UDK: 628.147

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O NEODREĐENOSTI INFRASTRUKTUKNOG INDEKSA GUBITAKA - ILI

UNCERTAINTY OF INFRASTRUCTURE LEAKAGE INDEX (ILI)

REZIME

U velikom broju vodovodnih sistema, naročito u zemljama u razvoju, podaci o elementima sistema, merenja protoka i potrošnje vode imaju veliku neodređenost. Ova neodređenost se u daljim proračunima propagira na izračunate vrednosti indikatora preformansi sistema – PI. Podaci velike neodređenosti mogu da navedu na pogrešne zaključke i samim tim dovedu do pogrešnih upravljačkih odluka. Analiza grešaka i neodređenosti obuhvata proučavanje i kvantifikovanje neodređenosti, a na osnovu dobijenih rezultata preduzimaju se mere za njeno minimiziranje. U ovom radu je prikazana primena ISO metodologije [1], koja uključuje i zakon propagacije neodređenosti, za procenu neodređenosti merenja i njene propagacije na PI vodovodnih distributivnih sistema - VDS. Na primeru grada Požarevca (centralna Srbija), prikazan je postupak za smanjuje neodređenosti ulaznih parametara na osnovu kojih se računaju komponente vodnog bilansa i indikatora ILI.

Ključne reči: vodovodni distributivni sitstemi, indikatori performansi, neodređenost, ILI

ABSTRACT

In many water systems, especially in developing countries, data on the elements of the system, flow measurements and water consumption have great uncertainty. This uncertainty in the further calculations is propagated to the calculated values of performance indicators - PI. Large data uncertainty may lead to wrong conclusions and thus lead to incorrect management decisions. Analysis of errors and uncertainties involves the study and quantification of uncertainty, and the obtained results are the basis for taking the necessary measures to minimize. This paper presents the application of ISO [1] methodology, which includes the law of propagation of uncertainty, the estimation of uncertainty of measurement and its propagation to the PI of water distribution systems - WDS. Example of the city of Pozarevac (central Serbia), provides a method for reducing the uncertainty of input parameters for calculating components of the water balance and ILI indicators.

Key words: water distribution systems, performance indicators, uncertainty, ILI

1. UVOD

Tačnost i pouzdanost proračuna komponenti vodnog bilansa, kao i indikatora performansi (PI), zavisi od tačnosti i pouzdanosti ulaznih (merenih) podataka. Da bi ispunili standarde kvaliteta u poređenju PI neophodno je poznavanje tačnosti i neodređenosti podataka. Podaci velike neodređenosti mogu da navedu na pogrešne zaključke i samim tim do pogrešnih upravljačkih odluka. Praksa je pokazala da, generalno, izvori koji dostavljaju podatake često nemaju detaljne informacije o njihovoj pouzdanosti i tačnosti. Testiranje sistema IWA PI pokazalo je da izvodljiva upotreba četiri kategorije tačnosti podataka i tri njihove pouzdanosti (ALEGRE et al. 2006).

Ni jedno merenje, ma koliko se pažljivo izvodi, nije bez neodređenosti. Iz tog razloga, potrebno je kvantifikovati neodređenost, i na osnovu dobijenih vred-

1. INTRODUCTION

Accuracy and reliability of the components of the water balance calculations, as well as performance indicators (PI), depends on the accuracy and reliability of the input (measured) data. To meet the quality standards for PI comparison it is necessary to know the accuracy and uncertainty of information. Large data uncertainty may lead to wrong conclusions and thus to incorrect management decisions. Practice has shown that, in general, the data sources often do not have detailed information about their reliability and accuracy. Testing of the IWA PI system revealed viable use of the four categories of data accuracy and three of their reliability (ALEGRE et al. 2006).

Neither measurement, no matter how carefully performed, is not without uncertainty. For this reason, it is necessary to quantify uncertainty and take the

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nosti preduzeti mere za njeno minimiziranje. Merna neodređenost definisana je kao parametar pridružen rezultatu merenja koji karakteriše disperziju vrednosti merene veličine [1].

U većini VDS u svetu, naročito u zemljama u razvoju, ulazni podaci, mereni ili nemereni, imaju veliku neodređenost. Ova neodređenost se u daljim proračunima propagira na PI. Neodređenost je generalno prouzrokovana brojnom kombinacijom faktora sa slučajno distribuiranim efektima. U tom slučaju, razlika između tačne i ocenjene (merene) vrednosti je promenljiva sa normalnom raspodelom. Neodređenost može da se izrazi i preko korespondirajuće standardne devijacije (σ). Uz pretpostavku da su greške slučajne i sa normalnom raspodelom, najčešća mera neodređenosti u praksi je [2]:

- 1σ (odgovara intervalu poverenja od oko 68%)
- 2σ (odgovara intervalu poverenja od oko 95%)
- 3σ (odgovara intervalu poverenja od oko 99%)

Da bi se odredio stepen neodređenosti, standardan način proračuna varijanse koja se odnosi na određenu zapreminu vodnog bilansa, na osnovu 95% intervala poverenja (CL), prikazan je narednom jednačinom (1) [6]:

$$var = (Zapremina\ u\ m^3 \times 95\%\ interval\ poverenja/1{,}96)^2 \qquad (1)$$

Za proračun PI koriste se razne promenljive. Jasno da se ni jedan podatak (promenljiva) ne može posmatrati kao tačna vrednost – svi oni su “najbolje procenjeni” u manjoj ili većoj meri. Često se neka veličina φ meri posredno, merenjem drugih veličina X_1, ¼, X_N, preko funkcije $\varphi = f(X_1, ¼, X_N)$. Da bi se odredila ukupna neodređenost veličine φ, u takvim slučajevima, primenjuju se pravila za propagaciju neodređenosti.

Preciznost procene vrednosti vode koja ne donosi prihod (NRW) iz vodnog bilansa zavisi od tačnosti merenja zapremine vode dotekle u sistem i vode koja donosi prihod. Potpuno tačna merenja nisu moguća usled netačnosti kako merača protoka kojim se meri dotok vode u sistem, tako i vodomera kojim se meri potrošnja vode korisnika. Takođe, nije moguće tačno odrediti komponentu vodnog bilansa koja se odnosi na nefakturisanu nemerenu legalnu potrošnju vode.

