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Danijel Orešić

Restauracija poplavnih ravnica: razvoj i pristupi istraživanja

Floodplain restoration: development and research approaches

Poplavne ravnice mnogih rijeka izmijenjene su raznim antropogenim utjecajima, a u novije vrijeme jača svijest o potrebi restauracije poplavnih ravnica prvenstveno radi bolje zaštite od poplava, ublažavanja klimatskih promjena, poboljšanja ekološkog stanja vodotoka. Inicijativa mnogih tijela Europske unije značajno je doprinijela razvoju strategija i izradi mnogih projekata povezanih uz restauraciju poplavnih ravnica.

Ovaj rad daje pregled i razvoj istraživanja o restauraciji poplavnih ravnica u zadnjih 25 godina vezanih za delinaciju poplavnih ravnica koje su se razvijale od jednostavnih preko hidrološko-hidrauličkih a od nedavno prema kompleksnim modelima koji uključuju višekriterijske analize. Također dan je pregled pristupa vezanih za procjenu pogodnosti za restauraciju poplavnih ravnica gdje je utvrđeno da se najčešće koristi kombinacija više izvora podataka kako bi se uklonile nepoznanice i što točnije definiralo stanje i pogodnost za restauraciju poplavne ravnice. Smjer kretanja i razvoja restauracija ide prema integralnim pristupima s multidisciplinarnim timovima.

Ključne riječi: restauracija poplavnih ravnica, određivanje pogodnosti, delinacija, hidromorfologija, Europska unija

The floodplains of many rivers have been modified by various anthropogenic influences, and recently there has been a growing awareness of the need for floodplain restoration, primarily for better flood protection, climate change mitigation and improvement of the ecological status of streams. The initiative of many European Union bodies has significantly contributed to the development of strategies and the creation of many projects related to the floodplain restoration.

This paper provides an overview and development of floodplain restoration research over the last 25 years related to floodplain delineation, which has evolved from simple models to hydrological-hydraulic models, and more recently to complex models that include multi-criteria analyses. It also provides an overview of approaches related to assessing the suitability or potential of floodplain restoration, where it has been determined that a combination of multiple data sources is most often used to eliminate uncertainties and more accurately define the condition and suitability for floodplain restoration. The direction of movement and development of restoration is moving towards integrated approaches with multidisciplinary teams.

Key words: floodplain restoration, assessing potential, delineation, hydromorphology, European Union

Uvod

Poplavne ravnice (katkad naplavne ili aluvijalne ravnice) općenito su zaravnjena područja neposredno uz tekućice koje su nastale pretežno kompleksnim fluvijalnim akumulacijskim procesima, a njihov izgled rezultat je snage vodotoka i obilježja sedimentacije (Nanson i Crooke, 2002). Na njima se mogu nalaziti različiti fluvijalni morfološki oblici (rukavci, otoci, grede i sl.), dok bočno mogu biti omeđene terasnim odsjecima (obrežja), što ovisi o sedimentacijskoj evoluciji. Potrebno je istaknuti da je tijekom proteklih 100 godina regulacijskim i hidrotehničkim radovima značajno degradirana morfologija tekućica, a time su izmijenjena i prirodna poplavna područja (Moss i Monstadt, 2008; Dufour i Piégay, 2009). Prirodne su tekućice kanalizirane i skraćene, a poplavna su područja meliorirana, ispresijecana ocjednim kanalima te su uvelike izgubila prirodni obuhvat i ulogu (Buijse i dr., 2002). Provedenim radovima znatan dio prirodnih poplavnih ravnica prenamijenjen je u poljoprivredne površine. Šume, prirodne vlažne livade i močvare koje se nalaze na prirodnim poplavnim ravnicama uvelike su nasipima odvojene od tekućica, što onemogućuje njihovo plavljenje. Prema procjenama (Tockner i Stanford, 2002) antropogeni zahvati rezultirali su prenamjenom 90 % poplavnih područja u Europi i Sjevernoj Americi. Za prostor Hrvatske malo se podataka nalazi u literaturi, npr. za poplavnu ravnicu rijeke Save objavljeno je da je 70 % njezine poplavne ravnice prenamijenjeno (WWF, 2006), ali nije precizno definirana granica te poplavne ravnice.

S obzirom na klimatske promjene i ekološku ulogu vlažnih područja u novije doba jača svijest o potrebi očuvanja i, gdje je to moguće, obnovi poplavnih ravnica (Ramsarska konvencija, Okvirna direktiva o vodama 2000/60/EZ i Direktiva o poplavama 2007/60/EZ).

Hidrološka uloga poplavnih ravnica posebno je važna jer pomaže u održavanju zalihama vode tijekom cijele godine prirodnim skladištenjem vode u vlažnom dijelu godine i polaganim otpuštanjem u sušnijem dijelu godine (Schneider, 2010). U poplavnim ravnicama tipično dolazi do infiltracije podzemne vode i u odgovaraju-

Introduction

Floodplains (or alluvial plains) are generally flat areas along rivers that have been formed mainly by complex accumulation of fluvial processes, and their appearance is the result of the strength of water flow and characteristics of sedimentation (Nanson and Crooke, 2002). Various fluvial morphological forms (side arms, islands, ridges, etc.) can be found upon them and can be bounded by terraced sections, which depends on sedimentary evolution. It should be noted that within the past 100 years, as result of river training regulations and hydrotechnical projects, river morphology has heavily degraded and natural floodplains have significantly altered (Moss and Monstadt, 2008; Dufour and Piégay, 2009). These rivers have been subject to training works and shortened in length while the natural floodplains have been drained and reclaimed, intersected by drainage channels, and largely lost their natural extent and functionality (Buijse et al., 2002). With such interventions, parts/areas of the former floodplains have been converted to agricultural land, while floodplains such as forests, natural wet meadows and wetlands have been disconnected from watercourses by levees, which prevents their natural flooding. According to estimates (Tockner & Stanford 2002), this has resulted in the conversion of 90% of European and North American floodplains. There is some data in the literature for the area of Croatia, for example, for the floodplain of the Sava River it was reported that 70% of its floodplain has been modified (WWF, 2006), but the boundary of its floodplain is not precisely defined.

Regarding to climate change and the ecological role of wetlands, awareness of the need to preserve and, where is possible to restore floodplains (Ramsar Convention, Water Framework Directive 2000/60/EC and Floods Directive 2007/60/EC) is growing in recent times.

The hydrological role of floodplains is particularly important because it helps maintain water supplies throughout the year by naturally storing water during the wet part of the year and slowly releasing it during the drier part of the year (Schneider, 2010). Floodplains typically infiltrate surface water to groundwater under

ćim sedimentacijskim uvjetima poplavne ravnice mogu znatno poboljšati kvalitetu podzemne vode (Serra-Llobet i dr., 2022.). Aktivne poplavne ravnice smanjuju troškove vezane za sivu infrastrukturu, kao što su nasipi za zaštitu od poplava, brane i crpne stanice (Browder i dr., 2019). Poplavne ravnice skladište poplavne vode i snižavaju razine poplava, čime se potencijalno smanjuju troškovi i/ili poboljšava otpornost izgrađenoga rješenja (Browder i dr., 2019). One pružaju ekološke usluge i mogu omogućiti rekreaciju stanovništva (Opperman 2013).

Restauracija poplavnih ravnica daje više prostora za meandriranje vodotoka i zdravih poplavnih područja, omogućuje očuvanje ili obnovu šuma i močvarnih staništa koja skladište vodu i smanjuju nizvodnu sedimentaciju (Green Infrastructure, 2014). Unazad 30-tak godina dolazi do raznih inicijativa vezanih za restauraciju vodotoka, a sve više i za restauraciju poplavnih ravnica.

Glavni razlozi pokretanja restauracije poplavnih ravnica mogu biti različiti, a često su i kombinirani. Pojedini projekti restauracije ili rehabilitacije poplavnih ravnica tako su pokrenuti radi poboljšanja ili oprirodnjavanja režima otjecanja vodotoka, poboljšanja ekološkoga stanja površinskih voda (Habresack i dr., 2015), zatim radi poboljšanja količinskoga stanja podzemnih voda (Serra-Llobet i dr., 2022.) ili smanjenja rizika od poplava uslijed ekstremnih hidroloških situacija i klimatskih promjena zajedno s poboljšanjem stanja staništa (Blackwell, 2006; Boughton i dr., 2013; Opperman i dr.; 2009; Smith i dr., 2017), katkad radi neadekvatne postojeće zaštite od poplava (Blackwell i dr., 2006; EEA, 2016), zatim poboljšanja lošega stanja voda (Blackwell i dr., 2006) i poboljšanja usluga ekosustava (Thorpe i dr., 2006; Gilvear i dr., 2013).

Uz restauraciju poplavnih ravnica vezana je i inicijativa o integralnom i održivom upravljanju vodama s višenamjenskim korištenjem zemljišta kao što je povremeno plavljenje prirodnih vlažnih livada kao potpora u održivoj bioraznolikosti (Pahl-Wostl, 2006; Schindler i dr., 2014) te višenamjenske koristi kao što je ekološka obnova i zaštita od poplava (Leyer i dr., 2012).

appropriate sedimentation conditions, floodplains can significantly improve groundwater quality (Serra-Llobet et al., 2022). Active floodplains reduce costs associated with grey infrastructure, such as flood protection levees, dams and pumping stations (Browder et al., 2019). Floodplains store floodwaters and lower flood levels, potentially reducing costs and/or improving the resilience of human-built solutions (Browder et al., 2019). They provide ecological services and can provide recreation for the population (Opperman, 2013).

Floodplain rehabilitation provides more space for meandering watercourses and healthy floodplains, allows for the preservation or restoration of forests and wetlands that store water and reduce downstream sedimentation (Green Infrastructure, 2014). In the last 30 years, there have been various initiatives related to the restoration of streams and, increasingly, the related restoration of floodplains.

The main reasons for initiating of the floodplain restoration can be different and are often combined. Floodplain rehabilitation or restoration projects have been initiated in order to improve or renaturalize watercourse flow regime, improve the ecological status of surface waters (Habresack et al., 2015), improve the quantitative status of groundwater (Serra-Llobet et al., 2022.), decrease flood risk as a result of extreme hydrological events and climate change along with the improvement of habitat quality (Blackwell, 2006; Boughton et al., 2013; Opperman et al., 2009; Smith et al., 2017), sometimes because of inadequate existing protection against floods (Blackwell et al., 2006 EEA, 2016,), poor water state (Blackwell et al., 2006), or ecosystem services (Thorpe et al., 2006; Gilvear et al., 2013).

