I. DEL:

RAZVOJ NA PODROČJU HIDROLOŠKEGA MONITORINGA

PART I:

DEVELOPMENTS IN THE FIELD OF HYDROLOGICAL MONITORING

SPREMEMBE V MREŽI HIDROLOŠKIH MERILNIH MEST

mag. Marjan Bat

Zaradi vsebinskih posebnosti delimo državno mrežo hidroloških opazovanj na mrežo za opazovanje podzemnih voda, mrežo za opazovanje izvirov, mrežo za opazovanje površinskih voda in mrežo za opazovanje morja.

V državni mreži za meritve površinskih voda je v letu 2007 delovalo 170 vodomernih postaj (v. p.). V številu ni upoštevanih šest naročniških v. p. in tri merilna mesta, za katere nam podatke o pretokih pošiljajo Dravske elektrarne Maribor. Čeprav tudi te podatke shranjujemo v podatkovni zbirki Agencije Republike Slovenije za okolje, jih ne objavljamo. V tem letopisu so podatki 160 vodomernih postaj. Na v. p. Ruta (šifra 2530) na Radoljni in Blejski most (3080) na Savi Dolinki so večji del leta potekala gradbena dela, v Stari Fužini (3300) na Mostnici pa so bila opazovanja z vodomera prekinjena že ob koncu zime, nato pa je visoka voda 18. septembra poškodovala vodomer in odnesla nadomestni podatkovni zapisovalnik. Za naštete tri v. p. podatkov ni ali pa so zelo pomanjkljivi. Na štirih lokacijah, v Hodošu (šifri 1350 in 1355) na Veliki Krki, v Podlehniku (2719 in 2720) na Rogatnici, v Črnolici (6690 in 6691) na Voglajni ter v Kalu (8240 in 8242) na Koritnici, so opazovanja potekala vzporedno ali zaporedoma na stari in novi vodomerni postaji. Za pare objavljamo seveda le po en podatkovni niz. Na novih lokacijah določeni pretoki so primerljivi s starimi. Podatkov v. p. Pšata (4553) na Pšati, Podroteja (8351) na kanalu Idrijce in Nova Gorica I (8545) na Korenu, ki imajo povsem antropogen pretočni režim, ne objavljamo. Ponovno je začela delovati v. p. Ptuj (2110) na Dravi, kjer naj bi bila po nekaterih podatkih opazovanja že leta 1850. Zaenkrat imamo v podatkovni zbirki nepopolne podatkovne nize vodostajev, pretokov in koncentracij ter transporta suspendiranega materiala iz obdobja med letoma 1938 in 1982. Takrat so bila opazovanja prekinjena, ker je do merilnega mesta že segala zajezitev Ptujskega jezera. V takšnih pogojih tedaj pretokov na v. p. niso določali. Na merilnem mestu je od leta 2006 horizontalni ultrazvočni merilnik hitrosti vode, ki sproti izračunava pretok (podrobnejša predstavitev merilnika je v članku R. Trčka: Določitev pretokov rek z uporabo horizontalnih merilnikov hitrosti (H-ADCP)). Za leto 2007 smo v letopisu objavili le vodostaje. Spet so objavljeni podatki za v. p. Cankova (1100) na Kučnici.

Čez leto je bilo narejenih 1054 hidrometričnih meritev, 567 z akustičnimi dopplerjevim merilnikom (ADMP) in 478 z ultrazvočnim hidrometričnim krilom (FlowTracker – FT). Devetkrat je bil merski profil ob obisku vodomerne postaje suh. Po več desetletjih ni bilo nobene meritve s klasičnim hidrometričnim krilom. Na Savi v Čatežu

CHANGES TO THE NETWORK OF HYDROLOGICAL MONITORING GAUGING STATIONS

Marjan Bat, MSc

Because of substantive differences, we divide the national hydrological monitoring network into the groundwater observation monitoring network, the spring monitoring network, the surface water monitoring network and the sea monitoring network.

170 water gauging stations (g. s.) were operational within the national monitoring network of surface water. This number does not include the six subscriber g. s. and the three gauging stations for which the data on discharges are sent by Dravske elektrarne Maribor. Even though we store these data in the database of the Environmental Agency of the Republic of Slovenia, we do not publish them. This yearbook contains the data of 160 water gauging stations. For the most part of the year, construction works were performed on the Ruta g. s. (code 2530) on the Radoljna River and Blejski most (3080) on the Sava Dolinka River, the observations on the Stara Fužina water gauging station (3300) on the Mostnica River were terminated at the end of the winter, and on 18 September high water damaged the gauging station and swept away the replacement data recorder. There is no data or they are incomplete for the three listed g. s. Observations at four locations, Hodoš (codes 1350 and 1355) on the Velika Krka River, Podlehnik (2719 and 2720) on the Rogatnica River, Črnolica (6690 and 6691) on the Voglajna River and Kal (8240 and 8242) on the Koritnica River, were conducted simultaneously or sequentially at the new and the old water gauging stations. Only one dataset has been published for the pairs. Discharges at new locations, are comparable to the old ones. The data on the Pšata g. s. (4553) on the Pšata River, Podroteja (8351) on the canal of the Idrijca River and Nova Gorica I (8545) on the Koren River, which have a completely anthropogenic discharge regime, are not published. The Ptuj g. s. (2110) on the Drava River where observations were already supposedly performed in 1850 came into operation again. For now, the database contains incomplete datasets of water levels, discharges and concentrations, as well as suspended material transportation from the period between 1938 and 1982. Afterwards, the observations were terminated because the damming of Ptuj Lake already reached as far as the gauging station. Under such conditions the discharges at the g. s. were not determined at that time. Since 2006, a horizontal ultrasonic velocimeter has been placed at the gauging station which calculates discharge in real time (a detailed presentation of the velocimeter can be found in the article by R. Trček: Determination of

(3850) je bil 19. septembra pri srednji hitrosti 3,01 m/s izmerjen pretok 2100 m^3/s dne. Istega je pretok ob konici v Jesenicah na Dolenjskem (3990) dosegel po pretočni krivulji celo 2511 m^3/s. Najvišji pretoki Mure, Drave in Soče leta 2007 niso presegli 1000 m^3/s.

Od 160 postaj, katerih podatke objavljamo, je brez vodostajev Kamnik. Zaradi gradbenih del se je merski presek Kamniške Bistrice večkrat spremenil in so čez leto zabeležene gladine vode neprimerljive. Tudi pretočne krivulje posledično s hidrometričnimi meritvami ni bilo mogoče umeriti. Nepopoln je letni pregled vodostajev za Lipnico v Ovsišu (4025), kjer je visoka voda 18. septembra poškodovala limnigraf. Višina vode ob poplavni konici (Hvk) je bila odčitana na vodomeru in ustreza pretoku 110 m^3/s. Na nekaj v. p. v Prekmurju, v Jadranskem povodju in na Pivki v Prestranku je voda v drugi polovici leta presihala, kar pa zadnjih 20 let ni nič nenavadnega. Na 37 merilnih mestih smo bili pri zbiranju podatkov o vodostajih še vedno odvisni le od vestnosti opazovalcev. Na 95 postajah so bili vodostaji odčitani z limnigrafskih zapisov, na 27 pa iz digitalnih zapisov avtomatskih merilnih postaj ali podatkovnih zapisovalnikov. Vedno več merilnih mest ima po dva neodvisna merilnika vodostajev (ultrazvočni merilnik in plovec ali tlačna sonda), s čimer je verjetnost izpada podatkov zelo zmanjšana.

Pretoki so objavljeni za 151 vodomernih postaj. Brez njih je tudi Robič (8730) na Nadiži, kjer so zaradi kopalcev s prodno pregrado občasno spreminjali višino vode. Vodostaje sicer objavljamo, pretočne krivulje pa se ne da umeriti. Temperature vode smo v letu 2007 spremljali že na 70 merilnih mestih – na 33 s klasičnim termometrom, na 35 z elektronskim merilnikom in na dveh z obema. V letopisu objavljamo podatke za 60 v. p. (leto poprej za 54).

Vzorce za določanje koncentracij suspendiranega materiala smo v letu 2007 zajemali le ob visokih vodah, zato popolnih letnih pregledov nimamo. Objavljamo podatke za vodomerni postaji Suha (4200) na Sori in Veliko Širje (6210) na Savinji.

Mreža za meritve podzemnih voda ni doživela večjih sprememb. V letopisu so objavljeni podatki za 139 postaj. Prvič so natisnjeni podatki za vodomerno postajo DE-1/05 Mercator (85006) na Ljubljanskem polju, kjer so se meritve poskusno začele leta 2005. Merilni mesti 0680 Sveti Duh (80050) na Sorškem polju in 0460 Kalce – Naklo (55080) na obrobju Krakovskega gozda sta dobili podatkovna zapisovalnika.

Opazovanje izvirov je v letu 2007 potekalo na 17 merilnih mestih. V sklopu meritev Idrijce, krških izvirov Podroteja in Divje jezero, so bila ponovno vzpostavljene občasne meritve pretokov na merilnem mestu Nad Podrotejo (8346). Zaradi okvare merilnikov so bila med letom prekinjena opazovanja na Rakitnici (merilno mesto Blate, 7498) na Ribniškem polju, ob visokih vodah v septembru pa je bil s prodom zasut

river discharges by using horizontal velocimeters (H-ADCP)). For 2007, only water levels were published in the yearbook. Again, the data for the Cankova g. s. (1100) on the Kučnica River were published.

During the year, 1054 hydrometric measurements were conducted, of these 567 with acoustic Doppler current profilers (ADCP) and 478 with ultrasonic velocimeters (FlowTracker – FT). The measurement profile was dry nine times at the visit to the water gauging station. After several decades, none of the measurements were performed with the traditional current meter. On 19 September, a discharge of 2100 m^3/s at a mean velocity of 3.01 m/s was measured on the Sava River in Čatež (3850). On the same day, the extreme discharge at Jesenice na Dolenjskem (3990) reached as many as 2511 m^3/s on the discharge curve. The highest discharges of the Mura, Drava and Soča rivers in 2007 did not exceed 1000 m^3/s.

From 160 stations of which the data are published Kamnik is without water levels. Because of construction works, the measurement cross-section of Kamniška Bistrica has changed several times, thus making the recorded water levels over the year incomparable. Consequently, the discharge curve using hydrometric measurements could not be calibrated. The annual overview of water levels for the Lipnica River in Ovsiše (4025), where high water damaged the water-level recorder on 18 September, is incomplete. The water level at the flood peak (Hvk) was observed on the staff gauge and fits the discharge of 110 m^3/s. At some g. s. in Prekmurje, the Adriatic Sea basin and on the Pivka River in Prestranek, water dried up in the second half of the year which is nothing unusual for the last 20 years. Data collection at 37 gauging stations still depended only on the conscientiousness of observers. At 95 stations, the water levels were read from the recordings made by water-level recorders, while at 27 stations they were read from digital recordings of automatic gauging stations or data loggers. Increasingly more gauging stations have two independent water level gauges (an ultrasonic gauge and a float or pressure probe) which greatly reduces the probability of missing data.

Discharges are published for 151 water gauging stations. Robič (8730) on the Nadiža River is without them since the water level was periodically changed with a gravel barrier because of bathers. Water levels are published but the discharge curve could not be calibrated. In 2007, the water temperature was observed at 70 gauging stations – with a classic thermometer at 33 stations, with an electronic gauge at 35, and with both at two. We have published data for 60 g. s. in the yearbook (54 the year before).

In 2007, samples for determining the concentrations of suspended material were taken only during high water, therefore, complete annual reviews are not available. We have published data for the water gauging stations merski profil v. p. Podljubelj na Mošeniku (4095). V letopisu so objavljeni podatki za 7 vodomernih postaj – namesto Vrhnike (5580) na Velikem Obrhu in Stopič (7350) na Težki vodi sta med njimi Metlika (4995) na Metliškem Obrhu in Spodnja Bilpa (4965) na kraškem izviru Bilpa ob Kolpi.

Mareografska postaja Luška kapitanija je v letu 2007 delovala normalno.

Suha (4200) on the Sora River and Veliko Širje (6210) on the Savinja River.

There were no major changes in the groundwater monitoring network. Data for 139 stations have been published in the yearbook. For the first time, the data for the DE-1/05 Mercator (85006) water gauging station on the Ljubljana Field were printed where test measurements started in 2005.

The gauging stations of 0680 Sveti Duh (80050) on the Sora Field and 0460 Kalce – Naklo (55080) at the edge of the Krakovo Forest were equipped with data loggers.

In 2007, spring observation took place at 17 gauging stations. In the frame of measurements of the Idrijca River, karstic springs of Podroteja and Divje jezero lake, periodical measurements of discharges at the Nad Podrotejo gauging station (8346) were re-established. Due to gauge malfunction, observations on the Rakitnica River (the Blate gauging station, 7498) on Ribnica Field were interrupted during the year, and in September, during high water, the Podljubelj g. s. measurement cross section on the Mošenik River (4095) was filled with gravel. Data for 7 water gauging stations have been published in the yearbook – Metlika (4995) on Metliški Obrh and Spodnja Bilpa (4965) on the Bilpa ob Kolpi karstic spring are listed instead of Vrhnika (5580) on Veliki Obrh and Stopič (7350) on Težka voda.

Luška Kapitanija tide gauge station operated normally in 2007.

OPTIMIZACIJA HIDROLOŠKEGA MONITORINGA POVRŠINSKIH VODA

dr. Mira Kobold

V letu 2005 je bil sprejet Nacionalni program varstva okolja 2005–2012 (Uradni list RS, št. 2/2006), ki za področje urejanja voda med drugim zahteva posodobitev in prilagoditev hidrološkega monitoringa za izboljšanje ocenjevanja količinskega stanja voda ter napovedovanja in opozarjanja pred ekstremnimi hidrološkimi pojavi. Vzpostavitev programov spremljanja stanja voda zahteva tudi t. i. vodna direktiva (direktiva 60/2000/ES), v skladu s katero je bilo na površinskih vodah v Sloveniji določenih 155 samostojnih vodnih teles (Uradni list RS, št. 63/2005). Zaradi omenjenega so bile izvedene analize pokritosti porečij in vodnih teles z vodomernimi postajami, pri čemer smo upoštevali še druge vidike in kriterije v zvezi z izvajanjem hidrološkega monitoringa in so opisani v nadaljevanju. Rezultati analiz in predlogi posodobitve merilne mreže so strnjeni v dokumentu »Strokovna izhodišča za razširitev in posodobitev merilne mreže hidrološkega monitoringa površinskih voda« (ARSO, september 2007). Ta izhodišča so služila kot podlaga za razširitev in posodobitev hidrološke merilne mreže površinskih voda v študiji izvedljivosti projekta SSSV »Nadgradnja sistema za spremljanje in analiziranje stanja vodnega okolja v Sloveniji«, ki je zdaj v operativni fazi izvedbe. Gre za ključni razvojni projekt Agencije RS za okolje na področju izvajanja meritev vodnega okolja ter priprave ustreznih operativnih analitičnih orodij za izvajanje analiz in prognoz stanja vodnega okolja, ki poleg nadgradnje ali gradnje merilnih mest površinskih voda obsega gradnjo merilnih mest padavin in podzemnih voda, gradnjo novega meteorološkega radarja, računskega centra, objekta za laboratorije ter izdelavo analitičnih orodij za analiziranje suše, analitično-prognostičnih orodij za porečji Save in Soče, orodja za odločanje pri upravljanju podzemnih voda ter analitičnega orodja za cirkulacijo in valovanje morja. Projekt se sofinancira iz evropskih kohezijskih sredstev in je vključen v Operativni program razvoja okoljske in prometne infrastrukture.

Razvoj hidrološke mreže površinskih voda

Sistem hidroloških opazovanj in meritev ter število vodomernih postaj na površinskih vodah se je v zgodovini na območju Slovenije spreminjalo in prilagajalo trenutnim potrebam in razvoju merilne opreme. Prve meritve na ozemlju današnje Slovenije segajo v drugo polovico 19. stoletja v obdobje avstro-ogrske monarhije. Med najstarejše danes delujoče vodomerne postaje sodijo po zapisih v arhivu Agencije RS za okolje Litija na Savi, Celje na Savinji, Vrhnika

OPTIMISATION OF SURFACE WATER HYDROLOGICAL MONITORING

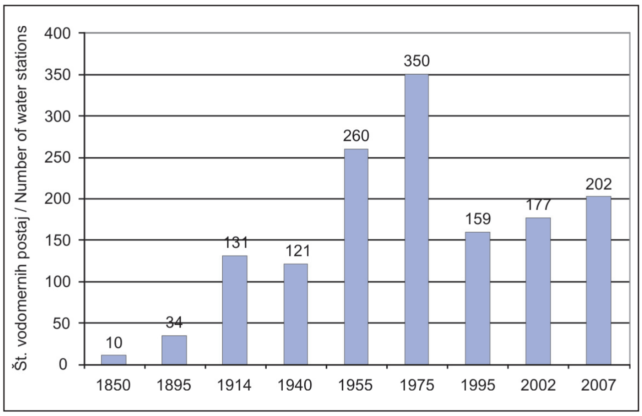
Mira Kobold, PhD

In 2005, the National Environmental Action Plan 2005-2012 (Official Gazette of RS, No. 2/2006) was adopted which, for the field of water regulation, requires the upgrading and adaptation of hydrological monitoring to improve the assessment of water quantitative status and forecasting and warnings of extreme hydrological phenomena. Implementation of water status monitoring programmes is also required by the Water Framework Directive (Directive 60/2000/EC) according to which 155 independent water bodies were determined on the surface waters of Slovenia (Official Gazette of RS, No. 63/2005). Thus, coverage analysis of river basins and water bodies with water gauging stations were conducted, whereby other aspects and criteria relating to the implementation of hydrological monitoring were taken into consideration and described in continuation. The analysis results and proposals for upgrading the gauging station network are summarised in the document “Professional bases for extending and upgrading the measuring network of hydrological monitoring of surface waters” (EARS, September 2007). These bases served as the basis for extending and upgrading the hydrological network of surface water gauging stations in the feasibility study of the “Upgrading the system for monitoring and analysing of water environment status in Slovenia” project (SSSV project) which is in the operational stage of implementation. It is a main development project of the Slovenian Environmental Agency in the field of performing measurements in the water environment and preparing appropriate operational analytical tools for conducting analyses and forecasts of the water environment state which, in addition to the upgrading or construction of surface water gauging stations, encompasses the construction of precipitation and groundwater gauging stations, the construction of a new meteorological radar, computer centre, laboratory building and the production of analytical tools for drought analysis, analytical and forecasting tools for the Sava and Soča river basins, decision-support tools for groundwater management, and analytical tools for sea circulation and waves. The project is co-financed from the European Cohesion Fund and included in the Operational Programme “Development of the Environment and Transport Infrastructure”.

Development of the surface water hydrological network

Throughout history in the territory of Slovenia, the system of hydrological observations and measurements and the number of water gauging na Ljubljanici, Planina na Unici in Gornja Radgona na Muri.

V začetku so bila opazovanja le občasna. Redna opazovanja nivoja vodne gladine so se postopoma razširila še na meritve vodnih količin, pojavov ledu in meritve temperature vode. Posledično se je izboljševala mreža vodomernih postaj. Za pridobivanje natančnejših podatkov so merilna mesta začeli opremljati z napravami za zvezno beleženje vodnega stanja (limnigrafi). Po ohranjenih zapisih je leta 1940 na ozemlju Slovenije delovalo 121 vodomernih postaj, po drugi svetovni vojni leta 1947 pa 124 postaj. Število postaj je pozneje naraščalo, meritve so postajale vse bolj sistematične, kakovost merjenih podatkov pa se je izboljševala predvsem z dodatno opremljenostjo postaj z limnigrafi, po letu 1980 pa tudi z nadgradnjo postaj v avtomatske merilne postaje (AMP). Limnigrafske zapise so začeli nadomeščati podatkovni zapisovalniki. Največ postaj je delovalo v šestdesetih in prvi polovici sedemdesetih let prejšnjega stoletja. Na razvoj hidrološke mreže so vplivali predvsem varstvo naselij pred poplavami, uporaba vode v energetske, tehnološke in vodooskrbne namene, danes pa vse bolj potrebe proučevanja in varovanja okolja. V osemdesetih letih je bilo veliko vodomernih postaj ukinjenih. Glavni vzroki ukinjanja postaj so bili različni, od zmanjšanja stroškov vzdrževanja, konca predvidenega obdobja delovanja do neustreznosti mikrolokacije ipd.