ISO metodologija za određivanje propagacije neodređenosti danas je prihvaćena kao standardna metoda za procenu neodređenosti merenja, kao npr. u vodnim kompanijama u UK [7].

Kombinovana neodređenost merenja dobija se kombinacijom pojedinačnih standardnih neodređenosti ulaznih vrednosti. Najčešće se koristi First Order Second Moment (FOSM) metoda propagacije neodređenosti u kojoj se nedodređenost parametra modela prenosi kroz model koristeći aproksimaciju modela Tejlorovim redom oko srednje vrednosti svakog ulaznog parametra. Neodređenost izlazne promenljive (rezultata) može se dobiti iz jednačine 2:

necessary measures to minimize on the basis of the obtained values. Measuring uncertainty is defined as a parameter associated with the result of measurement that characterizes the dispersion of the value of measured size [1].

In most of the WDS in the world, especially in developing countries, input data, measured or unmeasured, are of great uncertainty. This uncertainty in the further calculations propagates to PI. Uncertainty is generally caused by a combination of numerous factors with randomly distributed effects. In that case, the difference between the evaluated and the true (measured) value is the variable with normal distribution. Uncertainty can be expressed through the corresponding standard deviation (σ). Assuming that errors are random and normally distributed the most common measure of uncertainty in practice is [2]:

- 1σ (corresponding confidence level of approximately 68%)
- 2σ (corresponding confidence level of approximately 95%)
- 3σ (corresponding confidence level of approximately 99%)

To determine the degree of uncertainty, the standard way of calculating the variance related to the specific volume of water balance, based on 95% confidence level (CL) is shown in the following equation (1) [6]:

$$var = (Volume\ in\ m^3) \times 95\%\ confidence\ level)/1{,}96)^2 \qquad (1)$$

PI calculation is using a variety of variables. It is clear that any data (variable) can not be regarded as a true value - they are the “best estimated” to a greater or lesser extent. Often a size φ is measured indirectly by measuring other quantities X_1... X_N, via the $\varphi = f(X_1, ¼, X_N)$. To determine the overall uncertainties of the φ size, in such cases, are applied the rules for the propagation of uncertainty.

Accuracy of the valuation of Non-Revenue Water (NRW) from the water balance depends on the accuracy of measuring the volume of water running to the system and the water that brings revenue. Completely accurate measurements are not possible due to inaccuracies of flow-meter that measures the flow of water in the system, and the gauge that measures water consumption profile. Also, it is not possible to accurately determine the components of the water balance relating to invoiced legal unmeasured water consumption.

ISO methodology for determining the propagation of uncertainty is now accepted as a standard method for the evaluation of uncertainty of measurement, such as the water companies in the UK [7].

Combined uncertainty of the measurement is obtained by combining the individual standard uncertainty of the input values. The most commonly used is the First Order Second Moment (FOSM) method of propagation of uncertainty where the uncertainty

$$\mathrm{var}[f_k(x_1,\ldots,x_n)] = \sum_{i=1}^{n}\left(\frac{\partial f_k(x_1,\ldots,x_n)}{\partial x_i}\right)^2 \mathrm{var}[x_i] +$$

$$+2\sum_{i=1}^{n}\sum_{j=1}^{i-1}\frac{\partial f_k(x_1,\ldots,x_n)}{\partial x_i}\frac{\partial f_k(x_1,\ldots,x_n)}{\partial x_j}\mathrm{cov}[x_i,x_j] \quad (2)$$

gde je $f_k(x_1,\ldots,x_n)$ rezultat modela, $var[f_k(x_1,\ldots,x_n]$ označava varijansu izlazne promenljive, n je broj ulaznih promenljivih, $var[x_i]$ varijansa ulaza x_i, i $cov[x_i,x_j]$ predstavlja kovarijansu između ulaza x_i i x_j $\left(\mathrm{cov}[x_i,x_j]=\sigma_{x_i x_j}\right)$. Izvod $\partial f_k(x_1,\ldots,x_n)/\partial x_j$ predstavlja osetljivost rezultata modela u odnosu na promenu ulazne vrednosti ∂x_j. Prvi član u jednačini (2) predstavlja doprinos neodređenosti rezultata od neodređenosti svake ulazne promenljive koje deluju nezavisno. Drugi član označava doprinos neodređenosti rezultata od povezanosti parova ulaznih promenljivih. Međutim, Pošto se ulazni parametri u vodnom bilansu ne mere istovremeno, i imaju različite procedure procene, oni nisu korelisani i kovarijansa ima vrednost nula.

Postoje različite metode za analizu neodređenosti, ali ne postoji metodologija koja može dati tačne rezultate na osnovu netačnih ulaznih podataka. U ovom radu biće prikazan proračnun komponenti vodnog bilansa i indeksa ILI, kao i propagacija neodređenosti rezultata, na primeru VDS Požarevca.

2. METODA SMANJENJA NEODREĐENOSTI ILI

2.1 *Proračun vrednosti ILI i njegove neodređenosti*

Gubitke vode iz VDS je nemoguće u potpunosti eliminisati, pa je IWA predložila jednačinu za određivanje neizbežnih stvarnih gubitaka vode (*Unavoidable Annual Real Losses - UARL*):

$UARL = (18´L_m + 0,8´N_{conn} + 25´L_{conn}) ´ P$ (3)

gde su: *UARL* - neizbežni stvarni gubici vode (l/dan), L_m – ukupna dužina distributivne mreže (km), N_{conn} – broj priključaka, L_{conn} – dužina cevi priključaka od priključka na vodovodnu cev do vodomera (km), P – prosečan radni pritisak u sistemu (m).

