

REDUCED PERMEATION OF PRECIPITATION WATER INTO GROUNDWATER ON LJUBLJANSKO POLJE

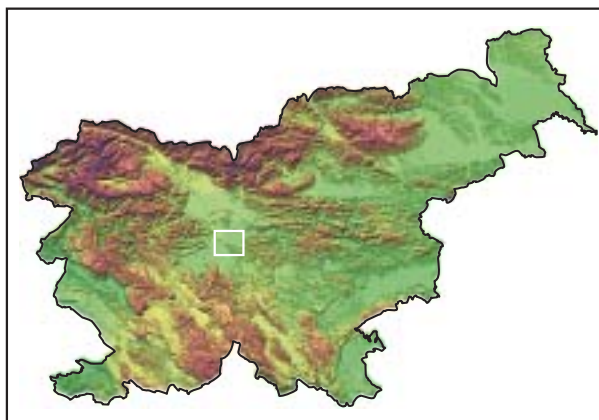
ZMANJŠANO PRENIKANJE PADAVINSKE VODE V PODTALNICO NA LJUBLJANSKEM POLJU

Aleš Smrekar



The interlace of built-up and open surfaces on Ljubljansko polje
(photography Aleš Smrekar).

Prepletanje odprtih in pozidanih površin na Ljubljanskem polju
(fotografija Aleš Smrekar).



Reduced Permeation of Precipitation Water into Groundwater on Ljubljansko polje

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COBISS: 1.01

ABSTRACT: The permeation of water into groundwater in an urban environment is considerably different than that in an untransformed landscape. Built-up and open surfaces have very different proportions of impermeable surfaces. Due to urban land use on Ljubljansko polje, the loss of permeating precipitation water is more than 0.5 m³/sec or 190 mm of precipitation.

KEY WORDS: groundwater, permeation, precipitation water, land use, city, Ljubljansko polje.

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Zmanjšano prenikanje padavinske vode v podtalnico na Ljubljanskem polju

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COBISS: 1.01

IZVLEČEK: Prenikanje vode v podtalnico je v mestnem okolju precej drugačno kot v nepreoblikovani pokrajini. Pozidane in odprte površine imajo zelo različne deleže neprepustnih površin. Izgube prenikajoče padavinske vode so zaradi mestne rabe tal na Ljubljanskem polju za več kot 0,5 m³/sek ali 190 mm padavin.

KLJUČNE BESEDE: podtalnica, prenikanje, padavinska voda, raba tal, mesto, Ljubljansko polje.

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1 Introduction

In the past, predominantly natural processes such as earthquakes, floods, fire, etc., caused changes in the existing landscape. The results of these processes depended on their intensity and duration. In time, many such changes could be completely eliminated and conditions returned to their original state, while in the case of radical and permanent influences, the old landscape systems were transformed into new systems with corresponding and balanced elements (Richling 1999).

A similar situation occurred with processes triggered by human activity. Among these, the process of urbanization has a special place since it causes considerable change in the natural environment and the way it functions. Greatly transformed urban centers, densely built up with a high proportion of asphalted surfaces, are still the consequence of natural conditions, particularly the formation of the surface and bedrock and the hydrological characteristics. These and many other factors influence the spatial development of cities.

In a natural environment, the intensity of water permeation depends to a large degree on the quantity of precipitation, the vegetation cover, evapotranspiration, the formation of the surface, the river network, the quantity of alloctone water, the structure of the soil, and the bedrock (Ward, Elliot 1995). In an urban environment, the processes are often substantially different depending on the type of cover because the proportion of the surface occupied by buildings and the street network is of key importance. How deep the foundations of buildings extend is also particularly important since this can completely change the movement of both the groundwater and the surface water. However, the general model of the functioning of the landscape system in a city still depends on the basic natural environment and is therefore the consequence of the natural conditions (Richling 1999).

2 Work methods

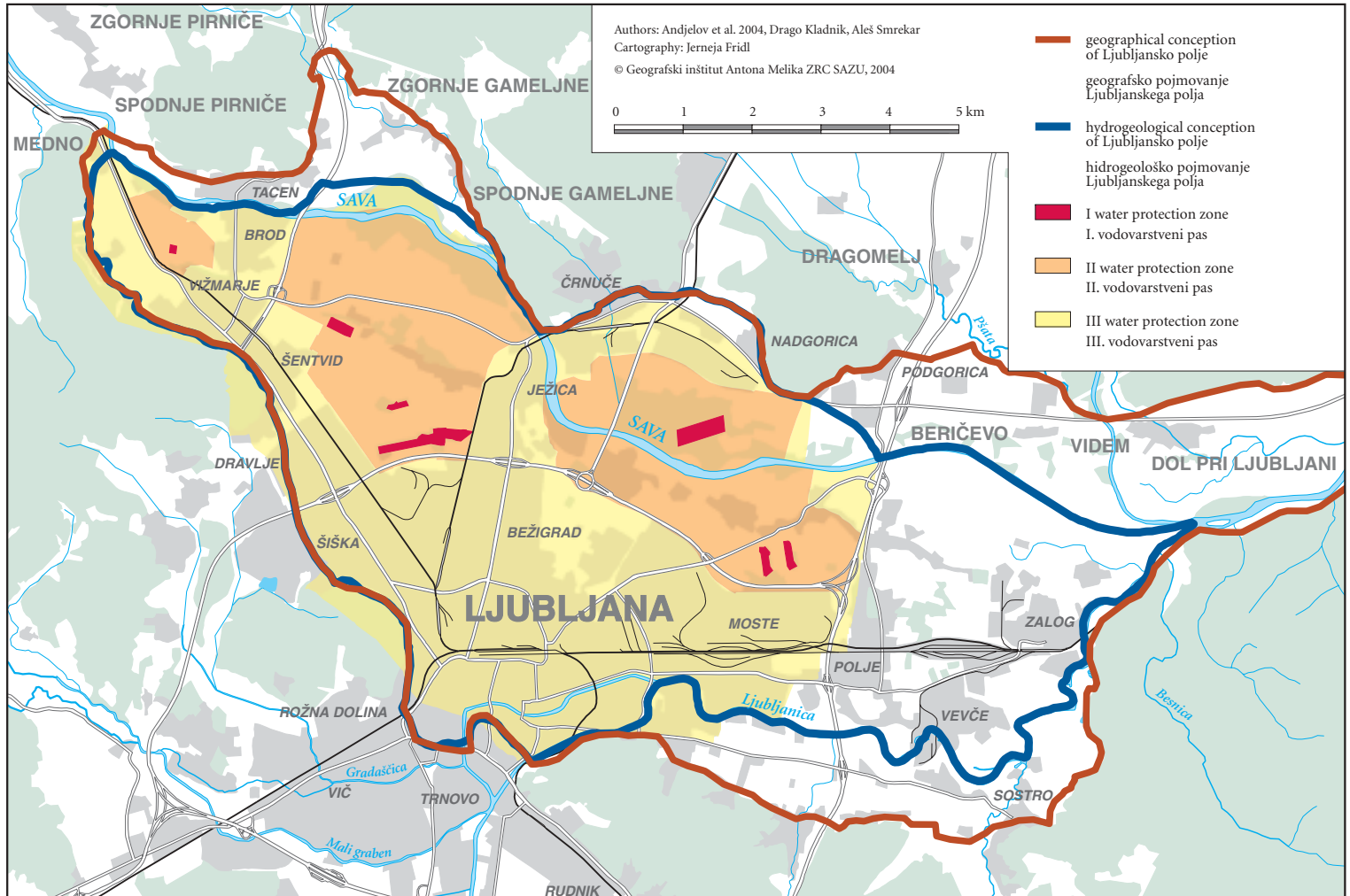
On the basis of the functional division of urban space (Richter 1984), an estimate was made of the proportion of land occupied by buildings or impermeable surfaces (Richling 1999).