Restoration of floodplains is also related to the initiative on integral and sustainable water management with multi-purpose land use such as temporary flooding of natural wet meadows as support in sustainable biodiversity (Pahl-Wostl, 2006; Schindler i dr., 2014), and multi-purpose benefits such as ecological restoration and flood protection (Leyer et al., 2012.)

U novije vrijeme osmišljeni su mnogi integralni pristupi koji se odnose na zaštitu od poplava, tj. kako živjeti s poplavama i organizirati prostor na održiviji način, a ističu se: Prostor za rijeke (Rohde, 2006), Flood pulsing concepts (Junk i dr., 1989), Natural Flood Management (Wren i dr., 2022), Nature-based solutions (EEA, 2015; Jakubínský, 2021), Prirodne mjere za zadržavanje voda (Strosser, 2015).

U praksi su prve restauracije počele u zapadnoj Europi i Sjevernoj Americi, a odnosile su se na velike rijeke, primjerice na Rajnu, Dunav i njihove pritoke (Buijse i dr., 2002; Stoffers i dr., 2021), a isprva su u prvom planu bile restauracije tokova i korita, a povezano s tim provodile su se i djelomično i povezivanje s poplavnom ravnicom. Pregledni rad Szalkiewiczza i dr. (2018) pokazao je da se u novije doba (u razdoblju 2000. do 2015.) veća pažnja poklanjala upravo restauraciji poplavnih ravnica, odnosno da se u novije vrijeme preko projekata integralno pristupa i obnovi toka te poplavne ravnice. Prema Szalkiewiczu i dr. (2018), u budućnosti se može predvidjeti rast integralnih projekata restauracije koji će uključivati restauracije korita, poplavnih ravnica, ali i područja porječja u cjelini. Iz provedenih restauracija i monitoringa može se zaključiti da je teško izvesti uspješnu i održivu restauraciju vodotoka, a da se ne uključe i barem djelomične restauracije naplavne ravnice, prvenstveno zbog zadržavanja vodnoga vala, smanjenja brzine vode u koritu te smanjenja rizika od poplava (Palmer i dr., 2005; Habersack i dr., 2015). Valja zaključiti da je preduvjet za uspješnu restauraciju korita vodotoka uključivanje poplavne ravnice.

Uloga Europske unije u restauraciji poplavnih ravnica

Razna tijela Europske unije (i zainteresirani znanstvenici i znanstvene ustanove koje sufinancira EU), a na prvom mjestu Europska agencija za okoliš, kroz razne projekte i provedbe direktiva (Dworak, 2008) potiču restauraciju tekućica i primjenu poplavnih ravnica odnosno poplavnih područja u njima radi smanjenja rizika od poplava. U tom smislu educiraju se nadležna tijela

In recent times, many integral approaches have also been designed related to flood protection, i.e. how to live with floods and organise space in a more sustainable way, and the following stand out: Room for rivers (Rohde, 2006), Flood pulsing concepts (Junk et al., 1989), Natural Flood Management (Wren et al., 2022), Nature-based solutions (EEA, 2015; Jakubínský, 2021), Natural water retention measures (Strosser, 2015)

In practice, the first restorations began in Western Europe and North America and they were related to large rivers, for example, the Rhine, Danube and their tributaries (Buijse et al., 2002; Stoffers et al., 2021), and initially the restoration of streams and riverbeds was in the foreground, and in connection with this, partial connections to the floodplain were also carried out. The review article by Szalkiewicz et al. (2018) showed that in recent times (between 2000 and 2015) more attention was paid to the restoration of floodplains, while more recently projects have been approached integrally to restore the stream and floodplain. According to Szalkiewicz et al., 2018, the growth of integral restoration projects can be predicted in the future, which will include the restoration of riverbeds, floodplains, but also the catchment. From the carried out restorations and monitoring, it can be concluded that it is difficult to carry out a successful and sustainable restoration of a watercourse without including at least partial restoration of its floodplain, primarily due to retention of the water wave, reduction of water speed in the riverbed and reduction of the risk of floods (Palmer et al., 2005; Habersack et al., 2015). Which means that a precondition for successful river restoration is the encompassing the floodplain.

The role of the EU in floodplain restoration

Many European Union institutions (both interested scientists and scientific institutions co-funded by the EU), and primarily the European Environment Agency, through various projects and implementation of directives (Dworak, 2008) encourage the restoration of rivers and the use of floodplains or floodplains in them to reduce the risk of floods. This means that competent authorities are being

i upoznaje zainteresirana javnost te se podiže javna svijest kako bi lokalno stanovništvo bilo zainteresirano i uvidjelo potencijalne koristi od restauracija tekućica i poplavnih ravnica.

Projektom FLOBAR2 (Hughes, 2003) sintetizirana su dotadašnja znanja u razumijevanju procesa i važnosti poplavnih šuma. Sljedeći važan dokument bio je *Ecoflood Guidelines: How to use floodplains for flood risk reduction* (Blackwell i dr., 2006). U prvom dijelu ovoga dokumenta dan je uvod u zaštitu od poplava, definiran je rizik od poplava te su opisani prirodni procesi i funkcije na poplavnim ravnica, dok drugi dio dokumenta koncipiran je kao vodič sa smjernicama za restauraciju za smanjenje rizika od poplava koristeći se prirodom poplavne ravnice.

Objavom *Nacrta zaštite europskih vodnih resursa* Europska je komisija 2012. godine „udarila” smjernice prema daljnjem razvoju „dobrog stanja” voda i naglasila potrebu za restauracijom i vraćanjem prirodnih poplavih područja u funkciju zaštite voda, tj. poboljšanja stanja voda.

U idućim godinama nastaju bitna izvješća koja promiču restauracije i rehabilitacije tekućica, a to su: *Prirodne mjere za zadržavanje voda* (Strosser, 2015), u kojemu se opisuje kako prirodna poplavna područja imaju bitnu ulogu za spremanje voda i smanjenje rizika od poplava i gdje je restauracija i upravljanje prirodnim poplavnim područjima navedena kao jedna od glavnih mjera. Na tematiku zelene infrastrukture i rizika od poplava (EEA, 2015; EEA, 2017) nastaju izvješća s ciljem promicanja troškovno učinkovita smanjenja rizika od poplava putem zelene infrastrukture, ali i objavljena metodologija (Alfieri i dr., 2014) za delineaciju potencijalnih naplavih nizina. Također je promovirana sinergija između obnove prirodnih poplavnih područja i upravljanja rizikom od poplava (EEA, 2016).

Jedan od prvih dokumenata koji je popisao moguće mjere i koristi od restauracije poplavnih ravnica jest *Floodplains: a natural system to preserve and restore* (EEA, 2019). U njemu je i primjer nekoliko studija slučaja koje su navedene kao ogledni primjeri izvedenih projekta.

educated, the interested public is being informed, and public awareness is being raised so that the local population is interested and sees the potential benefits of restoring streams and floodplains.

The FLOBAR2 project (Hughes, 2003) synthesised previous knowledge in understanding the processes and importance of floodplain forests. One important work was the *Ecoflood Guidelines: How to use floodplains for flood risk reduction* (Blackwell et al., 2006). In the first part of this document, an introduction to flood protection is given, flood risk is defined, and natural processes and functions on floodplains are described. The second part of the document is designed as a guide with restoration guidelines for flood risk reduction using floodplain properties.

With the publication of *A Blueprint to Safeguard Europe's Water Resources*, 2012 the EU “struck” guidelines for the further development of “good water status” and emphasised the need to restore and return natural floodplains to the function of water protection, i.e. improvement of water status.

In the following years, important reports were published that promoted the restoration and rehabilitation of rivers, such as: *Natural measures for water retention* (Strosser, 2015), which describes how natural floodplains play an important role in storing water and reducing flood risk, and where the restoration and management of natural floodplains is listed as one of the main measures. Reports on the topic of green infrastructure and flood risk (EEA, 2015 and EEA, 2017) are being produced with the aim of promoting cost-effective flood risk reduction through green infrastructure, as well as a published methodology (according to Alfieri et al., 2014) for the delineation of potential floodplains. The synergy between natural floodplain restoration and flood risk management was also promoted (EEA, 2016).

Among the first documents that listed possible measures and benefits from the restoration of floodplains is the document *Floodplains: a natural system to preserve and restore* (EEA, 2019). It also contains several case studies that are listed as exemplary examples of completed projects.

Europska unija sustavno je krenula prema obnovi narušenih ekosustava i putem novodonesene EU Strategije bioraznolikosti za 2030. i Uredbe o obnovi prirode (EU, 2024) koje među ostalim imaju za cilj obnovu slatkovodnih ekosustava od kojih je na prvom mjestu obnova longitudinalne povezanosti tekućica micanjem i/ili izmjenom poprečnih građevina da bi se omogućila migracija riba, obnova poplavnih područja te močvarnih područja radi zaštite od poplava i uspostave prirodnih funkcija šuma, pročišćavanja voda i dr.

Za sada na području Republike Hrvatske nije izveden ni jedan projekt koji bi bio usredotočen na restauraciju poplavne ravnice, ali je napravljeno nekoliko projekata kojima je bio cilj definirati prirodnu/morfološku naplavnu nizinu (u rijeke Dunav, Drava i Sava) koja je prije značajnih antropogenih zahvata bila geomorfološki i hidrološki aktivna (WWF, 1999; Schwarz, 2010; 2013; 2016; Marojević i Šustić, 2025).

S obzirom na navedeno, javlja se potreba za sustavnim prikazom metoda koje se mogu koristiti u određivanju poplavnih područja te promišljanjem o mogućnostima ocjenjivanja pogodnosti poplavnih ravnica za restauraciju kako bi se moglo pomoći u implementaciji takvih projekata, a u konačnici u skladu s ciljevima Okvirne direktive o vodama, 2000 i Uredbe o obnovi prirode, 2024.

Metode određivanja poplavne ravnice

Obično je prva prepreka pri definiranju obuhvata zahvata same restauracije ili rehabilitacije poplavne ravnice definiranje granica prirodne poplavne zone prije nego su provedene antropogene mjere koje su uzrokovale gubitak aktivnih poplavnih područja. Kod aktivnih poplavnih ravnica postavlja se pitanje utvrđivanja granica današnje aktivne poplavne ravnice i njezina stanja.

Za definiranje područja koja bi bilo moguće restaurirati u literaturi se često koriste pojmovi slična ili bliska značenja, npr. bivša poplavna ravnica (Eder i dr., 2022; Serra-Llobet i dr., 2022), potencijalna poplavna područja (Samela

The European Union has systematically moved towards restoring degraded ecosystems, both through the newly-adopted *EU Biodiversity Strategy* for 2030 and the *Nature Restoration Regulation* (EU, 2024) which, among other things, aims for the restoration of freshwater ecosystems, primarily by restoring the longitudinal connectivity of rivers by moving and/or replacing transverse structures to enable fish migration, restoring floodplains and wetlands for flood protection and the establishment of natural forest functions, water purification, etc.