U okviru analize vodnog bilansa, između ostalog određuju se i vrednosti stvarnih gubitaka vode u razmatranom vremenskom periodu *(Current Annual Real Losses – CARL)*. Pokazatelj stvarnih gubitaka vode ILI koristi se za poređenje ukupnih preformansi upravljanja stvarnim gubicima vode, a izračunava se jed-

of the model parameters is transmitted through the model using the Taylor approximation model around the mean values for each input parameter. Uncertainty of the output variables (results) can be obtained from Equation 2:

$$\mathrm{var}[f_k(x_1,\ldots,x_n)] = \sum_{i=1}^{n}\left(\frac{\partial f_k(x_1,\ldots,x_n)}{\partial x_i}\right)^2 \mathrm{var}[x_i] +$$

$$+2\sum_{i=1}^{n}\sum_{j=1}^{i-1}\frac{\partial f_k(x_1,\ldots,x_n)}{\partial x_i}\frac{\partial f_k(x_1,\ldots,x_n)}{\partial x_j}\mathrm{cov}[x_i,x_j] \quad (2)$$

where $f_k(x_1,\ldots,x_n)$ is a model result, $var[f_k(x_1,\ldots,x_n]$ stands for the variance of the output variable, n is the number of input variables, $var[x_i]$ variance of the input x_i, and $cov[x_i,x_j]$ represents the covariance between inputs x_i and x_j $\left(\mathrm{cov}[x_i,x_j]=\sigma_{x_i x_j}\right)$. $\partial f_k(x_1,\ldots,x_n)/\partial x_j$ represents the results of the sensitivity of the model in relation to the change in the input value of ∂x_j. First member the equation (2) represents the contribution of uncertainty results from the uncertainty of each input variable acting independently. Second member indicates the contribution of uncertainty results from the correlation pairs of input variables. However, as the input parameters in the water balance are not measured simultaneously, and have a variety of assessment procedures, they are not correlated and the covariance has the zero value.

There are different methods for the analysis of uncertainty, but there is no methodology that can provide accurate results based on incorrect input data. This paper presents the calculation of the water balance components and the ILI index, and the propagation of uncertainty of results, on the example of WDS of the city of Pozarevac.

2. ILI UNCERTAINTY REDUCTION METHOD

2.1 *Calculation of ILI value and its uncertainty*

Water Loss from the WDS is impossible to completely eliminate and IWA proposed equation for the determination of *Unavoidable Annual Real Losses - UARL*:

$UARL = (18´L_m + 0,8´N_{conn} + 25´L_{conn}) ´ P$ (3)

where *UARL* – are unavoidable annual real losses (l/dan), L_m – total length of the distribution network (km), N_{conn} – number of connections, L_{conn} – length of pipe connections from the connection to the water načinom (4):

$$ILI = \frac{CARL}{UARL} \quad (4)$$

Nepouzdanost merenja i procedure rukovanja podacima u VDS dalje se propagiraju na rezultate proračuna vodnog bilansa i ILI.

Primenom ISO metodologija za određivanje propagacije neodređenosti mogu se odrediti neodređenosti komponetni vodnog bilansa i ILI. U nastavku su priloženi izrazi za neodređenost nekih bitnih pokazatelja u VDS sa n_i izvorišta vode i *i* kategorija potrošača:

- ukupan dotok vode u VDS iz n_i izvorišta vode:

$$\Delta V_{inp} = \frac{\sqrt{\sum_{i=1}^{n_i}\left(V_{inp,i}\Delta V_{inp,i}\right)^2}}{\sum_{i=1}^{n_i} V_{inp,i}} \quad (5)$$

- ukupna zapremina vode koja ne donosi prihod *NRW* iznosi:

$$NRW = \sum_{i=1}^{n_i} V_{inp,i} - \left(\sum_{i=1}^{n_{BMAC}} V_{BMAC,i} + \sum_{i=1}^{n_{BUMC}} V_{BUMC,i}\right) \quad (6)$$

a neodređenost

$$\Delta NRW = \frac{\sqrt{\sum_{i=1}^{n_i}\left(V_{inp,i}\Delta V_{inp,i}\right)^2 + \sum_{i=1}^{n_{BMAC}}\left(V_{BMAC,i}\Delta V_{BMAC,i}\right)^2 + \sum_{i=1}^{n_{BUMC}}\left(V_{BUMC,i}\Delta V_{BUMC,i}\right)^2}}{NRW} \quad (7)$$

- neodređenost zapremine neizbežnih gubitaka vode UARL, izraženih u l/dan, iznosi:

$$\Delta UARL = \sqrt{\frac{\left(18L_m\Delta L_m\right)^2 + \left(0{,}8N_{conn}\Delta N_{conn}\right)^2 + \left(25L_{conn}\Delta L_{conn}\right)^2}{\left(18L_m + 0{,}8N_{conn} + 25L_{conn}\right)^2} + \Delta P_{aver}} \quad (8)$$

- neodređenost zapremine neizbežnih gubitaka vode UARL, izraženih u l/priklj.dan, iznosi:

$$\Delta UARL_{conn} = \sqrt{\left(\Delta N_{conn}\right)^2 + \left(\Delta UARL\right)^2} \quad (9)$$

- neodređenost indikatora *Op29 (ILI)* iznosi:

$$\Delta 29p = \Delta ILI = \sqrt{\left(\Delta CARL\right)^2 + \left(\Delta UARL\right)^2} \quad (10)$$

gde su $V_{inp,i}$ - dotok vode sa izvorišta u VDS (m³) i $\Delta V_{inp,i}$ - 95% CL, $V_{BMAC,i.}$ - fakturisana izmerena legalna potrošnja vode (m³) i $\Delta V_{BMAC,i.}$ - 95% CL, $V_{BUMC,i}$ - fakturisana neizmerena legalna potrošnja vode (m³) i $\Delta V_{BUMC,i}$ - 95% CL, n_{BMAC} i n_{BUMC} - ukupan broj kategorija potrošača, *VUAC* - nefakturisana legalna potrošnja vode (m³) i ΔV_{UAC} - 95% CL, V_{AC} - ukupna fakturisana legalna potrošnja vode (m³) i ΔV_{AC} - 95% CL, V_{UC} - nelegalna potrošnja vode (m³) i ΔV_{UC} - 95% CL, V_{CME} - zapremina vode usled greški na vodomerima (m³) i ΔV_{CME} - 95% CL, L_m - dužina glavnih cevi (km) i ΔL_m - 95% CL, N_{conn}

supply pipe to the gauge (km), *P* – average operating pressure in the system (m).