Table 1: Proportion of impermeable surfaces according to individual types of land use.

	Proportion of impermeable surfaces
Built-up surfaces:	
City centers with primarily administrative and service activities; dense, tall construction	under 90%
Mixed activities and residential function; dense, multi-story construction	over 80%
Residential areas; dense, multi-story construction	60–80%
Dense residential construction; low buildings on small parcels	40–50%
Dispersed residential construction; low buildings on large parcels	20–30%
Industrial areas and road surfaces	40–60%
Open surfaces:	
Sports fields	10–15%
Parks, gardens, and squares	under 10%
Forests and forest parks	none
Farmland	none

Source: Richling 1999.

Figure 1: Demarcation of Ljubljansko polje.



On the basis of the estimates above and some test calculations, we divided the land use into the following groups and determined the proportions of impermeable surfaces on Ljubljansko polje.

Table 2: Proportion of impermeable surfaces on Ljubljansko polje according to individual types of land use.

	Proportion of impermeable surfaces
Built-up surfaces:	
City centers (without parks)	85%
Mixed activities and dense high-rise residential construction	80%
Medium-dense high-rise residential construction	60%
Dense individual construction on small parcels	50%
Dispersed individual construction on large parcels	20%
Shopping centers	70%
Industrial small industrial areas	60%
Roads	80%
Railway stations	60%
Open surfaces:	
Sports fields	20%
Parks, cemeteries	15%
Forests	0%
Farmland, uncultivated land, gardens, gravel pits	0%

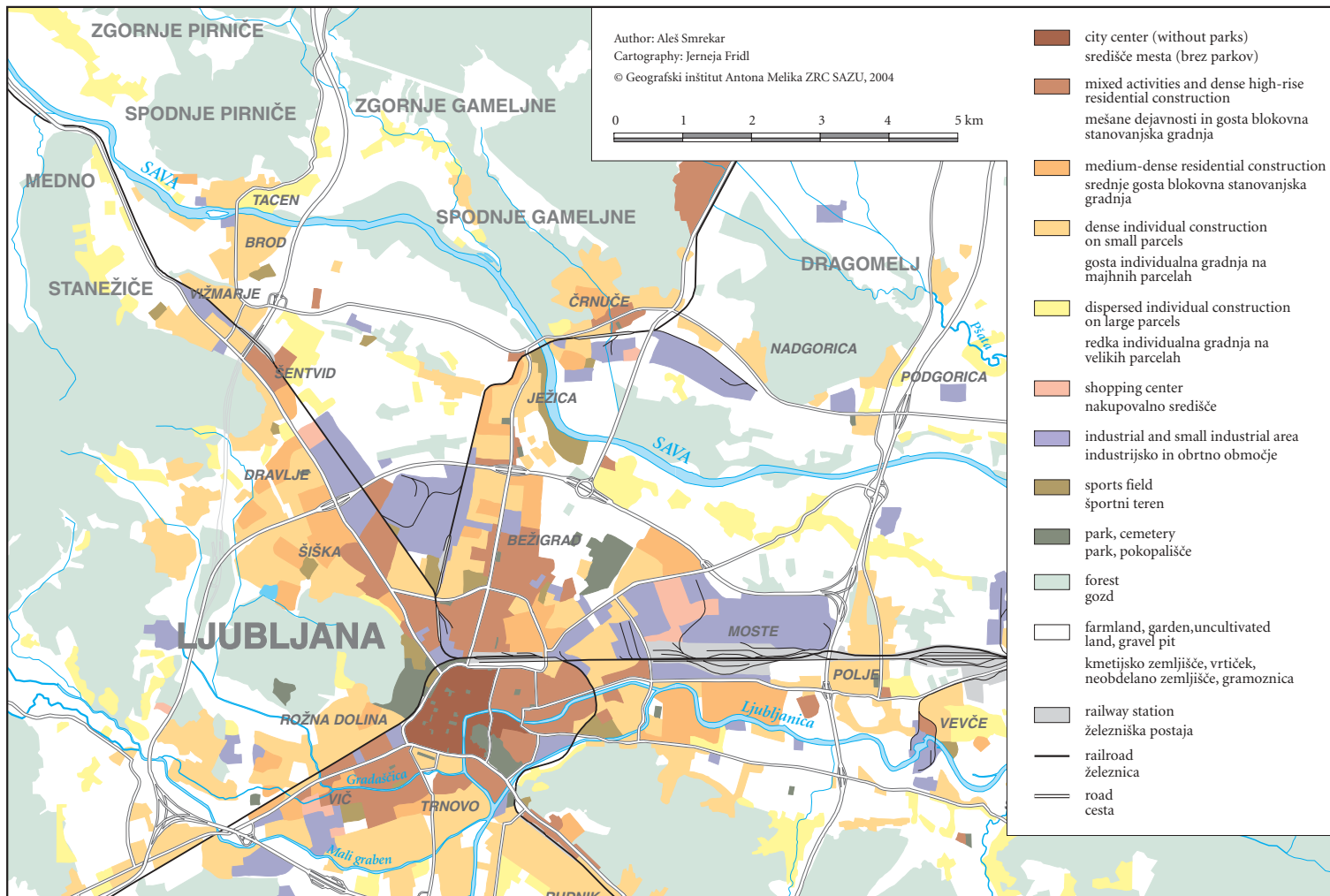
3 Results and discussion

Ljubljansko polje is an alluvial plain on the eastern edge of the Ljubljana basin. For millions of years, the Sava and Ljubljanica rivers have filled the subsiding basin with their detritus and formed the relief. The area is rich with both surface waters and groundwater. There are large quantities of groundwater in the aquifer of gravel-sand and conglomerate layers that line the depression of Ljubljansko polje. The soil is relatively shallow, light, and quite permeable for water (Bračič Železnik et al. 2004).