So far, not a single project focused on the restoration of the floodplain has been made in the Republic of Croatia, but several projects have been developed with the aim of defining the natural/morphological floodplain (of the Danube, Drava and Sava rivers) that was geomorphologically and hydrologically active before significant anthropogenic interventions (WWF, 1999; Schwarz, 2010; 2013; 2016; Marojević i Šustić, 2025).

In light of the aforementioned, there is a need for a systematic presentation of the methods that can be used to determine flood areas and to think about the possibilities of evaluating the suitability of floodplains for restoration in order to be able to help in the implementation of such projects, and ultimately in accordance with the goals of the Water Framework Directive, 2000 and the Nature Restoration Regulation, 2024.

Methods for floodplain delineation

Usually, the first obstacle when defining scope of the restoration or rehabilitation of the floodplain itself, is defining the boundaries of the natural flood zone before certain anthropogenic measures that caused the loss of active floodplains were implemented. With active floodplains, the question arises of determining the boundaries of today's active floodplain and its condition.

To define areas that could be restored in literature, terms with a similar or close meaning are often used, e.g. former floodplain (Eder et al., 2022; Serra-Llobet et al., 2022), potential flood-prone areas (Samela et al., 2018; EEA, 2020), and some-

i dr., 2018; EEA, 2020) te potencijalna poplavna ravnica (engl. Potential floodplain) (EEA, 2019), koja se češće koristi u smislu koliko određena antropogeno izmijenjena i dijelom ili u potpunosti neaktivna poplavna ravnica ima potencijala za restauraciju na temelju odabranih pokazatelja (Eder i dr., 2022). Najčešće se određuje da je potencijalna poplavna ravnica dio bivše (izvorne, neizmijenjene) poplavne ravnice koja je određenim radovima odvojena od vodotoka te više ne plavi.

Prva važnija studija u kojoj se određivao obuhvat prirodne naplavne ravnice za jedno veliko područje načinjena je 1999. godine pod vodstvom WWF-a, *Evaluation Of Wetlands And Floodplain Areas in the Danube River Basin*. Ovim projektom bio je zahvaćen tok Dunava te pet njegovih većih pritoka. Dokument je podijeljen na definiranje povijesne poplavne doline prije antropogenih intervencija te ocjenu pogodnosti za restauraciju. Korišteni podatci za definiranje povijesne poplavne ravnice su: povijesne karte, novije topografske karte te geomorfološke, pedološke i geološke karte ovisno o dostupnosti i području. Za analizu pokrova zemljišta korištena je podloga Corine Land Cover 1990 te daljinska istraživanja, točnije podatci satelitske platforme Landsat 5. Pomoću karata napravljena je ekološka klasifikacija područja i bioindikatori, korišteni su dostupni hidrološki podatci i podatci o zaštićenim područjima uključivo i područja Ramsar. Ovaj pristup s nadogradnjom preuzima Schwarz (2010) te izrađuje podlogu za rijeku Dunav, 2013. godine za rijeku Dravu te 2016. godine za rijeku Savu (Schwarz, 2016).

Važni su primjeri studija iz Njemačke, gdje su za potrebe Federalne agencije za zaštitu prirode Njemačke provedena istraživanja kojima je bio cilj utvrditi morfološko stanje aktivne i nekada aktivne poplavne ravnice na tekućicama kojima je porječje veće od 1000 km². Metodologija određivanja i ocjenjivanja podijeljena je u tri grupe: 1. Morfodinamika, reljef poplavnih ravnica i vodnih površina, 2. Hidrodinamika, odvodnja i poplavljanje, 3. Vegetacija i korištenje zemljišta (Koenzen, 2005; Brunotte i dr., 2009; prema Koenzen i dr. 2020), što je poslije bitno za definiranje pogodnosti/potencijala za restauraciju poplavnih ravnica.

times potential floodplain (EEA,2019) which is more often used in terms of how much a particular anthropogenically altered and partially or fully inactive floodplain has potential for restoration based on chosen indicators (Eder et al.,2022). Most often, it is determined that the potential floodplain is a part of the former (original, unaltered) floodplain that has been separated from the watercourse by certain works and is no longer flooded.

The first significant study to determine the natural floodplain for a large area was carried out in 1999 under the leadership of WWF, *Evaluation of Wetlands and Floodplain Areas in the Danube River Basin*. This project covered the Danube River and its five major tributaries. The document is divided into defining the historical floodplain before anthropogenic interventions and assessing the suitability for restoration. The data used to define the historical floodplain are: historical maps, recent topographic maps and geomorphological, pedological and geological maps depending on availability and area. For land cover analysis, the Corine Land Cover 1990 database and remote sensing, specifically data from the Landsat 5 satellite platform, were used. The maps were used to create an ecological classification of the area and bioindicators, and available hydrological data and data on protected areas, including Ramsar sites, were used. This approach with upgrades is taken over by Schwarz (2010) is making a basis for the Danube River, 2013 for the Drava River and 2016 for the Sava River.

Examples of studies from Germany are important, where research has been conducted for the needs of the Federal Nature Protection Agency, which aimed to determine the morphological state of the active and formerly active floodplains on the bodies of water that are more than 1000 km² in area. Determination and assessment methodology is divided into three groups: 1. Morphodynamics, floodplains and water surfaces; 2. Hydrodynamics, drainage and flooding; and 3. Vegetation and use of land (Koenzen, 2005, Brunotte et al., 2009 according to Koenzen et al., 2020) is important to define the benefits/potential for the restoration of floodplains.

Ogledni primjer pristupa određivanja naplavne nizine pomoću hidroloških i hidrauličkih analiza jest projekt *PRO_Floodplain* (Habersack, 2008), kojemu je cilj bio smanjiti rizike od poplava kroz restauraciju poplavnih ravnica. Projekt je bio podijeljen u tri cjeline prema kojima je kasnije i procjenjivana korist od restauracije: 1. hidromorfologija u smislu identifikacije i određivanja smanjenja rizika od poplava uz restauraciju poplavnih ravnica, 2. ekologija kroz povećanje poplavne ravnice radi smanjenja rizika od poplava i restauracija na velikim rijekama, 3. sociologija: percepcija rizika od poplava i upravljanje rizicima od poplava. Korištene bazne varijable za hidromorfologiju su nagib, širina vrha korita (eng. *bankfull*), prosječna dubina punog korita, koeficijent hrapavosti poplavne ravnice te širina poplavne ravnice, a kao rezultat su korištene mjerljive vrijednosti kao smanjenje vrha vodnoga vala, transformacija vodnoga vala itd.

Sljedeći je projekt u kojem je rađena procjena pogodnosti područja za zadržavanje velikih voda, hidrauličke i hidrološke koristi od restauracije te ekološkoga i sociološkoga stajališta, gdje je za svaki od tih elemenata dana ocjena (Habersack i dr., 2015; Habersack i Schober, 2020). Krajnji zbroj ocjena služi za usporedbu područja koja bi se mogla restaurirati u svrhu postizanja dobrog ekološkog stanja i potencijala voda sukladno Okvirnoj direktivi o vodama, 2000.

Važna je studija Globevnik i dr. (2020) u kojoj je određeno potencijalno poplavno područje na razini gotovo cijele Europe te napravljena preliminarna ocjena promjena u procesima i strukturi poplavnih ravnica. Ovo je ogledan primjer određivanja prirodnoga poplavnog područja pomoću kombinacije hidrauličkoga modeliranja, GIS-a i daljinskoga istraživanja pokrova.

Neki se autori koriste zabilježenim poplavama i visinom vode na manjem dijelu porječja da bi iz dostupnih podataka odredili vrijednosti za šire područje. Primjer je toga metoda kojoj je glavna pretpostavka da prema određenom pravilu s povećanjem slijevne površine raste i vodostaj tzv. razina plavljenja, a koja se nadalje koristi za određivanje naplavne nizine za što je bilo potrebno imati konzistentne podatke o velikim vodama (Déd, 2013; De Risi i dr., 2017).

A representative approach to floodplain determination using hydrological and hydraulic analyses is the *PRO_Floodplain* project (Habersack, 2008), which aimed to reduce flood risks via floodplain restoration. The project was divided into three units according to which the benefits of restoration were later assessed: 1. Hydromorphology in terms of identifying and determining flood risk reduction with floodplain restoration; 2. Ecology through floodplain enlargement for flood risk reduction and restoration on large rivers; 3. Sociology: perception of flood risk and flood risk management. The basic variables used for hydromorphology are slope, bankfull width, average full water depth, floodplain roughness coefficient and floodplain width, and as a result measurable values such as water wave peak reduction, water wave transformation, etc. were used.

The following project assessed the suitability of the area for retaining large waters, the hydraulic and hydrological benefits of restoration, and the ecological and sociological aspects, whereby each of these elements was given a score (Habersack et al., 2015; Habersack and Schober, 2020). The final sum of scores serves to compare areas that could be restored to achieve good ecological status and water potential in accordance with the Water Framework Directive.

An important study in which a potential floodplain was determined at the level of almost the whole of Europe, and a preliminary assessment of changes in the processes and structure of floodplains in Europe was conducted (Globevnik, et al., 2020); this is a prime example of determining a natural floodplain using a combination of hydraulic modelling, GIS, and remote sensing of land cover.

Some authors use recorded floods and water levels in a smaller part of the basin to extrapolate values for a wider area from available data. An example of this is a method that uses as a main assumption that according to a certain rule, with an increase in the catchment area, the water level, i.e. the level of flooding, also increases, which is further used to determine the floodplain, for which it was necessary to have consistent data on high waters (Déd, 2013; De Risi et al., 2017).

Uobičajeno se kao podloga pri delineaciji poplavnih ravnica koriste digitalni modeli reljefa odnosno razni derivati nastali GIS analizama (Clubb i dr, 2017; De Risi i dr., 2017; Diehl i dr., 2021; Samela i dr., 2018; Stout i Belmont, 2013; Woznicki i dr., 2019; Zaharia i dr, 2017), a te se često kombiniraju s hidrološkim/hidrauličkim podacima ili modelima o dosegu poplava (Děd, 2013; Samela i dr., 2018; Zaharia i dr, 2017).

