© *Acta hydrotechnica* **21/34 (2003)**, Ljubljana
ISSN 1581-0267

UDK/*UDC*: 627.15:627.4/.5(282.249)(497.14) Prejeto / *Received*: 21. 10. 2003
Strokovni članek – *Professional paper* Sprejeto / *Accepted*: 22. 3. 2004

MOŽNOSTI ZA REVITALIZACIJO URBANIH VODOTOKOV NA PRIMERU GLINŠČICE V LJUBLJANI
RIVER REHABILITATION OF URBAN WATERCOURSES ON THE EXAMPLE OF THE GLINŠČICA RIVER IN LJUBLJANA

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V članku so na konkretnem primeru ureditve odseka Glinščice predstavljene možnosti sonaravnega urejanja vodotokov v urbanem okolju. Glinščica poplavno ogroža obdajajoče urbane površine zaradi neustreznih regulacijskih posegov v preteklosti. Območje struge Glinščice je tako z ekološkega kot tudi s krajinskega vidika močno degradirano. S pomočjo hidravličnega računskega modela struge Glinščice, izdelanega s programom HEC-RAS verzija 3.1, sta predstavljeni dve variantni rešitvi ureditve odseka Glinščice, od Jamnikarjeve do Brdnikove ulice. Glavni cilj sonaravne ureditve Glinščice je normalizacija pretočnih razmer, ki med letom zelo nihajo. Predvidena je ureditev dvojnega prečnega prereza struge, pri čemer osrednja poglobljena struga prevaja nizke in srednje vode, razširjen prerez dvojne struge pa je namenjen odvodnji poplavnih voda. S predvideno zaščito brežin in dna struge vodotoka z inženirsko-biološkimi metodami bi za obdajajoče urbane površine zagotovili primerno varnost pred poplavami, hkrati pa omogočili normalne življenjske pogoje za vodne organizme v strugi vodotoka. V okviru variantnih rešitev sonaravne ureditve struge Glinščice so predstavljene tudi možnosti ureditve sprehajalnih poti ob strugi, kar bi omogočilo vključitev območja ob strugi Glinščice v rekreacijske površine predvidenega zelenega sistema mesta Ljubljana.
Ključne besede: *sonaravno urejanje vodotokov, inženirsko-biološke metode, živi konstrukcijski materiali, rečni koridor, rehabilitacija, dvojni prečni prerez struge*

Some possible solutions of remediation of river courses on a detailed description of remediation scheme for the channelized Glinščica stream in the urban area of Ljubljana are presented in the paper. The Glinščica stream has been flooding the surrounding urban areas. This is a result of the inappropriate river regulations in the past. The entire area of the stream channel is heavily degraded both from ecological and landscape points of view. Using the hydraulic computation model HEC-RAS version 3.1, two solutions for a remediation scheme for the section of the Glinščica stream channel from Jamnikarjeva street to Brdnikova street are presented. The primary goal of the proposed solutions is a normalization of discharge conditions, which fluctuate significantly during the year. A regulation of a two-stage channel is proposed. A first-stage channel conducts low summer and normal water flows, the second-stage channel is widened and conducts high flows up to floods with a return period of 100 years. The proposed regulation of the two-stage channel and the use of bioengineering techniques for bank and channel bottom stabilization would prevent the inundation of the surrounding urban areas. The proposed two-stage channel would also enable normal living conditions for water organisms. Special emphasis is also given to a proposed maintenance plan for the scheme, leaving a certain amount of vegetation in the cross section untouched. In this way a partial rehabilitation of the river corridor would be possible. Furthermore, both proposed solutions of the remediation scheme for the Glinščica stream consider the possibility to create a network of footpaths along the channel, so that the entire surrounding area could be included in the recreational area of the planned green system of the city of Ljubljana.
Key words: *remediation of river courses, water bioengineering techniques, live building materials, river corridor, rehabilitation, two-stage watercourse channel*

1. UVOD

Posledica preteklih ureditev mestnih vodotokov je, da so vodotoki v urbanem okolju pogosto obravnavani le kot geometrijski arhitekturni elementi ter kot odvodniki za odpadno komunalno in padavinsko vodo. Na območju Ljubljane so vodotoki Ljubljanica, Gradaščica in Glinščica umeščeni v sterilne prečne profile strug, ki so z visokimi betonskimi brežinami ločene od obdajajočih urbanih površin. Ureditve strug so bile usmerjene v izboljšanje varnosti pred poplavami in izboljšanje higienskih razmer, z zagotovitvijo dovolj velikih pretočnih hitrosti tudi v času nizkih voda, s čimer se zagotovi zadovoljiva odvodnja raznih odpadnih snovi, ki se nakopičijo v strugi (dolvodno).

Za izboljšanje ekološkega stanja vodotokov, ob zagotavljanju potrebne protipoplavne varnosti, se vse pogosteje uporabljajo sonaravni pristopi k urejanju vodotokov (RRC, 2001; SEPA, 2000; SWCS, 1998). Sonaravno urejanje vodotokov je usmerjeno v ohranjanje vodnih ter obvodnih površin (območja rečnega koridorja). Ekološko sprejemljivo upravljanje z vodnimi površinami zahteva pristope, pri katerih vodne površine upoštevamo kot dinamične geomorfološke sisteme, ki niso namenjeni zgolj prevajanju vode (Wharton, 2000). V članku so na konkretnem primeru odseka Glinščice, od Jamnikarjeve do Brdnikove, predstavljene nekatere možnosti sonaravnih ureditev manjših, močno degradiranih vodotokov v urbanem okolju.

1. INTRODUCTION

Due to past regulations, urban watercourses are frequently considered only as architectural elements or as conduits for sewer and rainfall. In the area of Ljubljana the watercourses Ljubljanica, Gradaščica and the Glinščica are regulated in sterile channel cross sections with high concrete banks, which separate the water bodies from the surrounding urban areas. Regulations of river channels were directed towards an improvement of flood protection and of hygienic conditions. Fast flowing water in concrete channels enables washing off of all waste that gathers in the channels downstream.

For the improvement of both, ecological state and flood protection, the ecologically sound approaches to watercourse regulations are more and more widely used (RRC, 2001; SEPA, 2000; SWCS, 1998). Rehabilitation of watercourses is directed towards the preservation of riparian areas (river corridors). The ecologically sound management of watercourses demands approaches that consider water bodies as dynamic geomorphological systems, going beyond the sole performing of the function of urban drainage (Wharton, 2000). In this paper, some rehabilitation possibilities of heavily degraded urban watercourses are presented by means of a description of the remediation scheme of the channelized Glinščica stream.

2. MATERIAL IN METODE

2.1 HIDROLOŠKA SLIKA POVODJA GLINŠČICE

Glinščica izvira pod severovzhodnimi obronki Toškega čela in pri Podutiku preide v ravninski del Ljubljanske kotline. Topografska slika porečja je sestavljena iz gričevnatega dela na vzhodu in zahodu ter ravninskega dela, ki se razširi v južnem delu. Relief porečja Glinščice je precej raznolik, od strmih povirnih območij do ravnic. Ravninski del porečja je slabo prepusten. Povirje Glinščice sega na severni strani v pobočje Toškega čela in Črnega vrha, razvodnica na vzhodu sega v urbano območje mesta Ljubljana (Dravlje,

2. MATERIAL AND METHODS

2.1 HYDROLOGICAL SITUATION OF THE GLINŠČICA WATERSHED

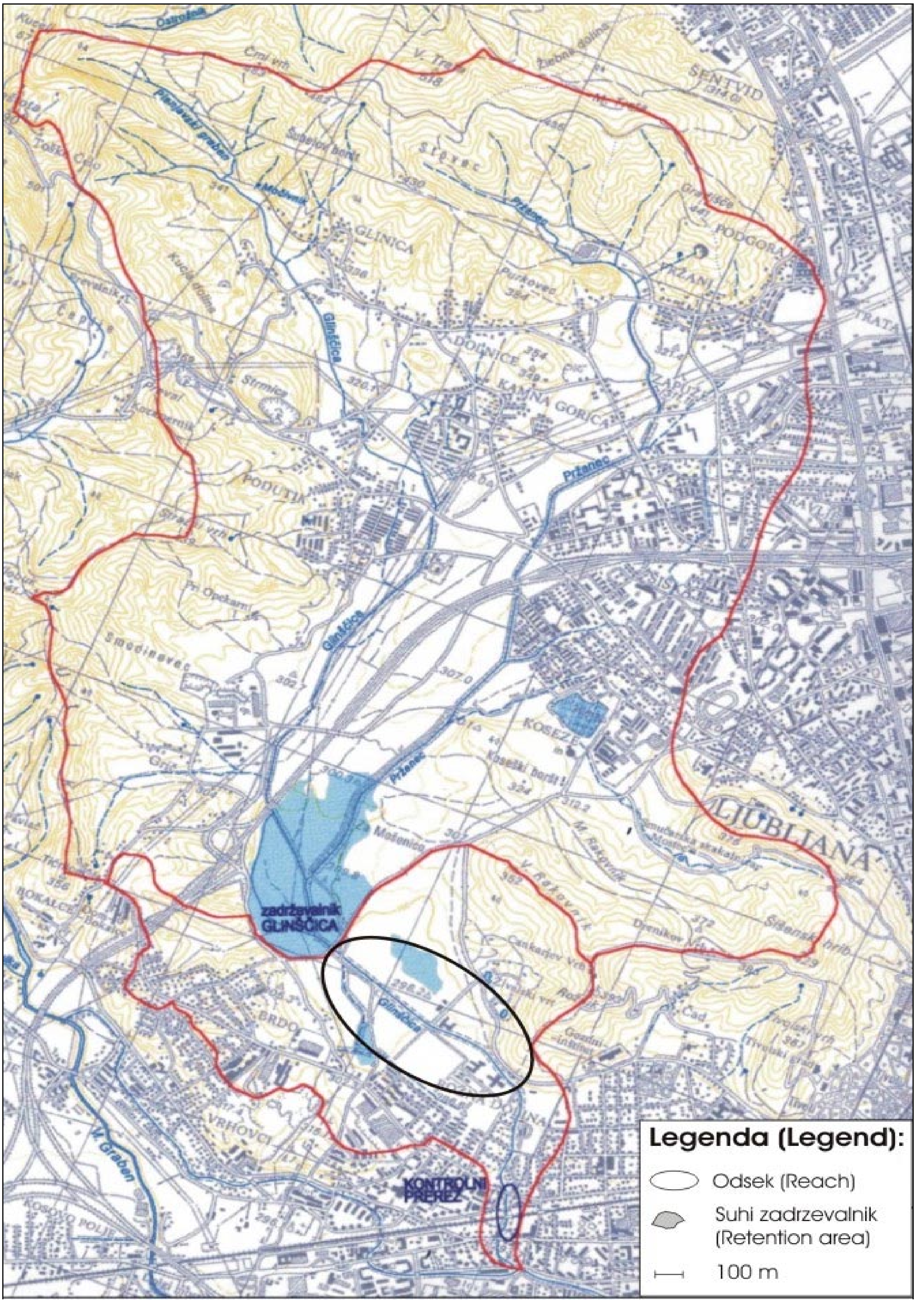
The Glinščica originates beneath the northeast hillsides of the Toško čelo and at Podutik enters the plain area of Ljubljana basin. The topography of the watershed consists of a hilly part on the east and west. The plain area widens on the southern side of the watershed. The relief of the Glinščica watershed is quite heterogeneous with steep headwater areas and plains. The plain area of the watershed is poorly permeable. On the north side, the watershed border crosses the hillsides of the Toško čelo and Črni vrh and

