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RIVER - THE BLOODSTREAM OF LANDSCAPE AND CATCHMENT

REKA – ŽIVLJENJSKI TOK KRAJINE IN POREČJA

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Abstract

Rivers are among the most important of planetary water resources. Over the past 50 years, rivers have suffered the single most intense onslaught of all planetary ecosystems. Pressures caused by human as well as natural factors on river ecosystems unstoppably increase. In order to mitigate negative consequences, it is of crucial importance to understand the deep and complex relationship between river morphology, hydrology and ecology. The paper treats river as a crucial part of the environment. Special attention is given to the role of riparian zone, hyporheic zone and floodplain on ecological processes. The role of ecohydrology as a new and promising interdisciplinary scientific field is explained. Furthermore, two very different roles of floods are discussed. From one point of view, a flood represents a very dangerous and devastating event, whereas from the other, it brings many benefits particularly for ecological variability and soil fertility. Finally, the role of dams and levees is discussed.

Keywords: river, riparian zone, hyporheic zone, floodplain, ecohydrology, dam, levee.

Izvleček

Reke so eden najpomembnejših vodnih virov na Zemlji. V zadnjih 50 letih so med vsemi zemeljskimi ekosistemi prav reke utrpele največ škode. Pritiski kot posledica vpliva umetnih in naravnih dejavnikov na ekosisteme rek neustavljivo naraščajo. Za ublažitev negativnih posledic je ključno razumevanje zapletenih povezav med rečno morfologijo, hidrologijo in ekologijo. Reke obravnavamo kot ključni del okolja. Posebno pozornost namenjamo vlogi obrežnega območja, hiporeične cone in poplavnih območij v povezavi z ekološkimi procesi. V članku razložimo vlogo ekohidrologije kot novega in obetavnega interdisciplinarnega znanstvenega področja. Nadalje obravnavamo dve zelo različni vlogi poplav. Po eni strani so poplave zelo nevarni dogodki s hudimi posledicami, po drugi strani pa prinašajo veliko koristi, predvsem za biotsko raznolikost in rodovitnost tal. Nazadnje obravnavamo tudi vlogo pregrad in nasipov.

Ključne besede: reka, obrežni pas, hiporeična cona, poplavno območje, ekohidrologija, pregrada, nasip.

MOTTO: We are guests on Earth.

Our function is to protect it for the next generations.

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1. Introduction

The term river used in this paper refers to larger and smaller (streams or creaks) as well as permanent and intermittent paths of moving surface water.

Planetary water resources are under severe stress. They are significantly affected by global change, which involves more than just climate change. The major drivers of global change are: (1) population growth; (2) climate change and/or variability; (3) uncontrolled and unsustainable urbanization, industrialization and agricultural activities; (4) expansion of infrastructure; (5) massive land use change; (6) massive pollution; (7) unsustainable water resources management; (8) massive deforestation; (9) wetlands drying up, and many others.

Within the totality of the planetary water resources, rivers play one of the most important roles. Rivers have greatly influenced human activities and civilizations over the millennia. They are a crucial component of the hydrologic cycle, due to dynamic and permanent water transport across continents. A vast majority of people worldwide rely on water circulating through rivers as their primary source of water for drinking, food, energy and other goods production. Rivers are also important for sustaining water cycling in lakes, wetlands and aquatic ecosystems in general.

Boon et al. (2000) argue that rivers have suffered the single most intense onslaught of all the world's ecosystems over the past 50 years. As the main problems in river management, they stress the following activities: (1) overconsumption of water and biota; (2) manipulation of natural droughts and floods; (3) organic and industrial pollution on varying but often very large scale; (4) manipulation of flow regimes for water supply and redistribution; (5) channelization and containment in the name of flood control due to land reclamation; (6) mining river beds and banks for alluvial minerals, fill and aggregate. We should be very much aware that pressures from both anthropogenic and natural causes on river environmental systems unstoppably increase. Human activity has profoundly affected rivers across the globe to such an extent that it is now extremely difficult to find a river that has not been altered in some way.

The comforting prospect is that Riverwatch and EuroNatur, a German NGO, launched the Save the Blue Heart of Europe campaign in 2013. The goal of the campaign is to protect all the rivers running between Slovenia and Albania, as they are the most intact ones on the entire European continent. These two organizations claim that the Balkan rivers represent a hidden European treasure. About 30% of all river beds in the region are in pristine, or near natural state, and another 50% are in good or satisfying morphological condition (RiverWatch, 2016). The author agrees that it is extremely important to preserve the Balkan rivers, but a big question is how to go about achieving this goal.

The main objective of this paper is to stress the extreme importance and irreplaceability of rivers in all physical and biological aspects of their broader landscape and catchments. The understanding of the complex relationship between river hydrology and geomorphology regimes and the related biological community might contribute to better management and conservation of unique riverine ecosystems and resources. They play a crucial role in Earth's sustainable development, and are in grave danger today.

2. River as a crucial part of the environment

Knowledge of the basic morphological (landforms) and ecological (distributions of organisms and ecosystem processes) interactions between a river bed and the associated floodplain, and how morphological and ecological processes are driven by the flow regime, is fundamental to sustainable development of rivers.