Slika 1: Število delujočih vodomernih postaj na površinskih vodah v izbranih letih
Figure 1: *The number of operational water gauging stations on surface waters in selected years*

Nadgradnja vodomernih postaj v AMP-postaje in testiranje nove merilne opreme, zlasti različnih tipov senzorjev in podatkovnih zapisovalnikov, je pripeljalo do tega, da na nekaterih merilnih mestih razpolagamo z več tipi hidroloških podatkov (opazovanja, limnigrafski, podatkovni zapisovalniki, AMP), kar naj bi zagotavljalo pridobivanje zanesljivih hidroloških podatkov za ukrepanje ob izrednih hidroloških razmerah, kakor so poplave in suše, zlasti pa za zagotavljanje podatkov v realnem času.

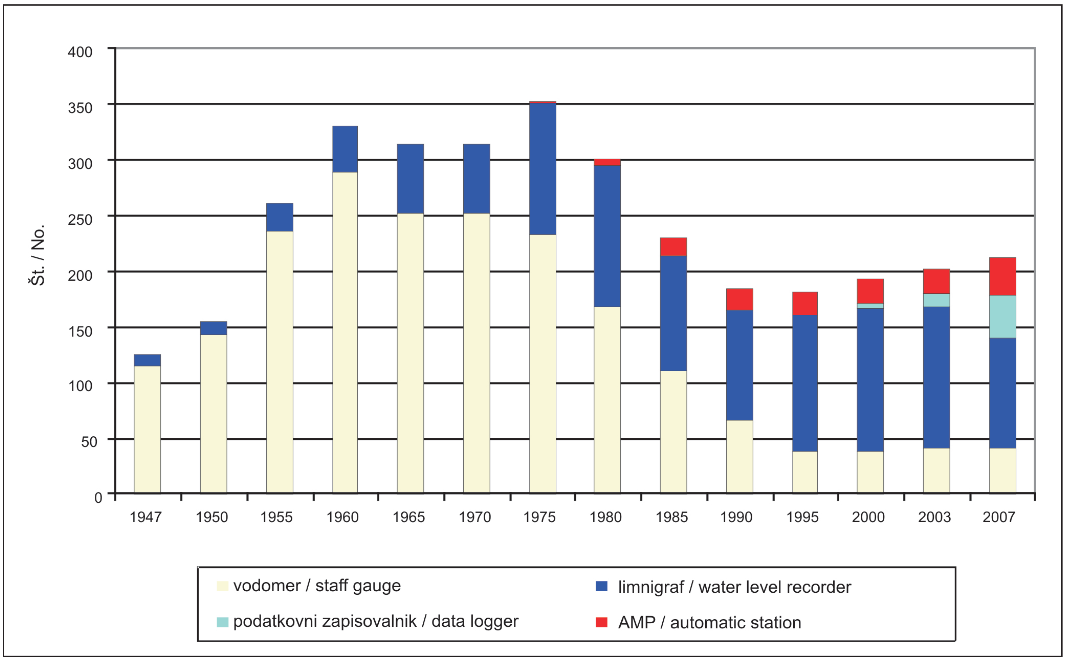
stations on surface waters has changed and been adapted to the existing needs and developments of the measuring equipment. The first measurements in the territory of present-day Slovenia extend from the second half of the 19th century in the period of the Austro-Hungarian monarchy. According to the records in the archives of the Environmental Agency of the Republic of Slovenia, Litija on the Sava River, Celje on the Savinja River, Vrhnika on the Ljubljanica River, Planina on the Unica River and Gornja Radgona on the Mura River are among the oldest water gauging stations still in operation.

In the beginning the observations were only periodic. Regular water level observations gradually extended to the measurements of water quantity, ice phenomena and water temperature measurements. Consequently, the gauging station network improved. To acquire more accurate data, the gauging stations started to be equipped with devices for the continuous recording of the water level (water-level recorders). According to the preserved records, 121 water gauging stations were operational in Slovenia in 1940 and 124 stations after World War Two in 1947. Later, the number of stations increased and the measurements became more systematic, the quality of the measured data improved, in particular with stations being additionally equipped with water-level recorders, and also after 1980 with the upgrading of stations to automatic gauging stations (AGS). Water-level recorders started to be replaced by data loggers. The highest number of operating stations was in the first half of 1970s. The development of the hydrological network was influenced in particular by the protection of settlements against floods and the use of water for energy, technological and water supply purposes, and nowadays increasingly more by the needs to study and protect the environment. In the 1980s, many water gauging stations were terminated. The main reasons were different, ranging from maintenance cost reduction, the end of the planned period of operation to unsuitable microlocation etc.

The upgrading of water gauging stations to AGS and the testing of new measuring equipment, in particular different types of sensors and data loggers, led to the situation that there are several types of hydrological data at some gauging stations (observations, water-level recorders, data loggers, AGS), which should ensure the gathering of accurate hydrological data for taking measures in the event of an emergency hydrological situation such as floods and droughts, and in particular for providing real-time data.

The existing network and gauging station equipment

In the past few years, the number of surface water hydrological monitoring gauging stations remained almost the same. There are 185 gauging stations on water courses and 17 gauging stations on karstic



Slika 2: Opremljenost vodomernih postaj po drugi svetovni vojni
Figure 2: *Equipment of water gauging stations after World War Two*

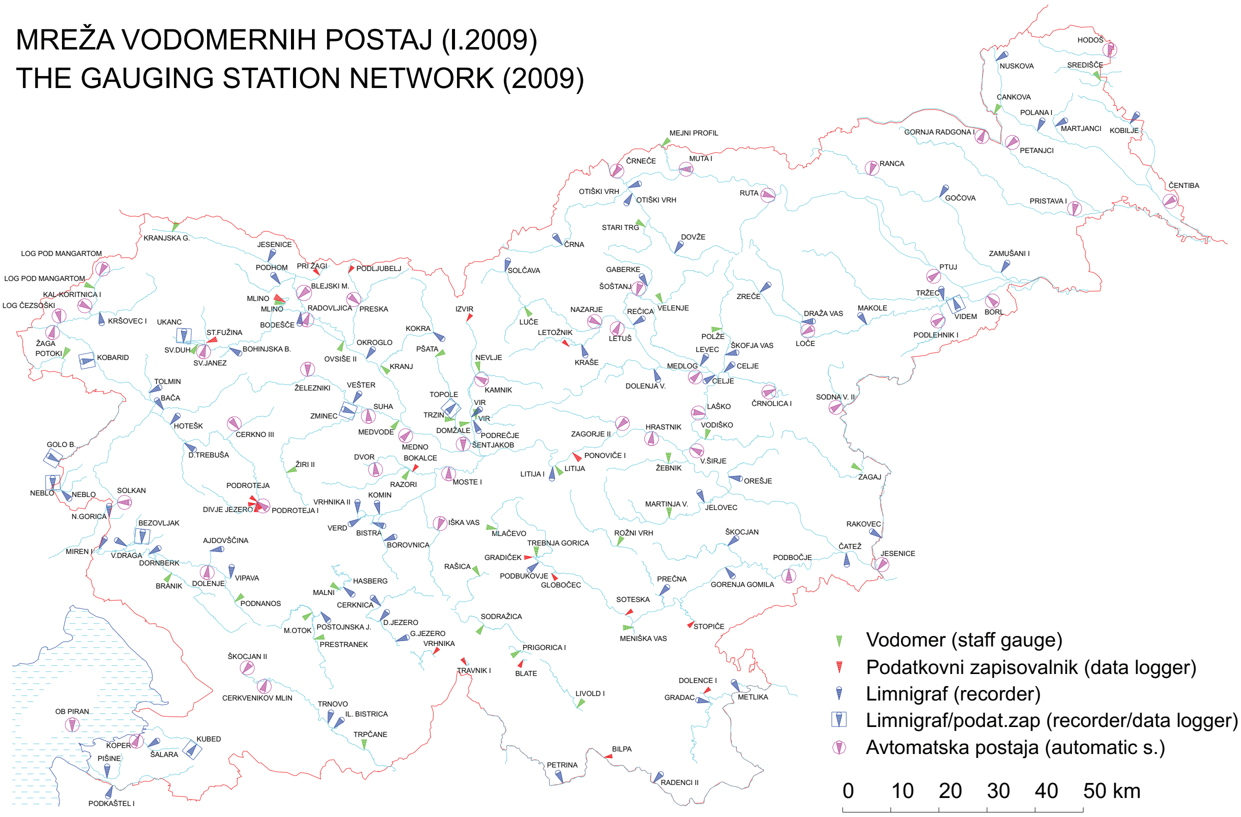
Obstoječa mreža in opremljenost merilnih mest

Zadnjih nekaj let je število merilnih mest hidrološkega monitoringa površinskih voda skoraj konstantno. Na vodotokih je 185 merilnih mest in 17 merilnih mest na kraških izvirih. Na 41 mestih poteka le enkrat ali večkrat na dan opazovanje vodostajev, na preostalih je zagotovljeno zvezno beleženje višine vodne gladine. Trenutno je avtomatski prenos podatkov v realnem času omogočen iz 48 vodomernih postaj. Te postaje so pomembne za redno spremljanje hidrološkega stanja in prognoziranje. Na 65 merilnih mestih se meri tudi temperatura vode, na 11 merilnih mestih pa poteka reden ali občasen odvzem vzorcev za ugotavljanje vsebnosti suspendiranega materiala v vodi. Podatki hidrološkega monitoringa so podlaga za spremljanje hidrološkega stanja, napovedovanje in obveščanje v izrednih razmerah kakor tudi ob naravnih in človeško pogojenih nesrečah. Nadalje so podlaga za pripravo vodnih bilanc, oceno vodnih virov, oceno hidroloških elementov ekološkega stanja voda, v zadnji letih pa so vse bolj podpora prognostičnim modelom kot osnovni vhodni podatki.

Opremljenost merilnih mest je različna, kar pogojuje različno frekvenco beleženja, od enkrat ali večkrat dnevnih opazovanj do zveznih zapisov (slika 3). Zvezno beleženje višine vodne gladine je zagotovljeno z različni tipi limnigrafov in podatkovnih zapisovalnikov, ponekod je tudi kombinacija obeh. Različni so tipi in načini prenosa podatkov z AMP-postaj, kar je povezano z razvojem sistemov in merilne opreme na področju hidrologije. Z različnimi tipi merilne op reme in njeno dotrajanostjo so povezani problemi vzdrževanja in servisiranja opreme, izpadi podatkov ter zagotavljanja

springs. At 41 locations, the observation of water levels is performed only once or several times a day, and at the rest the continuous recording of water level height has been provided for. Currently, 48 water gauging stations enable automatic data transmission in real time. These stations are important for the regular monitoring of the hydrological situation and forecasting. In addition, water temperature is measured at 65 gauging stations, and the regular or periodic sampling for determining the content of suspended material in water is performed at 11 gauging stations. The hydrological monitoring data are the basis of monitoring the hydrological situation, forecasting and informing the relevant authorities in an emergency situation as well as for natural disasters and accidents caused by human factors. Furthermore, they are the basis for preparing a water balance, an assessment of water sources, assessment of hydrological elements of ecological status of waters and, increasingly in the last number of years, a support to prediction models in the form of basic input data.

The gauging stations are equipped differently which means a different frequency of recording ranging from observations performed once or several times a day to continuous recording (Figure 3). Continuous recording of water level height is provided for with different types of water-level recorders and data loggers, or a combination of both in some places. Types and methods of data transmission from the AGS vary as well which is connected to the development of systems and measuring equipment in the field of hydrology. Various types of measuring equipment and its outdated condition are connected to the issues of equipment maintenance and service, data loss and data quality assurance. This is especially evident in



Slika 3: Opremljenost vodomernih postaj v letu 2009
Figure 3: *Equipment of water gauging stations in 2009*

kakovosti podatkov. To se še zlasti kaže ob izrednih hidroloških razmerah, ko je bistvena informacija v realnem času. Število postaj s prenosom podatkov v realnem času ne zagotavlja zadostnih informacij za učinkovito izvajanje ukrepov zaradi povečane stopnje ogroženosti škodljivega delovanja voda. Servisiranje in nadgradnja merilne mreže je zato stalna in nujna dejavnost, prav tako tudi uvajanje sodobnih merilnih metod in sistemov, samodejni prenos podatkov in avtomatska predhodna kontrola podatkov. Zaradi načrtovane nadgradnje in posodobitve merilnih mest v okviru projekta SSSV se je nadgradnja merilnih mest od leta 2007 izvajala v zelo omejenem obsegu, saj za to ni bilo razpoložljivih finančnih sredstev.

Izhodišča za optimizacijo merilne mreže na površinskih vodah

Pregled stanja in optimizacija merilne mreže na površinskih vodah, ki je bila izvedena v letu 2007, je bila poleg zahteve po načrtu prilagoditve mreže merilnih mest za potrebe napovedovanja ekstremnih hidroloških pojavov, zapisane v nacionalnem programu varstva okolja, narejena na podlagi kriterijev za različne potrebe:

- spremljanje hidroloških stanj in prognoziranje,
- ocenjevanje hidroloških parametrov za spremljanje stanja voda glede na zahteve vodne direktive,
- izračun vodne bilance,
- ocena količinskega stanja podzemnih voda glede

an emergency hydrological situation when essential information is provided or required in real time. The number of stations with real-time data transmission does not provide sufficient information for an efficient implementation of measures due to an increased risk level of the harmful effects of waters. Thus, the servicing and upgrading of the gauging station network is a permanent and necessary activity, as well as the introduction of modern measuring methods and systems, automatic data transmission and automatic data pre-control. Due to the planned upgrade and modernisation of gauging stations within the framework of the SSSV project, the upgrading of gauging stations has been implemented to a very limited extent since 2007 due to lack of funds.

Positions for optimisation of the gauging station network on surface waters

The review of the state and optimisation of the gauging station network on surface waters performed in 2007 was conducted based on the following criteria for different needs, in addition to the requirement for the plan to adapt the gauging station network for forecasting extreme hydrological phenomena written in the National Environmental Action Plan:

- monitoring of hydrological conditions and forecasting,
- assessment of hydrological parameters for water status monitoring relating to the Water Framework

na zahteve vodne direktive,
- meritve suspendiranega materiala,
- meritve temperature vode,
- meddržavne izmenjave in usklajevanja hidroloških podatkov,
- posredovanje hidroloških podatkov v evropske in globalne informacijske sisteme ter
- kontinuiteta hidroloških opazovanj.

Za vsak vidik optimizacije sta bila narejena pregled stanja in analiza primernosti obstoječe merilne mreže. Pri neustrezni pokritosti so bila evidentirana območja, na katerih merilna mreža ni zadostna in dani predlogi za širitev mreže z reaktivacijo opuščenih vodomernih postaj ali vzpostavitvijo novih merilnih mest. Končna analiza je vsakemu merilnemu mestu pripisala namembnost po zgoraj naštetih kriterijih.

Z vidika spremljanja hidroloških stanj in prognoziranja je pomembno, da je mreža hidroloških postaj zasnovana tako, da so podatki z vodomernih postaj dosegljivi v realnem času, lokacije vodomernih postaj pa naj bi bile gorvodno od poplavno ogroženih območij. Pri tem je pomembno tudi, da na teh lokacijah razpolagamo z dolgoletnim nizom opazovanj. Tovrstni podatki služijo kot osnova numeričnim simulacijam odtoka kot vhodni podatki v hidrološki prognostični sistem. Le s hidrološkimi podatki v realnem času je možno numerično simuliranje odtoka, kar izboljša zanesljivost hidrološke prognoze na 80–95 odstotkov. Podatki z vodomernih postaj v realnem času omogočajo učinkovito obveščanje in zaščito pred škodljivim delovanjem voda, v času hidrološke suše pa služijo kot osnova ukrepom za blaženje posledic pomanjkanja vode. Za vsako porečje je bila izdelana ocena ustrezne pokritosti poplavno najbolj ogroženih delov porečij. Za območja, kjer hidrometrična pokritost ni ustrezna, je bil dan predlog za vzpostavitev merilnih mest ali nadgradnjo že obstoječih vodomernih postaj.

Pri zahtevah ocenjevanja hidroloških parametrov za spremljanje stanja voda glede na zahteve vodne direktive je bila narejena analiza pokritosti merilnih mest na vodna telesa in pregled usklajenosti hidrološkega monitoringa in monitoringa kakovosti voda, kjer se je pokazalo, da so za tretjino merilnih mest lokacije iste ali v neposredni bližini, za preostala merilna mesta kakovosti, pri katerih ni v neposredni bližini hidrološke postaje, se bodo hidrološki parametri določali korelativno iz sosednjih merilnih mest. Kjer korelacija ni mogoča, so predlagana nova merilna mesta.

Izračun vodne bilance Slovenije je del programa nacionalne hidrološke službe ARSO in nacionalnega programa varstva okolja. Analiza primernosti delujoče mreže hidrološkega monitoringa za izračunavanje vodne bilance in posledično za ocenjevanje količinskega stanja voda kaže na pomanjkljivosti, kakor so prevelika zaledja merilnih postaj in njihova neenakomerna razporejenost. V obdobni bilanci

Directive requirements,
- water balance calculation,
- assessment of groundwater quantitative status relating to the Water Framework Directive requirements,
- suspended material measurements,
- water temperature measurements,
- transnational exchange and harmonisation of hydrological data,
- delivering of hydrological data to the European and global information systems, and
- continuity of hydrological observations.

A review of the state and a suitability analysis of the gauging station network were performed for every aspect of optimisation. By inappropriate coverage, the areas with inadequate gauging station network were recorded and the proposals to expand the network by reactivating the abandoned water gauging stations or establishing new gauging stations were given. The final analysis attributed the intended purpose to every gauging station according to the above listed criteria.

From the viewpoint of hydrological conditions of monitoring and forecasting, it is important that the hydrological station network is designed so that the water gauging station data are available in real time and that the water gauging station locations should be upstream of the flood risk areas. It is also important that we have a multi-annual series of observations for these locations. Such data serve as the basis for numerical simulations of discharge as input data for the hydrological forecast system. Numerical simulation of discharge is possible only with hydrological data in real time which improves the reliability of hydrological forecasts to 80-95%. Water gauging station data in real time enables efficient information and protection against the harmful effects of waters and serve as the basis of measures for mitigating the consequences of water shortage during hydrological drought. An assessment of the appropriate coverage of the most flood risk areas of river basins was prepared. For the areas without suitable hydrometric coverage, a proposal to establish gauging stations or to upgrade the existing water gauging station was given.

For the requirements of hydrological parameter assessment for water status monitoring relating to the Water Framework Directive requirements, an analysis of gauging station coverage per water bodies and a review of hydrological monitoring and water quality monitoring were carried out which showed that for one third of gauging stations the locations are the same or in the immediate vicinity, and for the rest of the quality gauging stations without a hydrological station in the immediate vicinity, the hydrological parameters will be determined correlatively from the neighbouring gauging stations. Where correlation is not possible, new gauging stations have been proposed.

The calculation of water balance in Slovenia is part

1971–2000 s klasičnim hidrološkim pristopom ni bilo mogoče izračunati bilance za 2872 km^2 (območja ob Dravi in Muri ter območje Krasa). Za nekatera območja je tako še vedno nemogoč bilančni izračun. Za potrebe natančnejšega izračuna vodne bilance so bila predlagana nova merilna mesta oziroma ponovna vzpostavitev opuščenih vodomernih postaj.