Uočeno je da hidraulički proračuni za određivanje poplavne ravnice mogu značajno varirati ovisno o pristupu (Alfieri i dr., 2014 prema Globevnik i dr, 2020), gdje se najčešće uzima stogodišnje povratno razdoblje kao referentno za utvrđivanje poplavne ravnice (Eder i dr., 2019). Ipak, katkad dolazi do podcijenjenih vrijednosti s obzirom na to da se koriste hidrološki podatci iz prošlosti, a u pojedinim je slučajevima regulacijskim i hidrotehničkim radovima znatno promijenjen hidraulički radijus i nagib korita vodotoka. U takvim slučajevima primjerice intenzivna padalina koja je nekada uzrokovala poplave 100-godišnjeg povratnog razdoblja danas ne bi poplavila isto područje. Također, primjerice uzvodne regulacije u smislu izravnavanja dovode do bržega dotoka vode u neka nizvodnija područja pa je izmijenjeno plavljenje u odnosu na ono koje možemo očekivati na temelju povijesnih hidroloških podataka.

Pri delineaciji poplavnih ravnica se, osim digitalnih modela reljefa i hidrauličkih proračuna, na mnogim projektima (neovisno jesu li rađeni za potrebe restauracije ili ne) koriste pedološke karte koje većim dijelom pokazuju dokle je dopro utjecaj poplava prilikom formiranja tala (WWF, 1999; Děd, 2013; Schwarz, 2013; Zaharia i dr., 2017).

Također, često su korištene karte staništa da bi se pronašao barem dio vegetacije u zaobalju koji odgovara vegetaciji prisutnoj prije nego što su napravljeni regulacijski radovi na vodotocima kako bi se pomoglo rekonstrukciji dosega prirodnih poplavnih voda (WWF, 1999; Henle i dr., 2006; Schwarz, 2013). Pri izradi karta staništa uglavnom se koriste daljinska istraživanja (Smith, 1997; Theiling i dr., 2012; Steinfeld i dr., 2013).

U nastavku je prikazan pregled dosadašnjih korištenih izvora podataka i metoda za definiranje (delineaciju) prirodnih poplavnih ravnica (tab. 1).

Digital terrain models, or various derivatives created by GIS analyses, are commonly used as a basis for floodplain delineation (Clubb et al., 2017; De Risi et al, 2017; Diehl et al., 2021; Samela et al., 2018; Stout and Belmont, 2013; Woznicki et al., 2019; Zaharia et al., 2017) and are often combined with hydrological/hydraulic data or flood reach models (Děd, 2013; Samela et al., 2018; Zaharia et al., 2017).

It has been noticed that hydrological and hydraulic data for determining the floodplain, which can vary significantly depending on the approach (Alfieri et al., 2014 according to Globevnik, et al., 2020), where the 100-year return period is most often taken (Eder et al., 2019) as a reference for determining the floodplain. However, sometimes underestimates occur because historical hydrological data are used, and in some cases, the hydraulic radius and slope of the watercourse bed have been significantly changed by river training works. In such cases, for example, intense rainfall that once caused floods with a 100-year return period would not flood the same area today. Also, for example, upstream river training works in terms of straightening lead to a faster flow of water into some downstream areas, so flooding has changed compared to what we can expect based on historical hydrological data.

When delineating floodplains, in addition to digital relief models and hydraulic calculations, many projects' pedological maps were used (regardless of whether they were made for restoration purposes or not), which largely show the extent to which floods have influenced soil formation (WWF, 1999; Děd, 2013; Schwarz, 2013; Zaharia et al., 2017).

Habitat maps were also used to find at least part of the vegetation on the bank that corresponds to the vegetation that existed before the regulatory works on the watercourses and to reconstruct the reach of flood waters (WWF, 1999; Henle i dr., 2006; Schwarz, 2013). When creating habitat maps, remote surveys are mainly used (Smith, 1997; Theiling i dr., 2012; Steinfeld i dr., 2013).

Below is an overview of data sources and methods used so far to define (delineate) natural floodplains (Tab 1).

Tab. 1. Pregled korištenih izvora podataka i metoda za delinaciju poplavnih ravnica
Tab. 1 Overview of data sources and methods for floodplain delineation

Podatci / Data	Literatura / Literature
karte i tematski kartografski prikazi / maps and thematic cartographic representations	topografske / topographic: (Děd, 2013), WWF (1999), povijesne / historical: Baart i dr. (2013), Guida i dr. (2015), Schoor i dr. (1999), Schwarz (2013), (WWF, 1999), tematske karte / thematic maps: geomorfološke, geološke, pedološke / geomorphological, geological, pedological: Děd (2013), WWF (1999)
daljinska istraživanja / remote sensing	Smith (1997), Steinfeld i dr. (2013), Straatsma (2013), Theiling i dr. (2012)
digitalni modeli reljefa i derivirani proizvodi / digital relief model and derived products	Clubb i dr. (2017), Děd (2013), Diehl i dr. (2021), Habersack i dr. (2015), Matt i dr. (2023), Rohde i dr. (2006), Schwarz (2013), Stout i Belmont (2013), Tcherkezova (2015), Theiling i dr. (2012), Yamazaki i dr. (2012), Zaharia i dr. (2017)
ekološke klasifikacije zemljišta i zemljišnoga pokrova / ecological classification of land and land cover	Eder i dr. (2022), Henle i dr. (2006), Hughes i dr. (2008), Schwarz (2013), WWF (2006)
hidrološki podatci i/ili hidraulički modeli / hydrological data and/or hydraulic models	Alfieri i dr. (2014 prema Globevnik i dr., 2020), Děd (2013), Eder i dr. (2022), Guida i dr. (2015), Habersack i dr. (2015), Moss i Monstadt (2008), Pavesi i dr. (2022), Theiling i dr. (2012), Zsuffa i Bogardi (1995)
geomorfološke analize ili istraživanja / geomorphological analyses or research	Děd (2013), Nanson i Croke (1992), Nardi i dr. (2006), O'Brien i dr. (2017), Tcherkezova (2015), Wierzbicki i dr. (2020), Wohl i dr. (2016)
zabilježene poplave / recorded floods	Děd (2013), Guida i dr. (2015), Samela i dr. (2018)
hidromorfološki monitoring kao podloga za referentno stanje / hydromorphological monitoring as a basis for reference condition	Brunotte i dr. (2009 prema Koenzen i dr., 2020), Schwarz (2013; 2016)

Procjene pogodnosti za restauraciju poplavnih ravnica

Područje koje će biti restaurirano često je odabrano na temelju kvalitativne argumentacije (Lóczy, 2012), tj. odabran je uvjetno „slobodan” prostor često bez intenzivnoga korištenja, a na kojem ujedno postoje određeni ekološki problemi koje bi bilo poželjno ukloniti. Radi se jednostavno o područjima čije je ekonomsko iskorištavanje skromno ili je došlo do prestanka intenzivnijega ekonomskog korištenja te se time otvorila prilika za restauracijske radove.

Assessing the potential for floodplain restoration

The area to be restored is often chosen based on qualitative argumentation (Lóczy, 2012), i.e. a conditionally “free” space is chosen, often without intensive use, and at the same time there are certain environmental problems that would be desirable to remove. These are simply areas whose economic exploitation is modest or whose more intensive economic use has ceased, thus opening an opportunity for restoration work.

U tom kontekstu odabira prostora za restauraciju korisno je definirati stanje naplavne nizine, tj. koliko je promijenjena naplavna nizina s obzirom na referentno stanje. Korisne su se pokazale hidromorfološke metodologije određivanja stanja vodotoka koje za ocjene imaju i definiranje interakcije korita i poplavnoga područja, tj. stupanj lateralne povezanosti rijeke i povezanost poplavnoga područja s rijekom, definiranje erozijskih procesa korita (usijecanje) (Schwarz, 2016), također pokazale su se korisne u praćenju uspješnosti restauracije (Belletti i dr., 2017).

U literaturi je katkad nejasno radi li se isključivo o definiranju bivših poplavnih područja ili o procjeni pogodnosti za restauraciju. Jedan je takav primjer i *Regio-FEM* (Eder i dr., 2019) koji se sastoji od četiriju glavnih „koraka” vezanih za procjenu naplavne nizine, od kojih se prvi odnosi na delineaciju poplavnoga područja, a sljedeća tri na procjenu.

Prvi kriterij za procjenu pogodnosti određena poplavnog područja za restauraciju najčešće je zemljišni pokrov u aktivnom ili neaktivnom poplavnom području koji se s obzirom na prirodnost svrstava u više ili manje pogodne za restauraciju (WWF, 1999; Negri i Casotti, 2008; Baart i dr., 2013; Schwarz, 2013, 2016). Za restauraciju se preferiraju neizgrađena područja te područja koja se ne koriste za intenzivnu poljoprivrednu proizvodnju. Preferiraju se i područja u kojima i dalje postoje zaostali prirodni elementi vodotoka kao što su zaostali stari rukavci ili dijelovi korita, prirodne šume, ostaci vlažnih livada, ostaci močvara ili cretova. Da bi se utvrdila površina i doseg navedenih područja, rade se najčešće analize povijesnih podataka, ponajprije temeljene na povijesnim kartama i zapisima (Baart i dr., 2013).

Površina je bitna u odnosu na cijelo područje, ali i oblik i položaj područja koja bi se mogla restaurirati, najviše radi moguće izvodljivosti te troškova obnove, kao što je duljina iskopa dovodnih/odvodnih kanala te izmještanje i/ili izgradnja nasipa odmaknutijih od rijeke u cilju definiranja što kompaktnijih površina (Děd, 2013; Schwarz, 2013; WWF, 1999).

In this context of choosing an area for restoration, it is useful to define the state of the floodplain, i.e. how much the floodplain has changed with respect to the reference state. Hydromorphological methodologies for determining the condition of watercourses, which have as one of the evaluations the definition of the interaction of the bed and the floodplain, i.e. the degree of lateral connection of the river and the connection of the floodplain with the river, defining erosion processes of the riverbed (incision) (Schwarz, 2016), also proved useful in monitoring the success of the restoration (Belletti et al., 2017).

In literature, it is sometimes unclear whether it is solely about the definition of former floodplains or solely about the assessment of suitability for restoration. One such example is the *Regio-FEM* (Eder et al., 2019), which consists of 4 main “steps” related to floodplain assessment, the first of which refers to the delineation of the floodplain and the next three to assessment.

Most often, the first criterion for assessing the suitability of a certain floodplain for restoration is the land cover in an active or inactive floodplain, which is classified as more or less suitable for restoration due to its naturalness (WWF, 1999; Negri i Casotti, 2008; Baart i dr., 2013; Schwarz, 2013, 2016). Undeveloped areas and areas not used for intensive agricultural production are preferred for restoration. Areas where residual natural elements of watercourses still exist, such as residual old branches or parts of riverbeds, natural forests, remnants of wet meadows, remnants of swamps or bogs, are also preferred. To determine the above areas, their area and extent, historical data analyses are most often carried out, most often based on historical maps and records (Baart et al., 2013).