Within the water balance analysis, among other things, is determined the value of the actual water loss in the studied time period (*Current Annual Real Losses - CARL*). Indicator of actual water loss, ILI, is used to compare the overall performance management of real water losses, as calculated in equation (4):

$$ILI = \frac{CARL}{UARL} \quad (4)$$

Unreliability of measurement and data handling procedures in WDS continues to propagate on the results of the calculation of the water balance and ILI.

Applying ISO methodology for determining the propagation of uncertainty can determine uncertainties of the water balance components and ILI. In the following are attached terms of uncertainty of some important indicators of the WDS from n_i water source and *i* consumer categories:

- total water supply to the WDS from n_i water source:

$$\Delta V_{inp} = \frac{\sqrt{\sum_{i=1}^{n_i}\left(V_{inp,i}\Delta V_{inp,i}\right)^2}}{\sum_{i=1}^{n_i} V_{inp,i}} \quad (5)$$

- total Non Revenue Water volume is:

$$NRW = \sum_{i=1}^{n_i} V_{inp,i} - \left(\sum_{i=1}^{n_{BMAC}} V_{BMAC,i} + \sum_{i=1}^{n_{BUMC}} V_{BUMC,i}\right) \quad (6)$$

And its uncertainty:

$$\Delta NRW = \frac{\sqrt{\sum_{i=1}^{n_i}\left(V_{inp,i}\Delta V_{inp,i}\right)^2 + \sum_{i=1}^{n_{BMAC}}\left(V_{BMAC,i}\Delta V_{BMAC,i}\right)^2 + \sum_{i=1}^{n_{BUMC}}\left(V_{BUMC,i}\Delta V_{BUMC,i}\right)^2}}{NRW} \quad (7)$$

- uncertainty of Unavoidable Annual Real Losses volume, expressed in l/day, is:

$$\Delta UARL = \sqrt{\frac{\left(18L_m\Delta L_m\right)^2 + \left(0{,}8N_{conn}\Delta N_{conn}\right)^2 + \left(25L_{conn}\Delta L_{conn}\right)^2}{\left(18L_m + 0{,}8N_{conn} + 25L_{conn}\right)^2} + \Delta P_{aver}} \quad (8)$$

- uncertainty of Unavoidable Annual Real Losses volume, expressed in l/conn.day, is:

$$\Delta UARL_{conn} = \sqrt{\left(\Delta N_{conn}\right)^2 + \left(\Delta UARL\right)^2} \quad (9)$$

- uncertainty of *Op29 (ILI)* indicator is:

$$\Delta 29p = \Delta ILI = \sqrt{\left(\Delta CARL\right)^2 + \left(\Delta UARL\right)^2} \quad (10)$$

where $V_{inp,i}$ - water inflow from the source into WDS (m³) and $\Delta V_{inp,i}$ - 95% CL, $V_{BMAC,i.}$ - invoiced measured legal water consumption (m³) and $\Delta V_{BMAC,i.}$ - 95% CL, $V_{BUMC,i}$ - invoiced non-measured legal water consumption (m³) and $\Delta V_{BUMC,i}$ - 95% CL, n_{BMAC} and n_{BUMC} - total number of consumer categories, *VUAC* - legal unbilled water consumption (m³) and ΔV_{UAC} - 95% CL,

- broj priključaka (-) i ΔN_{conn} - 95% CL, L_{conn} - dužina priključnih cevi (km) i ΔL_{conn} - 95% CL, P_{aver} - prosečan pritisak u VDS (m) i ΔP_{aver} - 95% CL.

2.2 Metodologija za smanjenje neodređenosti komponenti vodnog bilansa i ILI

U početnom koraku, analiziraju se postojeće podloge i raspoloživi podaci o VDS, kako o objektima tako i potrošačima i njihovoj potrošnji vode, postojećim bazama, merenjima itd. Na osnovu postojećih podataka izračunavaju se komponente vodnog bilansa i PI koji iz njega proističu, kao i neodređenost ulaznih podataka i njihova propagacija. Nakon izvršene analize neophodno je sprovesti sledeće aktivnosti:

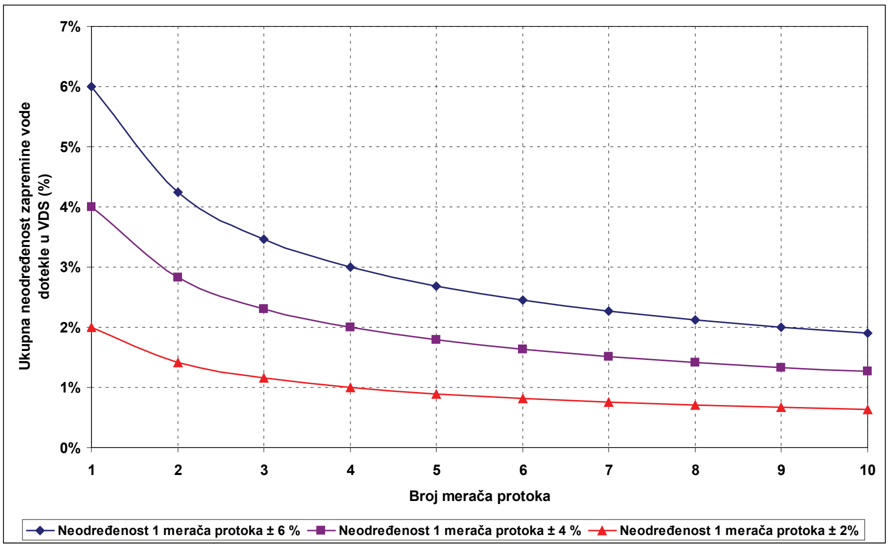
1. Ugradnja merača protoka velike pouzdanosti na svim izvorištima VDS-a, ukoliko ne postoje. Ukoliko postoje, kalibrišu se i razmatra eventualna zamena meračima veće tačnosti.
   Obzirom da zapremina dotekle vode u VDS ima najveću vrednost od svih komponenti vodnog bilansa, od izuzetne je važnosti da preciznost glavnih merača protoka bude velika, odnosno da neodređenost ove zapremine bude što manja (npr. manja od ± 2 %, pri intervalu poverenja od 95%). Obzirom na propagaciju neodređenosti, veća vrednost negativno utiče na pouzdanost daljih proračuna. Ugradnja uređaja tipa sonde (neodređenost se kreće oko +/-5% do 10%) je prihvatljiva za povremena merenja, ali je nezadovoljavajuće kao dugotrajno rešenje. Ovo je naročiti značajno ukoliko postoji samo jedno izvorište vodosnabdevanja. Pri većem broju izvorišta ukupna neodređenost ove zapremine vode se smanjuje, što se može videti na narednoj slici 1 (pretpostavka je da svi merači protoka registruju sličnu zpareminu vode). U većim sistemima sa jednim izvorištem, instalaciju dva merača u seriji treba posmatrati kao strategiju za smanjenje neodređenosti u proračunim vodnog bilansa [5]. Ako ima više merača protoka i svaki registruje različitu zapreminu vode i imaju različitu neodređenost, prioritetno treba proveriti prvo merače koji imaju najveću vrednost proizvoda registrovane zapremine i % neodređenosti.
2. Projektovanje baze podataka i GIS-a kako objekata VDS tako i potrošača, uključujući i softver za naplatu vode.
3. Evidentiranje i lociranje svih potrošača i unošenje u bazu evidencije potrošnje i GIS, kako potrošača kod kojih se meri potrošnja tako i potrošača kod kojih se paušalno fakturiše potrošnja vode.
   U skoro svim VDSs određivanje zapremine legalne fakturisane potrošnje vode tokom perioda vodnog bilansa je najčešće drugi najveći izvor greške, odnosno neodređenosti (odmah posle glavnih merača protoka). Da bi se smanjila neodređenost ove komponente neophodno je uspostaviti pouzdanu bazu podataka potrošača i naplate, ili analizirati, i po potrebi popraviti postojeću bazu, što uključuje i evidentiranje svih potrošača na terenu