Okvirna vodna direktiva v smislu varovanja podzemnih voda predvideva ocenjevanje količinskega stanja podzemne vode po posameznih vodnih telesih za ugotavljanje stanja podzemnih voda in doseganje okoljskih ciljev. Okoljski cilji za količinsko stanje obvezujejo države, da varujejo, izboljšujejo in obnavljajo telesa podzemne vode ter zagotavljajo ravnotežje med odvzemanjem in obnavljanjem podzemne vode. V vodnih telesih s prevladujočo kraško – razpoklinsko poroznostjo, kjer meritev gladin ni mogoča, se razpoložljiva količina podzemne vode izračuna z ustrezno metodo z uporabo baznega odtoka iz telesa. V ta namen je treba vzpostaviti ustrezen hidrološki monitoring na izvirih, ki predstavljajo reprezentativne iztoke iz posameznega vodnega telesa oziroma vodonosnega sistema podzemnih vod. Za spremljanje količin podzemne vode po Wundtovi metodi je bil izdelan predlog novih merilnih mest na površinskih vodah. Pri tem gre za reaktivacijo opuščenih merilnih mest in tudi za vzpostavitev novih.

Za potrebe meddržavne izmenjave in usklajevanja hidroloških podatkov je treba zagotoviti predvsem kakovostnejše delovanje merilnikov za beleženje vodostajev in izboljšati ureditev nekaterih vodomernih profilov, medtem ko širitev monitoringa ni potrebna.

Sporočanje podatkov v evropske informacijske sisteme (EEA, GRDC) terja večjo kakovost podatkov, kar bo doseženo z modernizacijo obstoječih postaj, za katere se podatki sporočajo.

Z vidika kontinuitete hidroloških opazovanj je pomembno zagotoviti zadostno število merilnih mest z dolgotrajnimi, neprekinjenimi opazovanji in z dolgimi podatkovnimi nizi. Čeprav imajo hidrološka opazovanja pri nas dolgo tradicijo, je merilnih mest, za katere na podlagi lokacije lahko trdimo, da imajo dolge in neprekinjene podatkovne nize, relativno malo. Še dodatno se njihovo število skrči, če analiziramo njihovo homogenost. Še pred dobrimi desetimi leti je veljalo, da 30-letni niz že omogoča ocenjevanje osnovnih hidroloških značilnosti, kakor so pretočni režim, določitev obdobnih srednjih in značilnih pretokov, ocenjevanje povratnih dob malih in velikih pretokov na merilnem mestu. Zaradi izrazitosti učinkov podnebne spremenljivosti so v zadnjem času močno zaželene daljše časovne vrste hidroloških podatkov, ki bi omogočale tudi dolgoročno oceno in napoved učinkov naravnih in antropogenih procesov. Ob prestavitvi merilnega mesta na novo lokacijo, kar se pri nadgradnji merilnih mest dogaja, kaj hitro lahko pride do prekinitve časovne vrste.

of the programme of the national hydrological service at EARS and the National Environmental Action Plan. The suitability analysis of the existing hydrological monitoring network for water balance calculation and, consequently, assessing the quantitative status of waters points to shortcomings, such as too large a rear area of gauging stations and their uneven distribution. In the 1971-2000 balance, it was not possible to calculate the balance for 2872 km^2 with a classical hydrological approach (areas along the Drava and Mura rivers and the Karst area). Thus, the balance calculation is still not possible for some areas. For a more accurate water balance calculation, new gauging stations or the re-establishment of abandoned water gauging stations were proposed.

Relating to groundwater protection, the Water Framework Directive foresees an assessment of groundwater quantitative status by particular water bodies to determine the groundwater status and meet the environmental objectives. Environmental objectives for quantitative status bind the countries to protect, improve and renew groundwater bodies and ensure a balance between the abstraction and restoration of water. In water bodies with predominant karst-fracture porosity where water level measurement is not possible, the available water quantity is calculated with an appropriate method by using the base flow from the body.

For this purpose, appropriate hydrological monitoring has to be implemented on the springs which represent representative discharges from a particular water body or groundwater system. A proposal for new gauging stations on surface water was prepared for the monitoring of groundwater quantity according to the Wundt method. It concerns the reactivation of abandoned gauging stations and the establishment of new ones.

For the transnational exchange and harmonisation of hydrological data, the operation of water-level recorders of higher quality, in particular, has to be provided for and the regulation of particular water gauging cross-sections has to be improved, while the expansion of monitoring is not necessary.

Communicating the data to the European information systems (EEA, GRDC) requires data of higher quality which will be achieved with the modernisation of the existing stations, for which the data are communicated.

From the viewpoint of continuity of hydrological observations, a sufficient number of gauging stations with long-term, uninterrupted observations and long data sets has to be provided for. Even though hydrological observations have a long tradition in Slovenia, there are relatively few gauging stations with long and uninterrupted data sets based on their location. Their number is further decreased if their homogeneity is analysed. Not more than 10 years

Pregled sedanjih merilnih mest z vseh obravnavanih vidikov je pokazal, da naj se ta ne ukinjajo, ampak bi bilo treba vzpostaviti dodatnih 36 merilnih mest. Strokovna izhodišča za razširitev in posodobitev hidrološke mreže (ARSO, september 2007) zajemajo pregled stanja na površinskih vodah in merjene hidrološke parametre, postopke in pogostost meritev, pa tudi prenovo merilnih mest z vidika opremljenosti vodomernih postaj in dotrajanosti merilne opreme. V predlogu za posodobitev hidrološke merilne mreže je tako evidentiranih 186 merilnih mest, za večino je nadgradnja predvidena v projektu SSSV. Vidiki in potrebe, za katere je bila izdelana analiza in izvedena optimizacija, so podrobno obravnavani, kot rezultat so izdelane karte pokritosti in karte lokacij predlaganih novih merilnih mest.

ago it was believed that a 30-year set enabled the assessment of basic hydrological characteristics, such as the discharge regime, determination of periodical mean and typical discharges, and assessment of return periods of small and large discharges at the gauging station. Due to explicit climate change impacts, longer time periods of hydrological data have been desired lately which would enable a long-term assessment and forecast of the effects of natural and anthropogenic processes. When a gauging station is moved to a new location, which happens during the upgrade of gauging stations, a time series is interrupted.

A review of the existing gauging stations from all mentioned aspects showed that they should not be terminated and that an additional 36 gauging stations should be established. Professional bases for extending and upgrading the measuring network of hydrological monitoring of surface waters (EARS, September 2007) include the review of surface water state and measured hydrological parameters, procedures and frequency of measurements, as well as the renovation of gauging stations from the viewpoint of water gauging stations' equipment and the decrepitude of the measuring equipment. The proposal to upgrade the hydrological gauging station network contains 186 gauging stations, most of which are planned to be upgraded within the framework of the SSSV project. The aspects and needs for which an analysis was performed and an optimisation implemented are discussed in greater detail as a result of the coverage map and the map of locations of proposed new gauging stations.

KONTROLA PRETOČNIH KRIVULJ Z UPORABO HIDRAVLIČNEGA MODELA

Miha Šupek

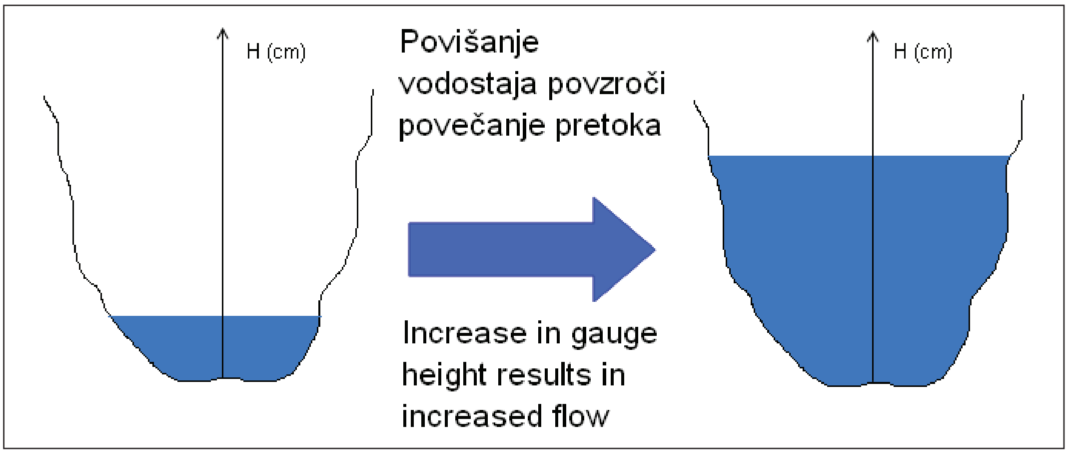
Osnovni parameter, ki ga neprekinjeno spremljamo v mreži merilnih mest hidrološkega monitoringa, je vodostaj ali višina vodne gladine. V odvisnosti od spremenjenih karakteristik prečnega in vzdolžnega prereza na vplivnem območju merskega profila se lahko pri določenem vodostaju skozi prečni prerez pretakajo različno velike količine vode. V ta namen se za izračun pretoka izvajajo terenske meritve hitrosti vode in geometrije prečnega prereza. Iz meritev pretoka (Q) pri različnih vodostajih (H) določimo funkcijsko odvisnost, ki jo imenujemo pretočna krivulja. Prikažemo jo lahko v grafični obliki kot preglednico ali enačbo. Krivulje so zasnovane na izhodiščih, da je tok vode v strugi enakomeren in se s časom ne spreminja (mirni tok). Na sliki 1 je prikazan potek pretočne krivulje pri neoviranem odtoku in potek, ko se zaradi dolvodnih ovir pojavi zajezitev (varianta a) ali pa se zaradi dolvodnega pojava deročega toka pojavi depresija (varianta b). Oba pojava lahko bistveno vplivata na določitev pretoka pri izmerjeni gladini na vodomerni postaji.

Posamezna meritev, ki daje podatek o vodostaju in pretoku, predstavlja eno točko na grafikonu pretočnih krivulj. Za posamezno merilno mesto se v povprečju izvede šest meritev na leto, odvisno od stabilnosti profila in hidroloških razmer. Večina hidrometričnih meritev je narejenih v spodnjem (mali pretoki) in srednjem (srednji pretoki) območju pretočne krivulje. V tem območju se odvisnost vodostaj - pretok odstotkovno gledano najbolj spreminja, medtem ko je pretočna krivulja v območju velikih pretokov relativno stabilna. Zlasti pri na novo vzpostavljenih merilnih mestih je na začetku potreben niz hidrometričnih meritev ob različnih vodostajih, da

CONTROL OF RATING CURVES BY USING A HYDRAULIC MODEL

Miha Šupek

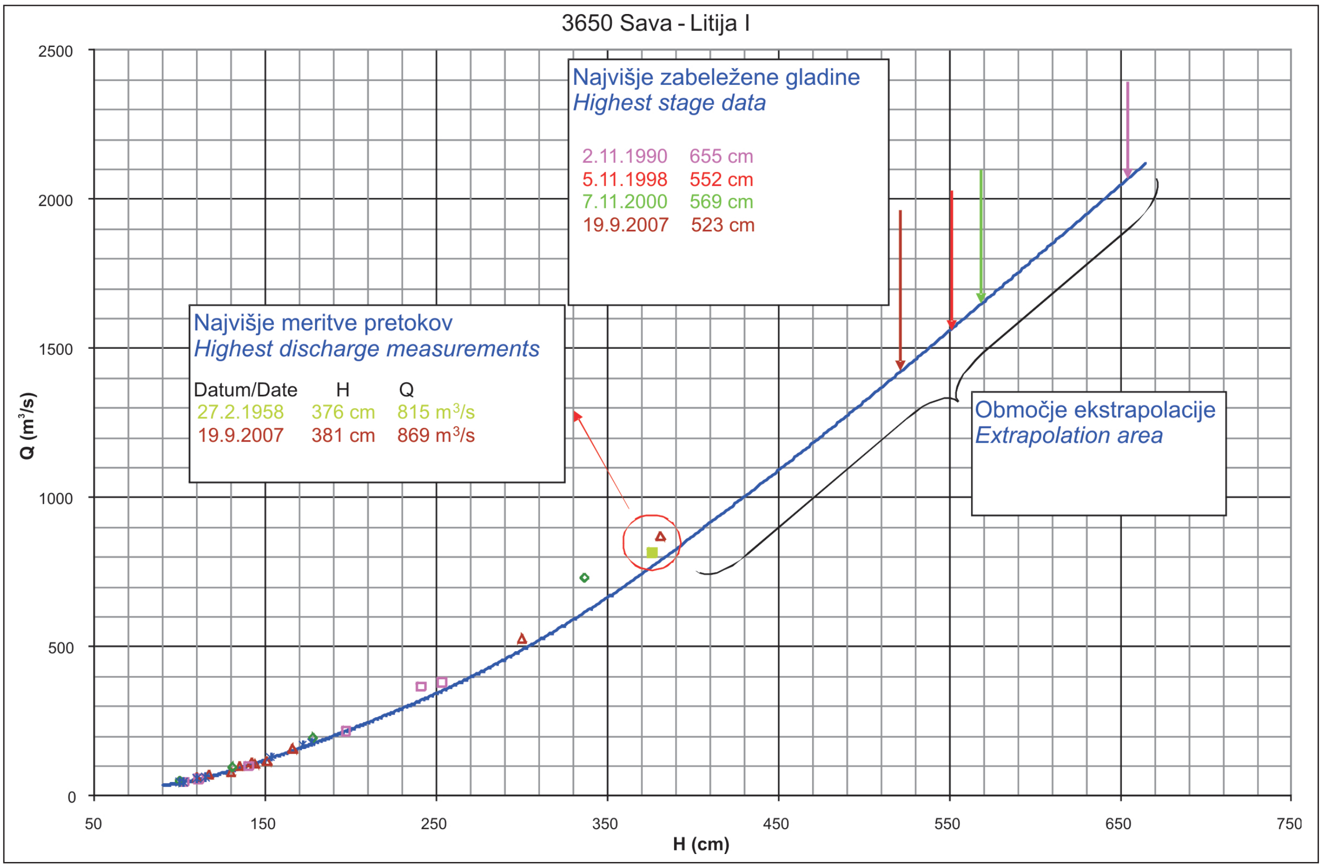
The basic parameter which is continuously monitored in the network of hydrological monitoring gauging stations is the water level or water level height. Depending on the changed characteristics of the cross section and longitudinal section in the influence area of the measuring profile, various quantities of water may flow through the cross section at a particular water level. Thus, field measurements of water velocity and cross section geometry are performed to calculate the discharge. Based on the discharge measurements (Q) at different water levels (H), a functional dependence is determined called a rating curve. It may be presented in graphic form as a table or an equation. The curves are based on basic premises that the water flow in the channel is steady and does not change with time (subcritical flow). The course of the rating curve at an unobstructed outflow and the course when, due to downstream obstacles, a capture occurs (variant a) or when, due to a downstream supercritical flow, a depression occurs (variant b) are shown in Figure 1. Both phenomena may significantly affect the determination of the discharge at the measured



Slika 1: Sprememba vodostaja (H) in pretoka (Q) za neoviran odtok in odvisnost Q - H pri zajezitvi (a) in depresiji (b).
Figure 1: *Change of water level (H) and discharge (Q) for an unobstructed outflow and dependence Q – H at capture (a) and depression (b).*

An individual measurement which provides the data on the water level and discharge represents one point on the rating curve graph. On average, six measurements a year are conducted for a particular gauging station depending on the profile's stability and hydrological conditions. Most hydrometric measurements are performed in the lower (small discharges) and middle (middle discharges) areas of the rating curve. In this area, the dependence of water levels – the discharge changes the most from the percentage viewpoint while the rating curve in the area of large discharges is relatively stable. In particular at dobimo čim natančnejši potek krivulje. Krivuljo (polinom tretje stopnje z več segmenti) izrišemo s prileganjem izvedenim meritvam *(curve fitting)*. Če meritev pretoka odstopa od trenutno veljavne pretočne krivulje za več kakor 5 % (tolikšna je namreč merilna negotovost), se uporabi oziroma izdela nova pretočna krivulja. Za določitev zgornjega dela pretočnih krivulj (območje velikih pretokov) je zaradi pomanjkanja podatkov treba opraviti t. i. ekstrapolacijo, pri čemer na podlagi podatkov pri nižjih vodostajih matematično določimo vrednosti pretoka za najvišje predvidene vodostaje (slika 2).

the newly established gauging stations, a series of hydrometric measurements at different water levels is required at the beginning in order to get as accurate a course of the curve as possible. The curve (third order polynomial with several segments) is drawn with curve fitting. If the discharge measurement deviates from the currently valid rating curve by more than 5% (which is the measurement uncertainty), a new rating curve will be used or created. To determine the upper part of rating curves (the area of large discharges), extrapolation has to be performed due to missing data whereby, based on the data for lower water levels,



Slika 2: Primer pretočne krivulje št. 46 za vodomerno postajo Sava – Litija I.
Figure 2: *An example of rating curve No. 46 for the Sava – Litija I water gauging station.*

Eden od možnih načinov točnejše določitve zgornjih delov pretočnih krivulj je ekstrapolacija z uporabo hidravličnega modela, ki je v nadaljevanju predstavljena na primeru vodomerne postaje Litija I na reki Savi. Na tej vodomerni postaji so namreč nekatere hidrometrične meritve izvedene z merilno opremo ADCP, ki omogoča meritve pri višjih vodnih stanjih, kar s klasičnim hidrometričnim krilom ni bilo možno, nakazovale možnost, da dajejo pretočne krivulje pri višjih vodostajih podcenjene vrednosti pretokov. Na sliki 2 je prikazana v letu 2006 veljavna pretočna krivulja št. 46 skupaj s točkami hidrometričnih meritev. S hidravličnim modelom HEC-RAS, ki lahko precej natančno upošteva obliko prečnega prereza na območju vodomerne postaje, smo preverili zgornji del pretočne krivulje za v. p. Litija.

the values for the highest estimated water levels are determined mathematically (Figure 2).

One of the possible methods to accurately determine the upper parts of rating curves is extrapolation using a hydraulic model, which is presented in continuation on the example of the Litija I water gauging station on the Sava River. Namely, some hydrometric measurements at this water gauging station conducted with the ADCP measurement equipment which enables measurements at higher water levels, which is not possible with a traditional current meter, pointed to the possibility that the rating curves provide underrated values of discharges at higher water levels. Rating curve No. 46, valid in 2006, along with the points of hydrometric measurements is shown in Figure 2. Using the HEC-RAS hydraulic model which considers the shape of the

Model HEC-RAS je bil razvit pod okriljem ameriške vojske *(US Army Corps of Engineers – Hydrologic Engineering Center)*. V začetku je bila s tem programom možna le hidravlična analiza stalnega neenakomernega toka, danes pa program omogoča izvedbo modela enodimenzijskega stalnega oziroma nestalnega toka, transporta sedimentov in spreminjanja temperature vode. V prvi fazi projektiranja je treba hidravličnemu modelu podati geometrijo rečnega odseka, kjer definiramo posamezne prečne profile ter različne objekte v in ob vodotoku. Vsak prečni profil mora imeti poleg osnovnih podatkov o stacionaži in nadmorski višini definirane tudi točke prelivanja in vrednosti koeficientov hrapavosti. Pomemben podatek simulacije predstavljajo hidravlični robni pogoji *(Boundary Conditions)*, s katerimi podamo dejansko stanje na gorvodnem ali dolvodnem koncu odseka vodotoka. Za različne režime toka so zahtevani različni robni pogoji. Za mirni tok zadošča dolvodni robni pogoj, za deroči tok pa se poda gorvodni robni pogoj. Kadar imamo opravka z izmenjavajočim se režimom toka, je treba podati oba robna pogoja.