On Ljubljansko polje, urban land use is very heterogeneous, not only in individual parts of the city but even within blocks of streets (Pak 2000). In spite of this, we can observe the concentration of residential, supply-service, education, and health-care land uses on one hand and industrial and larger surfaces devoted particularly to railway transportation on the other.

The hydrogeological conception of Ljubljansko polje (6,966.1 ha), which includes the area between the Sava and Ljubljanica rivers and the Jarški prod area separated by the regulation of the Sava (Andjelov et al. 2004), differs considerably from the geographical conception of Ljubljansko polje since the latter is larger by almost a quarter (8,787.8 ha). The largest discrepancies are in the south and east where geographers demarcate Ljubljansko polje along the contact between the plain and the Golovec elevations and further east, the Kašeljjski grič hills. Similarly, the geographical conception of Ljubljansko polje extends onto the left bank of the Sava River (not just to Jarški prod), as a rule to the bottom edge of elevations such as Šmarna gora, Rašica, and Soteški hrib.

On the basis of balance calculations, hydrogeologists have provided a synthesized survey of the basic elements of the water balance on Ljubljansko polje (Andjelov et al. 2004). The principle of water balance is the assumption that the quantity of precipitation is equal to the sum of the flowing and evaporating water,



although we must also consider changes in the reserves and consumption of water (Pristov 1998a). Ljubljansko polje is an imperfect hydrogeological basin because in addition to precipitation and evapotranspiration – perfect basins only have these two components – other inflows and outflows also influence the quantity of water (Kranjc-Kušlan 1995).

Table 3: Survey of established estimates of inflows and outflows according to the hydrogeological conception of Ljubljansko polje.

Inflows	m ³ /s	Outflows	m ³ /s
Precipitation	3.2	Evapotranspiration	1.5
Inflow from Ljubljansko Barje	0.2	Direct outflow	0.3
Inflow from the Sava River	1.6	Pumping	0.9
		Outflow across Dravljje	
		Outflow into the Sava River	
		Outflow into the Ljubljanica River	
Inflow from remaining hinterland	0.3	Data on the outflow of groundwater is unreliable and the quantity is not measured	
Total	5.3	Total	2.7

Source: Andjelov et al. 2004.

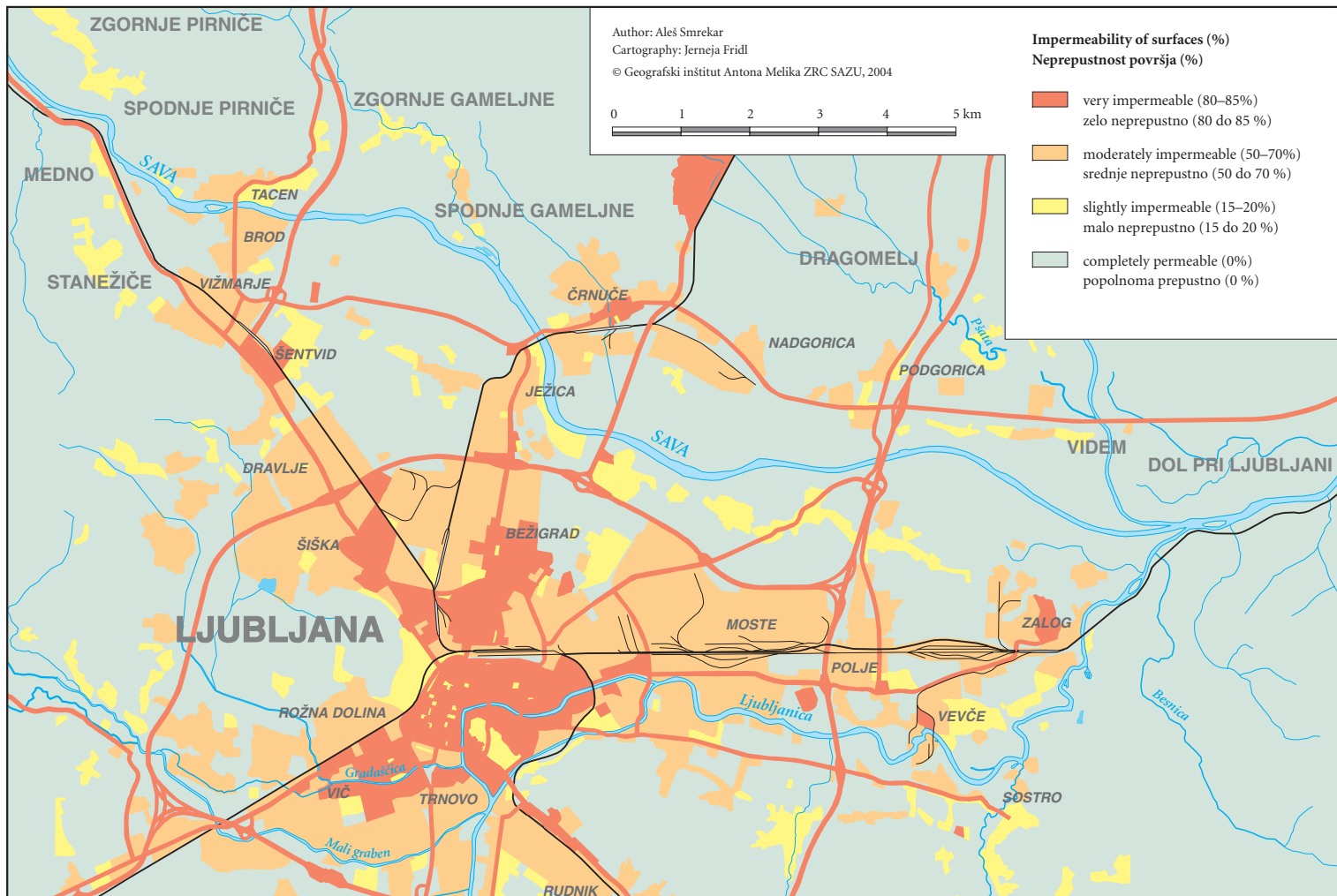
Precipitation is the basic element of any water balance. According to data from the Bežigrad and Šentvid meteorological stations in Ljubljana and the precipitation map elaborated by Pristov for the 1961–1990 period, Ljubljansko polje receives between 1,400 and 1,500 mm of precipitation annually. The mean average annual quantity of precipitation is therefore 1,450 mm (Pristov 1998a), which we applied for the entire Ljubljansko polje area. Precipitation (without losses) therefore saturates the »hydrogeological« Ljubljansko polje at 3.2 m³/s (Andjelov et al. 2004), and on the larger »geographical« Ljubljansko polje at 4.0 m³/s.