V_{AC} – total invoiced legal water consumption (m³) and ΔV_{AC} - 95% CL, V_{UC} – illegal water consumption (m³) and ΔV_{UC} - 95% CL, V_{CME} - water volume due to errors on water meters (m³) and ΔV_{CME} - 95% CL, L_m - length of main pipes (km) and ΔL_m - 95% CL, N_{conn} – number of connections (-) and ΔN_{conn} - 95% CL, L_{conn} – lenght of connecting pipes (km) and ΔL_{conn} - 95% CL, P_{aver} – average operating pressure in the WDS (m) and ΔP_{aver} - 95% CL.

2.2 Methodology for the uncertainty reduction of the water balance components and ILI

In the initial step, are analyzed the existing surfaces and the available information on WDS, about the facilities and consumers and their water consumption, existing databases, measurements, etc. Based on existing data are calculated the water balance components and PI resulting from it, as well as the uncertainty of the input data and its propagation. After the analysis it is necessary to carry out the following activities:

1. Installation of high reliability flow meters at all sources of WDS and their calibration. In some cases a possible replacement with greater accuracy gauges is needed.
   Since the input water volume has the highest value of all components of the water balance, it is of utmost importance that the accuracy of the main flow meter is high, and that uncertainty of this volume is as small as possible (e.g. less than ± 2%, with confidence interval of 95 %). Due to the propagation of uncertainty, the greater value has a negative impact on the reliability of further calculations. Installing the probe (uncertainty is around +/- 5% to 10%) is acceptable for occasional measurements, but it is unsatisfactory as a long-term solution. This is especially important if there is only one source of supply. With large number of sources total uncertainty of the water volume is reduced, as can be seen in figure 1 (the assumption is that all flow-meters register similar water volume). In larger systems with a single-source, installation of the two meters in series should be viewed as a strategy to reduce uncertainty in the calculation of water balance [5]. If there are several flow-meters and each register different water volume and have different uncertainty, priority should be to check first those that have the highest product value of registered volume and % of uncertainty.
2. Database and GIS design for WDS facilities and consumers, including software for the water invoicing.
3. Recording and locating of all consumers and entry of consumption and GIS in the records.
   In almost all WDS determination of the volume of legal billed water consumption during periods of water balance is usually the second largest source of error or uncertainty (immediately after



Slika 1: Neodređenost zapremine vode dotekle u VDS [5]
Figure 1: Uncertainty of the input water volume of the WDS [5]

(i kod kojih se meri potrošnja preko vodomera i kod kojih se paušalno fakturiše) i unošenje podataka u bazu i GIS. Tokom terenskog rada moguće je otkriti i nelegalne potrošače, neispravne vodomere i neovlašćeno podešavanje vodomera.

4. Očitavanje vodomera tokom perioda od najmanje godinu dana i unošenje u bazu, analiza potrošnje svih kategorija potrošača.
   U ovoj fazi radova poželjno je izvršiti procenu tačnosti različitih kategorija vodomera kod potrošača koja se vrši na statističkom uzorku vodomera. Neregistrovanje malih protoka predstavlja treći najveći izvor greške, i u razvijenim zemljama u VDS-u kojim se dobro upravlja preporučuje se standardna vrednost od +/-2% od stvarne zapremine koja je prošla kroz vodomer (ne 2% registrovane zapremine) za ove prividne gubitke [5]. Nakon toga analizira se vodni bilans i procenjue vrednost PI.
5. Detekcija i evidentiranje svih objekata VDS-a (prečnik, dužina i vrsta cevnog materijala, dužina priključnih cevi) i unošenje u GIS. Preračunavaju se PI koji zavise od ovih fizičkih veličina.
   Proračun indeksa ILI zahteva i pouzdano poznavanje podataka o objektima VDS. Uporedo sa smanjenjem neodređenosti komponenti vodnog bilansa neophodno je i izvršiti detekciju svih cevi VDS i uneti ih u GIS, ne samo zbog proračuna ILI već i za potrebe izrade matematičkog modela i njegove kalibracije. Ovo je naročito važno, obzirom da indeks ILI, između ostalog, zavisi i od UARL, a ovaj zavisi od dužine cevovoda, broja priključaka i prosečnog pritiska u VDS.
6. Formiranje matematičkog modela u softverskom paketu za modeliranje rada VDS, koji po mogućstvu ima vezu sa bazama potrošača i GIS-om. U matematički model unosi se čvorna potrošnja vode svih kategorija potrošača na nivou srednje godišnje potrošnje. Na osnovu formiranog matematičkog modela VDS-a određuju se merna mesta protoka i pritiska za potrebe kalibracije modela.