Rivers are dynamic systems with changes occurring over a range of time scales, from instantaneous to geological ones. Adjustment of bed form is of interest both to geomorphologists studying the behaviour of natural rivers over long periods and to hydraulic engineers concerned with shorter-term changes affecting channel stability near bridges, dams and property boundaries. Ecologists, who study the evolution, distribution and interaction of organisms and their adaptations to the environment, are concerned with both long-term changes, which form and re-form habitats, and the short-term fluctuations which have a more immediate impact (Gordon et al., 2004).

Physical factors in open-stream watercourses of essential importance to biota are: (1) current (discharge, velocity, depth of water, channel and near flow environment, boundary layers); (2) substrate; (3) temperature; (4) oxygen. The most important ecological areas in the open stream watercourses are (Fig. 1): (1) river bed; (2) hyporheic zone; (3) floodplain; (4) riparian zone; (5) zone of riparian influence.

2.1 Riparian zone

A green zone along the river bed, known as the riparian zone, represents a zone of life. It spreads at the interface between land and a flowing surface water body influencing the entire ecosystem. Plant communities along the river margins, called riparian vegetation, are characterized by hydrophilic plants. Riparian zones are transitional areas at the interplay of terrestrial and freshwater ecosystems, with distinctive soil, hydrology and biotic conditions strongly influenced by the streamflow (Naiman et al., 2005). In this way, riparian zones refer not only to floodplains and wetlands, but also include uplands where a direct water-land interaction is important. The concept and definitions are described in detail elsewhere (Clerici et al., 2011; Clerici et al., 2013). Riparian zones provide shelter to aquatic and terrestrial animals by limiting water contamination, slowing the water down, filtering the sediments and debris, and shading the water. Riparian zones are significant in ecology, environmental management, and civil engineering due to their role in soil conservation, their biodiversity, and their influence on aquatic ecosystems.

There are many forms of riparian zones such as grassland, woodland, wetland or even non-vegetative zones. Each organism in a riparian zone has its own important role or niche. Riparian zones are easily affected by natural and human-induced changes, such as spring flooding, destruction of vegetation by cattle, or diverse human activities.

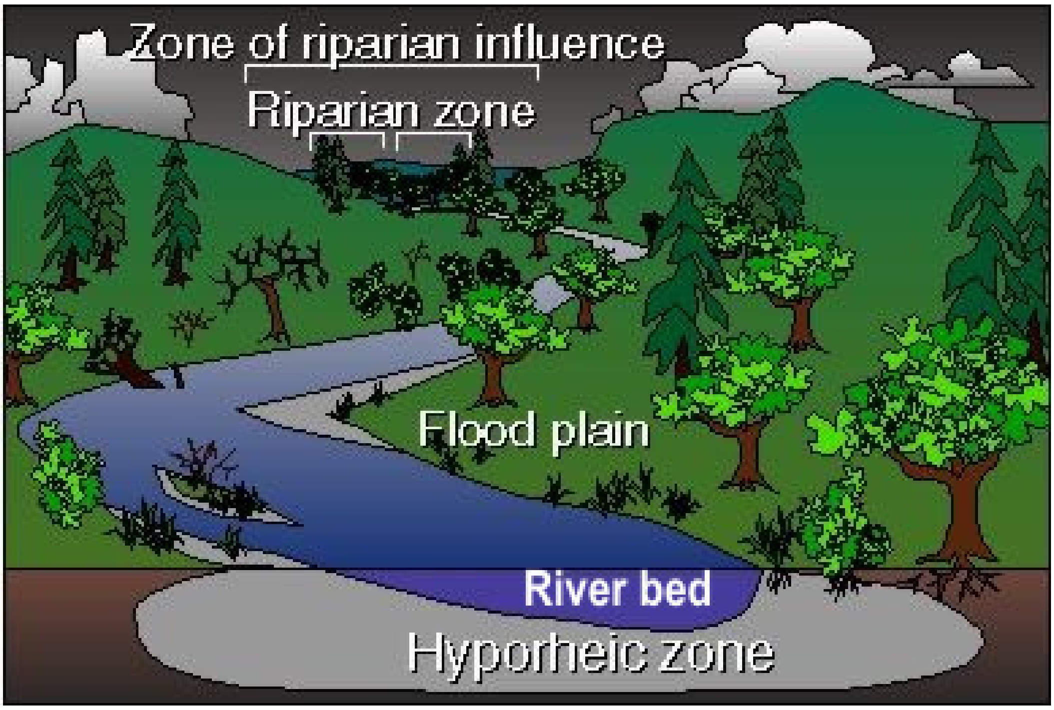

Figure 1: *The ecological areas in river watercourses (Washington NatureMapping Program, 2016).*

Slika 1: *Ekološke površine rečnega vodnega telesa (Washington NatureMapping Program, 2016).*

Some of the important functions of riparian zones are (Naiman and Décamps, 1997; Clerici et al., 2011; Hagai and Ahuva, Kerem, 2012.): (1) dissipation of stream energy (meandering river curves, combined with vegetation and root systems dissipate stream energy, resulting in less soil erosion and a reduction in flood damage); (2) trapping sediment (reduction in suspended sediments creates less turbid water, replenishes soils, and builds stream banks); (3) filtering pollutants from surface runoff that enhance water quality via biofiltration; (4) providing wildlife habitats, increasing biodiversity and forage for wildlife and livestock; (5) providing wildlife corridors, i.e. enabling aquatic and riparian organisms to move along river systems avoiding isolated communities; (6) providing native landscape irrigation by extending seasonal or perennial flows of water; (7) contributing nutrients from terrestrial vegetation to aquatic food webs; (8) shading water to mitigate water temperature changes; (9) contributing wood debris to streams, which is important in maintaining river geomorphology; (10) contributing to nearby property value through amenity and views; (11) improving enjoyment in footpaths and bikeways by supporting foreshore way networks; (12) providing space for riparian sports like fishing, swimming and launching for vessels and paddle craft; (13) acting as a sacrificial erosion buffer for absorbing impacts of climate change, increased runoff from urbanisation and increased boat wake without damaging structures located behind the setback zone.