According to the evapotranspiration map, the average annual calculated evapotranspiration in Ljubljana is between 650 and 700 mm of water per year, with a mean value therefore of 675 mm (Pristov 1998b). We employed this value, which was calculated on the basis of direct measurements of grasslands since measurements for forest surfaces have not yet been done, for the entire area, acquiring totals for the »hydrogeological« Ljubljansko polje of 1.5 m³/s (Andjelov et al. 2004) and 1.9 m³/s for the »geographical« Ljubljansko polje. The permeation of precipitation is therefore assumed to be 1.7 m³/s or 2.2 m³/s respectively.

The hydrogeologists (Andjelov et al. 2004) are aware of the great anthropogenic influence and calculated that permeation was reduced by 0.28 m³/s due to artificial surfaces in this area. Although the method by which this figure was obtained is not described, it appears from the use of the term »artificial surfaces« that the land use was surveyed using the Corine Land Cover method. Believing this estimate to be too low, we decided to recalculate what the permeation of precipitation is more likely to be as a consequence of urban and suburban land use in the studied area. Based on the proportions of impermeable surfaces in Table 2, we calculated that permeation was reduced by 0.47 m³/s for the »hydrogeological« Ljubljansko polje, which indicates a difference between the two calculations amounting to 0.19 m³/sec or 86 mm of precipitation. This great quantity of precipitation water, which due to urban and suburban land use does not manage to permeate directly into the groundwater, is largely lost to Ljubljansko polje because the greater part of it flows through the city drain system into the Ljubljanica River.

Due to urban and suburban activities, the permeation of precipitation water into the groundwater is reduced by 0.53 m³/s or 190 mm for the »geographical« Ljubljansko polje area that covers almost 90 km². Permeation is not possible on 2,138.3 hectares or 24.3% of the entire area.

Figure 3: Impermeability of surfaces on Ljubljansko polje.



In built-up areas that include city centers, mixed activities and dense high-rise residential construction, medium dense high-rise residential construction, dense individual construction on small parcels, dispersed individual construction on large parcels, industrial and small industrial areas, shopping centers, railway stations, and roads and together occupy 3,531.7 hectares or 40.1% of Ljubljansko polje, the permeation of precipitation water into the groundwater is not possible on 2,048.1 ha, which is 58.0% of the built-up area or 23.3% of the entire area.

The largest impermeable surfaces, covering more than 450 ha, are occupied by industrial and small industrial areas and dense individual construction on small parcels. Following closely are areas of mixed activities and dense high-rise residential construction covering just under 370 ha. Large impermeable surfaces are also occupied by medium dense high-rise residential construction that covers almost 200 ha. The transportation network is like the circulatory system that must supply the entire organism, and the road network in fact leads to every door. Due to the complexity of the procedure, we decided to include local streets in the other spatial categories, pointing out in particular only the most important, usually wide traffic arteries that occupy a total of almost 240 hectares. The railroad network is less branched, and the permeation of water on the tracks is reduced negligibly; however, more than 115 ha of extensive impermeable surfaces are found at railway stations.

On open surfaces that include sports fields, parks, cemeteries, forests, farmland, uncultivated land, gardens, gravel pits, and river beds and a total of 5,256.1 ha or 59.9% of Ljubljansko polje, the permeation of precipitation water into the groundwater is not possible on only 90.2 ha, which is 1.7% of the open surfaces or 1.0% of the entire area. The larger part of occurs in parks and cemeteries (70.8 ha) and a smaller part on sports fields (19.4 ha); on other open surfaces, permeation is not hindered.

The *Decree on the Protection of Resources of Drinking Water (Official Gazette of the Socialist Republic of Slovenia 13/1988)* defined water protection zones with a total area of 5,602.2 hectares that cover a considerable part of the »hydrogeological« Ljubljansko polje.

This *Decree* defines the protection zones and sets out the conditions and methods for supplying Ljubljana with water.

The water protection zones are divided into three zones:

- I, the narrowest water protection zone intended exclusively for facilities for supplying drinking water and limited to the immediate area of water pumping stations (total of 50.6 ha);
- II, a narrow water protection zone with a strict protection regime intended for the direct protection of pumping areas from pollution (total of 1,933.6 ha);
- III, a wider water protection zone with moderate protection regime intended to protect the flow of groundwater toward pumping areas (total of 3,618.0 ha).

In spite of the numerous regulations in the existing water protection zones, Ljubljana is increasingly encroaching upon these areas. According to calculations, some 1,637.8 ha or 29.2% of all water protection zones are covered with anthropogenic impermeable surfaces. In the majority of types of land use here, there are no substantial differences compared with the »hydrogeological« Ljubljansko polje; we only recorded considerably less impermeable surface at railway stations (71.9 ha) in water protection zones because the railway cargo station in Zalog is not located in a water protection zone.

The majority of impermeable surface areas, 93.4%, are fortunately located in the wider (III) water protection zones. In the narrow water protection zones (II) with a strict regime of protection, there are only 102.0 ha of impermeable land or 5.3% of all the land. Industrial and small industrial areas occupy 10.2 ha of the impermeable surfaces, dense individual construction on small parcels occupies 12.6 ha, dispersed individual construction on large parcels occupies 23.6 ha, and major roads occupy 45 ha.

Table 4: Impermeable surfaces as a consequence of anthropogenic land use on Ljubljansko polje.