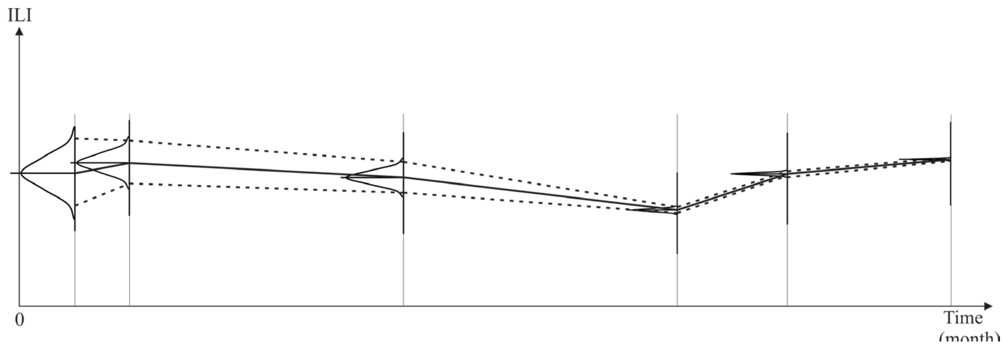
the main flow meter). In order to reduce the uncertainty of the components it is necessary to establish a reliable customer and billing database, or analyze, and if necessary, repair the existing database, which includes records of all customers in the field and entering the data into a GIS. During the field work it is possible to detect the illegal consumers, faulty water meters and water meter tampering.

4. Meter reading over a period of at least one year and enter into the database, the analysis of the consumption of all categories of consumers.
   At this stage, it is preferred that the works to assess the accuracy of the various categories of water meters, which is carried out on the statistical water meter sample. Non-registration of low flows is the third largest source of errors and developed countries with well-managed WDS have recommended default value of +/- 2% of the actual volume that has passed through the meter (not 2% of the registered volume) for this apparent loss [5]. After that, the water balance and the value of PI are being analyzed.
5. Detection and identification of all WDS facilities (diameter, length and type of pipe material, length of connecting pipe) and their input into GIS. PIs which depend on these physical quantities are then calculated.
   Calculation of the ILI index requires reliable knowledge of data about WDS structures. Along with the reduction of uncertainty components of the water balance it is necessary to carry out the detection of all WDS pipes and enter them into the GIS, not only because of ILI calculation, but for the purposes of making a mathematical model and its calibration. This is particularly important, given that ILI index, among other things, depends on UARL, and this depends on the length of the pipeline, the number of connections and the average pressure in the WDS.
6. Formation of a mathematical model in the software package for WDS modeling, which preferably has a connection with the consumer bases and GIS. In the mathematical model is entered the node water consumption of all categories of consumers at the level of average annual consumption. On the basis of a WDS mathematical model are determined flow and pressure measurement points for the calibration of the model. Measuring points are formed, measurements are carried out and mathematical model is being calibrated. Operation of the WDS is being analyzed followed by PI values recalculation.
7. During these calculations is performed propagation of uncertainty of input data and calculation

Formiraju se merna mesta, vrše se merenja i kalibriše matematički model. Analizira se rad VDS i preračunavaju vrednosti PI.

7. Tokom ovih proračuna vrši se i propagacija neodređenosti ulaznih podataka, odnosno izračunava se neodređenost konačnih rezultata, kako komponenti vodnog bilansa, tako i PI.

Na narednoj slici 2 šematski je prikazan uticaj pojedinih faza na smanjenje neodređenosti komponenti vodnog bilansa i PI. Treba napomenuti da se navedenim aktivnostima samo poboljšava pouzdanost PI, a ne i njihova vrednost. Za poboljšanje PI primenjuju se druge mere.



Slika 2. Promena neodređenosti indeksa ILI nakon sprovođenja aktivnosti 1-6

Figure 2 Change of uncertainty ILI index after the implementation of activities 1-6

3. PRIMER VDS POŽAREVAC

3.1 Opis VDS Požarevca

VDS Požarevca (centralna Srbija) snabdeva vodom oko 50.000 stanovnika, industriju na teritoriji grada i ustanove. Krajem 2008. godine započet je sveobuhvatni projekat rekonstrukcije i poboljšanja efikasnosti vodovoda grada Požarevac. Projekat se sastojao od rekosnstrukcije i izgradnje novih cevovoda i rezervoara, a posebna komponenta projekta je bila implementacija porgrama povećanja efikasnosti vodovoda, uključujući i smanjenje gubitaka vode. Celokupan projekat je implementiran u periodu 2008-2013 [9], a finansiran je od strane lokalne samouprave i EU fondova za podršku razvoja lokane infrastrukture u Srbiji.

VDS Pozarevca je podeljen u 3 visinske zone: I zona <100mnm, 100mnm< II zona <150mnm i 150mnm<III zona< 200mnm, a najveći broj potrošača je u I visinskoj zoni. Voda se obezbeđuje crpenjem podzemne vode iz okolnog izvoršta Ključ. Voda iz bunara dovodi se do rezervoara Ključ (V=2x2500 m^3), a zatim PS Kljuc potiskuje vodu prema gradu i rezervoaru I zone - Tulba. Potis pumpi povezan je na potisno-distributivni cevovod Ø600 na kome je, u toku projekta, zamenjen stari i ugrađen novi elektromagnetni merač protoka. Iz rezervoara I zone pumpnom stanicom voda se potiskuje cevovodom prečnika Ø250 ka rezervoaru II visinske zone - Čačalica. U okviru rezervora II zone smešteno je hidroforsko postrojenje za plasman vode u treću visinsku zonu. Na slici 3 prikazana je šema VDS Pozarevca.