2.2 Hyporheic zone

Natural river beds are formed of material that is generally coarse and porous, which enables the formation of a hyporheic zone. The zone represents saturated interstitial areas stretching from beneath the stream bed and into the banks that contain some channel water (White, 1993). The hyporheic flow may comprise the entire flow in arid areas with sandy soils, such as desert areas when the surface waters have dried up. This is the zone in which groundwater and surface water interactions occur within an open channel system. The water flowing within a hyporheic zone becomes a hydrologic connection between streams and catchments. This connection is a dynamic bi-directional link that consists of multiple flow paths. Hyporheic zones have become the focus of intense study over the past 50 years. Figure 2 shows the position of and processes in a hyporheic zone.

From the ecological point of view, this is one of the most challenging river zones for investigation. The hyporheic zone provides many functions such as (Wondzell, 2011; Cardenas, 2015): (1) spawning habitat; (2) biogeochemical processes; (3) aquifer and riparian exchange etc. All of them are vital to a sustainable, healthy river. This space represents a transition between the river water and groundwater environments, combining biogeochemical and physical characteristics of both. The hyporheic zone provides an ideal habitat for a wide array of microbes and invertebrates.

Due to particularities of water circulation in rivers, the coupling of surface water - groundwater processes is a very important prerequisite for understanding constraints to sustainable development. The hyporheic flow is not visible. It is the percolating flow of water through sand, gravel, sediments and other permeable soils under and beside an open streambed. It is the subsurface flow between the water table and surface flow. The water volume in the hyporheic zone can even be as large as in the river itself.

From the ecological viewpoint, this zone is very valuable and extremely vulnerable at the same time. There are numerous natural and human-induced influences that may alter the boundaries or, be it temporally or permanently, change processes within this zone. Some of them, especially anthropogenic ones such as river regulation and canalization and different land-use activities in the catchment, could be ecologically very dangerous. The interactions between the surface water and groundwater make them areas of great biological and chemical activity (Franken et al., 2001).

In a hyporheic zone, a lot of organic material is consumed and the nutrients are converted to inorganic ions. Many bacteria, insect larvae, and other small organisms live there and enhance water purification. Plants have a good source of nutrients in this space. Thus, the hyporheic zone is important for the removal of nutrients from the water body.

2.3 Floodplain and river corridor

A floodplain can be defined as: (1) a nearly flat plain along the course of a river that is naturally subject to flooding; (2) a plain bordering a river and subject to flooding; (3) a low plain adjacent to a river that is formed chiefly of river sediment and is subject to flooding; (4) a flat land bordering a river, made up of alluvium (sand, silt, and clay) deposited during floods; (5) a strip of land bordering a river that is normally inundated during seasonal floods (Bridge, 2003). The floodplain is the area that is irregularly but more or less frequently covered with water in times of high water discharges in its adjacent rivers (EEA, 2016). Despite several individual case studies there is no comprehensive classification of floodplains (Nanson and Croke, 1992). The genetic floodplain, the alluvial landform adjacent to a river and built of its sediments, differs from the hydraulic floodplain, the area inundated with a certain frequency regardless of land use, soil, etc. The EEA (2016) uses the term ‘floodplain’ to describe intermittently inundated lands next to river beds and channels (e.g. Matella and Jagt, 2014). The extent of a floodplain depends on specific geomorphologic and vegetation characteristics.

Historically, floodplains have been the sites of socio-economic activity. This is evident from the very high density of human settlements along rivers throughout the world. Floodplains are extremely fertile areas that have played an important role in the development of civilisations. In arid areas, floodplains are oases of agricultural development. In mountain areas, they represent the only extensive tracts of flat land favourable to cultivation and communication. The modern society places extreme demands on floodplains. Floodplains are of major socio-economic and ecological importance.

The role of a floodplain is to accommodate a large number of interrelated natural and human-induced processes that change over time. For hydrologists, a floodplain represents an area flooded at a recurrent interval of at least once in 100 years, while for ecologists this space is periodically inundated (usually (bi) annually). For ecologists, the interaction between the ecosystems of rivers and their floodplains is of a crucial scientific as well as practical interest.