Built-up surfaces:													
	Proportion of impermeable surfaces	Ljubljansko polje (ha) – geographical conception	Impermeable surfaces (ha)	Ljubljansko polje (ha) – hydrogeological conception	Impermeable surfaces (ha)	Water protection zones (km ²)	Impermeable surfaces (km ²)	Water protection zone I (km ²)	Impermeable surfaces (km ²)	Water protection zone II (km ²)	Impermeable surfaces (km ²)	Water protection zone III (km ²)	Impermeable surfaces (km ²)
City center (without parks)	85%	105.7	89.8	104.5	88.8	70.7	60.1		0.0		0.0	70.7	60.1
Mixed activities and dense high-rise residential construction	80%	460.7	368.6	459.9	367.9	423.4	338.7		0.0	6.1	4.9	417.3	333.8
Medium dense high-rise residential construction	60%	321.2	192.7	273.4	164.0	325.8	195.5		0.0	1.8	1.1	324.0	194.4
Dense individual construction on small parcels	50%	937.3	468.7	809.3	404.7	627.8	313.9		0.0	25.3	12.6	602.6	301.3
Dispersed individual construction on large parcels	20%	401.9	80.4	289.5	57.9	227.3	45.5		0.0	118.0	23.6	109.3	21.9
Industrial and small industrial areas	60%	757.4	454.4	696.2	417.7	632.5	379.5		0.0	17.0	10.2	615.6	369.3
Shopping centers	70%	59.4	41.6	59.4	41.6	59.4	41.6		0.0		0.0	59.4	41.6
Roads	80%	295.3	236.2	232.8	186.2	199.8	159.8		0.0	56.2	45.0	143.6	114.9
Railway stations	60%	192.8	115.7	193.0	115.8	119.9	71.9		0.0		0.0	119.9	71.9
Built-up surfaces total		3,531.7	2,048.1	3,118.0	1,844.7	2,686.7	1,606.5	0.0	0.0	224.4	97.4	2,462.3	1,509.2
Open surfaces:													
Sports fields	20%	96.9	19.4	97.3	19.5	96.8	19.4		0.0	23.4	4.7	73.4	14.7
Parks, cemeteries	15%	83.3	70.8	78.7	66.9	84.5	71.8		0.0		0.0	84.5	71.8
Forests	Without	516.2	0.0	466.8	0.0	552.6	0.0	41.7	0.0	295.3	0.0	215.6	0.0
Farmland, uncultivated land, gardens, gravel pits	Without	4,559.7	0.0	3,205.3	0.0	2,181.7	0.0	8.9	0.0	1,390.5	0.0	782.3	0.0
Open surfaces total		5,256.1	90.2	3,848.1	86.4	2,915.6	91.2	50.6	0.0	1,709.2	4.7	1,155.8	86.5
Total		8,787.8	2,138.3	6,966.1	1,931.0	5,602.2	1,697.7	50.6	0.0	1,933.6	102.0	3,618.0	1,595.7
Decreased permeation (m ³ /sec)			0.53		0.47		0.42		0.00		0.03		0.39

4 Conclusion

The permeation of precipitation water into the groundwater is a process that in a natural environment depends only on physical and geographical factors. Processes that occur in urban and suburban environments, that is, changes in land use, have a key influence on the permeation of precipitation to the groundwater. Large concrete and asphalt surfaces in cities stop or at least reduce the normal permeation of water from the surface. Until now, only more or less rough estimates of the water lost as a result to the of Ljubljansko polje aquifer have been made. Our detailed analysis using the ArcView software shows that anthropogenic water-impermeable surfaces above the Ljubljansko polje aquifer, a source of drinking water of regional importance, are far from small, occupying in fact more than 2,000 ha or almost a quarter of all the land.

The reduction of permeation on Ljubljansko polje by more than $0.5 \text{ m}^3/\text{s}$ or almost a quarter of all potential permeating precipitation water (after evapotranspiration) is undoubtedly a very negative phenomenon, particularly in view of the lowered quantities of water in the aquifer from which almost 40 million m^3 is pumped annually into the public water supply system for anthropogenic uses. Pumping »burdens« the groundwater by around $0.9 \text{ m}^3/\text{s}$ (Bračič Železnik, Jamnik 2004). This means that due to human activities in the area, the quantity of water reaching the groundwater of Ljubljansko polje has been reduced by about $1.5 \text{ m}^3/\text{sec}$, a phenomenon that can no longer be ignored. The fact that permeation to the groundwater is very obstructed and reduced by $0.42 \text{ m}^3/\text{s}$ even in the water protection zones is quite alarming, although fortunately mainly in the wider water protection zones ($0.39 \text{ m}^3/\text{s}$), which suggests that the legal restrictions to reduce urbanization in the narrow water protection zone have proven effective for their preservation.

The quality of the precipitation water that collects in the drain network is very poor due to human activities, so for the state of groundwater it is an advantage that polluted water does not reach the aquifer but instead flows away from Ljubljansko polje on the surface.

We must not allow the quantity of water in the Ljubljansko polje aquifer to decrease further since this will intensify the threat to its natural vulnerability on one hand and increase its burdening on the other. The consequences, if they are not already present, will pose a threat to a high quality source of water that provides Ljubljana and the surrounding area with drinking water.

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1 Uvod

V preteklosti so pretežno naravni procesi povzročali spremembe obstoječe pokrajine, kot na primer potresi, poplave, požari... Rezultati teh procesov so bili odvisni od intenzivnosti in njihovega trajanja. Spremembe so lahko bile sčasoma popolnoma odstranjene, kar je pomenilo vrnitev v prvotno stanje. V primeru radikalnih in trajnih vplivov pa so se stari pokrajinski sistemi spreminjali v nove z ustreznimi in uravnoteženimi elementi (Richling 1999).

Podobno se je dogajalo s procesi, ki jih je sprožil človek. Med njimi ima proces urbanizacije prav posebno mesto, saj povzroča znatne spremembe v naravnem okolju in načine, kako ta deluje. Močno preoblikovana mestna središča, gosto pozidana in z velikim deležem asfaltiranih površin, je vseeno posledica naravnih razmer, še zlasti oblikovanosti površja in kamninske osnove ter hidroloških značilnosti. Ti in še mnogi drugi faktorji vplivajo na prostorski razvoj mest.

V naravnem okolju je intenziteta vodnega prenikanja odvisna predvsem od količine padavin, rastlinskega pokrova, evapotranspiracije, izoblikovanosti površja, rečne mreže, količine alohtone vode, sestave prsti in kamninske osnove (Ward, Elliot 1995). Procesni v mestnem okolju so marsikdaj bistveno drugačni, odvisno pač od pokrovnosti, saj je ključno, kakšen delež površin zasedajo zgradbe in komunikacijsko omrežje. Zlasti pri objektih je pomembno tudi, kako globoko segajo njihovi temelji, saj je zaradi tega lahko popolnoma spremenjeno njihovo gibanje tako podtalnice kot tudi površinske vode. Vseeno je splošni model delovanja pokrajinskega sistema v mestu odvisen od temeljnega naravnega okolja in je torej posledica njegovih naravnih razmer (Richling 1999).