Na početku projekta (kraj 2008. godine), na osnovu podataka kojima je raspolagao JKP "Vodovod" Požarevac, ukupan dotok vode u VDS u 2008. godini iznosio je oko 6.540.000 m^3/god (prosečno 207 l/s).

of the uncertainty of the final results, for components of the water balance and PI.

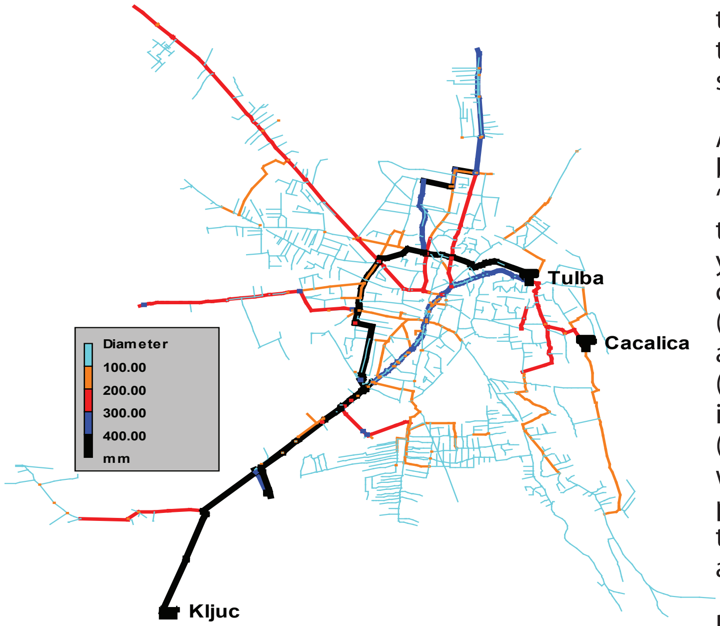
Following figure 2 schematically shows the influence of certain phases on the reduction of uncertainty components of the water balance and PI. It should be noted that these activities can only improve the reliability of PI, but not their value. For PI improvement are applied other measures.

3. EXAMPLE OF WDS POŽAREVAC

3.1 Description of WDS Požarevac

WDS Pozarevac (central Serbia) supplies water to about 50,000 residents, industries in the city and the institutions. In late 2008, was initiated a comprehensive project for the reconstruction and improvement of the efficiency of the water supply system of the city of Pozarevac. Project consisted of the renovation and construction of new pipelines and reservoirs, and a separate component of the project was the implementation of the program to increase the efficiency of water supply, including the reduction of water losses. The entire project was implemented in the period 2008-2013 [9], and is funded by the local government and EU funds to support the development of municipal infrastructure in Serbia.

WDS Pozarevac is divided into three altitude zones: Zone I <100mnm, 100mnm <Zone II <150mnm and 150mnm <Zone III <200mnm, with a majority of the consumers in the I-altitude zone. Water is provided by extraction of groundwater from the surrounding spring Kljuc. Water from the wells is transfered to the reservoir Kljuc (V = 2x2500 m^3), and then PS Kljuc delivers water to the city and the reservoir of the zone I - Tulba. Output of the pumps is connected to the output-distribution pipeline Ø600 where, in the course of the project, was replaced the old and the new electromagnetic flow meter was built-in. From the Zone I reservoir water is suppressed by pipeline to the Ø250 diameter reservoir in the II altitude zone



Slika 3. VDS Požarevca
Figure 3 WDS Pozarevac

Ukupna fakturisana potrošnja vode iznosila je oko 3.930.000 m³/god (124,6 l/s), a stanovništvo (individualne kuće i stambene zgrade) je učestvovalo sa 64,3 % (individualne kuće 46,9 %, a stambene zgrade 17,4 %). Prosečan broj mesečnih računa (faktura) iste godine iznosio je oko 12.400, od toga 10 % za privredu a

- Čačalica. Within the reservoir zone II is placed the water pump for the placement of the water in the third altitude zone. Figure 3 shows a schematic of the WDS Pozarevac.

At the beginning of the project (end of 2008), based on data that were available to the PUC "WaterWorks" Pozarevac, the total water supply to the WDS in 2008 was about 6.54 million m³/year (an average of 207 l/s). Total billed water consumption was about 3.93 million m³/year (124.6 l/s) and population (individual houses and apartment buildings) accounted for 64.3% (46.9% in individual houses and apartment buildings 17,4 %). Average number of monthly bills (invoices) in the same year was about 12.400, of which 10% of the economy and 90% of the population (45% of individual houses and 45% of the building). Data on illegal consumers were at the level of rough estimates.

Data on total length of pipelines have been unreliable; Master Plan shown about 100 km of distribution pipelines, and internal data in water supply companies were extremely unreliable. According to available information, the most common pipe materials are asbestos cement (53.5%) and plastics (35.0%).

3.2 Obtained results

Tabela 1. Procenjene vrednosti kompinenti vodnog bilansa i ILI na početku projekta (2008. god.)
Table 1 Estimated values of the components of the water balance and ILI at the beginning of the project (2008).

Ulazni podatak / Input data	Najbolje procenjena vrednost Best estimated value	95% CL (±)
Dotok vode sa izvorišta u VDS (m³/god) / Inflow of water from springs in the WDS (m³/year) - $V_{inp,i}$	6.539.440	± 20 %
Fakturisana izmerena legalna potrošnja vode (m³/god) / Billed measured legal water consumption (m³/year) - $V_{BMAC,i.}$	3.741.978	± 20 %
Fakturisana neizmerena legalna potrošnja vode (m³/god) / Billed unmetered legal water consumption (m³/year) - $V_{BUMC,i}$ - (5 % $V_{BMAC,i.}$)	196.454	± 50 %
Nefakturisana legalna potrošnja vode (m³/god) / Legal unbilled water consumption (m³/year)- V_{UAC} - (5 % $V_{inp,i}$)	187.099	± 80 %
Ukupna fakturisana legalna potrošnja vode (m³/god) / Total invoiced legal water consumption (m³/year)- V_{AC}	3.929.075	*računa se* ± 14 %
Nelegalna potrošnja vode (m³/god) / Illegal water consumption (m³/year)- V_{UC} - (2% $V_{inp,i}$)	130.789	± 80 %
Zapremina vode usled greški na vodomerima (m³/god) / Volume of water due to errors on water meters (m³/year) - V_{CME} - (10 % $V_{BMAC,i.}$)	374.198	± 50 %
Dužina glavnih cevi (km) / Length of the main pipeline (km)- L_m	140	± 30 %
Broj priključaka / Number of connections (-) - N_{conn}	11.000	± 30 %
Dužina priključnih cevi (km) / Length of connecting pipes (km) - L_{conn}	110	± 50 %
Prosečan pritisak u VDS (m) / Average pressure in the WDS (m) - P_{aver}	45	± 20 %
Non Revenue Water (m³/god) / (m³/year)	2,610,365	± 54,4 %
ILI	7.7	± 87,0 %