Za izdelavo hidravličnega modela na območju v. p. Litija je bil izbran rečni odsek dolvodno od vodomerne postaje v dolžini 5 km z devetimi izmerjenimi prečnimi profili. Zaradi predhodno predpostavljenega režima mirnega toka je bilo treba v simulaciji definirati spodnji robni pogoj, ki ga predstavlja podatek o znani višinski koti gladine Save v dolvodnem profilu odseka, zato je bil tam dodatno nameščen podatkovni zapisovalnik za beleženje vodostajev.

Dobro umerjen hidravlični model je pogoj za zagotavljanje pravilnih rezultatov simulacije. Umerjanje modela je bilo izvedeno s postopnim spreminjanjem koeficientov hrapavosti v posameznih prečnih profilih. Na obravnavanem odseku so se namreč v letih 2006 in 2007 izvajale hidrometrične meritve pretokov, podatki o koeficientih hrapavosti pa so bili izbrani tako, da so se preračunane gladine ujemale z izmerjenimi na terenu.

Edini zabeleženi visokovodni dogodek v obravnavanem obdobju (2006 in 2007) na v. p. Litija je bil 19. septembra 2007, ko je maksimalni vodostaj znašal 523 cm. Za celotno preostalo obdobje leta 2006 in 2007 je bilo ugotovljeno, da vsi ostali vodostaji ustrezajo srednjim oziroma nizkim vodostajem brez izrazitega povišanja.

Podatkovni zapisovalnik, ki je bil nameščen v dolvodnem prečnem profilu, je beležil podatke o gladini Save od 28. novembra 2006. Časovni interval zapisa podatkov o vodostajih je bil nastavljen na 15 minut. S primerjavo gladin gorvodno se je lahko določila sprememba vzdolžnega padca gladine reke Save pri visokih vodostajih v primerjavi s padcem pri nizkih vodostajih. Z rednimi kontrolnimi opazovanji je bilo potrjeno pravilno delovanje zapisovalnika za obdobje do visokovodnega dogodka dne 19. septembra 2007. Ob nastopu visoke vode pa je bilo ugotovljeno, da

cross section at the water gauging station area fairly accurately, we checked the upper part of the rating curve for the Litija g. s.

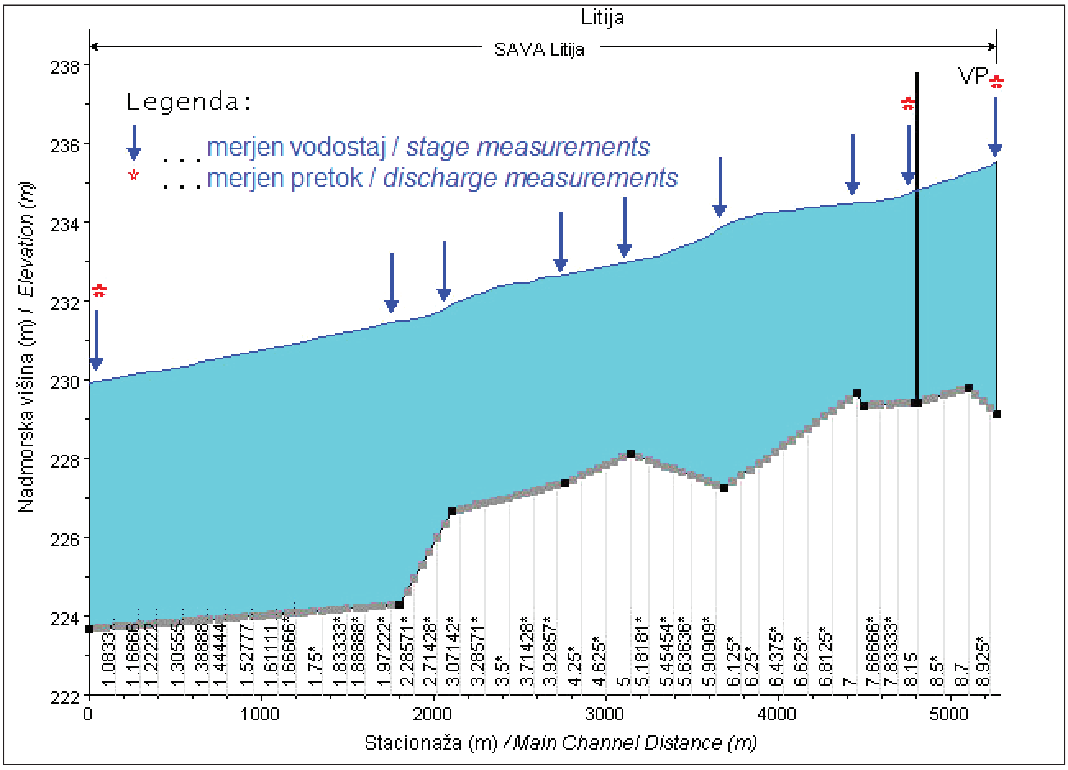
The HEC-RAS model was developed by the US Army Corps of Engineers - Hydrologic Engineering Center. In the beginning only a hydraulic analysis of the permanent unsteady flow was possible with this computer programme, however, today the programme enables modelling of one-dimensional steady or unsteady flow, sediment transportation and water temperature changes. In the first design phase, we have to provide the geometry of the river section where particular cross sections are defined as well as various objects in and along the watercourse to the hydraulic model. Every cross section has to include spilling points and values of roughness coefficients in addition to the basic data on stationing and above mean sea level. The boundary conditions which provide the actual state on the upstream or downstream part of the watercourse section are also important data of the simulation. Different boundary conditions are required for different flow regimes. A downstream boundary condition suffices for a subcritical flow and an upstream boundary condition for a supercritical flow. When dealing with mixed flow regime, both boundary conditions have to be provided.

For the creation of the hydraulic model in the area of Litija g. s., the river section downstream from the water gauging station, 5km in length, with nine measured cross sections was chosen. Due to a previously planned subcritical flow regime, a lower boundary condition had to be defined in the simulation which presents the data on the known height of the water level of the Sava River in the downstream section profile, thus, a data logger for the recording of water levels was installed additionally.

A well calibrated hydraulic model is a condition for providing correct simulation results. Model calibration was performed with a gradual changing of roughness coefficients - in particular cross section profiles. Namely, in 2006 and 2007, hydrometric measurements of discharges were conducted on the section concerned, and the roughness coefficient data was gathered by matching the calculated water levels with those measured in the field.

The only recorded high water event in the period concerned (2006 and 2007) at the Litija g. s. Litija occurred on 19 September 2007 when the maximum water level reached 523cm. For the entire remaining period in 2006 and 2007, it was determined that all other water levels correspond to middle or low water levels without a significant increase.

The data logger installed in the downstream cross section recorded the data on the water level of the Sava River from 28 November. The time interval of water-level data recording was set to 15 minutes. By comparing the water levels upstream, the change in the



Slika 3: Vzdolžni prerez obravnavanega območja pri pretoku Q = 1400 m^3/s.
Figure 3: *Longitudinal section of the relevant area at a discharge of Q = 1400m^3/s.*

je aparat zabeležil 40 cm nižjo gladino, kot je bila dejansko posneta na terenu na podlagi sledi visoke vode. S tem se je pokazala kot pravilna odločitev, da je treba ob vsakem pojavu visoke vode čim prej zabeležiti sledi maksimalne gladine v vseh izbranih prečnih profilih, saj so tako dobljeni podatki zelo pomembni za umerjanje modela. Prav novejša opazovanja gladin v posameznih prečnih profilih in hidrometrične meritve ob visokih vodah v letu 2007 predstavljajo najpomembnejše podatke za umerjanje hidravličnega modela in določitev koeficienta hrapavosti.

Najvišji pretok reke Save 1400 m^3/s je bil določen pri vodostaju 503 cm 19. septembra 2007. Za višje gladine nimamo podatka o pretoku vode v dolvodnem profilu, zato je za te pretoke treba upoštevati nov spodnji robni pogoj, ki je podan s povprečnim padcem energijske črte. Padec je določen s pomočjo rezultatov hidravličnega izračuna za pretoke do 1400 m^3/s (slika 3), kjer je kot povprečni padec energijske črte na obravnavanem odseku dobljena vrednost 0,8 ‰. S to vrednostjo, če predpostavimo paralelen dvig gladine, se nato simulirajo ostali višji pretoki.

Na sliki 4 so vse pretočne krivulje izrisane le od pretoka 500 m^3/s naprej, saj so krivulje v spodnjem delu do tega pretoka enotne in dostikrat preverjene z zadostnim številom meritev, zato spodnji del krivulj ni vprašljiv. Problemi nastopijo vedno z zgornjimi deli pretočnih krivulj, kjer ni na voljo meritev. Za čim boljši izris pretočne krivulje smo uporabili 80 pretokov za simulacijo z vrednostmi med 500 m^3/s in 2120 m^3/s.

Pretočna krivulja, dobljena z uporabo hidravličnega

longitudinal fall of the water level of the Sava River at high water levels was determined compared to the fall at low water levels. With regular control observations, correct operation of the recorder was confirmed for the period until the high-water event on 19 September 2007. During high water it was determined that the device recorded a 40 cm lower water level than the one actually recorded in the field based on high water traces. This proved that the decision to record the traces of maximum water level in all selected cross sections during every occurrence of high water as soon as possible was correct, because the data gathered in this manner are very important for model calibration. The newer water level observations, in particular cross sections and hydrometric measurements during high waters, in 2007 represent the most important data for calibrating the hydraulic model and determining the roughness coefficient.

The highest discharge of the Sava River, an amount of 1400m^3/s, was determined at a water level of 503cm on 19 September 2007. There are no data on the water discharge in the downstream profile for higher water levels, therefore, the new downstream boundary condition has to be considered for these discharges which is provided by the mean fall of the energy line. The fall is determined with the help of results from the hydraulic calculation for discharges up to 1400m^3/s (Figure 3) with the value of 0.8‰ as the mean fall of the energy line on the relevant section. Assuming a parallel increase of the water level, then other higher discharges may be simulated with this value.

modela 1-D HEC-RAS, kaže na večjo pretočnost kot obstoječa (statistično) ekstrapolirana pretočna krivulja ARSO, saj imamo enak pretok skozi prerez pri nižjem vodostaju in obratno – pri enakem vodostaju imamo večji pretok skozi obravnavani prečni prerez. Iz slike 4 je razvidno, da se v območju okrog vodostaja 300 cm krivulji med seboj razlikujeta za približno 10 %, medtem ko se od vodostaja 550 cm naprej modelska pretočna krivulja še bolj odmakne od obstoječe ekstrapolirane pretočne krivulje. Tako imamo pri vodostaju 550 cm razliko med pretoki približno 8 %, medtem ko znaša razlika med pretokoma pri vodostaju 610 cm že 12 %.

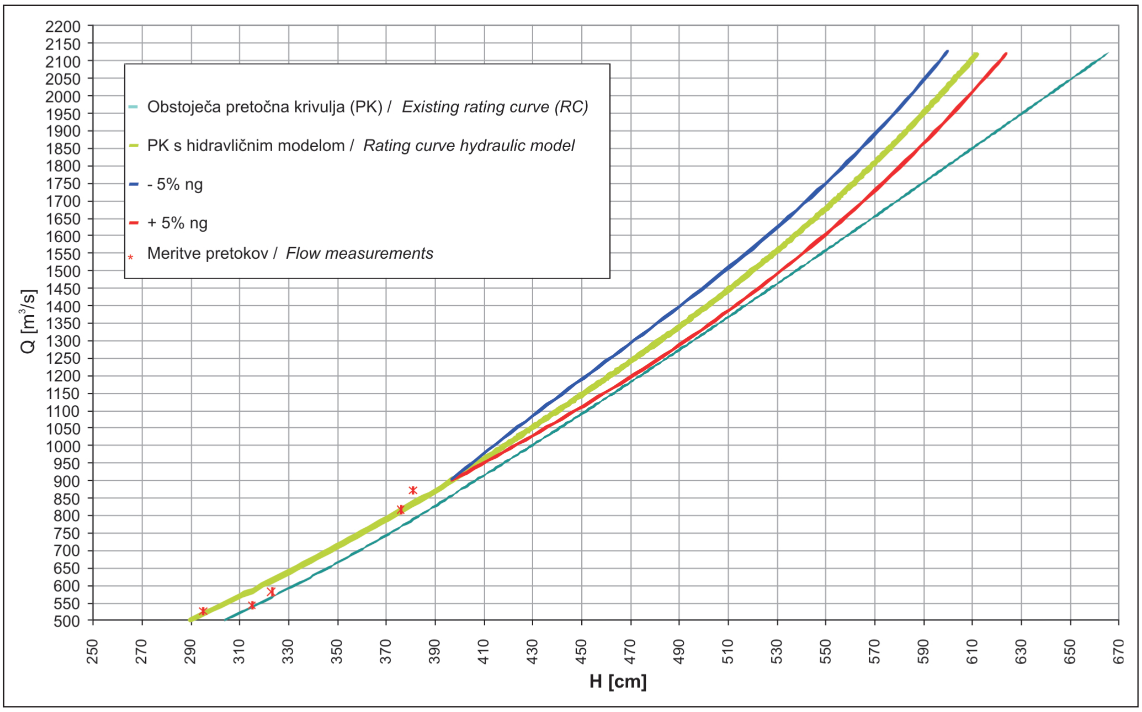
Zaradi dejstva, da je umerjanje modela izvedeno z izbiranjem koeficienta hrapavosti ter možnih napak zaradi netočnosti topografskih podatkov, je bilo treba izvesti tudi analizo občutljivosti koeficienta hrapavosti, in sicer z uporabo 5-odstotnega povečanja oziroma zmanjšanja osnovnih umerjenih vrednosti koeficientov.

Iz rezultatov simulacij je razvidno, da pretočne krivulje za maksimalne pretoke tudi pri 5-odstotnem povečanju koeficienta hrapavosti ne dosežejo obstoječe pretočne krivulje. S tem se nakaže možnost, da obstoječe pretočne krivulje dejansko prikazujejo manjšo pretočnost pri enakem vodostaju. Pri vodostaju 550 cm daje pretočna krivulja ARSO vrednost pretoka 1556 m^3/s, medtem ko dajejo pretočne krivulje hidravličnega modela vrednosti med 1600 m^3/s (5 % povečanje ng) in 1750 m^3/s (5 % zmanjšanje ng), kar predstavlja razliko v pretočnih krivuljah med 3 % in

All rating curves in Figure 4 have been plotted only from the discharge of 500m^3/s onwards because the curves in the lower part up to this discharge are uniform and verified many times with a sufficient number of criteria, therefore, the lower part of the curves is not questionable. The problems always occur with the upper parts of rating curves where no measurements are available. For the best possible plotting of the rating curve we used 80 discharges for the simulation with the values ranging from between 500m^3/s and 2120m^3/s.

The rating curve obtained with the hydraulic model 1-D HEC-RAS points to a higher discharge than the existing EARS (statistically) extrapolated rating curve because the discharge through the section at a lower water level is the same and vice versa – the discharge is higher through the cross section concerned at the same water level. Figure 4 shows that in the area around the water level of 300cm the curves differ from each other by 10%, while the model rating curve moves further away from the existing extrapolated rating curve from a water level of 550cm and above. Thus, the difference between the discharges at a water level of 550cm is approximately 8% and almost 12% between the discharges at a water level of 610cm.

Due to the fact that model calibration is performed by selecting the roughness coefficient and possible errors due to the inaccuracy of topographic data, the analysis of roughness coefficient sensitivity had to be conducted, namely, by using the 5-percent increase or decrease of basic calibrated values of coefficients.



Slika 4: Primerjava obstoječe pretočne krivulje s krivuljo, dobljeno z uporabo hidravličnega modela. Prikazana sta tudi primera s 5-odstotnim povečanjem in zmanjšanjem koeficienta hrapavosti ng.
Figure 4: *Comparison of the existing rating curve with the curve obtained with a hydraulic model. The examples with a 5-percent increase and the roughness coefficient decrease ng are presented as well.*

12 %. Pri višanju gladine se te razlike še povečujejo, saj imajo pretočne krivulje med seboj drugačen potek kar se tiče ukrivljenosti. Zaradi boljšega upoštevanja oblike prečnega prereza je namreč pri krivulji, dobljeni s hidravličnim modelom, opazna rahla ukrivljenost krivulje v zgornjem delu, medtem ko je potek obstoječe pretočne krivulje skoraj linearen (slika 4). Pri maksimalnem upoštevanem pretoku 2100 m^3/s je po pretočni krivulji ARSO dosežen vodostaj 663 cm, s pretočnimi krivuljami hidravličnega modela pa le 624 cm oziroma 599 cm, kar v povprečju znaša približno 50 cm razlike v gladini pri istem pretoku.

Na podlagi dobljenih rezultatov hidravličnega modela se je za vodomerno postajo Litija I na Savi popravil zgornji del pretočnih krivulj in se z letom 2008 tudi že uporabljajo na novo določene krivulje. Hidravlični model se je tako potrdil kot uspešna metoda za ekstrapolacijo pretočnih krivulj, če le imamo dobro posneto geometrijo struge in terena ter podatke o hidravličnih razmerah z ogleda razmer na terenu (tip zarasti, točke prelivanja, sledi visokih vod) in bo zagotovo zelo uporabno orodje tudi za preverjanje pretočnih krivulj na drugih vodomernih postajah.

The simulation results show that the rating curves for maximum discharges do not reach the existing rating curve even at a 5-percent increase of the roughness coefficient. This reveals the possibility that the existing rating curves actually show a lower discharge at the same water level. At the water level of 550cm, the EARS rating curve shows a discharge value of 1556m^3/s while the hydraulic model rating curves show values between 1600m^3/s (5% increase of ng) and 1750m^3/s (5% decrease of ng) representing the difference in rating curves of between 3% and 12%. When the water level rises, these differences increase because, relating to the curvature, the rating curves behave differently. Due to better consideration of the cross section's shape, the curve obtained with the hydraulic model is slightly curved in the upper part, while the existing rating curve is almost linear (Figure 4). At the maximum observed discharge of 2100m^3/s, a water level of 663cm was reached according to the EARS rating curve and only 624cm or 599cm according to the hydraulic model rating curves, which on average amounts to approximately 50cm of a difference in the water level at the same discharge.

Based on the acquired results of the hydraulic model, the upper part of the rating curves for the Litija I water gauging station on the Sava River had been corrected and the newly determined curves began to be used in 2008. The hydraulic model was confirmed to be an efficient method for extrapolating rating curves if the channel and field's geometry is well recorded and the data on hydraulic conditions from the field visit are available (type of overgrowth, spilling points, high water traces), and it will definitely become a useful tool for verifying the rating curves at other water gauging stations as well.

DOLOČITEV PRETOKOV REK Z UPORABO HORIZONTALNIH MERILNIKOV HITROSTI (H-ADCP)

mag. Roman Trček

V prispevku je razložen postopek izvajanja meritev hitrosti s horizontalnim merilnikom (H-ADCP) in uporaba rezultatov za (kontinuirno) določitev pretoka pri nestalnem neenakomernem toku. Na praktičnih primerih z merilnih mest na Savi pri Ljubljani (v. p. Šentjakob) in Dravi na dotoku v Slovenijo (v. p. Črneče) ter v Ptujsko (akumulacijsko) jezero (v. p. Ptuj) so prikazane lastnosti merilnika in primerjava z obstoječim načinom pridobivanja podatkov o pretoku.