2 Metode dela

Na podlagi funkcijske členitve mestnega prostora (Richter 1984) je bila izdelana ocena, kakšen delež zemljišč zasedajo objekti oziroma neprepustne površine (Richling 1999).

Preglednica 1: Delež neprepustnih površin posameznih tipov rabe tal.

	delež neprepustnih površin
pozidane površine:	
središče mesta s prevladujočimi administrativnimi in služnostnimi dejavnostmi; gosta, visoka gradnja	manj kot 90 %
mešane dejavnosti in stanovanjska funkcija; gosta, večnadstropna gradnja	več kot 80 %
stanovanjska območja; gosta, večnadstropna gradnja	60–80 %
gosta stanovanjska gradnja; nizke zgradbe na majhnih parcelah	40–50 %
razpršena stanovanjska gradnja; nizke zgradbe na velikih parcelah	20–30 %
industrijska območja in prometne površine	40–60 %
odprte površine:	
športni tereni	10–15 %
parki, vrtovi, trgi	manj kot 10 %
gozdovi in gozdnati parki	brez
kmetijska zemljišča	brez

Vir: Richling 1999.

Na podlagi zgornjih ocen in nekaterih testnih izračunov smo na primeru Ljubljanskega polja rabo tal razdelili v naslednje skupine in jim določili deleže neprepustnih površin.

Preglednica 2: Delež neprepustnih površin posameznih tipov rabe tal na Ljubljanskem polju.

	delež neprepustnih površin
pozidane površine:	
središče mesta (brez parkov)	85 %
mešane dejavnosti in gosta blokovna stanovanjska gradnja	80 %
srednje gosta blokovna stanovanjska gradnja	60 %
gosta individualna gradnja na majhnih parcelah	50 %
redka individualna gradnja na velikih parcelah	20 %
nakupovalna središča	70 %
industrijska in obrtna območja	60 %
ceste	80 %
železniške postaje	60 %
odprte površine:	
športni tereni	20 %
parki, pokopališča	15 %
gozdovi	0 %
kmetijska zemljišča, neobdelana zemljišča, vrtički, gramoznice	0 %

3 Rezultati in diskusija

Ljubljansko polje je aluvialna ravnina na vzhodnem robu Ljubljanske kotline. V milijonih let sta reki Sava in Ljubljanica polnili pogrezajočo se kotlino s svojimi nanosi in oblikovali relief. Območje je bogato s površinskimi in podzemnimi vodami. V vodonosnih prodno-peščenih in konglomeratnih plasteh, ki zapolnjujejo udorino Ljubljanskega polja, so namreč velike količine podtalnice. Prst je relativno plitva, lahka in dobro prepustna za vodo (Bračič Železnik s sodelavci 2004).

Na Ljubljanskem polju je zelo heterogena raba mestnega prostora, ne samo posameznih mestih predelov, ampak celo uličnih blokov (Pak 2000). Kljub temu lahko opazimo zgoščevanje stanovanjske, oskrbno storitvene, izobraževalne ter zdravstvene rabe prostora na eni strani in industrije ter večjih površin, namenjenih zlasti železniškemu prevozu, na drugi strani.

Slika 1: Razmejitve Ljubljanskega polja.
Glej angleški del prispevka.

Hidrogeološko pojmovanje Ljubljanskega polja (6966,1 ha), ki vključuje območje med reko Savo in Ljubljanico ter Jarški prod, ločen z regulacijami reke Save (Andjelov s sodelavci 2004), je precej drugačno od geografskega pojmovanja Ljubljanskega polja, saj je slednje za približno četrtno večje (8787,8 ha). Največja odstopanja so na jugu in vzhodu, kjer geografi razmejimo Polje na stiku ravnine in vzpetin Golovca ter naprej proti vzhodu in Kašeljkega griča. Prav tako sega geografsko pojmovanje Ljubljanskega polja na levi breg Save (ne le na Jarški prod) praviloma do vznožja vzpetin, kot so na primer Šmarna gora, Rašica in Soteški hrib.

Preglednica 3: Pregled ugotovljenih ocen dotokov in odtokov hidrogeološkega pojmovanja Ljubljanskega polja.

dotoki	m ³ /s	odtoki	m ³ /s
padavine	3,2	evapotranspiracija	1,5
dotok iz Barja	0,2	direktni odtok	0,3
zatekanje Save	1,6	črpanje	0,9
		odtok čez Dravlje	
		iztekanje v Savo	
		iztekanje v Ljubljanico	
dotoki iz zaledja	0,3	podatki o iztekanju podtalnice so nezanesljivi in količina ni merjena	
skupaj	5,3	skupaj	2,7

Vir: Andjelov s sodelavci 2004.

Hidrogeologi so na podlagi bilančnega izračuna podali sintezni pregled temeljnih elementov vodne bilance na Ljubljanskem polju (Andjelov s sodelavci 2004). Osnova vodne bilance je predpostavka, da je količina padavin enaka vsoti odtokov in izhlapele vode, pri čemer je treba upoštevati tudi spremembe zaloge in porabo vode (Pristov 1998a). Ljubljansko polje je nepopoln hidrogeološki bazen, saj poleg padavin in evapotranspiracije (popolni bazeni imajo namreč le ti dve komponenti) na količino vode vplivajo še drugi dotoki in odtoki (Kranjc-Kušlan 1995).

Padavine so temeljni element vsake vodne bilance. Po podatkih meteoroloških postaj v Ljubljani za Bežigradom in v Šentvidu je po padavinski karti, ki jo je za obdobje 1961–1990 izdelal Pristov, na Ljubljanskem polju med 1400 in 1500 mm padavin. Srednja vrednost povprečne letne količine padavin je torej 1450 mm (Pristov 1998a), ki je bila prevzeta za vse Ljubljansko polje. Padavine (brez izgub) torej namakajo hidrogeološko pojmovano Ljubljansko polje s $3,2 \text{ m}^3/\text{s}$ (Andjelov s sodelavci 2004), geografsko pojmovano Polje pa s $4,0 \text{ m}^3/\text{s}$.