Šiška), preko Šišenskega hriba in Rožnika do izliva v Gradaščico, ki predstavlja najjužnejšo točko porečja. V smeri proti zahodu poteka razvodnica skozi urbano območje, preko Brda vse do Tičnice, kjer se usmeri proti severu preko Stražnega vrha, Prevala do Toškega čela. Večji pritok Glinščice je Pržanec, čigar povirje sega v pobočje Velike trate in Male trate in odvaja vodo z večinoma ravninskega dela vzhodno od Glinščice. Padavinsko prispevno območje Glinščice obsega 17,4 km^2. Položaj odvodnice znotraj urbanega območja določa odvodnja meteornih voda s kanalizacijskim sistemom, zato orografska razvodnica ne sovpada vedno s prispevnim območjem Glinščice. Skupno prispevno območje Glinščice je nekoliko večje in zajema 19,3 km^2 površine. Padavinski odtok z območja med Guncljami, železnico in orografsko razvodnico med porečjema Glinščice in Save ter del urbanih površin ob izlivnem delu Glinščice je namreč preko kanalizacijskega meteornega omrežja speljan na območje porečja Glinščice. Ob tem se na porečje Glinščice steka tudi večji del meteornih vod z 1,9 km^2 površin z območja Šentvida. Prispevno območje Glinščice je prikazano na sliki 1.

S širitvijo tlakovanih neprepustnih urbanih površin na ravninske predele območja porečja Glinščice se je hidrološka slika povodja močno spremenila, zlasti v obdobju zadnjih 20 let. Obsežna urbana območja so se razširila predvsem na območju Podutika, Dravelj, Kosez in Brda. Ta ravninska območja so pred pozidavo le malo prispevala k izoblikovanju vrhov hidrogramov odtoka. S povečanjem deleža neprepustnih površin (pozidava, prometne površine) so se povečali odtočni koeficienti, izgradnja meteorne kanalizacije je dodatno prispevala k zmanjšanju časa koncentracije. Ocenjeno je bilo, da je na celotnem porečju Glinščice delež urbanih površin 38 % oziroma 6,6 km^2. Groba ocena povprečnega koeficienta odtoka s prispevnega območja Glinščice, izračunana iz povprečne letne količine padavin (1376 mm) ter povprečnega letnega pretoka Glinščice (0,383 m^3/s), znaša 0,58, kar je pokazatelj intenzivnega odtoka padavinskih voda v strugo Glinščice.

enters the urban area of Ljubljana (Dravlje, Šiška) on the east. The divide then crosses Šišenski hrib and Rožnik towards the southern point of the watershed and the outfall into the Gradaščica river. Westwards, the watershed divide passes through the urban area of Brdo, towards Tičnica, where it turns north over Stražnji vrh, Preval and the Toško čelo. A major tributary of the Glinščica is the Pržanec. The watershed of the Pržanec includes the hillslopes of Velika trata and Mala trata and drains water from the plain area east of the Glinščica. The orographic drainage area of the Glinščica has an area of 17.4 km^2. The position of the watershed border inside the urban area is defined by a drainage system network. This is the reason why the orographic border of the watershed does not always coincide with the actual watershed area. The actual watershed area is larger than the orographic drainage area and measures 19.3 km^2. Namely, the rainfall runoff from the area between Gunclje, railway and the orographic watershed border between the Glinščica and Sava rivers, and the rainfall runoff from the urban area near the Glinščica outfall, is diverted to the Glinščica watershed via the urban drainage system. The Glinščica also conduits great part of the runoff from the urban area in Šentvid, measuring 1.9 km^2. The Glinščica watershed is shown in Figure 1.

By extending the paved impermeable urban areas on the plain parts of the watershed, the hydrology of the entire watershed has changed dramatically in the last 20 years. Extensive urban areas have spread in the areas of Podutik, Dravlje, Koseze and Brdo. Prior to intensive urbanization, these plain areas did not contribute in the formation of peaks of runoff hydrographs. The increase in impervious surfaces (extension of building, traffic surfaces) brought about the augmentation of the runoff coefficient, furthermore, the drainage system caused a further decrease in the concentration time of rainfall runoff. Urban areas present 38 % of the entire Glinščica watershed, i. e. 6.6 km^2. The approximate value for the average runoff coefficient, computed from the average annual rainfall (1376 mm) and average annual discharge in the Glinščica River (0.383 m^3/s), is 0.58. This indicates an intensive precipitation runoff into the Glinščica River channel.



Slika 1. Prispevno območje Glinščice z označenim obravnavanim odsekom struge (VGI, 2001).
Figure 1. Catchment area of the Glinščica River, the reach discussed is marked (VGI, 2001).

2.2 STRUGA GLINŠČICE PRED IZVEDENIMI REGULACIJSKIMI DELI IN OPIS OBSTOJEČEGA STANJA

Struga Glinščica je po celotni dolžini trase pred regulacijskimi deli blago vijugala. Struga je bila široka 3 do 6 m in globoka 60 do 90 cm, bregova pa sta bila glede na višino vode visoka 30 do 60 cm. Dno struge Glinščice je bilo muljasto. Glinščica je v času obsežnejših padavin poplavljala obdajajoče pozidane površine vasi Vič. Do konca druge svetovne vojne je imela Glinščica od Rožne doline gorvodno še vedno večinoma naravno vijugajočo strugo, ki se je vila v meljastih glinah. Struga je bila zaraščena, brežine in dno naravno. Prisotno je bilo izmenjevanje globljih odsekov struge – tolmunov in plitvin. Sestava ribje populacije v strugi je bila raznolika, med drugimi je bila v strugi prisotna tudi potočna postrv. Večji tolmuni so bili primerni tudi za kopanje. Glinščica je bila skupaj z Rožnikom, Malim in Velikim Rakovnikom ter Večno potjo privlačno naravno območje, kjer so se ljudje radi sprehajali. Takoj po koncu druge svetovne vojne se je struga Glinščice od že nekoliko urejenega izlivnega odseka (regulacija iz leta 1928) navzgor začela urejati. Pri tem ni šlo za načrtno regulacijo. Strugo so čistili lastniki zemljišč, posamezne rečne zavoje so odrezali od matične struge, hkrati pa so izkopavali melioracijske jarke. Struga Glinščice je bila na območju urbanih površin (na Viču) pred ureditvijo iz leta 1974 zelo zanemarjena.

Dno struge Glinščice je na celotnem odseku od izliva v Gradaščico do dolvodno od mostu Brdnikove ulice z regulacijo iz leta 1974 tlakovano z betonskimi ploščami. Trasa struge je bila izravnana. Na dnu struge je urejena betonska kineta (korito), širine 1 m in globine 0,25 m, ki je namenjena odvodnji srednjih letnih ter nizkih voda v sušnih obdobjih. Z betonskimi ploščami je obložen tudi del brežin, katerih nagib se giblje med 1 : 3 in 1 : 2.

Izbira takšne ureditve struge je bila utemeljena predvsem s tem, da se z ureditvijo osrednje kinete na dnu tudi v času nizkih voda zagotavljajo dovolj velike pretočne hitrosti in tako onemogoči zastajanje umazanije na dnu

2.2 THE GLINŠČICA CHANNEL BEFORE REGULATION WORKS AND DESCRIPTION OF PRESENT CONDITION

Before the regulation works, the Glinščica River channel gently meandered along its course. The channel was 3 to 6 m wide and 60 to 90 cm deep. The banks were 30 to 60 cm above the normal water level and the river bottom was muddy. The Glinščica flooded the areas of the village of Vič in rainy periods. Until the end of World War II, the Glinščica River was mostly unregulated upstream of Rožna dolina with a natural meandering channel. The channel area was overgrown and both, the banks and bottom were natural. Along the stream course, deep stream reaches with pools and shallow reaches alternated. The structure of fish population was varied and among fish species, the trout could also be found in the Glinščica. Larger pools were suitable for swimming. With Rožnik, Mali Rakovnik and Veliki Rakovnik and Večna pot the Glinščica provided an attractive natural gateway for promenading. After World War II, regulations took place on the Glinščica channel from the outfall section (regulation from 1928) upstream. This was not a planned regulation. The channel was being cleaned by landowners of the surrounding land, some drainage ditches were excavated, and meanders were cut off from the new straightened river channel. Before the regulation in 1974, the Glinščica channel was neglected, especially in the urbanized area (Vič).

