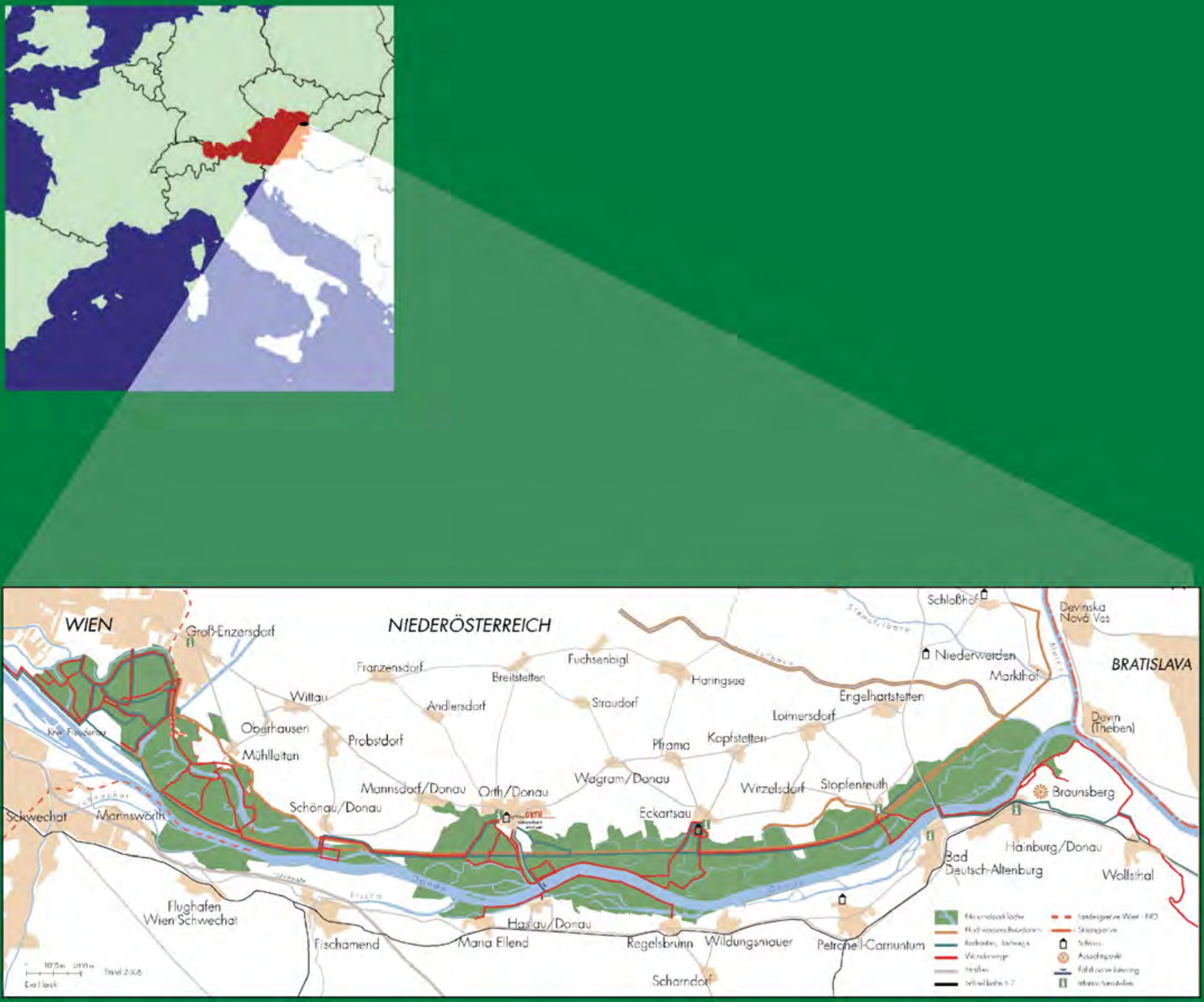

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