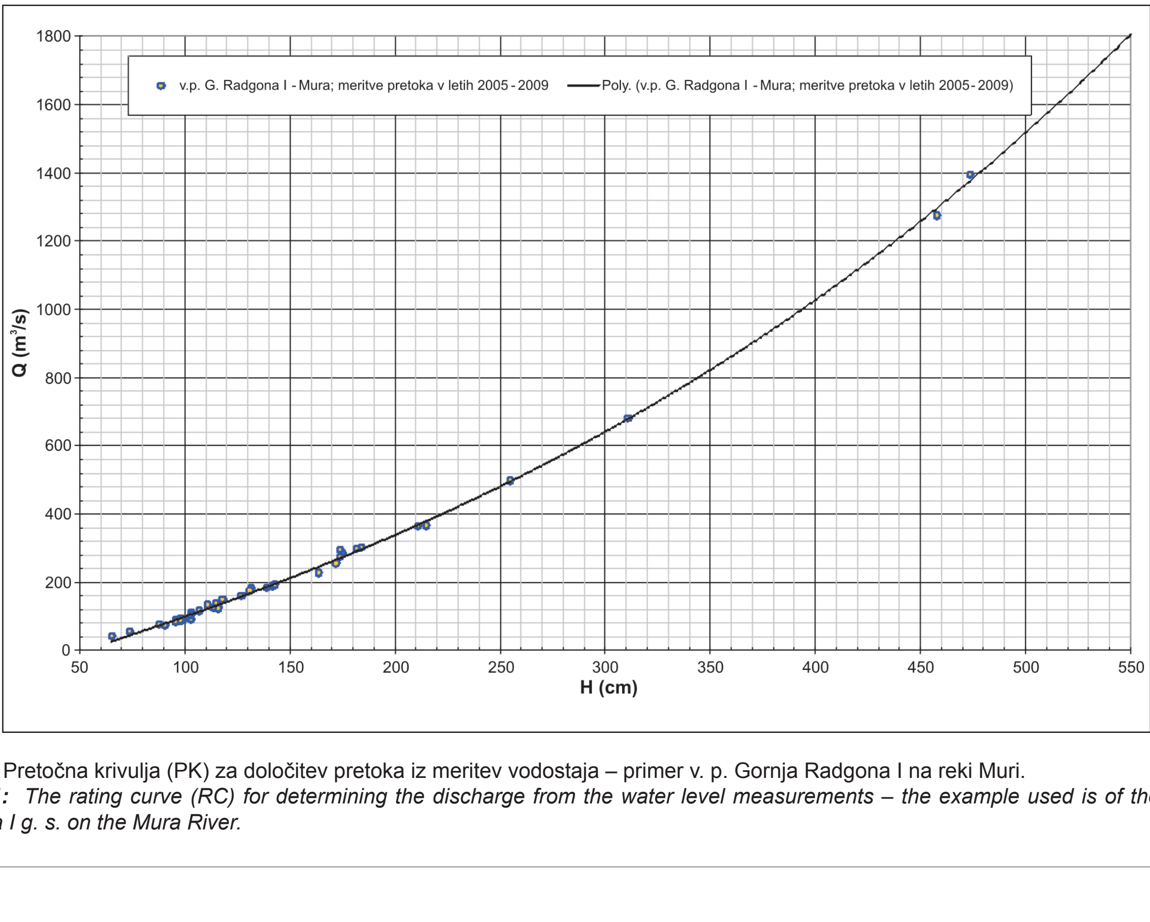
S pojmom normalni tok označujemo tok s prosto gladino, kjer se hitrost časovno in prostorsko-linijsko s časom ne spreminja. Iz tega sledi drugo ime za normalni tok, tj. stalni (časovna nespremenljivost) enakomerni (prostorsko-linijska nespremenljivost) tok. Definicija normalnega toka torej določa, da so globina, površina, pretok in hitrost v vsakem prečnem preseku na daljšem odseku vodotoka konstantne. V praksi oziroma v naravi je zgornji pogoj redko izpolnjen, zato se uporabljajo ustrezne predpostavke, da lahko uporabimo koncept normalnega toka, ne da bi v izračunih vnesli bistveno napako. V ta namen se uporabljajo t. i. časovni in prostorski koraki, ki so (še) dovolj majhni, da so zgornje zahteve izpolnjene.

DETERMINTION OF RIVER DISCHARGES BY USING HORIZONTAL VELOCIMETERS (H-ADCP)

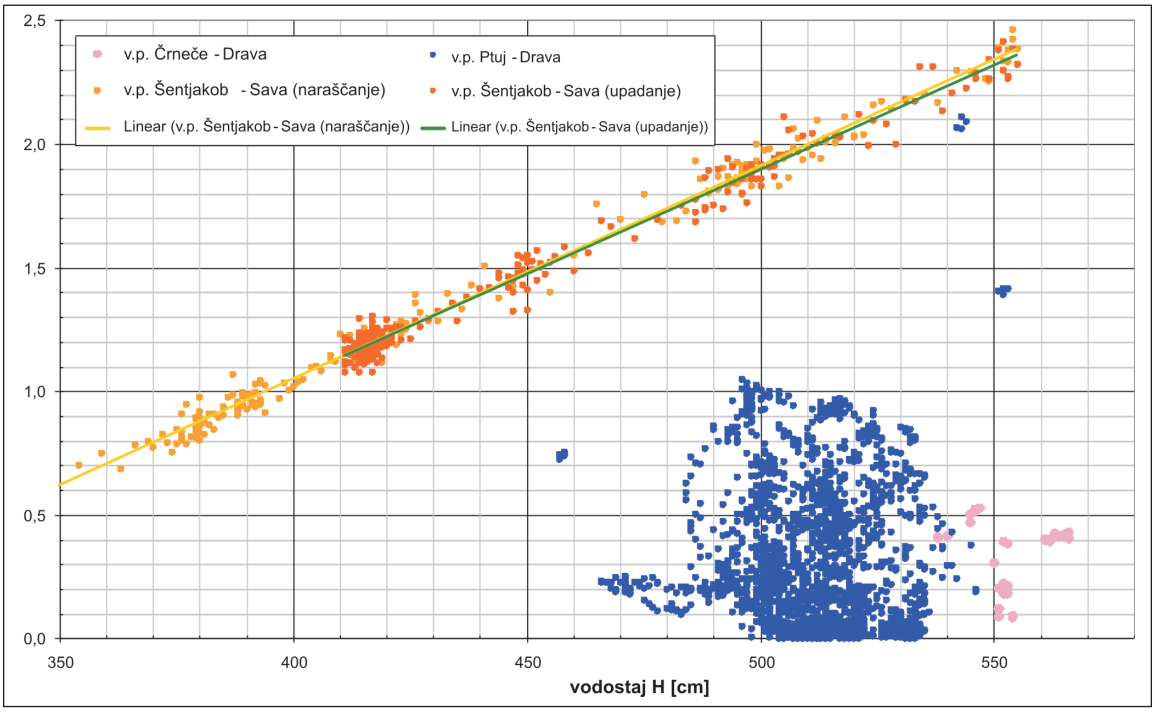
Roman Trček, MSc

This article explains the process of performing velocity measurements with a horizontal velocimeter (H-ADCP) and using the results for a (continuous) determination of a discharge at unsteady, varied flow. The characteristics of the velocimeter and comparison to the existing method of the discharge determination are presented using practical examples of the gauging stations (g. s.) on the Sava River near Ljubljana (Šentjakob g. s.) and on the Drava River at the inflow into Slovenia (Črneče g. s.) and the Ptuj (accumulation) Lake (Ptuj g. s.).

The term uniform flow characterises a flow with a free water level where the velocity does not change with time. .For steady uniform flow. steady relates to temporal stability and uniform to spatial stability. Thus, the definition of uniform flow determines that the depth, surface, discharge and velocity of every cross section on a longer watercourse section are constant. In practice or in nature the above condition is rarely met, therefore, appropriate assumptions that the uniform flow concept may be used without making a significant error in the calculations have to be made. In this purpose temporal and spatial steps are used



Slika 1: Pretočna krivulja (PK) za določitev pretoka iz meritev vodostaja – primer v. p. Gornja Radgona I na reki Muri.
Figure 1: *The rating curve (RC) for determining the discharge from the water level measurements – the example used is of the Gornja Radgona I g. s. on the Mura River.*



Slika 2: Povezava med vodostajem H in hitrostjo vode v za v. p. na rekah Savi in Dravi. V primeru v. p. na Dravi zveza med H in v ne obstaja, zato je pri določitvi pretoka potrebno meriti še dodatno veličino. Zaradi odstopanj od teoretičnih pogojev normalnega toka pa imamo v času (hipnih) povišanj gladine pri določitvi pretoka s pomočjo PK še dodatno negotovost v obliki histereze.
Figure 2: *The connection between the water level H and water velocity v for g. s. on the Sava and Drava rivers. The connection between H and v does not exist in the case of g. s. on the Drava River, therefore, an additional quantity has to be measured in determining the discharge. Due to deviations from theoretical conditions of the uniform flow, there is another uncertainty in determining the discharges with RC during the period of (momentary) increases of water level in the form of hysteresis.*

Eden od načinov kontinuirne določitve pretoka je določitev odvisnosti oz. funkcijske zveze med pretokom (Q) in gladino vode (H) oz. vodostajem, t. i. Q - H odvisnost (slika 1). To odvisnost, določeno iz meritev pretoka pri različnih gladinskih stanjih, pogosto imenujemo pretočna ali konsumpcijska krivulja (PK).

Bolj ko so ta stanja (višine vode) različna, natančnejša je določitev odvisnosti. Vsaka meritev predstavlja točko v koordinatnem sistemu, kjer je os x vodostaj H in os y pretok Q. Skozi točke določimo krivuljo, ki se najbolj prilega meritvam. Rezultat predstavlja pretočno krivuljo. Z njo je mogoče izračunati pretok enostavno prek meritve vodostaja. Natančnost izračunanega pretoka je odvisna od natančnosti kontrolnih meritev, raznolikosti stanj, pri katerih so bile merjene, in predvsem od zadostitve pogoja normalnega toka na mestu oz. v okolici, kjer se beleži vodostaj.

Najočitnejša lastnost normalnih tokov je enakost naklonov gladine vode, dna struge in energijske črte. Slednja predstavlja seštevek višine gladine in kinematičnega člena kot posledica hitrosti vode. Odstopanja od idealnih pogojev nastopijo tako pri vsakem zvišanju gladine, ki se vzdolžno gledano izraža kot t. i. visokovodni val. Če tak val spremljajo poplave, ga imenujemo poplavni val. Sprememba naklonov na naravnih vodotokih v času valov je najbolj izrazita pri prehodih rek med posameznimi deli tokov – povirje oz. zgornji tok, srednji tok in nižinski tok. Prehodi se izražajo kot lomi padcev nivelet na vzdolžnih prerezih.

which are (still) small enough to meet the requirements above.

One of the methods of continuous determination of discharge is to determine the dependences or functional connection between the discharge (Q) and water level (H), i.e. Q – H dependence (Figure 1). This dependence determined from the measurements at different water levels is often called the rating or consumption curve (RC).

The more water level heights differ, the more accurate is the determination of dependence. Every measurement represents a point in the coordinate system where water level H represents the axis x and discharge Q represents the axis y. The curve which suits the measurements the most is plotted through the points. The result is the rating curve. It can be used to calculate the discharge with the help of water level measurements. The accuracy of the calculated discharge depends on the accuracy of control measurements, diversity of states at which they were taken, and in particular on satisfying the uniform flow condition at the site or in the surrounding area where the water level is recorded.

The most obvious characteristic of uniform flows is the equality of water surface gradient, channel bottom and energy line. It represents the sum of the water level height and the kinematic element as the result of water velocity. Deviations from the ideal conditions occur

Najbolj znan primer iz naše okolice je npr. sprememba naklona Ljubljanice pred razlitjem na Barju. V takih primerih govorimo o naravnih zajezitvah, ki nastopijo kot posledica omejene pretočnosti oz. prepustnosti, npr. kraški ponori. Zajezitve so lahko tudi posledica močno dvignjene gladine vode (tudi morja), ki lokalno zajezi pritoke. Vse omenjene naravne pojave je potrebno upoštevati pri izbiri mest za meritve gladin oz. pretokov po metodi Q - H.

Z vidika meritev lahko stalni enakomerni tok opazujemo kot enoznačno povezavo med gladino in hitrostjo, tj. določenemu vodostaju ustreza točno določena hitrost in posledično pretok. Odstopanja (glede na opazovani časovni korak) nastopijo predvsem v času občutnejšega naraščanja ali upadanja vodostaja kot posledica naravnih ali človeško pogojenih sprememb pretoka (slika 2). Na spodnji sliki lahko to opazimo v obliki razhajanja med črtama za čas naraščanja in upadanja, t. i. histereza.

Odstopanja od razmer normalnega toka zaradi umetnih zajezitev oz. akumulacij predstavljajo velik problem za uporabo odvisnosti Q - H. Stalna dnevna nihanja gladin, hitrosti ter pretoka so izdatna in hipna. Govorimo o nestalnem, neenakomernem toku. Merilna mesta za kontinuirno določitev pretokov so v takih razmerah najpogosteje v profilu zajezitvenega objekta, bodisi iztoki skozi izpuste ali čez prelive.

Drugi način določitve pretoka v takih pogojih predstavlja sočasno (neprekinjeno) beleženje gladine in hitrosti vode. Na podlagi prvega določimo velikost površine prečnega prereza (slika 3) in na podlagi drugega srednjo hitrost v merskem profilu (slika 4). Zmnožek obeh predstavlja pretok.

Napaka določitve prečnega prereza iz gladine vode (t. i. odvisnost A - H) je pogojena s spremenljivostjo oblike korita struge. Pri umetnih zajezitvah je geometrija bistveno manj podvržena spremembam kot v naravnih strugah, zato je določitev površine iz gladine vode sorazmerno natančna. Pri pravokotnih koritih ali če širina prevladuje nad globino, narašča površina linearno z globino, sicer pa s kvadratom globine.

Za določitev srednje hitrosti v merskem profilu je potrebno izvajati kontinuirne meritve hitrosti, v našem primeru z merilnikom H-ADCP. V nadaljevanju je potrebno določiti odvisnost med izmerjeno hitrostjo z merilnikom H-ADCP (vhadcp) in dejansko srednjo hitrostjo v profilu (vsr). Slednjo določimo ob kontrolni meritvi pretoka tako, da delimo izmerjeni pretok s površino prereza v merskem profilu, ki jo dobimo iz odvisnosti A - H; če izvajamo meritev pretoka v merskem profilu v. p., potem je hitrost vsr že rezultat meritve same in dodaten izračun ni potreben.

Meritve pretoka v teh primerih izvajamo z namenom določitve odvisnosti med hitrostma v merskem profilu: srednjo hitrostjo in kontinuirno izmerjeno hitrostjo ter z namenom (občasne) kontrole odvisnosti A - H. Pri

at every water level increase expressed as the high water wave from the longitudinal viewpoint. If such a wave is accompanied by floods, it is called the flood wave. The change of inclines at natural watercourses during the period of waves is the most characteristic at river transitions between particular flow parts – headwaters or upper flow, middle flow and lowland flow. The transitions are expressed as the breaks of water surface gradient at longitudinal sections. The most well-known example from our surroundings is the gradient change of the Ljubljanica River before overflowing at Barje. These cases are known as natural dykes which occur as the result of limited discharge or permeability, e.g. Karst sinkholes. The dykes may also be the result of a highly increased water level (even sea level) which locally dams up the tributaries. All the mentioned natural phenomena have to be taken into consideration when selecting the sites for water level or discharge measurements according to the Q – H method.

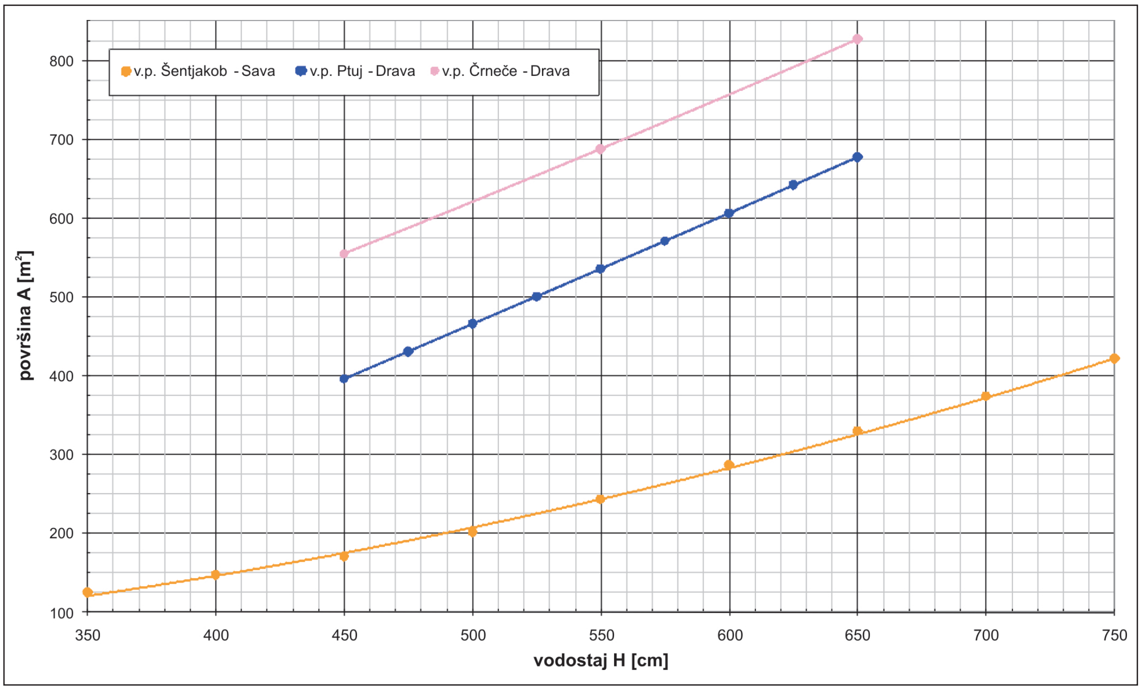
From the viewpoint of measurements, an uniform flow may be observed as a unique connection between the water level and velocity, i.e. a particular water level has a clearly specified velocity and consequently discharge. Deviations (relating to the observed temporal step) occur in particular during a significant rising or falling stage of water level as the result of natural changes of the discharge or those caused by human factors (Figure 2). This is shown in the figure below as the discrepancy between the lines for the rising and falling stage, i.e. hysteresis

Deviations from the uniform flow conditions due to artificial damming or accumulation are a major problem for the application of Q - H dependence. Permanent daily fluctuations of water level, velocity and discharge are significant and momentary. This is an unsteady varied flow. The gauging stations for a continuous determination of discharges under such conditions are most often located at the profile of the damming object, either through the outflows or over the weir.

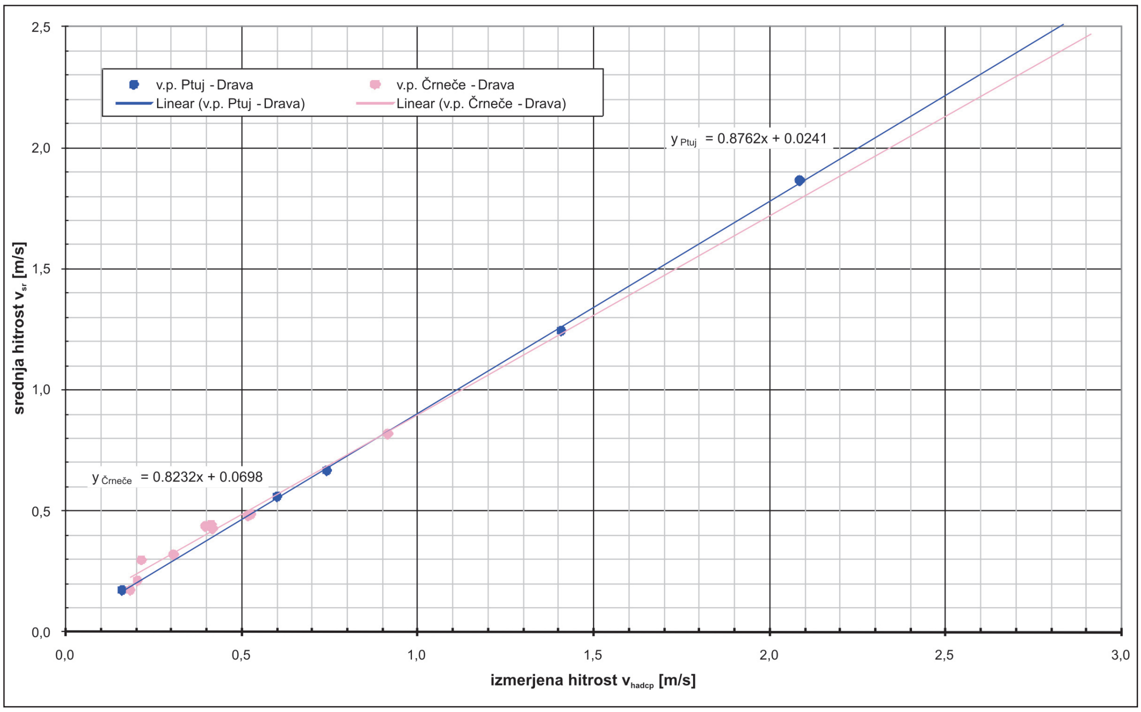
The second method of determining a discharge under such conditions is simultaneous (continuous) recording of the water level and velocity. The size of the cross sectional surface area is determined (Figure 3) on the basis of the first method, and the mean velocity in the measuring profile (Figure 4) on the basis of the second method. The product of both represents the discharge.