Povprečna letna izračunana evapotranspiracija v Ljubljani je po karti evapotranspiracije v povprečju med 650 in 700 mm vode na leto, srednja vrednost je torej 675 mm (Pristov 1998b). Ta vrednost, ki je bila izračunana na podlagi neposrednih meritev travinja, saj meritve za gozdne površine niso bile izvršene, je bila prevzeta za celotno območje in znaša za hidrogeološko pojmovano Ljubljansko polje $1,5 \text{ m}^3/\text{s}$ (Andjelov s sodelavci 2004), za geografsko pojmovano Polje pa $1,9 \text{ m}^3/\text{s}$. Torej naj bi bilo prenikanje padavin $1,7 \text{ m}^3/\text{s}$ oziroma $2,2 \text{ m}^3/\text{s}$.

Slika 2: Raba tal na Ljubljanskem polju.
Glej angleški del prispevka.

Hidrogeologi (Andjelov s sodelavci 2004) se zavedajo velikega antropogenega vpliva in zmanjšanja prenikanja zaradi umetnih površin na tem območju za $0,28 \text{ m}^3/\text{s}$. Metoda, po kateri je bila narejena ta ocena, sicer ni predstavljena, vendar se glede na uporabljen termin umetne površine zdi, da gre za pogled na rabo tal s pomočjo Corine Land Cover metode. Ocenili smo, da je ta ocena vseeno prenizka, zato smo se odločili, da naredimo nov izračun, kakšno naj bi bilo prenikanje padavin kot posledica mestne in primestne rabe tal na obravnavanem območju.

Na podlagi v Preglednici 2 določenih deležev neprepustnih površin smo za hidrogeološko pojmovano Ljubljansko polje izračunali zmanjšanje prenikanja za $0,47 \text{ m}^3/\text{s}$, kar kaže na razliko med obema izračunoma v višini $0,19 \text{ m}^3/\text{s}$ ali 86 mm padavin. Tako velika količina padavinske vode, ki zaradi mestne in primestne rabe tal ne uspe neposredno prenikati v podtalnico, je za njo na Ljubljanskem polju večinoma izgubljena, saj odteka večji del po kanalizaciji v Ljubljanico.

Geografsko pojmovano Ljubljansko polje na skoraj 90 km^2 ima zaradi mestnih in primestnih dejavnosti za $0,53 \text{ m}^3/\text{sek}$ ali 190 mm padavin zmanjšano prenikanje padavinske vode v podtalnico. Prenikanje je onemogočeno na 2138,3 ha ali 24,3 % vseh zemljišč.

Slika 3: Neprepustnost površin na Ljubljanskem polju.
Glej angleški del prispevka.

Na pozidanih površinah, med katere uvrščamo središče mesta, mešane dejavnosti in gosto blokovno stanovanjsko gradnjo, srednje gosto blokovno stanovanjsko gradnjo, gosto individualno gradnjo na majhnih parcelah, redko individualno gradnjo na velikih parcelah, industrijska in obrtna območja, nakupovalna središča ter železniške postaje in ceste, ki na Ljubljanskem polju skupaj zasedajo $3531,7 \text{ ha}$ oziroma 40,1 %, je prenikanje padavinske vode v podtalnico onemogočeno na kar $2048,1 \text{ ha}$ oziroma 58,0 % oziroma 23,3 % vseh zemljišč.

Največje neprepustne površine, po več kot 450 ha, zasedajo industrijska ter obrtna območja in gosta individualna gradnja na majhnih parcelah. Le malo, z nekaj manj kot 370 ha, zaostajajo območja mešanih dejavnosti in goste blokovne stanovanjske gradnje. Velike neprepustne površine zavzema tudi srednje gosta blokovna stanovanjska gradnja s po skoraj 200 ha. Komunikacijsko omrežje je kot ožilje, oskrbovati mora

celoten sistem. Cestno omrežje dejansko pripelje do vsakih vrat. Zaradi zapletenosti postopka smo se odločili, da lokalne ceste vključimo v druge prostorsko pripadajoče kategorije, pri čemer posebej izpostavljamole najpomembnejše, praviloma široke prometnice, ki skupaj zavzemajo skoraj 240 ha. Železniško omrežje je sicer manj razvejano, prenikanje vode je na samih progah zanemarljivo zmanjšano, so pa obsežne neprepustne površine na postajah in takšnih je več kot 115 ha.

Na odprtih površinah, med katere štejemo športne terene, parke, pokopališča, gozdove, kmetijska zemljišča, neobdelana zemljišča, vrtičke, gramoznice in rečne struge, ki jih je na Ljubljanskem polju 5256,1 ha oziroma 59,9 %, je prenikanje padavinske vode v podtalnico onemogočeno le na 90,2 ha (1,7 %) odprte površine oziroma 1,0 % vseh zemljišč. Od tega večji del v parkih in pokopališčih (70,8 ha) ter manjši na športnih terenih (19,4 ha), medtem ko na drugih površinah prenikanje ni omejeno.

Odlok o varstvu virov pitne vode (Uradni list Socialistične republike Slovenije 13/1988) določa, da se vodovarstveni pasovi s površino 5602,2 ha raztezajo na precejšnjem delu hidrogeološko pojmovanega Ljubljanskega polja.

Obseg je določen na podlagi, ki določa varstvene pasove ter pogoje in način oskrbe z vodo. Z njim je območje razdeljeno na tri vodovarstvene pasove:

- I. ali najožji vodovarstveni pas, ki je namenjen izključno objektom za oskrbo s pitno vodo in skrčen na območja vodarn (skupaj znaša 50,6 ha);
- II. ali ožji vodovarstveni pas s strogim režimom varovanja je namenjen neposredni zaščiti črpališč pred onesnaženjem (skupaj 1933,6 ha);
- III. ali širši vodovarstveni pas z blagim režimom varovanja je namenjen varovanju toka podtalnice proti črpališčem (skupaj 3618,0 ha).

kljub številnim prepovedim in obveznostim na obstoječih vodovarstvenih pasovih, se je Ljubljana vse bolj širila tudi na to območje. Po izračunih je namreč kar 1637,8 ha ali 29,2 % vseh vodovarstvenih pasov pokritih z antropogeno neprepustnimi površinami. Pri večini tipov rabe tal ni bistvenih razlik v primerjavi s hidrogeološko pojmovanim Ljubljanskim poljem, le pri neprepustnih površinah na železniških postajah zabeležimo precej manj teh površin (71,9 ha) na vodovarstvenih pasovih, kar je posledica tega, da tovarna železniška postaja v Zalogu ni na vodovarstvenih pasovih.