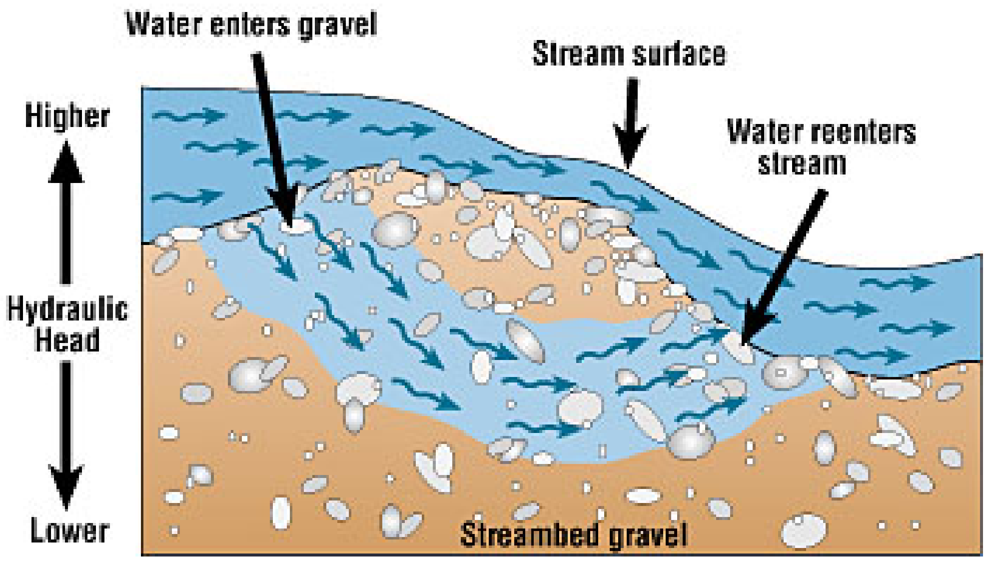

Figure 2: *Schematic presentation of the position and processes in a hyporheic zone (Washington NatureMapping Program, 2016).*

Slika 2*: Shematični prikaz lokacije in procesov v hiporeični coni (Washington NatureMapping Program, 2016).*

Floodplains are highly heterogeneous and extremely complex and important ecosystems (Marriott and Alexander, 1999). The floodplain micro-topography presents a maze of small channels, depressions, backwaters, hillocks, oxbow lakes and ridges. Depressions within floodplains are wetlands, important for biodiversity and livelihood support. They are often connected to the main river channel via small channels, which bring in floodwater and associated fine sediment and nutrients, and allow for the migration of fish, which spawn and breed on the floodplain. Such wetlands retain floodwater permanently or temporarily after the river level has dropped. Some depressions support particularly important ecosystems, such as floodplain forests, which provide habitats for large populations of birds (WMO, 2006) and other functional groups, amphibians, reptiles and invertebrates.

Floodplain habitats are highly diverse and they change in space and time (Gordon et al., 2004). Their spatial heterogeneity is determined by whether the habitat is: (1) in deep or shallow water; (2) in sunny or shaded areas; (3) on flat mud or gravel; (4) with or without aquatic vegetation; (5) in a fast or slow current; (6) in clear or turbid water; (7) in small streams or large rivers; (8) in a spring brook or main channel etc. (WMO, 2006). The temporal variability depends on: (1) the alteration of low and high flow conditions; (2) seasonal changes between warm and cold water; (3) single or multiple channels contracted and expanded into the floodplain etc. (Mariott and Alexander, 1999; WMO, 2006).

The extremely important role of floodplains is the retention of high water during floods. In this manner, floodplains protect downstream parts of rivers from flooding. This is why floodplain restoration is one of the crucial goals of the new, integrated flood risk management approach. In order to achieve this goal, the most important prerequisite is the improvement of the management and understanding of floodplain ecology. Recent extreme flooding events have attracted much publicity.

3. Role of ecohydrology

Rivers and their corridors evolve in concert with and in response to surrounding ecosystems. Changes within a surrounding ecosystem impact the physical, chemical and biological processes occurring within a stream corridor (Brilly et al., 2003). Stream systems normally function within natural ranges of flow, sediment movement, temperature, and other variables, in what is termed the "dynamic equilibrium". When changes in these variables go beyond their natural ranges, the dynamic equilibrium may be lost (WMO, 2006).

Calow and Petts (1992) conclude that river ecosystems, more than any others, are moulded by physical forces. The main reason for this lies in the fact that flow rates can vary dramatically over short spaces and periods of time. Uncontrolled and massive constructing works and land reclamation activities on rivers and their entire catchments worldwide have resulted in elimination of their natural flow regimes and especially in draining the wetlands. Much of the riparian vegetation along river banks has been removed. As a result, many habitats have been destroyed and biological diversity has been threatened (Wohl, 2004).

The growing world population and the commensurate increase in demand for limited freshwater resources, in addition to potential impacts of climate change or variability on river ecosystems, are the main reasons for a required interdisciplinary scientific co-operation in management and protection of water resources. Interdisciplinary research efforts to integrate the ecological aspects of river hydrology with its physical and societal roles emerged as a new science discipline called ecohydrology. This term was popularized about thirty years ago and was soon applied to river management. Ecohydrology tries to understand, explain and use links between ecology and hydrology. It also integrates landscape hydrology with freshwater biology. It is realistic to expect that the cooperation between hydrology and ecology can help in solving many critical problems dealing with sustainable development and management of many aspects of rivers.

It is of crucial importance to understand and control the effects of hydrological processes on the distribution, structure, and function of joint ecosystems, as well as the effects of biotic processes on elements of the river water cycle. Ecohydrology attempts to integrate hydrological processes with biota dynamics over varied spatial and temporal scales.