The result of the regulation from 1974 is a concrete channel bottom in the section from the outfall into the Gradaščica river to Brdnikova street. The line of the channel was completely straightened. In the channel bottom a 1 m wide and 25 cm deep concrete ditch was arranged. This ditch conveys the average annual and low summer (dry) waters. A part of the channel banks, with a slope from 1 : 3 to 1 : 2, is paved with concrete plates.

The decision of arranging a concrete ditch on the channel bottom was based on the fact that the central concrete ditch assures sufficient velocity of flowing water in periods of average annual and even low summer water levels. In this way, the gathering of all sorts of pollution and waste inside the channel cross struge. Skupna dolžina odseka struge Glinščice od Jamnikarjeve (dolvodni konec odseka) do Brdnikove ulice (gorvodni konec odseka) je 1173 m (slika 2). Dno tlakovane struge je rahlo prekrito z drobnimi plavinami in drugimi snovmi, ki jih voda nanaša iz gorvodnih odsekov vodotoka, kjer je dno struge netlakovano, in iz iztokov meteorne kanalizacije. Intenzivnejše odlaganje plavin ob nizkih vodah na obravnavanem odseku onemogoča enakomerna porazdelitev hitrosti vodnega toka v osrednji betonski kineti. Na posameznih poškodovanih delih tlakovanega dna in brežin ter v razpokah med betonskimi ploščami se razrašča zarast. Raznolikosti vodnega toka tako rekoč ni. Prav tako na obravnavanem odseku ni sprememb v globini vode in širini vodnega toka. Prisotna je biološka obrast na dnu osrednje betonske kinete. Struga je skoraj na celotnem odseku nezasenčena. Glede na ekomorfološko kategorizacijo vodotokov, s katero opisujemo stopnjo naravne ohranjenosti vodotokov, je obravnavani odsek Glinščice uvrščen v 4. razred, v katerega so uvrščeni z ekološkega vidika najbolj degradirani odseki vodotokov (VGI, 1994a; 2002).

section is disabled. The channel reach from Jamnikarjeva street (downstream end point) to Brdnikova street (upstream end point) is 1173 m in length (Figure 2). The bottom of the paved channel is softly covered with fine sediments and other particles, which are transported from the upper reaches, where the channel bottom material remained natural and from the outlets of the urban drainage system. As mentioned before, the intensive depositing of sediments at low summer water levels is disabled by a uniform water velocity profile in the concrete ditch. Where the concrete pavement is damaged, vegetation grows through the cracks. There is no variety in the water current and no changes in stream width and depth. Some algae (periphyton) are present on the concrete bottom. The channel is almost completely unshaded on the reach discussed. According to the ecomorphological categorisation of the watercourse reaches, which considers the degree of natural conservation of a watercourse, the described reach is placed in class 4. The class is reserved for watercourses that are heavily degraded from the ecological point of view (VGI, 1994a; 2002).

Slika 2. Glinščica gorvodno od Jamnikarjeve ulice.
Figure 2. The Glinščica upstream of Jamnikarjeve street.

Vpliv regulacijskih del na poslabšanje življenjskih razmer v strugi Glinščice na obravnavanem odseku je razviden iz ihtiološke raziskave, ki je bila opravljena v sklopu nalog Voda in prostor (VGI, 1994b). Raziskava je zajela odsek reke Glinščice od Glinc do Biološkega središča. Glavni namen raziskave je bil pridobiti oceno dinamike ribjih populacij v posameznih odsekih vodotoka. Rezultati raziskave so pokazali, da obstaja velika razlika v sestavi ribjih populacij med odsekom Glinščice, kjer je dno struge in brežine netlakovano, ob posameznih odsekih struge pa je prisotna tudi delna preraščenost struge z grmičevjem, ter odsekom dolvodno, kjer je dno in del brežin tlakovano z betonskimi ploščami. Na odseku stare regulacije z zemeljskimi brežinami je naseljenost z ribami 755 kg/ha, na odseku struge, utrjene z betonskimi ploščami, pa 260 kg/ha vodne površine. Razlika v strukturi ribjih populacij in v letnem naravnem prirastku posameznih ribjih vrst je posledica spremenjenih življenjskih pogojev po izvedbi regulacijskih in melioracijskih del. Globljih tolmunov, v katerih lahko svoj prostor najdejo večje ribe, ni. Prav tako v strugi ni zatonov ter ribjih zavetišč, ki so primerna za razvoj ribjega zaroda, hkrati pa se v njih lahko ribe skrijejo v času visokih voda. Zaradi redne košnje brežin struge ni obrežne vegetacije, ki bi zasenčila strugo in s tem vplivala na znižanje temperature vode in povečane koncentracije raztopljenega kisika v vodi, predvsem poleti. Kjer je obrežna vegetacija prisotna (posamezni krajši odseki), betonsko tlakovanje onemogoča prodiranje koreninskega sistema v strugo, s čimer bi se popestrila struktura osiromašenega vodnega življenjskega prostora.

Hidravlična prevodnost struge na obravnavanem odseku ni ustrezna. Visoke vode s 5-letno povratno dobo (12,8 m^3/s) že preplavljajo predvsem levi breg in ogrožajo objekte Biološkega središča. Pri 10-letni visoki vodi (16,5 m^3/s) so že poplavljene obsežne obrežne površine na levi in desni strani struge Glinščice. Glede na izvrednotene hidrološke podatke z modelom HEC 2 (VGI, 1999) na podlagi analize padavin, znašajo visoke vode s 100-letno povratno dobo 39 m^3/s. Višina brežin struge na tem odseku znaša od 1,5 do 2

The influence of channel regulations on the deterioration of living conditions inside the channel profile is evident from ichthyological research. This research was performed within the framework of Water and Space (VGI, 1994b). A channel reach from Glince to the Biološko središče was evaluated. The principal objective of the research was to acquire an estimation of dynamics of fish population inside several channel reaches. Results have shown that there is a great difference in structure of fish population between the reach, where the channel bottom remained natural with dense vegetation on the banks, and the reach, where the concrete channel bottom is present. The abundance of fish in the more natural reach is 755 kg/ha (weight per water surface) in comparison to the reach where the channel is confined, where the abundance of fish is estimated at 260 kg/ha. Differences in the composition of fish population and in the annual natural accretion of different fish species are a direct result of the changed living conditions following the regulation and melioration works. Deep pools, where fish can live, were removed from the channel. There are also no suitable places for propagation nor any hiding places for fish during high water. Due to regular clearing of the vegetation on channel banks, the channel is not shaded, and thus, water temperature in summer is high and the concentration of dissolved oxygen is very low. In short subreaches, where the vegetation cover is present, the concrete paving of the channel does not allow for advancement of roots inside the channel, which could influence and improve the monotone structure of poor ecological conditions of the water body.

The hydraulic conductivity of the Glinščica channel is not sufficient. High water levels with a return period of 5 years (12.8 m^3/s) inundate especially the area on the left side of the channel and endanger the buildings of the Biological Centre. Areas on both sides of the Ginščica channel are inundated during floods with a return period of 10 years (16.5 m^3/s). Considering the hydrological data gathered with the hydrological model HEC 2 (VGI, 1999) and based on the analysis of rainfall events, the estimated floodwaters with a return period of 100 years amount to 39 m^3/s. The height of the channel banks on the discussed reach is from 1.5 to 2 m and the width of the channel cross section on the top is estimated at m, pri tem pa širina struge merjena na vrhu brežin 8 do 12 m. Padec dna struge na tem odseku je majhen in znaša 0,19 %, kar dodatno prispeva k slabši hidravlični prevodnosti struge.

2.3 OSNOVE ZA OBLIKOVANJE SONARAVNE UREDITVE STRUGE GLINŠČICE

Glavni namen sonaravne ureditve struge Glinščice na odseku od Jamnikarjeve do Brdnikove ulice je predvsem normalizacija pretočnih razmer. Tako bi zagotovili potrebno poplavno varnost obdajajočih urbanih površin in dosegli bolj raznolike pretočne razmere, predvsem v času srednjih letnih voda ter nizkih voda v sušnih obdobjih. Rešitev problema visokih voda na obravnavanem odseku Glinščice ni zgolj v povečanju hidravlične prevodnosti obstoječe struge na odsekih, kjer je poplavna ogroženost obrežnih urbanih površin največja (odsek ob Biološkem središču ter Biotehnični fakulteti). Tako bi se še povečal problem odtoka visokih voda na dolvodnem odseku Glinščice na območju Viča. Reševanje problematike visokih voda Glinščice mora biti usmerjeno v normalizacijo odtočnih razmer na celotnem prispevnem območju. V okviru projekta (VGI, 1999; 2001) je predvidena ureditev suhega zadrževalnika v profilu Brdnikove ulice. Z ureditvijo suhega zadrževalnika na tem mestu bi neposredno vplivali na pretočne razmere v dolvodnih odsekih vodotoka na območju Biološkega središča in urbanih območij ob izlivu v Gradaščico. Visokovodni val s povratno dobo 100 let bi se v profilu vodomerne postaje Rožna dolina z 38 m^3/s zmanjšal na približno 11 m^3/s in ob izlivu z 39 m^3/s na 17 m^3/s.

S povečano raznolikostjo pretočnih razmer je povezano izboljšanje ekološkega stanja v vodotoku ter razvoj primernih življenjskih prostorov za vodne in obvodne organizme. Za zasnovo sonaravne ureditve struge Glinščice na obravnavanem odseku, ki upošteva specifičnost pretočnih razmer v sušnih obdobjih, je bilo treba pridobiti vrednosti nizkih pretokov. V juliju 2003 smo izvedli meritve pretoka Glinščice ob Biološkem središču. V osrednji, 1 m široki betonski kineti

8 to 12 m. The gradient of the channel ground is only 0.19 %. This is an additional reason of the poor hydraulic conductivity.