Furthermore, the narrower area is important in relation to the entire area, but also the shape and position of the area that could be restored, and mostly for the sake of possible feasibility and costs of restoration, such as the length of excavation of supply/drainage channels and the relocation and/or construction of embankments further away from the river in order to define as compact an area as possible (Děd, 2013; Schwarz, 2013; WWF, 1999).

Pogodnost područja nadalje ovisi o promjenama hidroloških obilježja, odnosno koliko restauracija može dovesti do poboljšanja hidrološke situacije. Tipično se želi postići smanjenje vrha vodnoga vala, transformaciju vodnoga vala te smanjenje utjecaja nizvodno, zatim poboljšanje režima malih voda te održavanje močvarnih područja i posljedično smanjenje plavljenja urbanih ili poljoprivrednih površina. Razmatraju se i hidrauličke koristi restauracije kao što je smanjenje dubine vode, brzine otjecanja ili smanjenje posmičnoga naprezanja u vodotoku (Habersack i dr., 2015).

Iz navedenoga je vidljivo da valorizacija hidroloških, ali i hidrauličkih pogodnosti restauracije može znatno varirati i može im se dati određena subjektivna težina ovisno o cilju. Najčešće se valorizira smanjenje velikih poplavnih voda kao što je smanjenje 100-godišnjega povratnog razdoblja ako se cilja na smanjenje rizika od poplava (Habersack, 2015), što je često vrlo dobro društveno i ekonomski prihvaćeno, dok se rjeđe i manje daje važnost učestalijem povećanju plavljenja naplavne nizine, npr. kao što je to kod dvogodišnjega povratnog razdoblja iako bi tipičnoj flori i fauni u poplavnom području više značilo učestalije plavljenje. Stoga Newson (2002) opravdano upozorava na potrebu za vrlo finim i detaljnim podešavanjem budućega sustava prilikom restauracije poplavnih ravnica. Pataki (2013) ističe da je prilikom odabira bitno uvrstiti i analizu ranjivosti područja na razne čimbenike koji mogu ugroziti ekološku sastavnicu poplavnih područja kao što je usijecanje vodotoka, utjecaj klimatskih promjena, smanjenje zaliha vode i dr. Ovdje se posebno ističe rizik od sedimentacije koja može nataložiti sediment na poplavnu ravnicu i dovesti do nestanka ugroženih staništa (Asselman, 1999), a pogotovo kad su u pitanju planinske rijeke s mnogo suspendiranoga sedimenta ili, suprotno, gdje je rizik od usijecanja korita kao vjerojatno najčešći problem prilikom restauracije poplavnih područja, a nakon toga intenzitet i trajanje poplava (Pataki, 2012; Schwarz, 2013).

Prilikom definiranja potencijala za restauraciju projekt restauracije treba imati višestruke koristi od restauracije te je potrebna prioritizacija projekata (Schwarz, 2010; Schindler i dr., 2014;

The suitability of the area further depends on the changes in hydrological characteristics, i.e. how much the restoration can lead to an improvement in the hydrological situation. Typically, the aim is to reduce the peak of the water wave, transform the water wave and reduce downstream impacts, then improve the low-water regime and maintain wetlands and consequently reduce flooding of urban or agricultural areas. Furthermore, the hydraulic benefits of restoration are also considered, such as reducing water depth, runoff velocity or reducing shear stress in the watercourse (Habersack et al., 2015).

From what has been read, it is evident that the valorisation of hydrological and hydraulic benefits of restoration can vary significantly and can be given a certain subjective weight depending on the goal. The most frequent valorization is the reduction of large flood waters, such as the reduction of the 100-year return period if the goal is to reduce flood risk (Habersack, 2015), which is often very well accepted socially and economically, while less importance is given to a more frequent increase in flooding of the floodplain, e.g. as with a two-year return period, although more frequent flooding would mean more to the typical flora and fauna in the floodplain. Therefore, Newson (2002) justifiably warns and points out the need for fine and detailed adjustment of the future system during floodplain restoration. Pataki (2013) points out that when selected, it is important to include an analysis of the vulnerability of the area to various factors that can threaten the ecological component of floodplains, such as: cutting of watercourses, the impact of climate change, reduction of water supplies, etc. Here, the risk of sedimentation that can bury the floodplain and lead to the disappearance of endangered habitats is particularly emphasised (Asselman, 1999), especially when it comes to mountain rivers with a lot of suspended sediment, or vice versa, where risk from the riverbed incision is probably the most common problem during the restoration of floodplains, followed by the intensity and duration of floods (Pataki, 2012; Schwarz, 2013).

When defining the restoration potential, the restoration project should have multiple benefits from the restoration, and it is necessary to prioritise projects (Schwarz, 2010; Schindler et al., 2014;

Serra-Llobet i dr., 2022), i to na nekoliko razina (očuvanje dobroga stanja voda, poboljšanje zaštite od poplava, očuvanje ekosustava itd. (O'Brien i dr., 2017), ali i u smislu mogućega redoslijeda izvođenja. Višenamjenska rješenja posebno su korisna jer restauracija znači i poboljšanje stanja, ali i mogućnost nekih oblika iskorištavanja kao što je ispaša stoke. Dobar je primjer Yolo Bypass u Kaliforniji, gdje nakon restauracije poljoprivrednici koriste dio površina koje se katkad plave radi smanjenja rizika od poplava (Serra-Llobet i dr., 2022). U Hrvatskoj se na sličan način koriste Lonjsko i Odransko polje iako u pravom smislu nikada nijedno nije restaurirano, već su uvelike posrijedi prirodne retencije u koje se dodatno upušta ili zadržava poplavni vodni val.

Važan element prilikom procjene pogodnosti jest i usporedba troškova održavanja sadašnjega sustava naspram budućega održavanja porječja (Langhans i dr., 2014; EEA, 2017; Smith i dr., 2017; Samela i dr., 2018).

Da bi došlo do uspješne realizacije takvih projekata, potrebno je pravovremeno uključiti prostorno planiranje u razvoj restauracijskih projekata, uz koje se vežu i troškovi otkupa zemljišta radi okrupnjavanja, tj. stvaranja jedne funkcionalne cjeline prostora koji se svrsishodno može restaurirati (Rohde, 2006; Schwarz, 2010).

Nadalje, potrebno je napraviti iteraciju u prostoru prilikom ocjene pogodnosti za restauraciju (Eder i dr., 2019), a okvirni su koraci: 1. identifikacija potencijalno pogodnih područja za restauraciju na većem prostoru, 2. preliminarna procjena pogodnosti na temelju dostupnih podloga te 3. detaljna procjena pogodnosti kroz hidrauličko modeliranje, prikaz troškova i koristi te optimizaciju rješenja.

U nastavku je prikazan pregled dosadašnjih korištenih kriterija za definiranje pogodnosti za restauraciju poplavnih ravnica (tab. 2).

Budući je izazov procijeniti koliko je nizvodno ili uzvodno potrebno kvantificirati korisne učinke određene restauracije na transformaciju vodnoga vala uslijed smanjenja poplava, koliko restauracija utječe na prihranu podzemnih voda, smanjenje suša ili doprinosi driftu vodenih organizama.

Serra-Llobet et al., 2022) on several levels (preserving good water conditions, improving flood protection, preserving the ecosystem, etc. (O'Brien et al., 2017.), but also in terms of the possible order of implementation. Multi-purpose solutions are particularly useful because restoration means both improvement of the condition and the possibility of some forms of exploitation such as grazing by livestock. A good example is the Yolo Bypass in California, where after restoration, farmers use part of the areas that sometimes flood to reduce the risk of flooding (Serra-Llobet et al., 2022). In Croatia, Lonjsko and Odransko poljes are used in a similar way, although they have never been restored in a true sense, but are largely natural retentions that additionally absorb or retain flood waters.

An important element when evaluating benefits is the comparison of the costs of maintaining the current system versus future maintenance of the basin (Langhans i dr., 2014; EEA, 2017; Smith i dr., 2017; Samela i dr., 2018).

In order to achieve the successful implementation of such projects, it is necessary to timely include spatial planning in the development of restoration projects, which also involve the costs of land acquisition for the purpose of consolidating, i.e. creating one functional unit of space that can be purposefully restored (Rohde, 2006; Schwarz, 2010).

Furthermore, it is necessary to make an iteration in the space during the evaluation of potential for restoration (Eder et al., 2019) and approximate the following steps: 1. Identification of potentially suitable areas for restoration in a larger area; 2. Preliminary assessment of convenience based on available substrates; and 3. Detailed assessment of convenience through hydraulic modelling, presentation of costs and benefits and optimisation of solutions.

Below is an overview of the criteria used so far to define the benefits for the restoration of floodplains (Tab. 2).

The future challenges is to assess how far downstream or upstream it is necessary to quantify the benefits of a particular restoration on the transformation of flood potential due to flood reduction, how much restoration affects groundwater recharge, drought reduction, and contributes to aquatic organism drift.

Tab. 2. Pregled korištenih kriterija prilikom definiranja pogodnosti za restauraciju poplavnih ravnica
Tab. 2 Overview of criteria used when defining potential for floodplain restoration

Kriteriji / Criteria	Literatura / Literature
korištenje zemljišta u potencijalnoj zoni restauracije / land use in the potential restoration zone	Baart i dr. (2013), Harms i dr. (2018), Negri i Casotti (2008), Schwarz (2013; 2016), WWF (1999)
hidromorfološke značajke bivših poplavnih područja / hydromorphological features of former floodplains	Habersack i Schober (2020), Lóczy (2014), Schwarz (2013; 2016), Tcherkezova (2015), WWF (1999)
konfiguracija terena radi prikladnosti za restauraciju i zadržavanje voda / terrain configuration for suitability for restoration and water retention	Děd (2013), Harms i dr. (2018), Schwarz (2013), WWF (1999)
položaj u odnosu na zaštićena područja / the position in relation to protected areas	Harms i dr. (2018), Schwarz (2013, 2016)
hidrološke i hidrauličke koristi u smislu definiranja opsega i volumena poplavne vode / hydrological and hydraulic benefits in terms of defining the extent and volume of flood water	Downs i Thorne (2000), Eder i dr. (2019), Guida i dr. (2015), Habersack i Schober (2020), Moss i Monstadt (2008), Schober i dr. (2015), Schwarz (2016)
cijena regulacijskih i restauracijskih radova / price of regulation and restoration works	Guida i dr. (2015), Langhans (2014), Schwarz (2013, 2016)
usluge ekosustava i bioraznolikost poplavnoga područja / ecosystem services and floodplain biodiversity	Brouwer i dr. (2009), Chovanec i dr. (2003), de Nooij (2005), Fischer i dr. (2019), Jakubínský (2021), Negri i Casotti (2008), Palmer i dr. (2014), Rohde i dr. (2006), Schindler i dr. (2014), Zöckler i dr. (2001)
analiza ranjivosti ili sedimentacija / analysis of vulnerability or sedimentation	Asselman (1999), Pataki i dr. (2013)
ograničenja u prostoru / space limitations	Harms i dr. (2018)

Prilikom planiranja pogodnosti za restauraciju poplavnih područja bitno je stvoriti pokazatelj odnosa veličine vodotoka i čitavoga porječja, u smislu indeksa, koji bi pokazao koliko planirani zahvat doprinosi cijelom porječju zajedno s pripadajućim dijelom okoliša.