Developing the research interface between hydrology and ecology has been recognised as a research frontier in all geosciences. A great problem is that both still operate independently and based on different philosophies, conceptual frameworks, terminology and experimental approaches. In order to overcome this gap, Harte (2002) proposes a synthesis of the Newtonian and Darwinian approaches in the following way: "Physicists seek simplicity in universal laws. Ecologists revel in complex interdependencies. A sustainable future for our planet will probably require a look at life from both sides. Physicists and ecologists approach their crafts from different intellectual traditions, as exemplified by the differing values they attach to the search for simplification and universality. Very often scientists have witnessed dysfunctional consequences of this bimodal legacy".

Hydrological processes involve flows of matter and energy (water, nutrients, sediments, species, seeds, heat, etc.) between different landscape components. The spatial structure and temporal dynamics of river-landscape-biota processes are driven by climatic factors, mediated by catchment characteristics and obstructed by anthropogenic actions in the rivers and their catchments. The connectivity between different landscape components is extremely variable and until now its role in ecosystem development has not been well understood. It is especially important in open river systems, due to their extreme surface and underground morphological and biological complexity and connectivity.

The importance of maintaining the morphological and ecological connectivity of the river watercourses should be stressed. Connectivity of various habitats is important for fulfilling the needs of organisms to move throughout the landscape and for sustaining a series of physical, biological and chemical processes that control the structure and functioning of the river corridor.

For organisms to survive in and around rivers, the following conditions have to be met: (1) adequacy of water quality; (2) availability of an appropriate quantity and variability of water to support natural biological processes; (3) availability of diverse physical habitats (Gordon et al., 2004). One of the most important roles of ecohydrology in river management is to build a knowledge base for ecosystem management. The ecological health of a river corridor depends not just on the water quality, or on the percentage of the total flows released, but also on a naturally variable quantity and timing of flows throughout the year. Ecohydrology is in an early phase of formation. It should be stressed that there are a lot of scientific papers in the area, but implementation of this knowledge into management is weak. Ecohydrology offers many scientific challenges and possibilities for exciting, hardly foreseeable and dynamic development. It has a potential to provide scientists with environmentally friendly and sustainable solutions to several problems related to river hydrology and ecology (Bonacci, 2003). Rivers, as a specific type of landscape and environment, definitely require new ecohydrological achievements for their sustainable development and protection.

4. Role of floods

A flood is a temporary covering of land by water outside its normal confines. They are one of the most dramatic interactions between human beings and environment (Ward, 1978). They emphasise the sheer force of natural events and man's inadequate efforts to control them. There is clear evidence that the flood situation is worsening in terms of damage caused by flooding all over the world. Despite huge expenditures on flood control, flood losses continue to rise both in highly developed and in developing countries. Protective measures are often counterproductive. They may result in higher damages than would otherwise have occurred (WMO, 2006; Kundzewicz et al., 2013; Sapač and Brilly, 2014).

We should be well aware that flood is an integral and inalienable part of an ecosystem. Flooding brings many benefits particularly to ecological variability and soil fertility. It promotes exchange of materials and organisms between habitats and plays a key role in determining the level of biological productivity and diversity. The beneficial aspects of flooding are less obvious to many people, and particularly to those whose dwellings are at risk of flood inundation. Due to two controversial roles (positive and negative) of flood in floodplain management it is important to understand all the different aspects of flood flow behaviour.

The predominant human desire to reduce or prevent flooding may not be the best long-term management strategy. Many of the flood management measures have the potential to cause hydrological, morphological and environmental impacts, with consequent significant impacts on socio-economic development (Horvat et al., 2006).

Humans domiciled in floodplains should be prepared to live with floods. It is obvious that long systems of levees (embankments) and dams and reservoirs alone cannot represent the final and safe solution to the problem of protection against floods. A scheme of deliberate and induced inundation of washland storages or selected areas, for which flooding damages are smaller than for downstream areas, could be a successful solution (WMO, 2006).

Dams and reservoirs are the main flood-control structures, but they also serve many other purposes (Bonacci, 2015). In recent years, their construction has become a controversial issue. The current debate on dams and reservoirs has become dogmatic, emotional and counterproductive (Biswas, 2004). The result is that construction of artificial reservoirs has decreased drastically all over the world. Today very often they mainly serve only one purpose, which can be the main reason for disagreement among different stakeholders. The best decision on reservoir operation should be based on an environmentally sensitive evaluation of the river and its catchment system, and the relative values of its use, both economic and ecological. Reservoir performances in economic, social and especially environmental terms should be maximised and their adverse impacts should be minimised (Biswas, 2004).

A new trend in river management, especially in the US, is removal of dams. As every dam has a finite life span, its age can be an important factor affecting the removal decision. Dam removal brings a variety of benefits to local communities such as restoring river health and clean water, revitalizing fish and wildlife, improving public safety and recreation, and enhancing local economies (Doyle et al., 2003; Conyngham et al., 2006; Downs et al., 2009). A decision of dam removal is complex because there is great scientific uncertainty over potential environmental benefits arising from it. More fundamentally, a scientific framework is lacking in considering how the tremendous variation in dam and river attributes determines the ecological impacts of dams and the restoration potential following removal (LeRoy Poff and Hart, 2002). Removal of dams, where feasible, should be undertaken after a comprehensive study.