2.3 BASES FOR IMPLEMENTATION OF THE GLINŠČICA CHANNEL REHABILITATION SCHEME

The primary purpose of the proposed rehabilitation scheme on the discussed reach of the Glinščica from Jamnikarjeva street to Brdnikova street is the normalization of discharge conditions in sense of improvement of flood protection for the surrounding urban areas. The rehabilitation scheme also considers the possibilities to improve the variegation of flow conditions in time of mean annual and low summer water levels. The problem of high flows on the discussed reach, where the flood threat of the surrounding urban areas (reach at the Biological Centre and Biotechnical Faculty) is greatest, cannot be solved only by improving the hydraulic conductivity of the existing channel. This could only enlarge the flooding of the urban area on the downstream reach (Vič). The solution should be oriented into a normalization of discharge conditions on the entire Glinščica catchment area. The project (VGI, 1999; 2001) anticipates the arrangement of a retention area for floodwaters in the profile of Brdnikova street. The retention area would directly influence the discharge conditions downstream on the discussed reach and further downstream in the urban areas near the outfall section. The highflow wave with a return period of 100 years on the section of the gauging station of Rožna dolina would be reduced from 38 m^3/s to approximately 11 m^3/s and in the outfall section from 39 m^3/s to 17 m^3/s.

The increased variety of discharge conditions would influence the improvement of the ecological state of the water body and would enable development of suitable habitats for the riparian flora and fauna. To properly draft the rehabilitation scheme, values of low summer discharges were measured in July 2003 in the channel near the Biological Centre. The depth of water in the concrete ditch was only 6 cm. Measurements with the hydrometrical wing or the acustic Doppler je bila globina vode le 6 cm, kar onemogoča izvedbo meritve pretoka s hidrometričnim krilom ali profilnim ultrazvočnim merilcem hitrosti. Meritev pretoka je bila izvedena z metodo razredčenja z instrumentom Flo-Tracer, ki s pomočjo beleženja spremembe elektroprevodnosti vode ob vnosu sledila (v našem primeru 1 litra raztopine NaCl) v vodotok, določi pretok vode v strugi. Izmerjen je bil sušni pretok 11 l/s.

V nadaljevanju sta predstavljeni dve variantni rešitvi sonaravne ureditve struge Glinščice na obravnavanem odseku. Upoštevane so hidrološke razmere, kakršne se bodo pojavile po ureditvi suhega zadrževalnika v profilu Brdnikove ulice, ki bo prispeval k znižanju konic poplavnih valov. Merodajen pretok, ki ga bo po ureditvi suhega zadrževalnika morala prevajati struga Glinščice dolvodno od Brdnikove ulice, je ocenjen na 18 m^3/s (VGI, 2001). Obe variantni rešitvi sonaravne ureditve predvidevata odstranitev obstoječe betonske kinete ter betonskega tlakovanja brežin. Premajhno hidravlično prevodnost obstoječe struge je mogoče rešiti z razširitvijo struge in s povečanjem prečnega prereza struge brez obsežnejšega nadvišanja brežin. Dolvodno od predvidene sonaravne ureditve struge se nadaljuje obstoječa ureditev tlakovane struge.

2.4 HIDRAVLIČNI MODEL

Hidravlični računski model struge Glinščice, ki zajema odsek Glinščice od premostitve severne obvoznice do izliva v Gradaščico, je bil izdelan v programu HEC-RAS (Hydrological Engineering Center´s River Analysis System), verzija 3.1. Geodetski posnetek obravnavanega odseka smo pridobili na Inštitutu za vode Republike Slovenije. Podatke iz hidravličnega modela obstoječe struge, ki je bil izdelan na Inštitutu za vode Republike Slovenije v programu HEC-2, smo prenesli v program HEC-RAS. S programom HEC-RAS smo nadalje v hidravlični model vnašali spremembe prečnih prerezov ter tlorisnega poteka sonaravno urejene struge na obravnavanem odseku Glinščice, kakršne so predvidene v variantnih rešitvah 1 in 2. Tako je bila omogočena analiza pretočnih razmer ob nastopu različnih pretokov. Obstoječa struga z

velocimeter in such shallow waters cannot be performed. Measurements of the discharge were performed with Flo-Tracer, which measures the change in electroconductivity of water when dissolved salt (in our case 1 litre of dissolved NaCl) is poured into the channel. The measured low summer discharge in the concrete ditch was 11 l/s.

In continuation, two solutions for the rehabilitation scheme of the discussed reach of the Glinščica channel are represented. Hydrological conditions that would be established after the arrangement of a retention area for floodwaters in the profile of Brdnikova street, which would decrease peaks of the discharge hydrogram, are considered. A decisive discharge that would discharge out of the retention area downstream is estimated at 18 m^3/s (VGI, 2001). This is also the discharge used to determine the cross section of the rehabilitated channel. In both proposed solutions, the existing concrete pavement of the channel bottom and banks would be removed. The problem of insufficient hydraulic conductivity would be solved by widening the existing channel and an enlargement of the channel cross section without an intensive elevation of the channel banks. Downstream of the discussed reach, the existing paved channel would remain unchanged.

2.4 HYDRAULIC MODEL

Hydraulic computation model of the Glinščica channel includes the reach from the north motorway bridge to the outfall into the Gradaščica river. The model was made with software HEC-RAS (Hydrological Engineering Center´s River Analysis System), version 3.1. Geodetic data of the discussed reach were acquired at the Water Management Institute. Data from the hydraulic model of the existing channel made by the Water Management Institute software HEC 2 were transformed into the hydraulic model in HEC-RAS software. The software was used to determine the necessary changes of the channel cross section and the ground plan position of the rehabiliated channel in proposed solutions 1 and 2, so that the analyses of different discharge condition were betonskim koritom na dnu struge in zatravljenimi brežinami, ki so tudi delno obložene z betonskimi ploščami, ima zelo nizke vrednosti Manningovega koeficienta hrapavosti in omogoča hiter in nemoten odtok vode (VGI, 1999). V okviru sonaravne ureditve struge Glinščice na obravnavanem odseku je predviden drugačen pristop k vzdrževanju brežin struge Glinščice, pri čemer se vegetacija znotraj profila strugo selektivno redči, tako da se v strugi še vedno zagotavlja načrtovano hidravlično prevodnost. Na podlagi analize globin vode pri posameznih pretokih, pretočnih hitrosti in pripadajočih strižnih napetosti, ki so podane v izhodnih podatkih hidravličnega modela, so bili predvideni ukrepi, s katerimi bi preprečili morebitne poškodbe predvidenih ureditev sonaravno urejene struge Glinščice.

3. REZULTATI

3.1 TLORISNI POTEK IN UREDITEV PREČNEGA PREREZA SONARAVNO UREJENE STRUGE

Večji del trase predvidene nove sonaravno urejene struge v obeh variantnih rešitvah poteka po območju obstoječe struge, ki je večinoma speljana po terenu z najnižjimi nadmorskimi višinami. Zaradi prostorskih omejitev so spremembe v poteku trase nove sonaravno urejene struge predvidene predvsem gorvodno od Biološkega središča, kjer je predvidena ureditev blagih zavojev, ki se izmenjujejo na obeh straneh obstoječe ravne trase struge. Dolžina obravnavanega odseka struge bi bila po izvedeni ureditvi 1195 m.

Zaradi specifičnosti pretočnih razmer z izjemno nizkimi vodami poleti ter občasnimi izjemno visokimi vodami, je v obeh variantnih rešitvah predvidena ureditev dvojnega prečnega prereza struge Glinščice. Pri tem razširjen dvignjen profil, ki je na vrhu brežin širok 12 do 22 m (variantna rešitev 1) oziroma 15 do 28 m (variantna rešitev 2, slika 3), večinoma poteka skladno z obstoječo traso kanalizirane struge. Razširjen dvignjen profil je namenjen odvodnji merodajnega pretoka 18 m^3/s (variantna rešitev 1) (slika 4) oziroma 25 m^3/s (variantna rešitev 2) (slika 5), ki bi se ga ob nastopu visokih voda izpuščalo iz suhega

possible. The existing channel with concrete armouring of the bottom and banks has very low values of Manning´s roughness coefficient, which enable fast and undisturbed outflow (VGI, 1999). In combination with the rehabilitation scheme, a special emphasis is also given to a proposed maintenance plan, leaving a certain (admissible) amount of vegetation in the cross section untouched, having in mind the projected hydraulic conductivity. Results of hydraulic computation model, such as depth of water at different discharges, velocity and combining shear stress, were the basis for further analysis and selection of protective measures, which would prevent the possible damages of remediation works in the rehabilitated Glinščica channel.

3. RESULTS

3.1 GROUND PLAN AND THE REGULATION OF THE REHABILITATED CHANNEL CROSS SECTION

A greater part of the foreseen rehabilitated channel on the discussed reach would coincide with the existing channel, which passes on the area with the lowest altitudes. The lack of available space for channel rehabilitation in the downstream part of the discussed reach (the area around and downstream from the buildings of the Biological Centre) is the main reason, why the regulation of a few small-sized meanders on both sides of the existing lined channel is possible only in the upper part of the reach (upstream of the Biological Centre). The length of rehabilitated reach would be 1195 m.

Due to specific discharge conditions with extremely low water levels in summer and periodic high water levels, in both proposed solutions a regulation of a two-stage watercourse channel is proposed. The widened, elevated part of the cross section has a width of 12 to 22 m (solution 1) and 15 to 28 m (solution 2, Figure 3), respectively. The ground plan of the widened cross section mainly coincides with the existing channel and is planned for the conveyance of the decisive discharge of 18 m^3/s (solution 1) (Figure 4) or 25 m^3/s (solution 2) (Figure 5), which would discharge out of the retention area in the section of Brdnikova street in periods of zadrževalnika v profilu Brdnikove ulice.