The error in determining the cross section from the water level (A – H dependence) depends on the variability of the channel's shape. The geometry in artificial damming is significantly less subjected to changes than natural channels, which makes determining of the surface from the water level relatively accurate. In rectangular channels or if the width is greater than the depth, the surface increases linearly with the depth, and otherwise with the square of the depth.

In order to determine the mean velocity in the measuring profile, continuous velocity measurements



Slika 3: Povezava med gladino H in površino A za prečne prereza v. p. Prereza na Dravi sta širša, zato je naraščanje površine z globino bolj linearno kot pri prečnem prerezu na v. p. Šentjakob, ki je ožji.
Figure 3: *The connection between the water level H and surface area A for cross sections of water gauging stations. The cross sections on the Drava River are broader, resulting in a more linear increase of the water level based on the depth compared to the cross section of the Šentjakob g. s. which is narrower.*

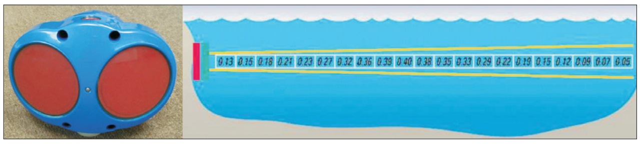


Slika 4: Povezava med izmerjeno hitrostjo s H-ADCP in dejansko srednjo hitrostjo v profilu v. p. Črneče in v. p. Ptuj. Opazimo, da sta si obe odvisnosti precej podobni.
Figure 4: *The connection between the measured velocity with H-ADCP and the actual mean velocity in the profile of Črneče g. s. and Ptuj g. s. We can notice that both dependences are quite similar.*

tem izbira metode meritve pretoka (ADCP – Acoustic Doppler Current Profiler, hidrometrično krilo, krilo na magnetno indukcijo, ultrazvočno krilo ipd.) ni pomembna. Stalni oz. kontinuirni merilnik hitrosti pa je običajno horizontalni ultrazvočni merilnik hitrosti.

have to be performed, in our case with the H-ADCP velocimeter. In continuation, the dependence between the measured velocity with the H-ADCP velocimeter (vhadcp) and the actual mean velocity in the profile (vsr) has to be specified. The dependence is specified

V našem primeru merilniki H-ADCP CM 600 podjetja TRDI (slika 5).



Slika 5: Merilnik H-ADCP CM 600 podjetja TRDI ter ilustracija prečnega prereza struge s prikazom rezultatov meritve hitrosti po posameznih celicah in slojih.
Figure 5: *The H-ADCP CM 600 velocimeter by the TRDI company and the graphic illustration of the channel's cross section with the presentation of velocity measurement results by particular cells and layers.*

Postavitev merilnika H-ADCP in postopek pridobitve podatkov o pretoku

Postavitev merilnika H-ADCP in postopek pridobitve kontinuirnih podatkov o pretoku poteka v sledečih fazah:

1) meritev geometrije prečnega prereza merskega profila (batimetrija) in navezava na geodetski posnetek brežin za določitev površine prereza pri višjih vodostajih,
2) namestitev merilnika H-ADCP v pravilen položaj; pomembna je globina potopitve, usmerjenost v vseh treh smereh, robustnost izvedbe,
3) izbira parametrov za kontinuirno izvajanje meritev hitrosti: velikost in število celic, število žvižgov v eni meritvi, število meritev za določitev povprečne hitrosti, časovna resolucija meritev (interval povprečenja); nekateri od naštetih parametrov so določeni eksperimentalno, tj. s poskušanjem na merskem mestu samem, pomemben parameter za določitev robnih pogojev meritev je moč signala,
4) po uspešno izvedenem izboru parametrov začnemo zbirati podatke o hitrostih v merskem profilu,
5) sočasno z zbiranjem meritev hitrosti se izvajajo meritve pretoka (npr. z ADCP), zaradi možnosti motenj jih ne izvajamo v merskem profilu, ampak v neposredni bližini,
6) določitev razmerja med izmerjenima hitrostma, izračun pretoka iz produkta površine ter srednje hitrosti ter primerjava s pretokom iz drugih virov (pretok sosednjih postaj, pretočne krivulje, pretok na zajezitvenem objektu ipd.).

Na v. p. Šentjakob na reki Savi je bila izvedena testna namestitev merilnika CM600. Namen testiranja je bila kontrola metodologije določitve oz. meritve pretoka ter delovanja vertikalnega ultrazvočnega senzorja za določitev nivoja gladine. Slednji se je primerjal z neodvisnima merilnikoma in metodama – tlačnim senzorjem PS1 in mikrovalovnim radarjem Kalesto, oba iz podjetja A-Ott. Rezultati so bili navdušujoči: odstopanje je bilo minimalno (±1 cm), kljub občutnim nihanjem gladine (slika 6).

Na podlagi izvedenih odvisnosti A - H ter vhadcp

at the discharge control measurement by dividing the measured discharge with the section's surface area in the measuring profile obtained from the A – H dependence; if the discharge measurement is performed in the g. s. measuring profile, then the velocity vsr is already the result of the measurement itself and additional calculation is not required.

The discharge measurements in these cases are performed in order to determine the dependence between the velocities in the measuring profile: mean velocity and continuous measured velocity, and to (periodically) check the A – H dependence. The selection of the discharge measurement method (ADCP – Acoustic Doppler Current Profiler, current meter, magnetic induction meter, ultrasonic velocimeter etc.) is not important. The horizontal ultrasonic velocimeter is usually a permanent or continuous velocimeter. In our case, the H-ADCP CM 600 velocimeters are manufactured by the TRDI company (Figure 5).

Installation of the H-ADCP velocimeter and the process of acquiring data on discharge

The installation of the H-ADCP velocimeter and the process of acquiring data on discharge are performed in the following steps:

1) measurement of the geometry of the measuring profile's cross section (bathymetry) and connection to the geodetic image of the banks to determine the section's surface at higher water levels;
2) installation of the H-ADCP velocimeter in the correct position – immersion depth, orientation in all three directions, and robustness of the unit are of great importance;
3) selection of parameters for a continuous performance of velocity measurements; the size and number of cells, the number of pings in one measurement, the number of measurements for determining mean velocity, time resolution of measurements (the averaging interval); some of these parameters are specified experimentally, i.e. by testing at the gauging station, but the important parameter for determining boundary conditions of measurements is the signal's strength;
4) a successful selection of parameters is followed by the gathering of data on velocity in the measuring profile;
5) simultaneously with gathering velocity measurements, discharge measurements (e.g. with ADCP) are performed; because of possible interferences, they are not performed in the measuring profile but in the immediate vicinity;
6) determination of the relationship between the measured velocities, discharge calculation from the product of the surface area and mean velocity, and comparison to the discharge from other sources (discharge of the neighbouring stations, discharge curves, discharge at the damming object etc.);

- vsr izračunamo pretok, ki ga lahko primerjamo z izvrednotenim pretokom iz pretočne krivulje (slika 7). Ujemanje je odlično za nižje pretoke, medtem ko so pri višjih odstopanja 5 do 10 %.

Testni namestitvi merilnika je sledila postavitev oz. obnova merilnih mest na reki Dravi. S postavitvijo zajezitvenih objektov v energetske namene so bile namreč vse klasične v. p. na reki Dravi postopno ukinjene zaradi zajezitve in porušitve enoznačne odvisnosti med H in Q. Kot zanimivost naj na tem mestu navedemo, da spadajo prav v. p. na reki Dravi med postaje z najdaljšo tradicijo. Za v. p. Ptuj imamo namreč zapise v temeljni knjigi že iz leta 1850!

Izbrali smo dve merilni mesti: v bližini vtoka Drave v državo je bil izbran merski profil Črneče (na fotografiji), za iztok iz države pa smo izbrali enega zadnjih profilov, preden se reka razdeli na derivacijski kanal in staro, »naravno« strugo, tj. Ptuj (na fotografiji).

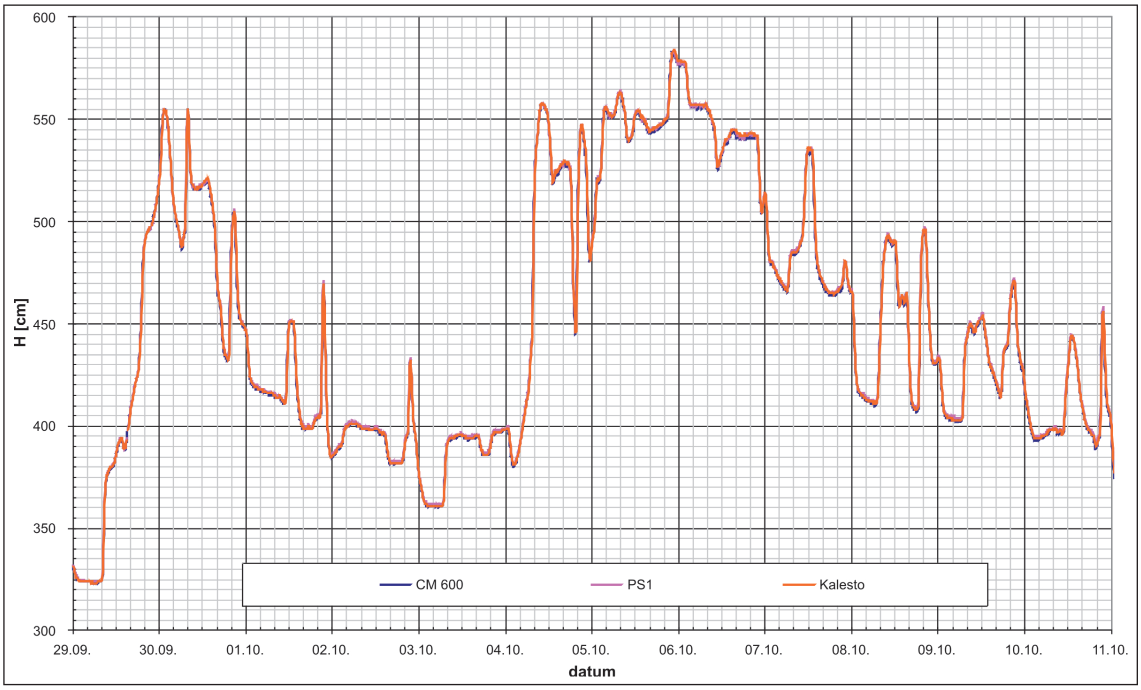
S pomočjo namestitve kontinuiranih merilnikov hitrosti in določitve potrebnih odvisnosti A - H in Q - H dobimo kontinuirne podatke o pretoku Drave (slika 8). Podatki predstavljajo prve, od pregradnega objekta neodvisne, kontinuirne meritve pretokov po graditvi verige HE na Dravi. V profilu v. p. Črneče je to od leta 1944, ko je bila ustvarjena zajezitev zaradi HE Dravograd, in v profilu v. p. Ptuj od leta 1978, ko sta bila zgrajena HE Formin in z njo jez v Markovcih.

The test installation of the CM600 velocimeter was conducted at the Šentjakob g. s. on the Sava River. Its purpose was to check the methodology of determining or measuring the discharge and the operation of a vertical ultrasonic sensor for determining the water level. The latter was compared to independent meters and methods – a PS1 pressure sensor and a Kalesto microwave radar, both from the A-Ott company. The results were encouraging: the deviation was minimal (±1 cm) despite significant water level fluctuation (Figure 6).

Based on A - H dependences and vhadcp - vsr, the discharge is calculated which can be compared to the evaluated discharge from the discharge curve (Figure 7). The agreement is excellent for lower discharges while a 5-10% deviation was recorded at higher discharges.

The test installation of the meter was followed by the placement or renovation of gauging stations on the Drava River. By placing damming objects for energy purposes, all traditional g. s. on the Drava River were gradually terminated due to damming and the demolishment of the unique dependence between H and Q. As an interesting fact, we should mention that g. s. on the Drava River is one of the stations with the longest tradition. Namely, the records for the Ptuj g. s. date back to 1850!

We selected two gauging stations: the measuring profile of Črneče (in the photo) was selected in the vicinity of the inflow of the Drava River into Slovenia, and one of the last profiles was selected for the outflow from Slovenia before the river divides to the derivation canal and the old, "natural" channel, i.e. Ptuj (in the photo).

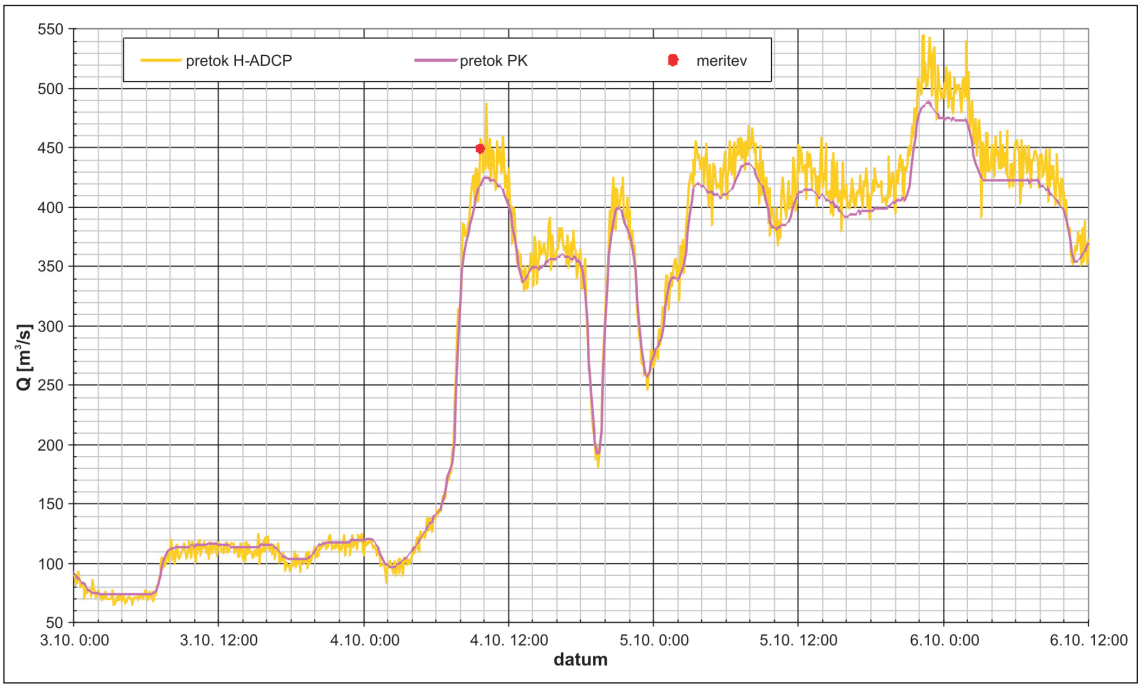


Slika 6: Povezava med izmerjeno hitrostjo s H-ADCP in dejansko srednjo hitrostjo v profilu v. p. Črneče in v. p. Ptuj. Opazimo, da sta si obe odvisnosti precej podobni.

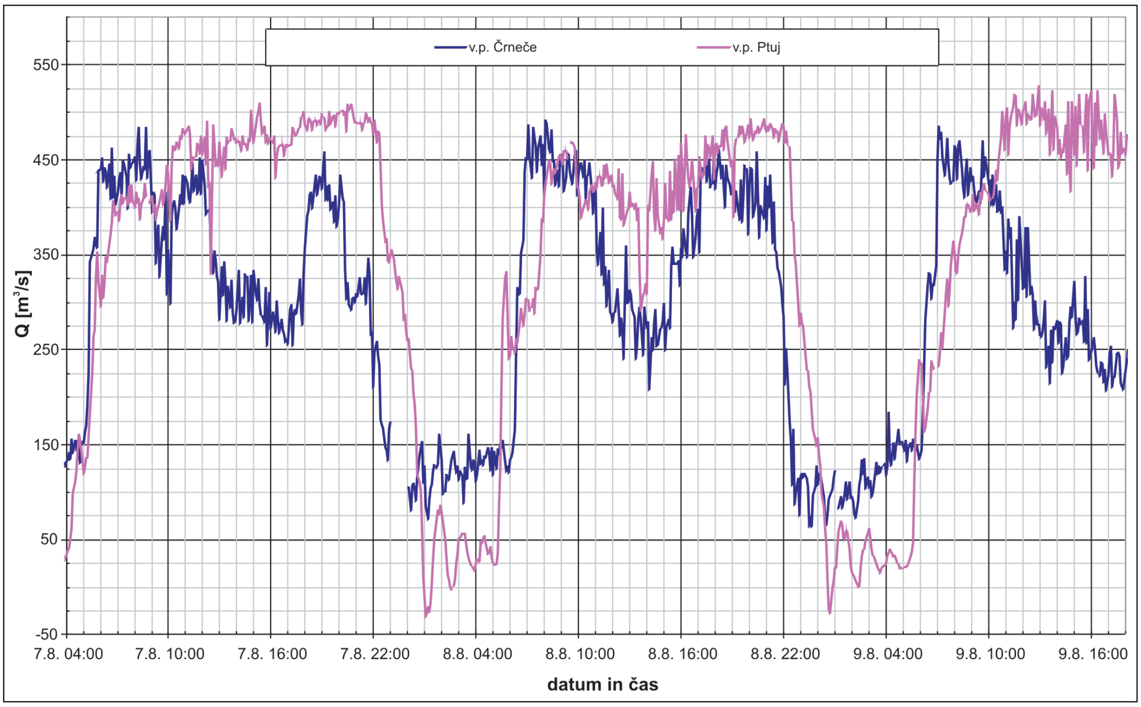
Figure 6: *Primerjava izmerjenih gladin, dobljenih z različnimi senzorji: tlačna sonda, mikrovalovni senzor in ultrazvočni senzor. Podatki veljajo za v. p. Šentjakob na reki Savi.*

Izvajanje meritev pretoka na v. p. Črneče – Drava. Blizu desne brežine (na sredi fotografije) opazimo vertikalno vodomerno letev, na katero je nameščen merilnik CM 600 (foto: Marko Burger).
Performance of discharge measurements at the Črneče g. s. - the Drava River. A vertical stage gauge with a CM 600 meter installed is near the right bank (in the centre of the photo) (photo: Marko Burger).

With the help of an installed continuous velocimeter and determined required A – H and Q – H dependences, we obtain the data on the Drava River discharge (Figure 8). The data represent the first, and from the barrier object, independent, continuous measurements of discharges after the construction of the series of hydroelectric power plants on the Drava River. Namely, from 1944 for the profile of the Črneče g. s. when the damming was created due to the Dravograd hydroelectric power plant, and from 1978 for the profile of the Ptuj g. s. when the Formin hydroelectric power plant and the dam in Markovci were built.