Zaključak

Poplavne ravnice mnogih rijeka značajno su izmijenjene raznim antropogenim utjecajima, a u novije vrijeme jača svijest o potrebi očuvanja i obnove poplavnih ravnica, prvenstveno radi bolje zaštite od poplava, ublažavanja klimatskih promjena te ekološke uloge.

And when planning the benefits of floodplain restoration, it is important to create an indicator of the relationship between the size of the watercourse and the entire basin, in the form of an index, which would show how much the planned intervention contributes to the entire basin together with the associated parts of the environment.

Conclusion

The floodplains of many rivers have been significantly altered by various anthropogenic influences, and recently there has been a growing awareness of the need to preserve and restore floodplains, primarily for better flood protection, climate change mitigation and their ecological role.

Europska je unija donošenjem zakona i financiranjem doprinijela razvoju inicijativa koje su povezane s restauracijom vodotoka odnosno prirodnih poplavnih područja te stvaranju edukacijske dokumentacije o restauracijama vodotoka i poplavnih ravnica.

Metode delinacije poplavnih ravnica razvijale su se od jednostavnih npr. pomoću karata i dosega zabilježenih poplava prema kompleksnim koji uključuju višekriterijske analize i hidrauličke modele kako bi se što točnije odredila poplavna ravnica.

Korištenjem i kombinacijom različitih dostupnih podloga mogu se postići svrsishodniji rezultati u identifikaciji i analizama pogodnosti područja za restauraciju. Kako bi restauracija poplavne ravnice bila što uspješnija bitno je prilagoditi se istraživanom području i uzeti u obzir specifičnu problematiku područja koja je proizašla iz fizičko-geografskih obilježja područja te povijesnih okolnosti.

The European Union, through legislation and funding, has contributed to the development of initiatives related to the restoration of watercourses and natural floodplains, and the creation of educational documentation on the restoration of watercourses and floodplains.

Floodplain delineation has evolved from simple methods using maps and recorded floods to complex models that include multi-criteria analyses and hydraulic models in order to determine the floodplain as accurately as possible.

By using and combining different available datasets more appropriate results can be achieved in the identification and analysis of the suitability of areas for restoration. To make floodplain restoration as successful as possible it is important to adapt to the research area and the specific problems of the area that have arisen from the physical and geographical characteristic of the area and historical circumstances.

- Alferi, L., Salamon, P., Bianchi, A., Neal, J., Bates, P., Feyen, L., 2014: Advances in pan-European flood hazard mapping, *Hydrological Processes*, 28, 4067–4077, DOI: 10.1002/hyp.9947
- Asselman, N. E.M., 1999: The use of floodplain sedimentation measurements to evaluate the effects of river restoration works, in: *Floodplains: Interdisciplinary Approaches*, (eds Marriott. S. B., Alexander, J.) The Geological Society, London, 111-122
- Baart, I., Hohensinner, S., Zsuffa, I., Hein, T., 2013: Supporting analysis of floodplain restoration options by historical analysis, *Environmental Science & Policy*, 34, 92–102
- Belletti, B., Nardi, L., Rinaldi, M., i dr., 2018: Assessing Restoration Effects on River Hydromorphology Using the Process-based Morphological Quality Index in Eight European River Reaches, *Environmental Management* 61, 69–84, doi.org/10.1007/s00267-017-0961-x
- Blackwell, M. S. A., Maltby, E., Gerritsen, A. L., Haasnoot, M., Hoffmann, C. C., Kotowski, W., Leenen, E. J. T. M., Okruszko, T., Penning, W. E., Piorkowski, H., Platteeuw, M., Querner, E. P., Siedlecki, T., & de Swart, E. O. A. M., 2005: *Ecoflood guidelines: how to use floodplains for flood risk reduction*. Ecoflood Project, https://d3n8a8pr07vhm.cloudfront.net/yyccares/pages/20/attachments/original/1498666598/EU__ecoflood_Guidelines__HOW_TO_USE_FLOODPLAINS_FOR_FLOOD_RISK_REDUCTION_compressed.pdf?1498666598 (1.12.2023.)
- Boughton, D. A., Pike, A. S., 2013: Floodplain Rehabilitation as a Hedge against Hydroclimatic Uncertainty in a Migration Corridor of Threatened Steelhead, *Conservation Biology*, 27 (6), 1158–1168
- Brouwer, R., Bliem, M., Flachner, Zs., Getzner, M., Kerekes, S., Milton, S., Palarie, T., Szerényi, Zs., Vadineanu, A., Wagtendonk, A., 2009: Ecosystem Service Valuation from Floodplain Restoration in the Danube River Basin, in: *17th Annual Conference of the European Association of Environmental and Resource Economists* at: Amsterdam, Netherlands
- Browder, G., Ozment, S., Rehberger Beskos, I., Gartner, T., Lange, G.-M., 2019: *Integrating Green and Gray: Creating Next Generation Infrastructure*, World Bank and World Resources institute, Washington, DC
- Buijse, A. D., Coops, H., Staras, M., Jans, L. H., van Geest, G. J., Griff, R. E., Ibelings, B. W., Oosterberg, W., Roozen, F. C. J. M., 2002: Restoration strategies for river floodplains along large lowland rivers in Europe, *Freshwater Biology*, 47 (4), Blackwell Science Ltd.
- Chovanec, A., Waringer, J., Straif, M., Graf, W., Reckendorfer, W., Waringer-Löschenkohl, A., Waidbacher, H., Schultz, H., 2003: The Floodplain Index - a new approach for assessing the ecological status of river/floodplain-systems according to the EU Water Framework Directive, *Large Rivers*, 15 (1-4), 169-185
- Clubb, F. J., Mudd, S. M., Milodowski, D. T., Valters, D. A., Slater, L. J., Hurst, M. D., and Limaye, A. B.: Geomorphometric delineation of floodplains and terraces from objectively defined topographic thresholds, *Earth Surf. Dynam.*, 5, 369-385, <https://doi.org/10.5194/esurf-5-369-2017>, 2017.
- De Nooij, R. J. W., Hendriks, H. W. M., Leuven, R. S. E. W., Lenders, H. J. R., Nienhuis, P. H., 2003: Evaluation of floodplain rehabilitation: a comparison of ecological and policy-based biodiversity assessment, *Large Rivers*, 15 (1-4), 413-424