Predvidena ureditev osrednje poglobljene struge je v obeh variantnih rešitvah enaka. Osrednji poglobljen del struge je širok 1,8 do 10 m in je namenjen prevajanju srednjih letnih voda (Q_{sr} = 383 l/s) in nizkih voda v sušnih obdobjih ($Q_{suš}$ = 11 l/s). Trasa osrednje struge je bolj razgibana s pogostim spreminjanjem širine struge in oblike prečnega prereza. Prav tako so pogoste spremembe pretočnih globin osrednje struge. Na odsekih, kjer je osrednja struga ozka, je globina vode v strugi pri srednjih pretokih 20 do 30 cm. Predvidena je ureditev 10 tolmunov. Dno tolmunov je dodatno razširjeno in poglobljeno. Globina vode v tolmunih bi bila tudi v času ekstremno nizkih pretokov 40 do 80 cm. Obstoječe betonsko tlakovanje dna struge omogoča hiter odtok vode ter s tem posledično zelo majhno vodnatost struge v sušnih obdobjih. S predvideno ureditvijo tolmunov bi v sušnih obdobjih dosegli počasnejši odtok vode ter tako povečali vodnatost struge.

Dodatno bi zadrževalno sposobnost struge za nizke vode povečali z vgradnjo nizkih kamnitih pragov ali pragov, zgrajenih iz lesenih oblic. Pragovi višine 20 cm bi se nahajali dolvodno od posameznega tolmuna ter na ta način prispevali k dvigu in umiritvi gladine vode v tolmunu. Nizki pragovi in stopnje bi obenem predstavljali fiksne točke v dnu struge ter na ta način ohranjali predvideni padec dna struge na posameznih pododsekih. Ob tem je treba poudariti, da nizki pragovi vplivajo le na nivoje nizkih voda in nimajo nobenega vpliva na poslabšanje pretočnih razmer v času nastopa visokih voda.

3.2 HIDRAVLIČNI IZRAČUN

Z rezultati hidravličnega modela struge Glinščice smo prikazali vpliv predvidene ureditve dvojne struge Glinščice na zmanjšanje poplavne ogroženosti obdajajočih urbanih površin ter možnosti za izboljšanje življenjskih pogojev za vodne organizme v strugi.

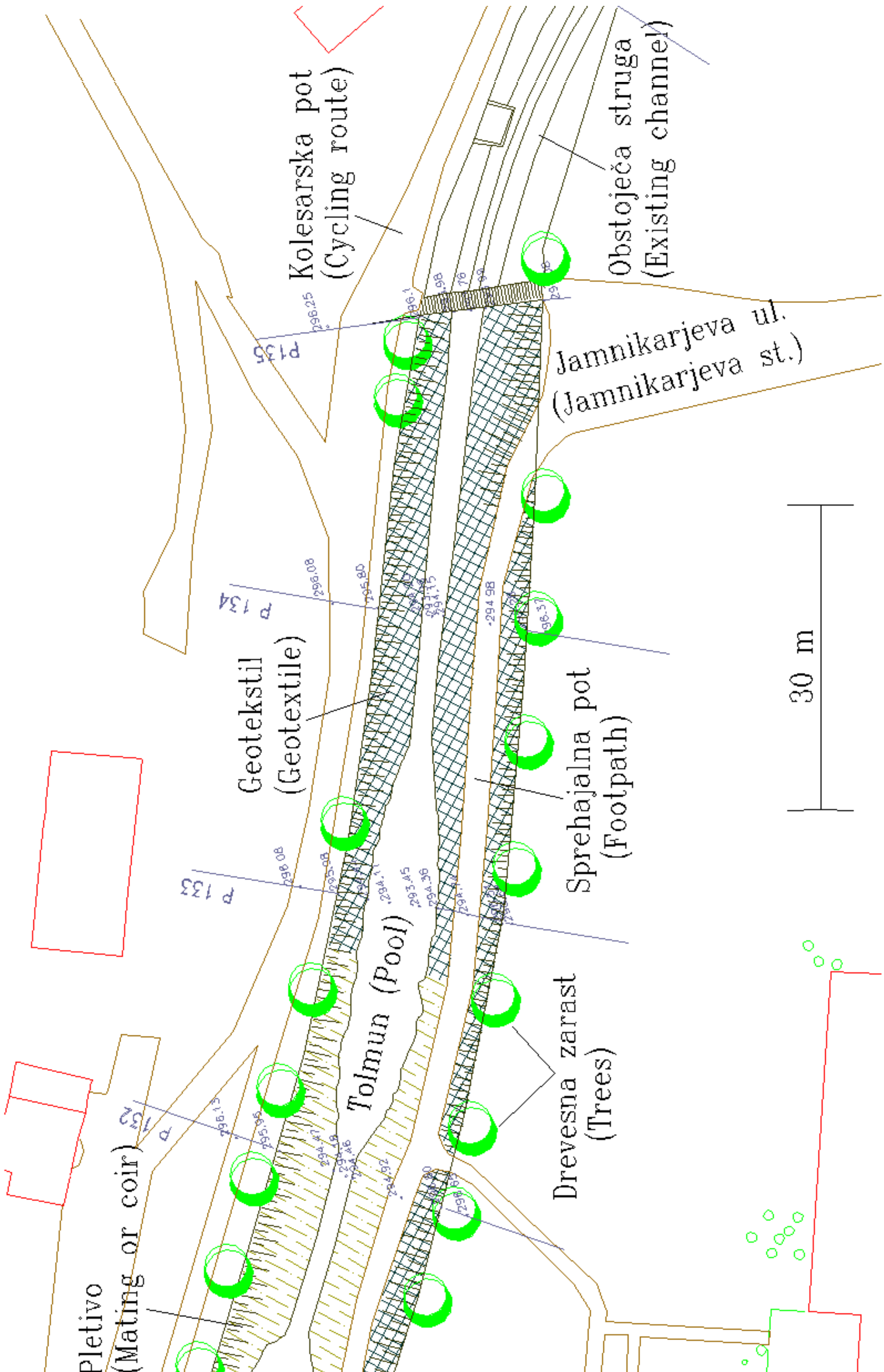
floodwaters.

The proposed regulation of the central, lowered part of the cross section is in both proposed solutions the same. The central, lowered part of the cross section is 1.8 to 10 m wide and is planned for the conveyance of low summer water levels (Q_{summer} = 11 l/s) up to mean annual discharges (Q_{mean} = 383 l/s). The central line of the lowered channel is not straight, frequently changing in width and shape of the central channel cross section. For example, the water depth is approximately equal to the mean annual discharge, ranging from 20 to 30 cm in sections where the central channel is narrow. The arrangement of 10 larger pools is anticipated. The bottom of each pool is widened and deepened. Even in periods of extremely low water (discharge approximately 11 l/s), the depth of water in pools would be from 40 to 80 cm. As mentioned, the existing paved channel enables fast flowing water, thus, the water abundance of the existing channel is very low. The proposed regulation of pools would reduce water velocity and increase water abundance especially in periods of extremely low water levels.

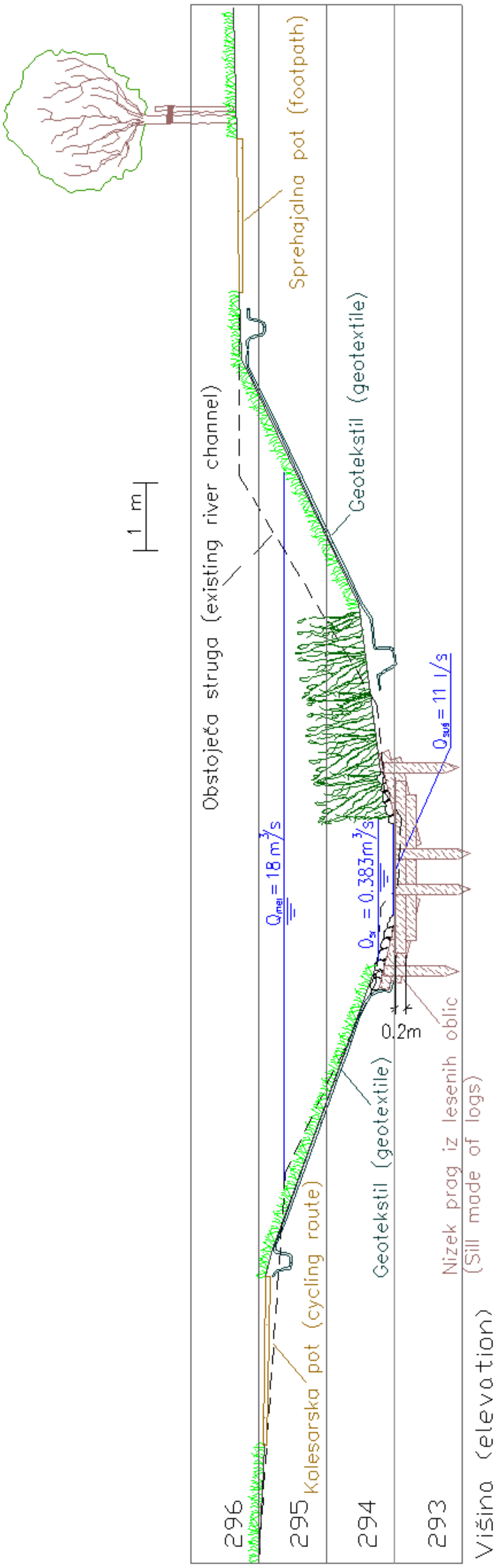
Additionally, the water abundance would increase by installation of low sills made of stone or logs. These sills, approximately 20 cm in height, would be positioned downstream of each pool, and they would directly influence the elevation and stabilization of water levels in the pool upstream. Also, the sills would present stable, fixed points of the rehabilitated channel bottom and preserve the planned gradient of the channel in the subreaches. It should be emphasized that sills influence only low water levels, however, they do not decrease the hydraulic conductivity of the rehabilitated channel during floodwaters.