Slika 7: Primerjava pretokov izvrednotenih iz odvisnosti Q - H ter pretokov, izmerjenih s H-ADCP. Ujemanje je boljše pri nižjih vrednostih, pri višjih pa nam da izračun iz izmerjenih hitrosti višje pretoke kot izvrednotenje iz pretočne krivulje. Za primerjavo je dodana izmerjena vrednost pretoka.
Figure 7: *The comparison of discharges evaluated from Q – H dependences measured with H-ADCP. The agreement is better at lower values but at higher values, the calculation provides higher discharges from the measured velocities than the evaluation from the discharge curve. The measured discharge value was added for comparison..*



Slika 8: Kontinuirni podatki o pretokih reke Drave na dveh profilih: v. p. Črneče in v. p. Ptuj.
Figure 8: *Continuous data on the Drava River discharges in two profiles: Črneče g. s. and Ptuj g. s.*

Izvajanje meritev pretoka na v. p. Ptuj – Drava. Na desni strani opazimo merilno mesto s podstavkom za sonde, omarico s komunikacijsko opremo ter drogom za anteno in solarni panel (foto: Roman Trček).
Performance of discharge measurements at the Ptuj g. s. - the Drava River. A gauging site with a plate for probes, cabinet for communication equipment and a bar for the antennae and solar panel is on the right (photo: Roman Trček).

VREDNOTENJE VSEBNOSTI SUSPENDIRANEGA MATERIALA S POMOČJO MERILNIKA SOLITAX SC

Luka Ravnik, mag. Florjana Ulaga

Za potrebe monitoringa suspendiranega materiala na ARSO smo v Uradu za hidrologijo in stanje okolja v sklopu ugotavljanja primernosti nove merilne tehnologije poskusno izvajali meritve motnosti z avtomatskim merilnikom SOLITAX sc podjetja Hach & Lange. Merilniki motnosti so na tržišču že dalj časa, na voljo so prenosne izvedbe in tudi laboratorijske izvedbe. Za monitoring suspendiranega materiala na ARSO so primerni prenosni merilniki motnosti. Merjeni parameter motnost tekočine služi kot posredna meritev pri določanju vsebnosti suspendiranega materiala. Rezultate meritev smo ustrezno vrednotili in izračunali vsebnost suspendiranih snovi v vodi površinskih vodotokov. Rezultate meritev smo primerjali z rezultati merilnika OBS 3+ in z laboratorijskimi analizami vzorcev, odvzetih z avtomatskim vzorčevalnikom. Meritve smo izvajali od junija do decembra 2007 na avtomatski merilni postaji Suha na Sori, kjer je že v letu 2006 potekalo testiranje merilnika OBS 3+. Ob testiranju smo upoštevali standarde:

1. *ISO 11923:1997 Determination of suspended solids by filtration through glass-fibre filters*
2. *ISO 5667-17:2000 Guidance on sampling of suspended sediments*
3. *ISO 5667/PRF-17 Guidance on sampling of bulk suspended solids*
4. *EPA 180.1 Turbidity measurement standard*

Merilnik SOLITAX sc zajema merilni del, podatkovni zapisovalnik ter komunikacijski del. Pripadajoča oprema zajema komunikacijski vmesnik (SC1000 ali SC100) s prikazovalnikom in sposobnostjo priklopa na internet. Komunikacijski protokol je ModBus, ki poteka po fizični povezavi RS485. Merilna metoda je sestavljena iz klasične nefelometrične metode in dodatnega senzorja v glavi merilnika, ki meri sipanje svetlobe še pod drugim kotom in s tem kompenzira vpliv barve na meritve motnosti ter posledično izračun suspendiranega materiala. Motnost vode merimo v enotah FNU (Formazin nephelometric unit). Konfiguracija merilnika je omogočena preko programskega dela komunikacijskega vmesnika SC1000. Sprednja stekla na merilni glavi čisti majhen brisalec, ki na izbrano časovno periodo obriše stekla. Faktorji, ki vplivajo na meritve motnosti, so umazano stekelce na merilni glavi, zračni mehurčki ter spremembe v velikosti in barvi delcev.

ASSESSMENT OF SUSPENDED MATERIAL CONCENTRATION USING A SOLITAX SC GAUGE

Luka Ravnik, Florjana Ulaga, MSc

For the needs of suspended material monitoring at EARS, the Hydrology and State of the Environment Office performed test measurements of turbidity with the SOLITAX sc automatic gauge by the Hach & Lange company in the frame of determining the suitability of new measuring technology. Turbidity gauges have been on the market for a long time as mobile and also laboratory units. Mobile turbidity gauges are suitable for suspended material monitoring at EARS. The measured parameter liquid turbidity serves as an indirect measurement in determining the suspended material concentration. The measurement results were appropriately evaluated and the suspended material concentration in the water of surface watercourses calculated. The measurement results were compared to the results of an OBS 3+ gauge and laboratory sample analysis taken with an automatic sampler. The measurements were performed from June to September 2007 at the automatic gauging station of Suha on the Sora River, where the testing of OBS 3+ gauge had already been conducted in 2006. During testing the following standards were considered:

1. *ISO 11923:1997 Determination of suspended solids by filtration through glass-fibre filters*
2. *ISO 5667-17:2000 Guidance on sampling of suspended sediments*
3. *ISO 5667/PRF-17 Guidance on sampling of bulk suspended solids*
4. *EPA 180.1 Turbidity measurement standard*

The SOLITAX sc gauge contains a measuring unit, data logger and a communication unit. The accompanying equipment includes a communication interface (SC1000 or SC100) with a display and access to the Internet. The communication protocol is ModBus over a RS485 physical connection. The measuring method consists of a traditional nephelometric method and additional sensor in the gauge's head which measures scattered light at another angle, thus compensating for the colour's influence on the turbidity measurements and consequently the suspended material calculation. Water turbidity is measured in FNU units (Formazin nephelometric unit). The gauge's configuration is enabled through the programme part of the communication interface SC 1000. The front glasses on the measuring head are cleaned by a small wiper which wipes the glasses at a selected time interval. The factors affecting the turbidity measurements are a dirty glass on the measuring head, air bubbles and changes in the size and colour of particles.

Merilniki serije Solitax sc in komunikacijski vmesnik SC1000.
Solitax sc gauges and SC1000 communication interface.

Potek meritev

Merilnik SOLITAX sc smo namestili na avtomatsko hidrološko postajo Suha na vodotoku Sora skupaj z merilnikom OBS 3+. Na postaji je v letu 2007 potekal reden odvzem vzorcev suspendiranega materiala z avtomatskim vzorčevalnikom WS Porti PP (AV). AV je služil kot referenca, saj zagotavlja operativne meritve vsebnosti suspendiranega materiala, medtem ko oba testna merilnika SOLITAX sc in OBS 3+ zagotavljata meritve motnosti. Meritve smo izvajali od konca junija 2007 do prve polovice decembra 2007. V obdobju meritev je bilo nekaj padavinskih obdobij. Med padavinskimi obdobji smo spremljali odziv merilnikov na spremembe hidroloških parametrov, v obdobju brez padavin pa stabilnost obeh merilnikov in vpliv kopičenja umazanije na steklu merilnikov, kar povzroča motnje pri meritvah. Referenčni merilnik AV je zajemal vzorce enkrat na dan, v padavinskem obdobju pa smo periodo vzorčenja povečali največ na enkrat na uro.

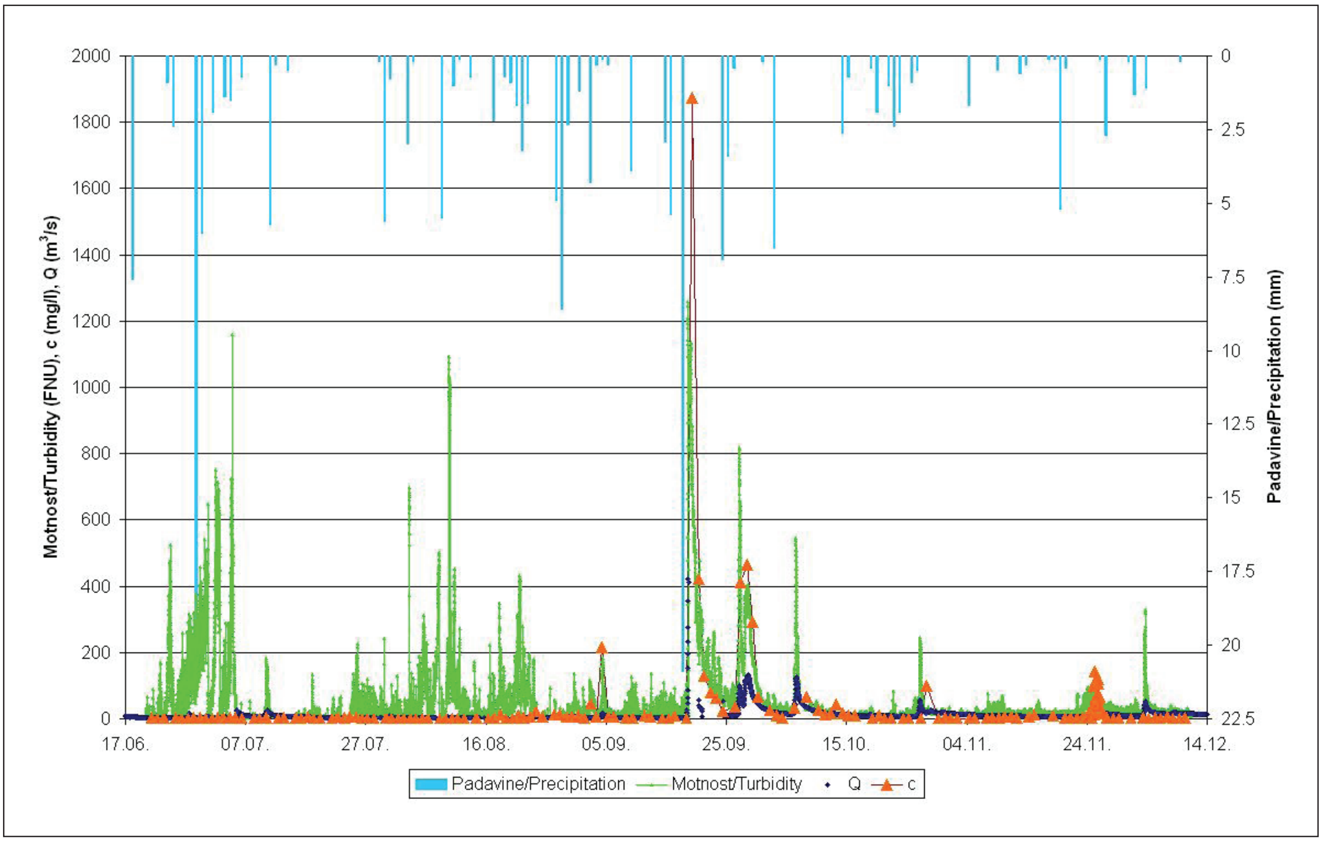
Pri analizi meritev motnosti in suspendiranega materiala smo upoštevali tudi meritve vodostaja in pretoka Sore ter padavin na območju zaledja vodomerne postaje Suha. Spodnja slika prikazuje potek meritev v celotnem testnem obdobju.

Primerjava potekov meritev motnosti za merilnik SOLITAX sc in OBS 3+ pokaže, da se je merilnik SOLITAX sc bolj realno odzival na pojav padavin, povečanje pretoka in posledično na povečanje motnosti. Predvidevamo, da je razlika v odzivu obeh merilnikov delno posledica razlik v izdelavi senzorskega

Performance of measurements

A SOLITAX sc gauge was installed at the automatic hydrological station Suha on the Sora River along with an OBS 3+ gauge. In 2007, regular sampling of suspended material was carried out with a WS Porti PP (AV) automatic sampler at the station. The AV served as a reference because it provides operational measurements of suspended solids concentration, while both test gauges, the SOLITAX sc and the OBS 3+, provide turbidity measurements. The measurements were performed from the end of June until the first half of December 2007. There were a few precipitation periods during the measurement period. During the precipitation periods we monitored the gauges' response to the changes in hydrological parameters, the stability of both gauges and the influence of accumulated dirt on the gauges' glass which causes interference of measurements in the period without precipitation. The AV reference gauge took samples once a day, and during the precipitation period, sampling was increased to once an hour.

In the measurement analysis of turbidity and suspended material, we also took into consideration the measurements of the water level and discharge of the Sora River in the rear area of the water gauging station Suha. The figure below shows the data for the entire test period.



Slika 1: Potek meritev na vodomerni postaji Suha na Sori v času testiranja avtomatskega merilnika SOLITAX sc. Prikazani so pretok (Q), motnost, vsebnost suspendiranega materiala (c) in padavine na v. p. Suha.

Figure 1: *Measurements at Suha water gauging station on the Sora River during the testing period of the SOLITAX sc automatic gauge. The discharge (Q), turbidity, concentration of suspended material (c) and precipitation at the Suha w. g. s. are presented in the figure.*

dela in uporabljeni optični merski metodi, delno pa posledica metode čiščenja stekelca na merilni glavi. Merilnik OBS 3+ nima avtomatskega načina čiščenja stekelca, zato je treba stekelce čistiti ročno. Merilnik SOLITAX sc ima nameščen brisalec, ki periodično čisti stekelce. V nadaljevanju smo analizirati rezultate meritev merilnika SOLITAX sc.

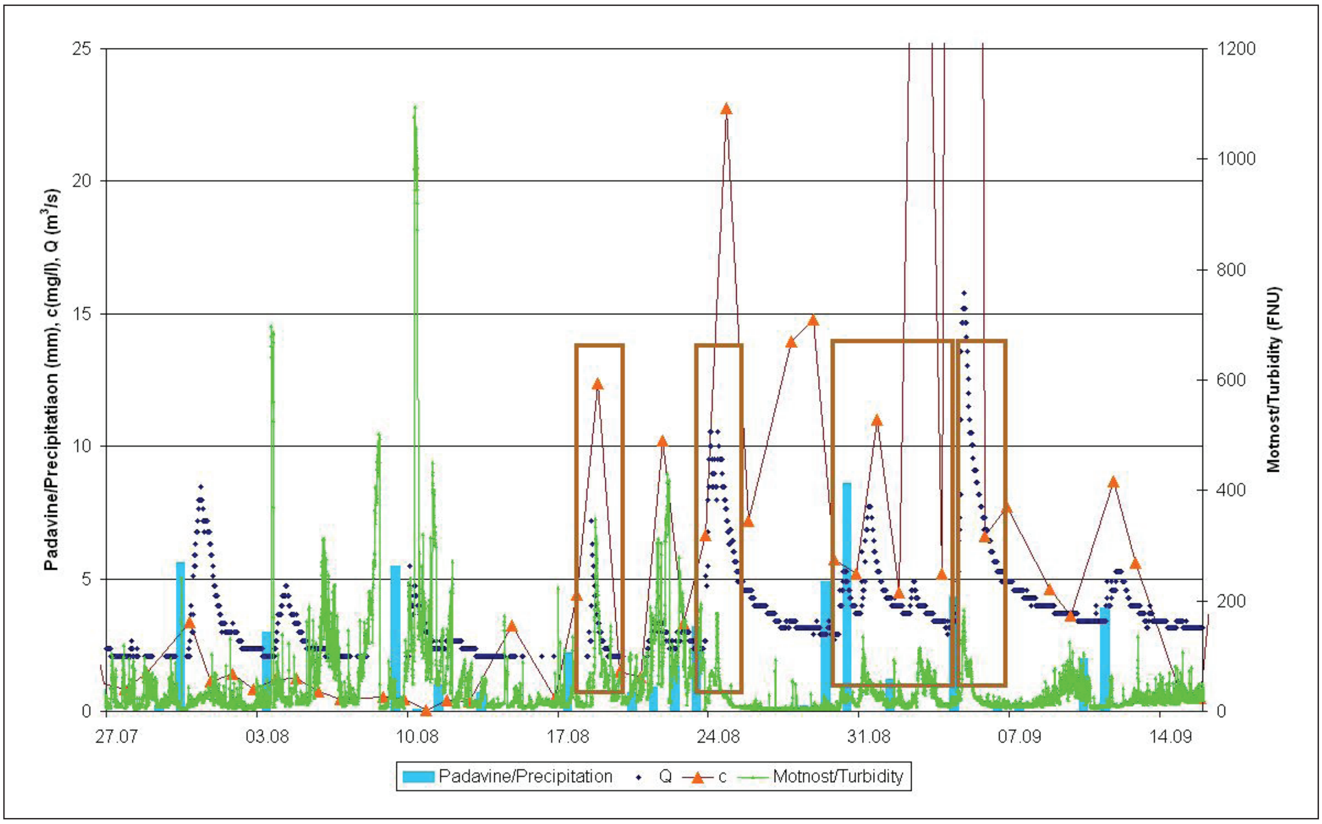
Signal za motnost je dokaj konsistenten s signalom za povečan pretok in padavine. Opazimo, da amplitude signalov za motnost, vsebnost suspendiranega materiala in pretok niso v očitni linearni zvezi. Obstaja pa korelacija med omenjenimi signali. Primeri najboljšega ujemanja med signalom za motnost in signalom za pretok in vsebnost so na sliki 2 dodatno označeni. Treba je opozoriti, da so omenjene meritve v območju zelo nizkih vrednosti, zato lahko pričakujemo večja odstopanja ali negotovosti posameznih meritev. Srednja obdobna vrednost vsebnosti suspendiranega materiala na Sori je v obdobju 2002–2006 20 mg/l.

Izreden padavinski dogodek v septembru 2007

V obdobju intenzivnih padavin smo lahko opazovali odziv merilnikov na zgornjem delu merilnega območja. V tem merilnem območju ni več problemov s šumom in je odziv merilnikov jasnejši. Rezultati meritev določenih časovnih intervalov niso prikazani (slika 3),

The comparison of turbidity measurements for the SOLITAX sc and OBS 3+ shows that the SOLITAX sc responded more realistically to precipitation, discharge increase and, consequently, turbidity increase. We presume that the difference in the response of both gauges is partly the consequence of the differences of sensor unit manufacture and used optical measuring method, and partly the consequence of the glass cleaning method on the measuring head. The OBS 3+ does not have an automatic glass cleaning method, therefore, the glass has to be cleaned manually. The SOLITAX sc has an installed wiper which periodically cleans the glass. In continuation, we analysed the measurement results of the SOLITAX sc.

The turbidity signal was quite consistent with the signal for increased discharge and precipitation. The data show, that the signal amplitudes for turbidity, suspended material concentration and discharge are not in an obvious linear connection. However, there is a correlation between these signals. The examples of the best agreement between the turbidity signal, the discharge and concentration signal are additionally marked in Figure 2. It has to be pointed out that these measurements are within the range of very low values, which is why major deviations or uncertainties of particular measurements may be expected. The mean periodical value of suspended material concentration on the Sora River in the period 2002-2006 is 20 mg/l.



Slika 2: Rezultati testnih meritev v avgustu in septembru.
Figure 2: *Test measurement results in August and September.*

ker je prihajalo do izpada meritev ob slabem vremenu. Merilnik SOLITAX sc se je smiselno odzival med padavinskim dogodkom od 19. 9. 2007 do 25. 9. 2007 in 27. 9. 2007 do 1. 10. 2007. Vsebnost suspendiranega materiala je bila iz motnosti izračunana z uporabo umeritvene krivulje. Krivuljo smo dobili iz podatkov za prikazano obdobje izrednih padavin.