Večina neprepustnih površin, kar 93,4 %, je na srečo na širšem vodovarstvenem pasu. Na ožjem, kjer je razglašen strogi režim varovanja, sta le 102,0 ha neprepustnih površin oziroma 5,3 % vseh zemljišč. Nad 10 ha neprepustnih površin zasedajo industrijska in obrtna območja (10,2 ha) goste individualne gradnje na majhnih parcelah (12,6 ha), redke individualne gradnje na velikih parcelah (23,6 ha) ter 45 ha veliko cestno omrežje.

4 Sklep

Prenikanje padavinske vode v podtalnico je proces, ki je v naravnem okolju odvisen samo od fizičnogeografskih dejavnikov. Procesi, ki so prisotni v mestnem in primestnem okolju, torej spremembe rabe tal, ključno vplivajo na prenikanje vode v podtalnico. Velike betonske in asfaltirane površine v mestih onemogočajo ali vsaj zmanjšujejo normalno pretakanje vode s površja v notranjost. Do sedaj so bile narejene samo bolj ali manj grobe ocene količine izgubljene vode za vodonosnik Ljubljanskega polja. Tokratna podrobna analiza, opravljena s programskim orodjem ArcView, je pokazala, da antropogene vodoneprepustne površine nad vodonosnikom Ljubljanskega polja, vira pitne vode regionalnega pomena, sploh niso majhne, obsegajo namreč več kot 2000 ha ali skoraj četrtno vseh zemljišč.

Izgube vode na Ljubljanskem polju za več kot 0,5 m³/sek ali skoraj četrtno vse potencialne prenikajoče padavinske vode (po evapotranspiraciji) so nedvomno zelo negativen pojav zaradi zmanjšanih količin vode v podtalnici, kjer zaradi antropogene rabe načrpajo tudi v javni vodovodni sistem letno skoraj 40 milijonov m³. Črpanje »bremeni« podtalnico z okrog 0,9 m³/s (Bračič Železnik, Jamnik 2004). Torej je zaradi

Preglednica 4: Nепrepustne površine kot posledica antropogene rabe tal na Ljubljanskem polju.

pozidane površine:	delež neprepustnih površin	Ljubljansko polje (ha) – geografsko pojmovanje	neprepustne površine (ha)	Ljubljansko polje (ha) – hidrogeološko pojmovanje	neprepustne površine (ha)	vodovarstveni pasovi (km ²)	neprepustne površine (km ²)	I. vodovarstveni pas (km ²)	neprepustne površine (km ²)	II. vodovarstveni pas (km ²)	neprepustne površine (km ²)	III. vodovarstveni pas (km ²)	neprepustne površine (km ²)
središče mesta (brez parkov)	85 %	105,7	89,8	104,5	88,8	70,7	60,1		0,0		0,0	70,7	60,1
mešane dejavnosti in gosta blokovna stanovanjska gradnja	80 %	460,7	368,6	459,9	367,9	423,4	338,7		0,0	6,1	4,9	417,3	333,8
srednje gosta blokovna stanovanjska gradnja	60 %	321,2	192,7	273,4	164,0	325,8	195,5		0,0	1,8	1,1	324,0	194,4
gosta individualna gradnja na majhnih parcelah	50 %	937,3	468,7	809,3	404,7	627,8	313,9		0,0	25,3	12,6	602,6	301,3
redka individualna gradnja na velikih parcelah	20 %	401,9	80,4	289,5	57,9	227,3	45,5		0,0	118,0	23,6	109,3	21,9
industrijska in obrtna območja	60 %	757,4	454,4	696,2	417,7	632,5	379,5		0,0	17,0	10,2	615,6	369,3
nakupovalna središča	70 %	59,4	41,6	59,4	41,6	59,4	41,6		0,0		0,0	59,4	41,6
ceste	80 %	295,3	236,2	232,8	186,2	199,8	159,8		0,0	56,2	45,0	143,6	114,9
železniške postaje	60 %	192,8	115,7	193,0	115,8	119,9	71,9		0,0		0,0	119,9	71,9
pozidane površine skupaj		3531,7	2048,1	3118,0	1844,7	2686,7	1606,5	0,0	0,0	224,4	97,4	2462,3	1509,2
odprte površine:													
športni tereni	20 %	96,9	19,4	97,3	19,5	96,8	19,4		0,0	23,4	4,7	73,4	14,7
parki, pokopališča	15 %	83,3	70,8	78,7	66,9	84,5	71,8		0,0		0,0	84,5	71,8
gozdovi	brez	516,2	0,0	466,8	0,0	552,6	0,0	41,7	0,0	295,3	0,0	215,6	0,0
kmetijska zemljišča, neobdelana zemljišča, vrtički, gramoznice	brez	4559,7	0,0	3205,3	0,0	2181,7	0,0	8,9	0,0	1390,5	0,0	782,3	0,0
odprte površine skupaj		5256,1	90,2	3848,1	86,4	2915,6	91,2	50,6	0,0	1709,2	4,7	1155,8	86,5
vse skupaj		8787,8	2138,3	6966,1	1931,0	5602,2	1697,7	50,6	0,0	1933,6	102,0	3618,0	1595,7
zmanjšano prenikanje (m ³ /sek)			0,53		0,47		0,42		0,00		0,03		0,39

človekovega delovanja v prostoru zmanjšana količina vode v podtalnici Ljubljanskega polja za približno $1,5 \text{ m}^3/\text{s}$, to pa nikakor ni več zanemarljivo. Precej vznemirljivo je dejstvo, da je zelo ovirano prenikanje v podtalnico tudi na vodovarstvenih pasovih in je zmanjšano za $0,42 \text{ m}^3/\text{sek}$, na srečo predvsem v širšem vodovarstvenem pasu ($0,39 \text{ m}^3/\text{sek}$), kar kaže na to, da so zakonske omejitve za zmanjšano urbanizacijo v ožjem vodvarstvenem pasu le koristile k njegovi ohranitvi.

Kakovost padavinske vode, ki se zbira v kanalizacijskem omrežju, je zaradi človekovega delovanja zelo slaba. Za stanje podtalnice je celo bolj ugodno, da onesnažena voda ne doseže vodonosnika, ampak površinsko odteka z Ljubljanskega polja.

Ne smemo dovoliti, da bi vodonosniku Ljubljanskega polja na katerikoli način še zmanjševali količino vode, saj je s tem poudarjeno ogrožena njegova naravna ranljivost na eni strani ter povečana obremenjenost na drugi strani. Posledica tega bo, v kolikor že ni, ogroženost kakovostnega vodnega vira za oskrbo Ljubljane in okolice s pitno vodo.

5 Literatura

Glej angleški del prispevka.