3.2 HYDRAULIC COMPUTATION

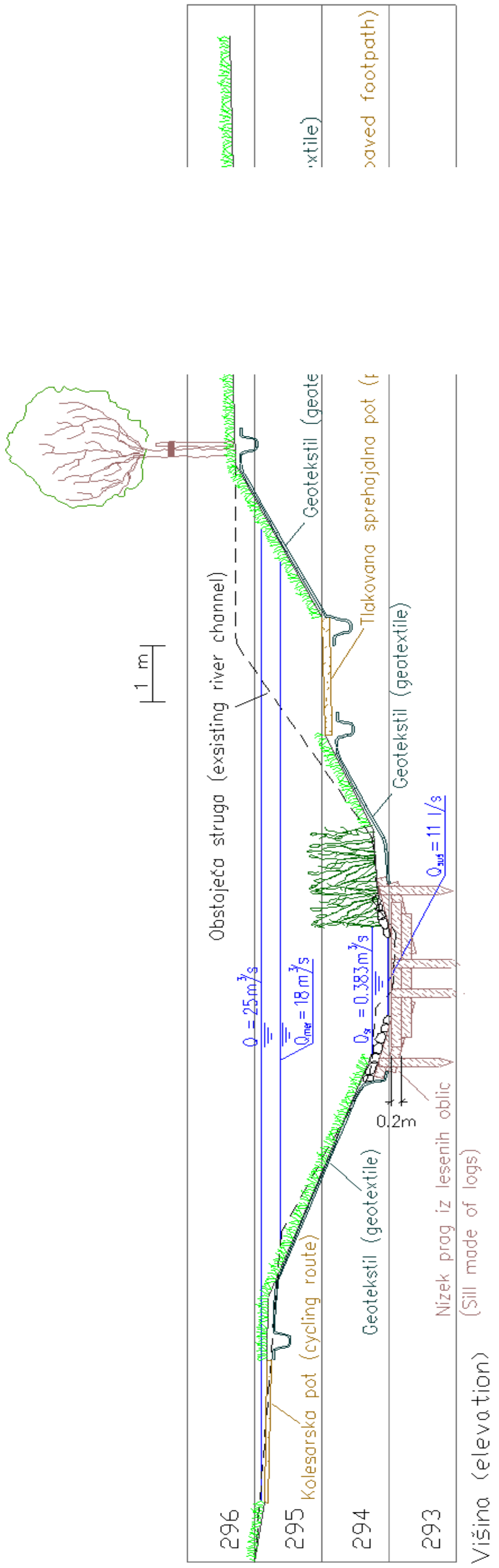
The results of the hydraulic computation model have shown the impact of the rehabilitation scheme and two-stage channel on the reduction of flood threat to the surrounding urban areas and provided guidelines for improvement of the ecological role of the water body for the riparian flora and fauna.



Slika 3. Odsek sonaravno urejene struge gorvodno od Jamnikarjeve ulice (variantna rešitev 2).
Figure 3. Section of the rehabilitated channel upstream of Jamnikarjeva street (Solution 2).



Slika 4. Prečni prerez struge (P134) z nizkim pragom iz lesenih oblic (variantna rešitev 1).
Figure 4. Cross section of rehabilitated river channel (P134) with sill made of logs (solution 1).



Slika 5. Prečni prerez struge (P134) z nizkim pragom iz lesenih oblic (variantna rešitev 2).
Figure 5. Cross section of rehabilitated river channel (P134) with a sill made of logs (solution 2).

Poseben poudarek je bil na možnostih ureditve osrednjega poglobljenega dela struge, ki prevaja srednje letne in sušne vode. Z ureditvijo osrednje struge bi dosegli koncentriranje vode v sušnih obdobjih, tako bi se zmanjšala temperatura vode in izhlapevanje v poletnih mesecih. Na območja tolmunov, kjer bi prišlo do zadrževanja vode, bi se vodni organizmi lahko umaknili v obdobjih izjemno nizkih pretokov. Prav tako pa bi območja tolmunov z nekoliko nižjimi pretočnimi hitrostmi predstavljala zavetišče za vodne organizme tudi v času visokih voda.

Prenos plavin v strugi Glinščice bi bil zaradi majhnih hitrosti vodnega toka ter posledično šibkih strižnih napetosti tako rekoč zanemarljiv, zato ne bi bilo nevarnosti, da bi prišlo do odlaganja plavin na območjih tolmunov. Na vmesnih odsekih med posameznimi tolmuni, kjer je osrednja struga široka le približno 2 m, bi prišlo do pospešitve vodnega toka, kar bi popestrilo strukturo pretočnih hitrosti v obdobjih srednjih pretokov ter obdobjih, ko je v strugi izjemno malo vode. Primerjava porazdelitve pretočnih hitrosti v vzdolžnem profilu obravnavanega odseka v obstoječi strugi ter v sonaravno urejeni strugi pri pretoku 11 l/s je prikazana na sliki 6. Iz slike je dobro razvidno zmanjšanje pretočnih hitrosti na območjih tolmunov ter pospešitev vodnega toka na vmesnih odsekih med posameznimi tolmuni.

Predvidena ureditev bi vplivala tudi na povečanje vodnatosti struge. Vodnatost je izražena v m^3 vode, ki se zadržujejo v strugi na določenem odseku ob sušnem pretoku 11 l/s. Vodnatost obstoječe struge znaša 5,04 m^3 na 100 m (vodnatost 100 m dolgega odseka struge). V sonaravno urejeni strugi se vodnatost poveča na vrednost 42,7 m^3 na 100 m struge.

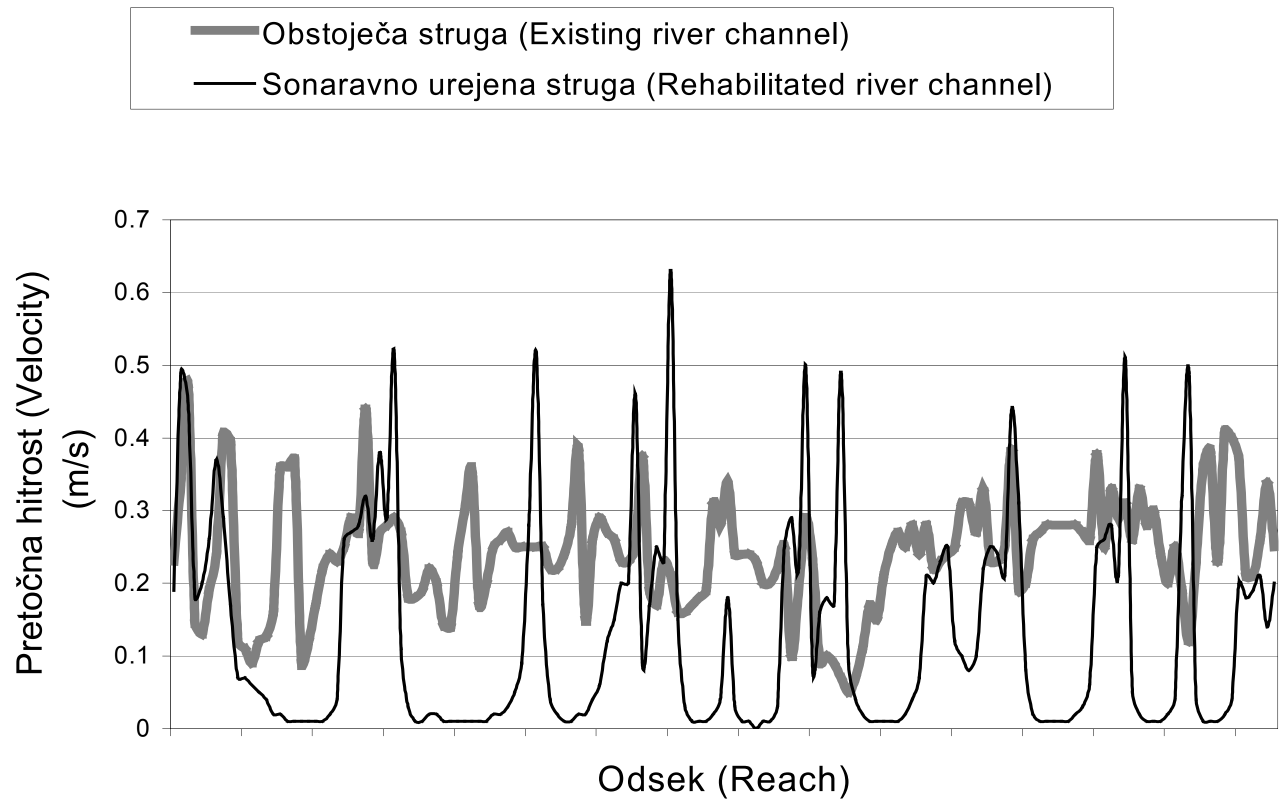
Razporeditev vegetacije v prečnem visokovodnem profilu struge je ključnega pomena tako s stališča zagotavljanja načrtovane hidravlične prevodnosti struge kot tudi z vidika zagotavljanja primernih življenjskih pogojev za vodne in obvodne organizme. V normalnem prečnem prerezu sonaravno urejene struge Glinščice so bila predvidena tri območja, ki se razlikujejo glede na vrednosti Manningovega koeficienta hrapavosti (slika 7).