Literatura References

- De Risi, R., Jalayer, F., De Paola, F. et al., 2018: Delineation of flooding risk hotspots based on digital elevation model, calculated and historical flooding extents: the case of Ouagadougou., *Stoch Environ Res Risk Assess* 32, 1545–1559, <https://doi.org/10.1007/s00477-017-1450-8>
- Déd, M., 2013: Hydrogeomorphological method of floodplain delineation, *Geographia Technica*, 8 (2), 13–22
- Diehl, R., Gourevitch, J., Drago, S., Wemple, B., 2021: Improving flood hazard datasets using a low-complexity, probabilistic floodplain mapping approach, *PLOS ONE*. 16, e0248683. 10.1371/journal.pone.0248683
- Dufour, S., Piégay, H., 2009: From the myth of a lost paradise to targeted river restoration: forget natural references and focus on human benefits, *River Research and Applications*, 25, 568–581
- Downs, P. W., Thorne, C. R., 2000: Rehabilitation of a lowland river: Reconciling flood defence with habitat diversity and geomorphological sustainability, *Journal of Environmental Management* 58, 249–268
- Dworak, T., 2008: Flood risk management and floodplain restoration in Europe: recent policy developments at EU level, in: Moss t., Mondstadt J. (ed.): *Restoring Floodplains in Europe*, London, IWA Publishing, 47–60.
- Eder, M., Herrnegger, M., Hognl, K., Löschner, L., Nordbeck R, Scherhauser P, Schober, B., Seher, W., Wesemann, J., Zahnt, N., Habersack, H.: RegioFEM: A Novel River-Basin Approach for Regional Flood Risk Management, in: *International Association for Hydro-Environment Engineering and Research -IAHR*, editor. IAHR World Congress Proceedings. 2019.
- Eder, M., Perosa, F., Hohensinner, S., & Tritthart, M., Scheuer, S., Gelhaus, M., Cyffka, B., Kiss, T., Van Leeuwen, B., Tobak, Z., Sipos, G., Csikós, N., Smetanová, A., Bokal, S., Samu, A., Gruber, T., Gálie, A., Moldoveanu, M., Mazilu, P., Habersack, H., 2022: How Can We Identify Active, Former, and Potential Floodplains? Methods and Lessons Learned from the Danube River, *Water* 14, 15, 10.3390/w14152295
- Evaluation of Wetlands and Floodplain Areas in the Danube River Basin Final Report, *Danube- WWF-Auen-Institut*,
- 1999, <https://www.icpdr.org/main/sites/default/files/EVALUATIONWETLANDSFLOODPLAINAREAS.pdf> (10.6.2016)
- European Environment Agency, (EEA), 2015: *Exploring Nature-Based Solutions: the role of green infrastructure in mitigating the impacts of weather and climate change-related natural hazards*, Publications Office, <https://data.europa.eu/doi/10.2800/946387>
- European Environment Agency (EEA), 2016: *Flood risks and environmental vulnerability; Exploring the synergies between floodplain restoration, water policies and thematic policies*, EEA Report No 1/2016; 78pp. ISBN 978-92-9213-716-8, DOI: 10.2800/039463
- European Environment Agency (EEA), 2017: *Green infrastructure and flood management : promoting cost-efficient flood risk reduction via green infrastructure solutions*, Publications Office, <https://data.europa.eu/doi/10.2800/324289>
- European Environment Agency (EEA), 2019: *Floodplains: a natural system to preserve and restore*, EEA Report No 24/2019, DOI: 10.2800/431107
- Fischer, C., Damm, C., Foeckler, F. & Gelhaus, M., & Gerstner, L., Harris, R., Hoffmann, T., Iwanowski, J., Kasperidus, H., Mehl, D., & Podschun, S., & Rumm, A., Stammel, B., Scholz, M., 2019: The „Habitat Provision“ Index for Assessing Floodplain Biodiversity and Restoration Potential as an Ecosystem Service-Method and Application, *Frontiers in Ecology and Evolution*, 7, 483, <https://doi.org/10.3389/fevo.2019.00483>
- Gilvear, D.J., Spray, Chris & Casas-Mulet, Roser., 2013: River rehabilitation for the delivery of multiple ecosystem services at the river network scale, *Journal of environmental management*. 126C. 30–43. 10.1016/j.jenvman.2013.03.026.
- Globevnik, L., Januschke, K., Kail, J., Snoj, L., Manfrin, A., Azlak, M., Christiansen, T., Birk, S., 2020: *Preliminary assessment of river floodplain condition in Europe*, ETC/ICM Technical Report 5/2020: European Topic Centre on Inland, Coastal and Marine waters, 121 pp.
- Green Infrastructure Guide for Water Management: Ecosystem-Based Management Approaches for Water-Related Infrastructure Projects*, United Nations Environment Programme, International Union for Conservation of Nature (IUCN), The Nature Conservancy (TNC), World Resources Institute (WRI), and U.S. Army Corps of Engineers. 2014, <https://wedocs.unep.org/bitstream/handle/20.500.11822/9291/-Green%20infrastructure%3a%20guide%20for%20water%20management%20%20-2014unep-dhigroup-green-infrastructure-guide-en.pdf?sequence=3&i=Allowed=y> (10.9.2025)
- Guida, R. J., Swanson, T. L., Remo, J. W. F., Kiss, T., 2015: Strategic floodplain reconnection for the Lower Tisza River, Hungary: Opportunities for flood-height reduction and floodplain-wetland reconnection, *Journal of Hydrology*, 521, 274–285
- Habersack H., Hauer C., Schober, B., Dister, E., Quick, I., Harms, O., Wintz, M., Piquette, E., Schwarz, U., 2008: Flood risk reduction by PReserving and restOring river FLOODPLAINs—PRO_FLOODPLAIN, in: *Floodrisk*, Oxford, UK
- Habersack, H., Schober, B., Hauer, C., 2015: Floodplain evaluation matrix (FEM): An interdisciplinary method for evaluating river floodplains in the context of integrated flood risk management, *Natural Hazards*, 75, 5–32
- Habersack, H., Schober, B., 2020: Floodplain evaluation matrix: A multiparameter assessment methodology, *Journal of Flood Risk Management*, 13, 3, <https://doi.org/10.1111/jfr3.12614>
- Harms, O., Dister, E., Gerstner, L., Damm, C., Egger, G., Heim, D., Günther-Diringer, D., Koenzen, U., Kurth, A., Modrak, P., 2018: *Potenziale zur naturnahen Auenentwicklung. Bundesweiter Überblick und methodische Empfehlungen für die Herleitung von Entwicklungszielen*. Bundesamt für Naturschutz, Bonn. <https://www.bfn.de/fileadmin/BfN/service/Dokumente/skripten/Skript489.pdf> (1.9.2025)
- Henle, K., Scholz, M., Dziock, F., Stab, S., Foeckler, F., 2006: Bioindication and Functional Response in Floodplain Systems: Where to from Here?, *International Review of Hydrobiology*, 91, 380–387
- Hughes, F.M.R. (ed.), 2003: *The Flooded Forest: Guidance for policy makers and river managers in Europe on the restoration of floodplain forests*, FLOBAR2,

- Department of Geography, University of Cambridge, UK
- Hughes, F.M.R., Moss, T., Richards K. S., 2008: Uncertainty in Riparian and Floodplain Restoration in: *River Restoration Managing the Uncertainty in Restoring Physical Habitat*, (eds. Darby, S., Sear, D.), John Wiley & Sons Ltd, West Sussex
- Jakubínský, J., Prokopová, M., Raška, P., Salvati, L., & Bezak, N., Cudlín, O., Cudlín, P., & Purkyt, J., Vezza, P., & Camporeale, C., & Danek, J. & Pástor, M., Lepeška, T., 2021: Managing floodplains using nature-based solutions to support multiple ecosystem functions and services, *WIREs Water*, 8. 10.1002/wat2.1545.
- Junk, W.J., Bayley, P.B. and Sparks, R.E., 1989: The flood-pulse concept in river-floodplain systems, in: *Proceedings of the International Large River Symposium (LARS)*, (eds. Dodge, D.P.), Canadian Journal of Fisheries and Aquatic Sciences Special Publication 106, NRC research press, Ottawa, 110-127.
- Koenzen, U., 2005: *Fluss- und Stromauen in Deutschland. Typologie und Leitbilder*, *Angewandte Landschaftsökologie* 65., Bonn-Bad Godesberg
- Koenzen, U., Kurth, A., Mach, S., Modrak, P., Gohrbandt, S., Ackermann, W., Ruff, A. & Diringner, D.-G., 2020: *Anleitung für die Erfassung und Bewertung des Auenzustandes an Flüssen. Band 1: Grundlagen und Vorgehensweise.* – Bonn-Bad Godesberg (Bundesamt für Naturschutz). – BfN-Skripten 548, 123 S
- Langhans, S.D., Hermoso, V., Linke, S., Bunn, S.E., Possingham H.P., 2014: Cost-effective river rehabilitation planning: optimizing for morphological benefits at large spatial scales, *Journal of Environmental Manage*, doi: 10.1016/j.jenvman.2013.11.021.
- Leyer, I., Mosner, E., Lehmann, B., 2012: Managing floodplain-forest restoration in European river landscapes combining ecological and flood-protection issues. *Ecological applications*: a publication of the Ecological Society of America. 22, 240-9. 10.2307/41416756.
- Lóczy, D., 2012: Floodplain rehabilitation schemes: Example of the Kapos floodplain, Hungary, *2nd International Conference - Water resources and wetlands*, (eds. Găștescu P. et al.), Tulcea, Romania
- Marojević, Ž., Šustić, D., 2025: Mogućnosti šire implementacije mjera zelene infrastrukture u smanjenju rizika od poplava, u: *Upravljanje rizicima od poplava u Hrvatskoj* (ur: Biondić, D., Holjević, D.) Hrvatske vode, Vinkovci, Hrvatska, 87-99
- Matt, J. E., Underwood, K. L., Diehl, R. M., Lawson, K. S., Worley, L. C., & Rizzo, D. M., 2023: Terrain-derived measures for basin conservation and restoration planning, *River Research and Applications*, 39(9), 1795–1811. <https://doi.org/10.1002/rra.4181>
- Moss, T., Monstadt, J., 2008: Coping with complexity: lessons for policy development, project management and research, in: *Restoring Floodplains in Europe: Policy Contexts and Project Experiences*, (eds. Moss, T., Monstadt, J.), IWA Publishing, London, 317-337.
- Nardi, F., Vivoni, E. R., Grimaldi, S., 2006: Investigating a floodplain scaling relation using a hydrogeomorphic delineation method, *Water Resources Research*, 42(9)
- Nanson, G.C., Croke, J.C., 1992: A genetic classification of floodplains, *Geomorphology*, 4, 459-486
- Nanson, G., Croke, J., 2002: Emerging issues in flood plain research, *The Structure, Function and Management Implications of Fluvial Sedimentary Systems*, Proceedings of an international symposium, Alice Springs, Australia, September 2002). IAHS Publ. no. 276
- Negri, P., Casotti, V., 2008: The Mosaic Evaluation System (MOS.E.S): A GIS based tool to support floodplain restoration, in: *4th International conference on river restoration* (ed. Pra Levis.,F), European Centre for River Restoration, Venice, Italy
- Newson, M.D., 2002: Geomorphological concepts and tools for sustainable river ecosystem management, *Aquatic Conserv: Mar. Freshw. Ecosyst.*, 12: 365-379. <https://doi.org/10.1002/aqc.532>
- O'Brien, G. R., Wheaton, J., Fryirs, K., McHugh, P., Bouwes, N., Brierley, G., & Jordan, C., 2017: A geomorphic assessment to inform strategic stream restoration planning in the Middle Fork John Day Watershed, Oregon, *USA. Journal of Maps*, 13(2), 369-381. <https://doi.org/10.1080/17445647.2017.1313787>
- Opperman, J.J., Galloway, G.E., Fargione, J., Mount, J.F., Richter, B.D., Secchi, S., 2009: Sustainable floodplains through large-scale reconnection to Rivers, *Science*, 326, 1487-1488
- Opperman, J.J., Galloway, G.E., and Duval, S., 2013. The multiple benefits of river-floodplain connectivity for people and biodiversity, in: *Encyclopedia of biodiversity, 2nd ed.*, Volume 7, ed. Levin S.A., Academic Press, Waltham, Massachusetts, 144-160.
- Pahl-Wostl, C., 2006: The importance of social learning in restoring the multifunctionality of rivers and floodplains, *Ecology and Society*, 11, 1-10
- Palmer, M.A., Bernhardt, E.S., Allan, J. D., Lake, P.S., Alexander, G. Brooks, S., Carr, J. and Clayton, S., Dahm, C. N., Follstad Shah, J., Galat, D. L. and Loss, S. G. and Goodwin, P., Hart, D.D., Hassett, B., Jenkinson, R., Kondolf, G.M., Lave, R., Meyer, J.L., O'Donnell, T.K., Pagano, L., Sudduth, E., 2005: Standards for ecologically successful river restoration, *Journal of Applied Ecology*, 42, 208-217
- Palmer, M. A., Filoso, S., Fanelli, R. M., 2014: From ecosystems to ecosystem services: Stream restoration as ecological engineering, *Ecological Engineering*, 65, 62-70
- Pataki, B., Zsuffa, I., Hunyady, A., 2013: Vulnerability assessment for supporting the revitalisation of river floodplains, *Environmental Science & Policy*, 34, 69-78
- Pavesi, L., D'Angelo, C., Volpi, E., Fiori, A. 2022: RESCUE: A geomorphology-based, hydrologic-hydraulic model for large-scale inundation mapping, *Journal of Flood Risk Management*, 15(4), e12841, <https://doi.org/10.1111/jfr3.12841>
- Rohde, S., Hostmann, M., Peter A., Ewald, K.C., 2006: Room for rivers: An integrative search strategy for floodplain restoration, *Landscape and Urban Planning*, 78, 50-70
- Samela, C., Albano, R., Sole, A., Manfreda, S., 2018: A GIS tool for cost-effective delineation of flood-prone areas, *Computers, Environment and Urban Systems*, 70. 10.1016/j.compenvurbssys.2018.01.013.
- Schindler, S., Sebesvari, Z., Damm, C., Euler, K., Mauerhofer, V., Schneider