While designing levees, the effects of lateral disconnection should be kept to a minimum. It is obvious that long systems of levees alone cannot represent the final and safe solution to the problem of protection against floods. At the same time, levees cause many negative ecological consequences and decrease groundwater recharge. Reinforcements and rising of levees have only made flood hazards less frequent, but have not prevented them. The evolution of the Mississippi River levees from the very beginning (year 1844) until today, given in Fig. 3 (CIRIA C731, 2013) serves as a good exemplification for that. Despite the fact that levees are extremely enlarged and elevated, the Mississippi River floods have not been stopped. On the contrary, the floods are even worse than before the levee construction, which is evident from the last three catastrophic Mississippi River floods that occurred in 1993, 2011 and 2015.

Potential mechanisms that can cause flood magnification are: (1) climate changes; (2) land use changes; (3) in-stream factors such a river engineering for navigation and flood control. The analysis made by Pinter and Heine (2005) reveals that for all flood conditions on the Lower Missouri River, stages have systematically raised for equal discharge volumes over the period of record. Equal-discharge analysis illustrates the mechanisms of channel change driving flood magnification. Decreased flow velocity has been the dominant mechanism driving stage changes. Constriction in channel cross-sectional area has increased flood stages. These changes in channel geometry and flow dynamics correlate with wing-dam construction and other engineering of the Lower Missouri River, but the changes occur progressively over the duration of record as a gradual and reach-scale re-equilibration of the fluvial system (Pinter and Heine, 2005). Bonacci and Ljubenkov (2008) indicate that engineering structures and other human activities in combination with natural processes have altered many aspects of the flood hazard of the Sava River near Zagreb.

“Making Space for the River” is a new programme established by the Dutch river water management policy and researchers as a response to two extreme floods in late 1993 and 1995 (Warner et al., 2013). They decide not to rely on levees only, but to restore the flood storage capacity of floods and enhance the river’s natural, scenic, recreational and economic values. This programme is comprised of 39 measures for enlargement of the discharge capacity of the main Dutch rivers, with a budget of two billion Euros. The authors stress that the programme should be considered for application in a local, regional and national setting, to explore patterns of interpreting and implementing this concept. The programme is controversial and one-sided. More space for the river means less space, or less opportunity, for other functions as for example: (1) housing; (2) business areas; (3) intensive and safe agricultural production etc.

A flood protection system that would guarantee complete safety is an illusion. Therefore, it is necessary to live with an awareness of the possibility of floods (Brilly and Polic, 2005). Current scientific paradigm emphasizes living with floods rather than fighting them. The existing paradigm, “Flood Protection”, should be changed into a new one: “Flood Risk Management”. This is already part of EU policy: Floods directive (art. 7 says: Flood Risk Management Plan has to be prepared until Dec. 2015). The topic of flood is very controversial in general and needs more attention and tools that should be investigated further.

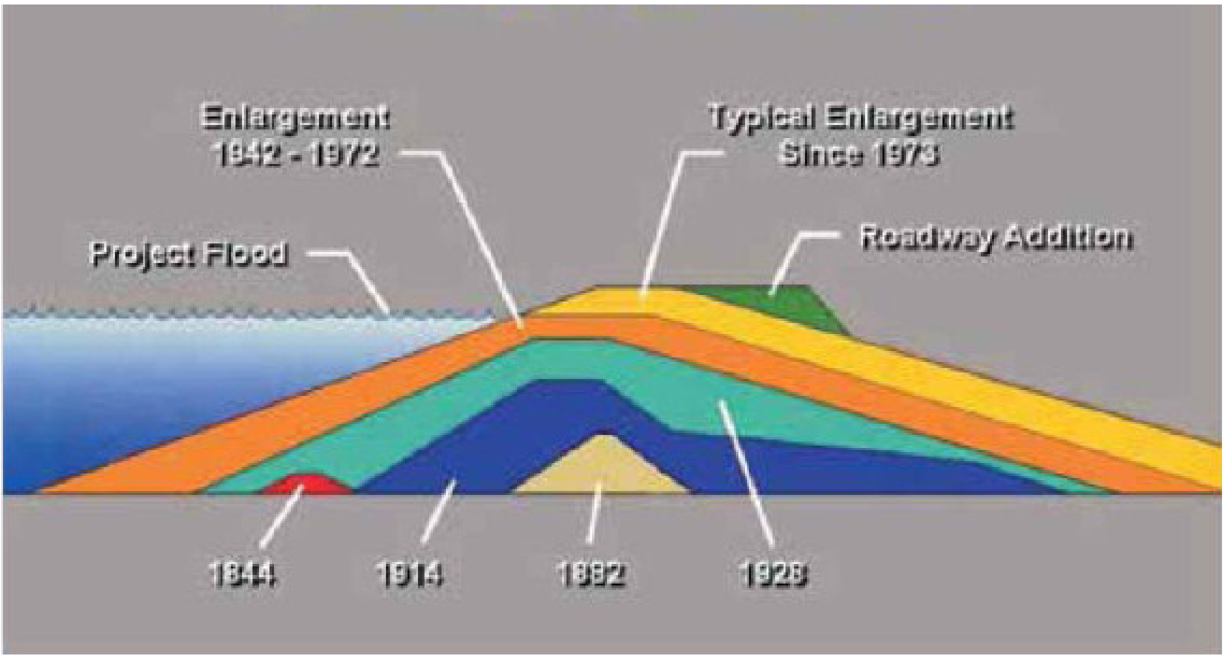

Figure 3: Evolution of Mississippi River levees (CIRIA C731, 2013).