Iskanje relacije med motnostjo in vsebnostjo suspendiranega materiala v padavinskem obdobju novembra 2007

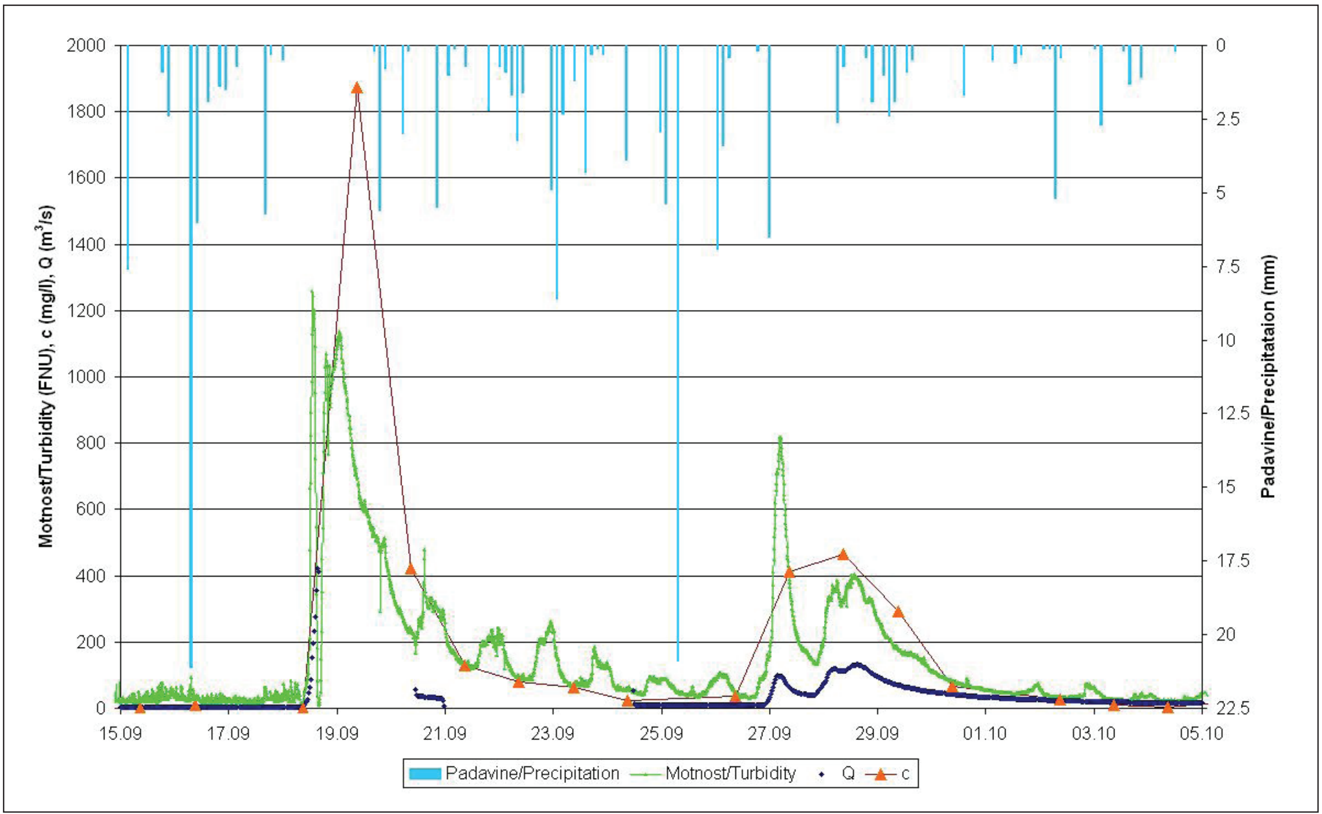
V času intenzivnih padavin od 25. do 26. 11. 2007 smo skušali izvesti umerjanje merilnika motnosti SOLITAX *sc*. Želeli smo dobiti relacijo med signalom za motnost in vsebnostjo suspendiranega materiala. Izbrano dvodnevno obdobje padavin smo vzeli kot reprezentativno padavinsko obdobje za potek dogajanja ob prehodu slabega vremena. Frekvenco vzorčenja z AV smo nastavili najprej na štiri ure, drugi dan slabega vremena pa na dve uri. Rezultat meritev je prikazan na sliki 4. Vidna sta dva vrhova v signalu za motnost in prav tako dva vrhova vsebnosti suspendiranega materiala. Potek motnosti je precej skladen tudi s potekom signala za pretok. Dogajanje pred intenzivnimi padavinami je malce nekonsistentno. Do 22. 11. 2007 je signal za motnost pod vrednostjo 25 FNU. Povečane vrednosti v signalu za motnost se začnejo pojavljati že 22. 11. 2007, med tem, ko pri drugih parametrih (pretok, vsebnost suspendiranega

Extraordinary precipitation event in September 2007

During the period of intensive precipitation, the response of gauges at the upper part of the measuring scale was observed. At this level the noise plays no important role. The missing data (Figure 3) are due to malfunctioning of sampling system during bad weather. The SOLITAX sc responded reasonably well during the precipitation event between 19 September 2007 and 25 September 2007 and between 27 September 2007 and 1 October 2007. The concentration of suspended material was calculated from turbidity by using the calibration curve. The curve was created from the data for the relevant period of extraordinary precipitation.

Search for the correlation between turbidity and suspended material concentration in the November 2007 precipitation period

During the period of intensive precipitation between 25 and 26 November 2007, we tried to conduct calibration of the SOLITAX *sc* turbidity gauge. We wanted to obtain the correlation between the signal for turbidity and suspended material concentration. The selected two-day precipitation period was taken as the representative precipitation period for the occurrence of weather front passage. The AV sampling frequency was set first to four hours and then to two hours on the second day of bad weather. The data are shown in



Slika 3: Rezultati meritev motnosti (SOLITAX sc), pretoka in padavin med izrednim padavinskim dogodkom, september 2007.
Figure 3: *Measurement results of turbidity (SOLITAX sc), discharge and precipitation during the extraordinary precipitation event, September 2007.*

materiala) ni videti nobenih povišanj. Treba je omeniti, da so vrednosti signalov v tem padavinskem obdobju očitno nižje od vrednosti med izrednim padavinskim dogodkom v septembru 2007. SOLITAX *sc* se je v obeh padavinskih obdobjih odzval na padavinski signal ter posledično povišanje vsebnost suspendiranega materiala v skladu s pričakovanji.

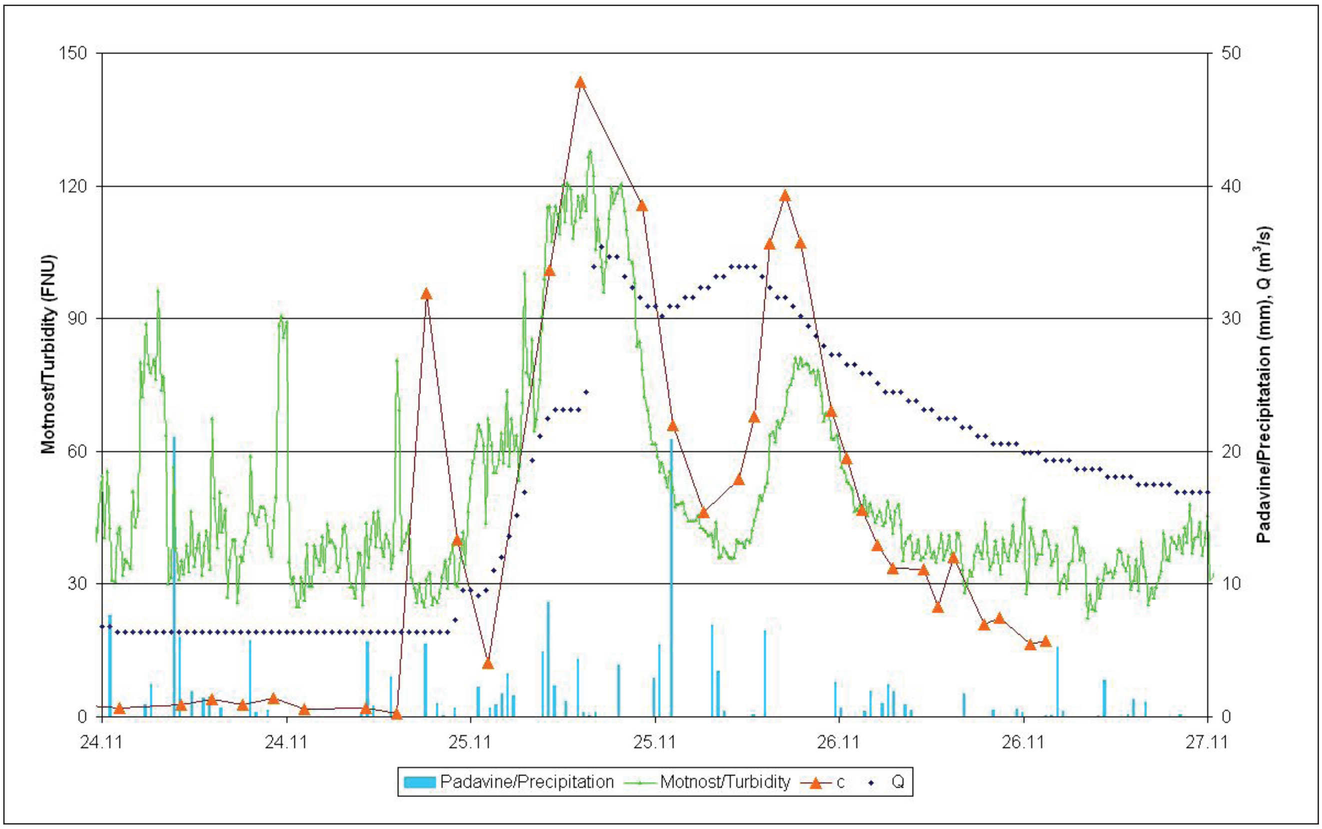
Primerjava rezultatov meritev avtomatskega vzorčevalnika WS Porti PP in merilnikom SOLITAX sc

V času intenzivnih padavin od 25. do 26. 11. 2007 smo skušali izvesti umerjanje merilnika motnosti SOLITAX sc. Želeli smo dobiti relacijo med signalom za motnost in vsebnostjo suspendiranega materiala. Izbrano dvodnevno obdobje padavin smo vzeli kot reprezentativno padavinsko obdobje za potek dogajanja ob prehodu slabega vremena. Frekvenco vzorčenja z AV smo nastavili najprej na štiri ure, drugi dan slabega vremena pa na dve uri. Rezultat meritev je prikazan na sliki 4. Vidna sta dva vrhova v signalu za motnost in prav tako dva vrhova vsebnosti suspendiranega materiala. Potek motnosti je precej skladen tudi s potekom signala za pretok. Dogajanje pred intenzivnimi padavinami je malce nekonsistentno. Do 22. 11. 2007 je signal za motnost pod vrednostjo 25 FNU. Povečane vrednosti v signalu za motnost se začnejo pojavljati že 22. 11. 2007, med tem, ko pri drugih parametrih (pretok, vsebnost suspendiranega materiala) ni videti nobenih povišanj. Treba je omeniti,

Figure 4. Two peaks are visible in the turbidity signal as well as in the concentration of suspended material. The course of turbidity is fairly consistent also with the course of the discharge signal. The events before the intensive precipitation were a bit inconsistent. The turbidity signal was below the value of 25 FNU until 22 November 2007. The increased values of the turbidity signal begin to occur already on 22 November 2007, while no increase is evident in other parameters (discharge, concentration of suspended material). It needs to be pointed out that the values of signals in this precipitation period are clearly lower than the values during the extraordinary precipitation event in September 2007. The SOLITAX *sc* responded to the precipitation signal in both precipitation periods and, consequently, the suspended material concentration increased as expected.

The comparison of measurement results of the WS Porti PP automatic sampler and the SOLITAX sc gauge

Figure 6 shows the measurements of suspended material concentration and turbidity in the entire period of measurements. The data on the figure are synchronised by time. In the first test period, the precipitation events were short and less intensive resulting in greater differences between the measurements. There were more characteristic precipitation periods in the second half of the test period, which were used in the analysis of results of the SOLITAX sc turbidity gauge. The



Slika 4: Rezultat poteka meritev motnosti (SOLITAX sc), pretoka in padavin med padavinskim dogodkom. Na prikazanem intervalu meritev smo ocenili korelacijo med merilnikom motnosti SOLITAX sc ter avtomatskim vzorčevalnikom.
Figure 4: *Measurement results of turbidity (SOLITAX sc), discharge and precipitation during the extraordinary precipitation event. At the presented measurement interval, we assessed the correlation between the SOLITAX sc turbidity gauge and an automatic sampler.*

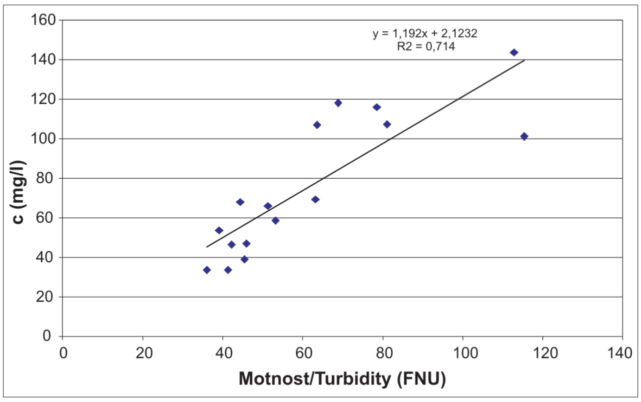
da so vrednosti signalov v tem padavinskem obdobju očitno nižje od vrednosti med izrednim padavinskim dogodkom v septembru 2007. SOLITAX sc se je v obeh padavinskih obdobjih odzval na padavinski signal ter posledično povišanje vsebnost suspendiranega materiala v skladu s pričakovanji.

Zaključek

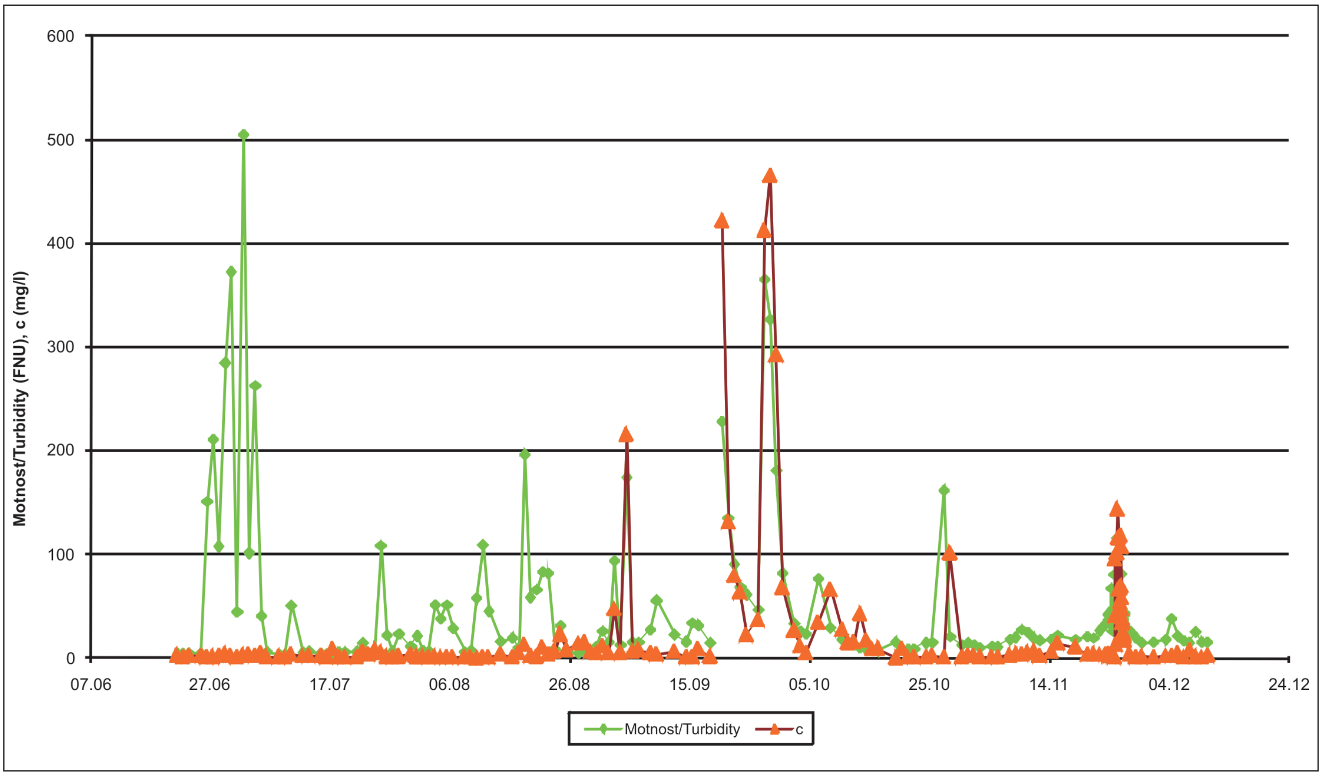
Odnos med motnostjo tekočine in vsebnostjo suspendiranega materiala ni enoličen. Pri določanju motnosti (barva, velikost, struktura delcev) je treba upoštevati značilnosti posameznega vodotoka in številne vplivne parametre. Vsak vodotok ima glede na geološko zgradbo zaledja značilno vrsto delcev. Razmerje med motnostjo in vsebnostjo suspendiranega materiala je treba preverjati v rednih intervalih za vsak vodotok posebej.

Med testiranjem merilnika so bile opravljene posredne meritve vsebnosti suspendiranega materiala z avtomatskim vzorčevalnikom, ki je služil kot referenčni merilnik. V večini primerov je merilnik motnosti SOLITAX *sc* podal dokaj realno sliko dinamike vsebnosti snovi v vodotoku, kar je lahko velikega pomena za stroko. Sočasna uporaba merilnika za motnost SOLITAX *sc* in avtomatskega vzorčevalnika ali ročnega zajema (občasno, kjer je to mogoče), bi lahko pripomogla k boljši analizi vsebnosti in premeščanja suspendiranega

analysed samples taken with AV for this period do not show an increased concentration of suspended material, while the SOLITAX sc produced an increased turbidity signal. One part of the signal is probably to some extent connected to the actual increase of water turbidity, and the other part of the signal is attributed to biological factors and other factors of influence.



Slika 5: Relacija med motnostjo in vsebnostjo suspendiranega materiala. Referenčni merilnik za vsebnost suspendiranega materiala je bil avtomatski vzorčevalnik WS Porti PP.
Figure 5: *The correlation between turbidity and concentration of suspended material. The reference gauge for suspended material concentration was a WS Porti PP automatic sampler.*



Slika 6: Primerjava sinhroniziranih podatkov avtomatskega vzorčevalnika in merilnika motnosti SOLITAX sc.
Figure 6: *The comparison of synchronised data of the automatic sampler and SOLITAX sc turbidity gauge.*

materiala v vodotokih.

Prenosni avtomatski merilnik *SOLITAX sc* je na podlagi rezultatov testnih meritev v letu 2007 primeren za izvajanje monitoringa, saj se je ob povečanju vsebnosti suspendiranega materiala v vodotoku ustrezno odzval in izkazoval povečano motnost vode. Največja dodana vrednost merilnika je v prikazovanju gibanj oziroma dinamike motnosti in posledično vsebnosti suspendiranega materiala v vodotoku. Pri vrednotenju vsebnosti suspendiranega materiala na podlagi rezultatov avtomatskega merilnika motnosti pa je treba upoštevati stopnjo relacije med veličinama in dejstvo, da služi parameter motnosti le kot ocena dejanski vsebnosti suspendiranega materiala v vodi.

Conclusions

The relationship between turbidity and suspended material concentration in water is not uniform. In determining turbidity, the characteristics of a particular watercourse and numerous influencing factors (colour, size, structure of particles) have to be considered. Every watercourse has a characteristic type of suspended particle bed related to the geological structure of the rear area. The relationship between turbidity and suspended material concentration has to be checked in regular intervals for every watercourse separately.

During the testing of the SOLITAX *sc* gauge, indirect measurements of suspended material concentration were performed with an automatic sampler as the reference gauge. In most cases the SOLITAX *sc* turbidity gauge data represented realistic image of the dynamics of material concentration in the watercourse, which can be considered as an important contribution for the monitoring of suspended solids. The simultaneous use of the SOLITAX *sc* turbidity gauge and the automatic sampler or manual sampling (occasionally where possible) could improve the analysis of the concentration and transportation of suspended material in watercourses.