Special emphasis was given to the options of remediating the central part of a two-stage channel for low summer to mean annual water levels. The regulation of the central channel would accumulate water in periods of low water level, and thus the water temperature and evaporation would decrease. Areas with pools would retain water. These would ensure water organisms their survival in periods of extreme low water levels. In periods of high waters, the pools would provide shelter for water organisms, because of slightly lower flow velocity.

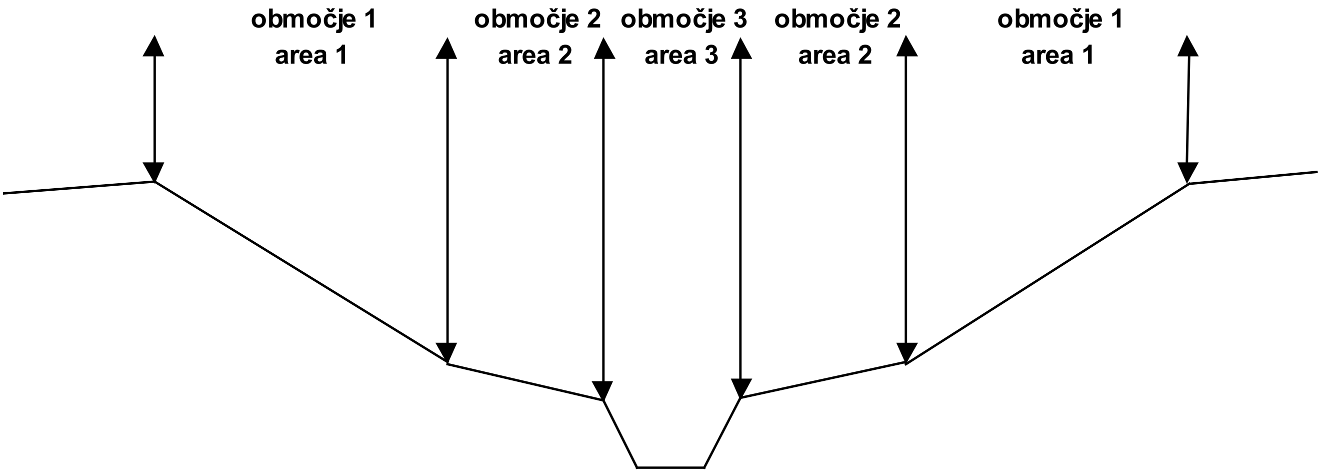
Due to low flow velocity in the rehabilitated channel, the quantity of possible sediment deposition in pools would be negligible. On sections between two pools, where the central channel is only about 2 m wide, the water velocity would slightly increase. These changes in the structure of the longitudinal velocity profile of the rehabilitated reach would contribute to the variegation of habitat conditions. Comparison of velocities in the longitudinal profile of the discussed rehabilitated reach for low summer discharge 11 l/s is shown in Figure 6. The influence of pools (low water velocity) and between reaches (high water velocity) with narrow central channel on the structure of longitudinal velocity profile is seen clearly.

As mentioned, the foreseen rehabilitation of the discussed reach would also influence the water abundance. The water abundance is defined as quantity of water in m^3, which is retained in a particular reach of a channel (in our case at a discharge of 11 l/s). Water abundance of a 100 m reach of the existing channel is 5.04 m^3, in comparison to the rehabilitated channel, where the water abundance rises to 42.7 m^3.

Distribution of vegetation cover inside the rehabilitated channel cross section is essential for assuring the planned hydraulic conductivity of the channel and also to ensure suitable habitats for riparian flora and fauna. Inside the normal cross section of the rehabilitated cross section, 3 areas with different structure of vegetation cover and therefore also different values of Manning´s roughness coefficient, were defined (Figure 7).



Slika 6. Primerjava porazdelitve pretočnih hitrosti v vzdolžnem profilu obravnavanega odseka v obstoječi ter sonaravno urejeni strugi pri pretoku 11 l/s.
Figure 6. Comparison of water velocity in the longitudinal profile of the reach in the existing river channel and the proposed rehabilitated river channel with a discharge of 11 l/s.



Slika 7. Razdelitev normalnega prečnega prereza sonaravno urejene struge na tri območja z različnimi vrednostmi Manningovega koeficienta hrapavosti.
Figure 7. Distribution of the Glinščica channel cross section onto 3 areas with different values of Manning´s roughness coefficient.

Intenzivnejše razraščanje predvsem emergentnih rastlinskih vrst bi bilo dovoljeno predvsem na območju 2, ki predstavlja položen prehod iz ožje poglobljene struge, namenjene odvodnji nizkih in srednjih voda v

Intensive growth of emergent vegetation cover would be allowed, especially in area 2, which represent a gradual transition from the central deepened channel planned for conveying water levels up to mean annual discharge, to the widened elevated second razširjen profil struge, ki prevaja merodajni pretok 18 m^3/s. S tem bi dosegli boljšo osenčenost osrednjega svetlega pretočnega profila struge (območja 3). Na območju 1 je predvideno redno čiščenje zarasti.

Glede na gostoto vegetacijskega pokrova in vegetacijske dobe, se vrednosti Manningovega koeficienta hrapavosti gibljejo od 0,35 do 0,55.

3.3 STABILIZACIJA DNA STRUGE IN BREŽIN

Sonaravno urejena struga bi po odstranitvi obstoječega betonskega tlakovanja v celoti potekala v meljastem in glinenem materialu, ki je prisoten na neutrjenem dnu struge gorvodno od Brdnikove ulice. Iz obstoječe neutrjene struge gorvodno od Brdnikove ulice ne prihaja do občutnejšega dotoka plavin v dolvodne odseke struge, kljub temu da dosežejo strižne napetosti na dnu struge pri pretoku 18 m^3/s, glede na rezultate hidravličnega modela struge, vrednosti do 30 N/m^2. Na podlagi hidravličnega modela struge Glinščice je bila pri merodajnem pretoku 18 m^3/s na obravnavanem odseku struge ugotovljena kritična strižna napetost na dnu struge 70 N/m^2. S pomočjo Shieldsovega diagrama za začetek prodnega premika, ob upoštevanju kritične brezdimenzijske strižne napetosti (običajno uporabljena vrednost po Shieldsu je 0,055) smo izračunali srednji premer zrn potrebnega nasutega lomljenca 7,9 cm, pri katerem še ne pride do premeščanja nasutega materiala.

Z nasutjem sloja lomljenca bi odsekoma popestrili zrnavostno sestavo plavin na dnu struge. Pod krovni sloj lomljenca je predvideno nasutje podložnega filtrnega sloja drobljenca, s katerim bi preprečili spiranje zrn meljastih temeljnih tal skozi vrzeli med posameznimi grobimi zrni nasutega krovnega sloja.

Z izračuni hidravličnega modela so bili predlagani tudi dodatni ukrepi, s katerimi bi zaščitili brežine struge vodotoka pred erozivnim delovanjem vodnega toka. V povezavi s sonaravnimi ureditvami vodotokov naj se spodbuja uporaba inženirsko-bioloških

stage of the channel cross section, which conveys discharges of up to 18 m^3/s. The purpose of such distribution of vegetation inside the cross section is to assure a better shading of the central clear part of the cross section (area 3). The vegetation in area 1 would be regularly cleaned.

Values of Manning´s roughness coefficient are between 0.35 and 0.55, depending on the density of vegetation cover and time of the year.

3.3 STABILIZATION OF THE CHANNEL BOTTOM AND BANKS

After removal of the existing concrete paving, a new watercourse channel would be arranged in silt and clay, which is also present upstream of Brdnikova street in the more natural channel. There is no considerable transport of sediments from the upstream reach downstream to the discussed reach, even if in some sections of the channel the values of shear stress reach 30 N/m^2, regarding the results of hydraulic model for a discharge of 18 m^3/s. Based on the results of shear stress on the rehabilitated reach for a discharge of 18 m^3/s, the critical shear stress on the bottom of rehabilitated channel is 70 N/m^2. Using Shields´ diagram for evaluation of the starting point of transportation for gravel and the value for critical dimensionless shear stress (the commonly used value proposed by Shields is 0.055), the mean diameter (7.9 cm) for particles of the confining layer was computed. Such granulometric structure of the confining layer assures that the material is not transported.

The confining layer of the quarry stone would also variegate the granulometric structure of bed material in some sections of the channel. Beneath the confining layer, the implementation of the underlying filter layer is proposed. The underlying layer would prevent the denudation of silt and clay material through the gaps between the rough particles of the confining layer.

Additional bank revetments were based on the results of the hydraulic computating model. The revetments would protect banks from the erosive forces of water. In combination with the regulations of rehabilitated channels, the usage of bioengineering techniques is advised. The following bioengineering techniques are included in the rehabilitation scheme:

metod zaščite brežin struge. Predvideni so naslednji načini zaščite tvoriva brežin:

- Po zaključku zemeljskih del bi bilo treba celotno območje brežin zatraviti.
- Na odsekih struge, kjer se nagibi brežin gibajo med 1 : 3 in 1 : 2, je v kombinaciji z zatravitvijo brežine predvidena vgradnja pletiva iz jute ali kokosovega pletiva, s čimer bi dodatno zaščitili zemljino v brežini ter preprečili izpiranje semen trav takoj po vgradnji. Na najbolj kritičnih odsekih, kjer so nagibi brežin največji (nagib brežin približno 1 : 2), je zaželeno prekritje brežine struge z biorazgradljivo geotekstilno mrežo. Pletiva in geotekstilna mreža morajo biti dobro pritrjeni na brežino, da ne pride do poškodb ali njihovega odplavljanja ter posledičnega izpiranja zemljine z brežine.
- Kjer bi bil material v brežini sonaravne struge na novo nasut, obstaja nevarnost pronicanja vode skozi nasuti nekonsolidiran material ter destabiliziranja brežine. Priporočena je obložitev teh odsekov s plastjo komprimirane zaglinjene zemljine, s katero bi se zmanjšalo možno pronicanje vode skozi nasuti material v brežini. Dodatno se brežino prekrije s kokosovim pletivom ali pletivom iz jute ter intenzivno zatravi. Ob tem mora biti stabilizacija brežine izvedena na odseku, ki je daljši od odseka brežin, kjer je bil material na novo nasut.