Slika 3: Razvoj nasipov reke Misisipi (CIRIA C731, 2013).

5. Conclusions

Water in rivers is the topic of the day on the international scene, because of the critical situation in numerous countries and regions. In some parts of the planet, river water represents the single most important resource. The world is faced with a growing vulnerability of society to natural and anthropogenic disasters coming from river waters. Previously, river management was dominated by the idea that man is capable of controlling river processes. However, it is clear today that this is not possible.

Understanding the environmental consequences of changing river water regimes is a daunting challenge for civil and environmental engineers, ecologists and river managers. The ultimate arbiter of sound science is to put principles into practice. This is the most important but at the same time very complex and uncertain procedure. Humanity has not only learned a great deal from its successful achievements, but also from its errors.

There are no universal criteria to determine optimum river management practices (Brierley and Fryirs, 2013). It is crucial to adopt practices that suit particular circumstances in a given hydrologic, climatic, ecologic, landscape and socio-economic setting and follow a rational and balanced approach in addressing issues in water management. Sustainable river management should be based on a new approach called risk-based management. It involves the integrated application of three key-principles: (1) being well informed; (2) manage adaptively; (3) take a participatory approach (Brils and Harris, 2009). We have to accept that science will never be able to explain all the complexity of river ecosystems. The consequence of this fact is that human beings will not be able to reduce the uncertainties in river development decision-making to very low levels.

There is growing recognition that successful management must be based on the natural flow regime, that the dry phase is as significant as flooding, and that this must be incorporated into policies for water resources management (Globevnik and Mikoš, 2009).

There are hard and soft river management strategies. While hard ones use traditional engineering techniques (Kryžanowski et al., 2014), soft ones work in harmony with the river and its natural processes, thus taking ecological needs into account. Both have some advantages and disadvantages. Each river requires an individual approach based on its morphological, hydrological and ecological specifics.

At present, the international scientific community is faced with an environment that is ecologically, climatically, geologically, and due to these socially and politically, very fragile and vulnerable to risks of floods, droughts, landslides and water and soil pollution. Hence, now is the decisive moment to start the process of a co-ordinated, international multi- and interdisciplinary research and other activities leading to knowledge and information exchange. The global natural and/or human-induced changes are the main reasons for the necessity of interdisciplinary scientific co-operation in river management and protection.

A severe environmental degradation observable in many rivers with variable flow regimes worldwide appears to have generated a new and more efficient approach to managing them. Protection and sustainable management of the river water resources is of crucial importance. Decision-makers need to take complex, interactive, technical, social, economic, environmental and cultural aspects of global water resources management into account.

References

Biswas, A.K. (2004). Dams: cornucopia or disaster?. *International Journal of Water Resources Development* **20(1),** 3–14.

Bonacci, O. (2003). *Ekohidrologija vodnih resursa i otvorenih vodotoka (Ecohydrology of water resources and open streamflows)* . Građevinsko-Arhitektonski Fakultet Sveučilišta u Splitu, Split.

Bonacci, O. (2015). Brane i akumulacije: jučer, danas, sutra (Dams and reservoirs: yesterday, today and tomorrow). *Hrvatske Vode* **23(91),** 43–49.

Bonacci, O., Ljubenkov, I. (2008). Changes in flow conveyance and implication for flood protection, Sava

River, Zagreb. *Hydrological Processes* **22(8)**, 1189–1196.

Boon, P.J., Davies, B.R., Petts, G.E. (2000). *Global perspectives on river conservation*: *science, policy and practice*. Wiley, Chichester etc.

Bridge, J.S. (2003). *Rivers and floodplains – forms, processes and sedimentary record.* Blackwell Publishing.

Brierley, G.J., Fryirs, K A. (2013). *Geomorphology and river management: applications of the river styles framework*. Balckwell Publishing, Malden.

Brilly, M., Polič, M. (2005). Public perception of flood risks, flood forecasting and mitigation. *Natural Hazards and Earth System Sciences* **5(3)**, 343–355.

Brilly, M., Štravs, L., Petkovšek, G., Toman, M.J. (2003). Ekohidrološki procesi na zajemnem objektu za Hidroelektrarno Plave, Slovenija (Ecohydrological processes on the intake structure of the Plave hydropower plant, Slovenia). *Acta Hydrotechnica* **21(35)**, 77–85.

Brils, J., Harris, B. (2009). *Towards risk-based management of European river basins: key-findings and recommendations of the RISKBASE project*. EC FP6 reference GOCE 036938, Utrecht.

Calow, P.P., Petts, G.E. (eds.) (1992). *The rivers handbook Volume 1*. Blackwell Science, Oxford.

Cardenas, M.B. (2015). Hyporheic zone hydrologic science: A historical account of its emergence and a prospectus. *Water Resources Research* **51(5)**, 3601–3616.

CIRIA C731 (2013). *The international levee handbook*. CIRIA, London.

Clerici, N., Weissteiner, C. J., Paracchini, L. M., Strobl, P. (2011). *Riparian zones: where green and blue networks meet : pan-European zonation modelling based on remote sensing and GIS.*, JRC Scientific and Technical Reports, European Commission - Joint Research Centre: Institute for Environment and Sustainability, Ispra.