- gruber, A., Biro M., Essl, F., Kanka, R., Lauwaars, S. G., Schulz-Zunkel, C., van der Sluis, T., Kropik, M., Gasso, V., Krug, V., Pusch, M. T., Peter Zülka, K., Lazowski, W., Hainz-Renetzeder, C., Henle, K., Wrška, T., 2014: Multifunctionality of floodplain landscapes: relating management options to ecosystem services, *Landscape Ecology* 29 (2), 229–244
- Schneider, E., 2010: Floodplain Restoration of Large European Rivers, with Examples from the Rhine and the Danube, in: *Restoration of Lakes, Streams, Floodplains, and Bogs in Europe – Principles and Case Studies* (eds. Eiseltova M.,) 185–223, Springer Netherlands. doi:10.1007/978-90-481-9265-6_11
- Schober, B., Hauer, C., Habersack, H., 2015: A novel assessment of the role of Danube floodplains in flood hazard reduction (FEM method), *Natural Hazards*, 75 (1), 35–50
- Schoor, M.M., Wolfert, H. R., Maas G. J., Middelkoop, H., Lambeek, J. J. E., 1999: Potential for floodplain rehabilitation based on historical maps and present-day processes along the River Rhine, The Netherlands, *Geological Society London Special Publications*, 163 (1), 123–137
- Schwarz, U., 2010: Assessment of the restoration potential along the Danube and main tributaries, For WWF International Danube-Carpathian Programme, 58 pp. Vienna, http://awsassets.panda.org/downloads/wwf_restoration_potential_danube.pdf, (1.12.2023.)
- Schwarz, U., 2013: Assessment of the restoration potential in the transboundary Unesco Biosphere Reserve “Mura–Drava–Danube”. for WWF Austria, Vienna, 167 pp., https://www.amazon-of-europe.com/wp-content/uploads/2024/09/mdd_restpot_05_02_2014web.pdf, (1.10.2025.)
- Schwarz, U., 2016: Sava White Book. The River Sava: Threats and Restoration Potential. Radolfzell/Wien: EuroNatur/Riverwatch, https://balkanrivers.net/sites/default/files/01_SavaWhite%20Book%20Study.pdf, (1.12.2023.)
- Serra-Llobet, A., Jähnig, S.C., Geist, J., Kondolf, G.M., Damm, C., Scholz, M., Lund, J., Opperman, J.J., Yarnell, S.M., Pawley, A., Shader, E., Cain, J., Zingraff-Hamed, A., Grantham, T.E., Eisenstein, W., Schmitt, R., 2022: Restoring Rivers and Floodplains for Habitat and Flood Risk Reduction: Experiences in Multi-Benefit Floodplain Management From California and Germany, *Frontier of Environmental Science*, 9:778568. doi: 10.3389/fenvs.2021.778568
- Smith, D.L., Miner, S. P., Theiling, C.H., Behm, R., Nestler, J. M., 2017: *Levee setbacks : an innovative, cost-effective, and sustainable solution for improved flood risk management*, (ERDC/EL SR-17-3., U.S. Army Engineer Research & Development Center (ERDC), <https://apps.dtic.mil/sti/pdfs/AD1036398.pdf> (1.10.20225)
- Smith, L. C., 1997: Satellite Remote Sensing of River Inundation Area, Stage, and Discharge: A Review, *Hydrological Processes*, 11, 427–1439
- Steinfeld, C. M. M., Kingsford, R. T. and Laffan, S. W., 2013: Semi-automated GIS techniques for detecting floodplain earthworks, *Hydrological Processes*, 27 (4), 579–591.
- Stoffers, T., Collas, F.P.L., Buijse, A.D., Geerling, G.W., Jans, L.H., van Kessel, N., Verreth, J.A.J., Nagelkerke, L.A.J., 2021: 30 years of large river restoration: How long do restored floodplain channels remain suitable for targeted rheophilic fishes in the lower river Rhine?, *Science of The Total Environment*, Volume 755, Part 1
- Stout, J.C., Belmont, P., 2013: TerEx Toolbox for semi-automated selection of fluvial terrace and floodplain features from LiDAR., *Earth Surface Processes and Landforms*, 39, 569–580.
- Straatsma, M.W., van der Perk, M.; Schipper, A.M., de Nooij, R.J.W., Leuven, R.S.E.W., Huthoff, F., Middelkoop, H., 2013: Uncertainty in hydromorphological and ecological assessments of lowland river floodplains resulting from land cover classification errors, *Environmental Modelling and Software*, 42, 17–29
- Strosser, P., Delacámara, G., Hanus, A., Williams, H., Jaritt, N., 2015: *A guide to support the selection, design and implementation of Natural Water Retention Measures in Europe: Capturing the multiple benefits of nature-based solutions*, Directorate-General for Environment, Bruxelles.
- Szałkiewicz, E., Jusik, S., Grygoruk, M., 2018: Status of and Perspectives on River Restoration in Europe: 310,000 Euros per Hectare of Restored River, *Sustainability*, 10, 129.
- Tcherkezova, E., 2015: Gis-based delineation and regionalization of geomorphographic units in the floodplain of Ogosta river between the settlement Gavril Genovo and the “Ogosta” reservoir (NW-Bulgaria), *Problems of Geography*, 1–2, Bulgarian Academy of Sciences, Sofia
- Theiling, C. H., Arthur Bettis E., Heitmeyer, M. E., 2012: Hydro-Geomorphic Classification and Potential Vegetation Mapping for Upper Mississippi River Bottomland Restoration, in: *Studies on Environmental and Applied Geomorphology*, (eds. Piacentini, T., Miccadei, E.), InTech, Rijeka, 163–190
- Thorpe, J.H., Thoms, M.C., Delong, M.D., 2006. The riverine ecosystem synthesis: biocomplexity in river networks across space and time. *River. Res. App.* 22, 123–147.
- Tockner, K., Stanford, J. A., 2002: Riverine flood plains: present state and future trends, *Environmental Conservation*, 29 (3), 308–330
- Wierzbicki, G., Ostrowski, P., Falkowski, T., 2020: Applying floodplain geomorphology to flood management (The Lower Vistula River upstream from Plock, Poland), *Open Geosciences*, 12(1), 1003–1016. <https://doi.org/10.1515/geo-2020-0102>
- Wohl, E., Mersel M., Allen, A., Fritz, K., Kichefski, S., Lichvar, R., Nadeau, T., Topping, B., Trier, P., Vanderbilt, F.: *Synthesizing the scientific foundation for ordinary high water mark delineation in fluvial systems*, U.S. Army Corps of Engineers, Galveston, Texas, 2016.
- Woznicki, S.A., Baynes, J., Panlasigui, S., Mehaffey, M., Neale, A., 2019 : Development of a spatially complete floodplain map of the conterminous United States using random forest, *Sci Total Environ*, 647:942–953. doi: 10.1016/j.scitotenv.2018.07.353. Epub 2018 Jul 25. PMID: 30180369; PMCID: PMC8369336.
- Wren, E., Barnes, M., Janes, M., Kitchen, A., Nutt, N., Patterson, C., Piggott, M., Robins, J., Ross, M., Simons, C., Taylor, M., Timbrell, S., Turner, D., Down, P., 2022: *The natural flood management manual*, CIRIA C802, London, UK (ISBN: 978-0-86017-945-0)

- Yamazaki, D., Baugh, C.A., Bates, P.D., Kanae, S., Alsdorf, D.E., Oki T., 2012: Adjustment of a spaceborne DEM for use in floodplain hydrodynamic modeling, *Journal of Hydrology*, 436-437, 81-91
- Zaharia, L., Costache, R., Prăvălie, R., Ioana-Toroimac, G., 2017: Mapping flood and flooding potential indices: a methodological approach to identifying areas susceptible to flood and flooding risk. Case study: the Prahova catchment (Romania), *Front. Earth Sci.*, 11: 229., <https://doi.org/10.1007/s11707-017-0636-1>
- Zsuffa, I., Bogardi, J. J., 1995: Floodplain Restoration by Means of Water Regime Control, *Physics and Chemistry of the Earth*, 20 (3) Europe, in: *Proceedings of the conference on River Restoration*, (eds. H.J. Nijland M.J.R. Cals), Wageningen, The Netherlands, Institute for Inland Water Management and Waste Water Treatment/RIZA Lelystad
- Zöckler, C., E. Wenger, J. Madgwick, 2001: Assessment of WWF River and Floodplain Restoration Projects in

2006 *Floods in the Danube River Basin - Flood risk mitigation for people living along the Danube: The potential for floodplain protection and restoration*, WWF, 2006, https://wwfeu.awsassets.panda.org/downloads/2006_floods_in_the_danube_river_basin_wwf_working_paper.pdf (1.10.2025)

Communication from the Commission to the European Parliament, The Council, the European Economic and Social Committee and the Committee of the Regions, 2012: Blueprint to Safeguard Europe's Water Resources, *EUR-Lex*, <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52012DC0673#> (1.10.2025)

Europska komisija / European Commission, 2000: Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy. *Official Journal L 327*, Brussels.

Europska komisija / European Commission, 2007: Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks. *Official Journal of the European Union L 288/27*, Brussels.

Europska komisija / European Commission, 2020: EU Biodiversity Strategy for 2030 Bringing nature back into our lives, *EUR-Lex*, <https://eur-lex.europa.eu/legal-content/HR/TXT/?uri=CELEX:52020DC0380> (1.10.2025)

Regulation (EU) 2024/1991 of the European parliament and of the Council of 24 June 2024 on nature restoration and amending Regulation (EU) 2022/869 *Official Journal of the European Union*, 2024, <https://eur-lex.europa.eu/eli/reg/2024/1991/oj> (1.10.2025)

M. Plantak
D. Orešić

**Restauracija
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**Izvori
Sources**

**Autori
Authors**

Mladen Plantak (dopisni autor) mplantak@net.hr
mag. geogr., i mag. educ. geogr., Elektroprojekt d.d., Alexandera von Humboldta 4,
10000 Zagreb, Hrvatska

Danijel Orešić doresic@geog.pmf.hr
prof. dr. sc., Sveučilište u Zagrebu, Prirodoslovno-matematički fakultet, Geografski odsjek, Trg Marka Marulića 19,
10000 Zagreb, Hrvatska