3.4 UREDITEV SPREHAJALNIH POTI

Poleg različne hidravlične prevodnosti struge zaradi različne razširitve prečnega prereza struge (v variantni rešitvi 1 je predvidena sonaravna struga sposobna prevajati 18 m^3/s, v variantni rešitvi 2 pa 25 m^3/s) se variantni rešitvi razlikujeta tudi glede na način preureditve obstoječih sprehajalnih poti ob strugi. V variantni rešitvi 1 je predvidena ureditev sprehajalnih poti ob robu sonaravno urejene struge Glinščice (slika 3). Variantna rešitev 2 predvideva umestitev sprehajalne poti v profil sonaravno urejene struge Glinščice (slika 4). V obdobjih nastopa poplavnih voda v strugi Glinščice, bi bili posamezni najnižji odseki sprehajalne poti preplavljeni in nekaj dni na leto neprehodni.

- After the conclusion of construction works, the entire area of the rehabilitated banks should be grassed.
- On the sections, where the banks have a slope of 1 : 3 to 1 : 2, in combination with grass turf, an implementation of jute matting or coconut coir is proposed. The matting or coir would additionally protect the bank material and prevent the washing of grass seeds immediately after the implementation. In the sections of the channel, where banks are steepest (about 1 :2), an implementation of the biodegradeable geotextile is proposed. Special attention must be given to a proper implementation of the matting, coir or geotextile to prevent the possible dislocations and destabilization of bank material.
- The water could seep through the unconsolidated material in sections, where the channel banks would be arranged through the unconsolidated material. This could cause the collapse of the new channel banks. Thus, the implementation of a layer of comprimated clay material on the threatened sections of banks is recommended. This layer would reduce the seepage of water through the unconsolidated bank material. Additionally, a layer of the comprimated clay material would be covered with jute matting or coconut coir. The described stabilisation method must be implemented on the section, which is longer than the section, where the material is expected to be unstable.

3.4 ARRANGEMENT OF FOOTPATHS

Beside different levels of hydraulic conductivity of the rehabilitated channel due to different sizes of channel cross sections (in solution 1, the channel conveys a discharge of up to 18 m^3/s, and in solution 2 up to 25 m^3/s), the essential difference between both solutions is the proposed repositioning of the existing network of footpaths. In solution 1, the footpath is positioned beside the rehabilitated channel (Figure 3). In solution 2, the footpath is positioned inside the channel cross section (Figure 4). In periods of elevated water levels in the Glinščica channel, some lowest parts of the footpath would be flooded and thus

Zaradi nevarnosti poškodb sprehajalne poti v času visokih voda bi bilo treba sprehajalno pot na odsekih, kjer bi prišlo do preplavitev, tlakovati s poravnanim lomljencem, najbolj strme odseke brežin ob sprehajalni poti pa zaščititi z geotekstilno mrežo oz. s popletom iz kokosovega pletiva ali jute. Namen takšne ureditve je približati vodno telo obiskovalcem sprehajalnih poti ter omogočiti varen dostop do vodnega telesa.

4. RAZPRAVA

Glavni pogoj za izvedbo sonaravnih ureditev strug vodotokov in pripadajočih obvodnih površin v urbanem okolju je predvsem zagotovitev razpoložljivega prostora. Površine neposredno ob strugi Glinščice na območju Viča do Rožne doline so pozidane. Na tem odsekih ni razpoložljivega prostora za sonaravno ureditev vodotokov, kot je izoblikovanje vijugaste trase struge in ureditev razširjene struge. Gorvodno od Rožne doline (Jamnikarjeva ulica) se ob regulirani strugi Glinščice konča strnjena pozidava, na obeh straneh struge so predvsem travnate in redke njivske površine. Z vidika pridobitve potrebnih površin za razširitev obstoječe struge in ureditev dvojnega prečnega prereza struge je torej izbrani odsek struge Glinščice primeren za izvedbo sonaravne ureditve. V preglednici 1 je za obe variantni rešitvi podana površina zemljišč ob obstoječi strugi, ki bi jih bilo treba pridobiti za ureditev prečnega prereza sonaravno urejene struge.

Poudariti je treba, da prostorski plan Mestne občine Ljubljana (MOL, 2002) na območju obravnavanega odseka Glinščice ne predvideva obsežnejše širitve urbanih površin. Cilji prostorskega razvoja na obravnavanem območju so usmerjeni v ureditev zelenih površin, ki bi bile funkcionalno vključene v predvideni zeleni sistem Ljubljane. Ta bi skupaj z drugimi urbanimi grajenimi površinami prispeval k izoblikovanju mestne strukture. Sonaravna ureditev struge bi torej prispevala k dvigu ekološke vrednosti kot tudi privlačnejšemu izgledu že sedaj dobro obiskanih zelenih rekreacijskih površin ob regulirani strugi Glinščice.

impassable for several days per year. Because of possible erosion, the footpath should be paved with quarry stone, steep sections of banks beside the footpath should be additionally protected with geotexstile, jute matting or coconut coir. Such arrangement of footpaths would bring the water body closer to visitors and ensure safe access to the watercourse channel.

4. DISCUSSION

The basic condition for the practical implementation of the rehabilitation scheme of watercourse channels and their surrounding areas in an urban environment is to assure the available space. On the reach of the Glinščica from the outfall section to Rožna dolina, the areas along the existing channel are densely urbanized. There is no available space for regulations on this reach in the sense of widening the existing channel or regulating the meandering channel. Upstream of Rožna dolina (Jamnikarjeva street), the surrounding areas are not urbanized as densely as in the downstream reach. The surrounding areas are mainly meadows and fields. The area for implementation of the rehabilitation scheme (widening of the existing channel and regulation of a two-stage cross section) is available. The area of landed property along the existing channel that should be acquired for the proposed rehabilitation of the channel in each solution is shown in Table 1.

The plan for future urban planning of the Municipality of Ljubljana (MOL, 2002) does not anticipate any extensive spreading of urbanization onto the surrounding areas of the discussed reach. Future urban planning aims at regulating the green system of the city of Ljubljana, which would, in combination with other planned uses of urban space, contribute to the formation of a complete image of the city. The proposed rehabilitation scheme would thus also contribute to the amelioration of the ecological state of the urban environment and to a more attractive appearance of the existing recreational area around the Glinščica channel.

Preglednica 1. Površina zemljišč, ki bi jih bilo treba pridobiti za ureditev prečnega prereza sonaravno urejene struge v posamezni variantni rešitvi.
Table 1. Area that should be acquired for regulation of a two-stage rehabilitated river channel in each proposed solution.

Površina v m^2 Area in m^2 of	obstoječe struge (current river channel)	sonaravno urejene struge (rehabilitated river channel)	potrebnih zemljišč (required land)
rešitev 1 – Solution 1	11 480	22 070	10 590
rešitev 2 – Solution 2	11 480	28 130	16 650

5. ZAKLJUČEK

Načela sonaravnega urejanja vodotokov so v državah zahodne Evrope (Švica, Velika Britanija, Nemčija, Danska) dobro uveljavljena. Izkušnje, pridobljene na pilotnih projektih sonaravnih ureditev vodotokov Cole and Skerne (RRC, 1999), kažejo, da se projekti ureditev vodotokov ne smejo zaključiti z dokončanjem zemeljskih del, ampak mora biti v okviru priprave sonaravnih ureditev vodotokov predviden tudi program predvidenih vzdrževalnih del. V sklop vzdrževalnih del, poleg odprave možnih poškodb, ki so posledica vodne erozije, spada tudi kontrola razraščanja vegetacijskega pokrova znotraj pretočnih profilov strug vodotokov. S selektivnim redčenjem vodne in obvodne zarasti se ohranjata načrtovana hidravlična prevodnost struge in vloga vodotoka kot habitata. Na obravnavanem odseku Glinščice se hidravlična prevodnost sonaravno urejene struge v primeru, da se predvideno redčenje zarasti nekaj let ne bi izvajalo, z 18 m^3/s zmanjša na približno 12 m^3/s. Nivo poplavnih voda se v tem primeru dvigne za 25 do 40 cm. Sonaravna ureditev struge Glinščice na obravnavanem odseku torej v primeru neizvajanja vzdrževalnih del kljub povečanju pretočnega prereza struge ne prispeva k zmanjšanju poplavne ogroženosti (predvsem objektov Biološkega središča), ampak poplavno ogroženost celo povečuje.

5. CONCLUSION

The basic principles of rehabilitation, restoration and remediation of watercourses are well known in the countries of Western Europe (Switzerland, Great Britain, Germany, Denmark). Experiences gathered with experimental projects of watercourse rehabilitation on the rivers Cole and Skerne (RRC, 1999) show that rehabilitation projects should not end with the completion of construction works. The project of watercourse rehabilitation must also consider a programme of a further maintenance plan. The maintenance plan should contain procedures for repairing the possible damages of revetments and also the control of growth of vegetation cover inside the channel cross section. A selective cleaning of riparian vegetation assures that the hydraulic conductivity does not deteriorate and that the role of a watercourse as a habitat remains unharmed. The hydraulic conductivity evidently deteriorates when the maintenance works are not carried out as planned. If the vegetation cover would not be cleaned for a few years, the hydraulic conductivity would drop from the planned 18 m^3/s to only 12 m^3/s. The level of floodwaters would rise by 25 to 40 cm. This shows that the rehabilitation of the Glinščica channel in case of unsuitable maintenance, in spite of the enlargement of the channel cross section, does not contribute to the diminishment of the flood risk (especially for buildings of the Biological Centre), on the contrary, the flood risk increases.

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