Clerici, N., Weissteiner, C. J., Paracchini, M. L., Boschetti, L., Baraldi, A.. Strobl, P. (2013). Pan-European distribution modelling of stream riparian zones based on multi-source Earth Observation data. *Ecological Indicators* **24**, 211–223 (doi: 10.1016/j.ecolind.2012.06.002).

Conyngham, J., Fischenich, J.C., White K.D. (2006). *Engineering and ecological aspects of dam removal - an overview*. Engineer Research and Development Center, U.S. Army Corps of Engineers, Vicksburg.

Downs, P., Cui, Y., Wooster, J., Dusterhoff, S., Both, D., Dietrich, W.E., Sklar, L.S. (2009). Managing reservoir sediment relese in dam removal projects: an approach informed by physical and numerical modelling of non cohecive sediment. *International Journal of River Basin Management* **7(4)**, 433–452.

Doyle, M.W., Stanley, E.H., Harbor, J.M. (2003). Channel adjustments following two dam removals in Wisconsin. *Water Resources Researsch* **39(1)**, 2.1–2.15.

EEA (2016). *EEA Report No 1/2016. Flood risks and environmental vulnerability - Exploring the synergies between floodplain restoration, water policies and thematic policies*. http://www.eea.europa.eu/publications/flood-risks-and-environmental-vulnerability

Franken, R.J.M., Storey R.G., Dudley Williams, D. (2001*).* Biological, chemical and physical characteristics of downwelling and upwelling zones in the hyporheic zone of a north-temperate stream. *Hydrobiologia* **444**, 183–195.

Globevnik, L., Mikoš, M., (2009). In sediment sources and sediment delivery under environmental change. *Catena* **79(3)**, 265–276.

Gordon, N.D., McMahon, T.A., Finlayson, B.L., Gippel, C.J., Nathan, R.J. (2004). *Stream hydrology - an introduction for ecologists 2nd edition.* Wiley, Chichester.

Hagai, H.K., Ahuva, K. (2012). Riparian zones: protection, restoration, and ecological benefits. *Nova Science Publishers, Inc*., New York.

Harte, J. (2002). Toward a synthesis of the Newtonian and Darwinian worldviews. *Physics Today* **55(10)**, 29–37.

Horvat, A., Brilly, M., Kryžanowski, A. (2006). Vpliv izgradnje hidroenergetskih objektov na vodni režim (The impact of hydropower plants on the water regime). *Acta Hydrotechnica* **24(41)**, 47–66.

Kryžanowski, A., Brilly, M., Rusjan, S., Schnabl, S. (2014). Structural flood-protection measures referring to several European case studies: review article. *Natural Hazards and Earth System Sciences* **14(1),** 135–142.

Kundzewicz, Z.W., Pińskwar I., Brakenridge, G.R. (2013). Large floods in Europe, 1985–2009. *Hydrological Sciences Journal* **58(1)**, 1–7.

LeRoy Poff, N., Hart, D.D. (2002). How dams vary and why it matters for the emerging science of dam removal. *BioScience* **52(8)**, 659–668.

Marriott, S.B., Alexander, J. (1999). *Floodplains: interdisciplinary approaches*. The Geological Society, London.

Matella, M., Jagt, K. (2014). Integrative method for quantifying floodplain habitat. *Journal of Water Resources Planning and Management* **140(8)**, 06014003.

Naiman R.J., Décamps, H. (1997). The ecology of interfaces: Riparian Zones, *Annual Review of Ecology and Systematics* **28(1)**, 621–658 (doi: 10.1146/annurev.ecolsys.28.1.621).

Naiman, R.J., Décamps, H., McClain, M.E. (2005). *Riparia: ecology, conservation, and management of streamside communities, Aquatic ecology series*, Elsevier, Academic Press, Amsterdam.

Nanson, G.C., Croke, J.C. (1992). A genetic classification of floodplains. *Geomorphology* **4(6)**, 459–486.

Pinter, N., Heine, R.A. (2005). Hydrodynamic and morphodynamic response to river engineering documented by fixed-discharge analysis, Lower Missouri River, USA. *Journal of Hydrology* **302**, 70–91.

RiverWatch (2016). www.riverwatch.eu/en/balkan-rivers (visited 11. 4. 2016)

Sapač, K., Brilly, M. (2014). Stroški varstva pred poplavami v Republiki Sloveniji (Costs of flood protection in the Republic of Slovenia). *Acta Hydrotechnica* **27(46)**, 57–72.

Ward, R.C. (1978). *Floods: a geographical perspective.* Macmillan Press, London.

Warner, J.F., van Buuren, A., Edelenbos, J. (eds.) (2013). *Making space for the river – governance experiences with multifunctional river flood management in the US and Europe*. IWA Publishing, London.

Washington NatureMapping Program (2016). http://naturemappingfoundation.org/natmap/water/field/hyporheic_zones.html (visited 12. 4. 2016)

White, D.S. (1993). Perspectives on defining and delineating hyporheic zones. *Journal of the North American Benthological Society* **12(1)**, 61–69.

Wohl, E. (2004). *Disconnected rivers: linking rivers to landscapes*. Yale University Press, Yale.

WMO (2006). *Environmental aspects of integrated flood management*. WMO Flood Management Policy Series. WMO-No.1009, Geneva.

Wondzell, S.M. (2011). The role of the hyporheic zone across stream networks. *Hydrological Processes* **25(22)**, 3525–3532.