Data available at the beginning of the project (data annually for 2008), was the basis for calculating components of the water balance and the ILI index, as well as their uncertainty (Table 1). Results are shown in accordance with standard IWA terminology.

Unavoidable annual real losses of water UARL amount to 231.100 m³/year and their uncertainty is 29.6%. Results are of great uncertainty and not usable for rendering of proper management decisions.

After activity 2 (installation of a high reliability flow meter at the source), NRW uncertainty was reduced from 54% to 22% and the ILI

Tabela 2. Procenjene kompinente vodnog bilansa i ILI nakon sprovođenja aktivnosti 1, 2, 3 i 4
Table 2 Estimated components of the water balance and ILI after the implementation of activities 1, 2, 3 and 4

Ulazni podatak / Input data	Najbolje procenjena vrednost / Best estimated value	95% CL (±)
Dotok vode sa izvorišta u VDS (m³/god) / Inflow of water from springs in the WDS (m³/year)- $V_{inp,i}$	6.690.000	± 2 %
Fakturisana izmerena legalna potrošnja vode (m³/god) / Billed measured legal water consumption (m³/year)- $V_{BMAC,i.}$	3.351.314	± 2 %
Fakturisana neizmerena legalna potrošnja vode (m³/god) / Billed unmetered legal water consumption (m³/year) - $V_{BUMC,i}$ - (5 % od $V_{BMAC,i.}$)	167.566	± 20 %
Nefakturisana legalna potrošnja vode (m³/god) / Legal unbilled water consumption (m³/year)- V_{UAC} - (1 % od $V_{inp,i}$)	66.900	± 80 %
Ukupna fakturisana legalna potrošnja vode (m³/god) / Total invoiced legal water consumption (m³/year) - V_{AC}	3.518.879	*računa se* ± 1,6 %
Nelegalna potrošnja vode (m³/god) / Illegal water consumption (m³/year) - V_{UC} - (0.1% od $V_{inp,i}$)	6.690	± 80 %
Zapremina vode usled greški na vodomerima (m³/god) / Volume of water due to errors on water meters (m³/year) - V_{CME} - (10 % od $V_{BMAC,i.}$)	335.131	± 50 %
Dužina glavnih cevi (km) / Length of connecting pipes (km) - L_m	140	± 30 %
Broj priključaka / Number of connections (-) - N_{conn}	13.190	± 2 %
Dužina priključnih cevi (km) / Length of connecting pipes (km) - L_{conn}	110	± 50 %
Prosečan pritisak u VDS (m) / Average pressure in the WDS (m) - P_{aver}	45	± 20 %
Non Revenue Water (m³/god) / (m³/year)	3,171,120	± 4,6 %
ILI	12.0	± 30,5 %

90 % za stanovništvo (45 % individualne kuće i 45 % stambene zgrade). Podaci o nelegalnim potrošačima bili su na nivou grubih procena.

Podaci o ukupnoj dužini cevovoda su bili nepouzda-

indicator from 87% to 49%.

After that, activities 3 and 4 were carried out and the following results were obtained, shown in table 2.

After completion of Activity 5, the following results

Tabela 3. Procenjene kompinente vodnog bilansa i ILI nakon sprovođenja aktivnosti 1, 2, 3, 4 i 5
Table 3 Estimated components of the water balance and ILI after the implementation of activities 1, 2, 3, 4 and 5

Ulazni podatak / Input data	Najbolje procenjena vrednost / Best estimated value	95% CL (±)
Dotok vode sa izvorišta u VDS (m³/god) / Inflow of water from springs in the WDS (m³/year)- $V_{inp,i}$	6.690.000	± 2 %
Fakturisana izmerena legalna potrošnja vode (m³/god) / Billed measured legal water consumption (m³/year)- $V_{BMAC,i.}$	3.351.314	± 2 %
Fakturisana neizmerena legalna potrošnja vode (m³/god) / Billed unmetered legal water consumption (m³/year) - $V_{BUMC,i}$ - (5 % od $V_{BMAC,i.}$)	167.566	± 20 %
Nefakturisana legalna potrošnja vode (m³/god) / Legal unbilled water consumption (m³/year)- V_{UAC} - (1 % od $V_{inp,i}$)	66.900	± 80 %
Ukupna fakturisana legalna potrošnja vode (m³/god) / Total invoiced legal water consumption (m³/year) - V_{AC}	3.518.879	*računa se* ± 1,6 %
Nelegalna potrošnja vode (m³/god) / Illegal water consumption (m³/year) - V_{UC} - (0.1% od $V_{inp,i}$)	6.690	± 80 %
Zapremina vode usled greški na vodomerima (m³/god) / Volume of water due to errors on water meters (m³/year) - V_{CME} - (10 % od $V_{BMAC,i.}$)	335.131	± 50 %
Dužina glavnih cevi (km) / Length of connecting pipes (km) - L_m	175	± 1 %
Broj priključaka / Number of connections (-) - N_{conn}	13.190	± 2 %
Dužina priključnih cevi (km) / Length of connecting pipes (km) - L_{conn}	131,9	± 10 %
Prosečan pritisak u VDS (m) / Average pressure in the WDS (m) - P_{aver}	45	± 20 %
Non Revenue Water (m³/god) / (m³/year)	3,171,120	± 4,6 %
ILI	9.9	± 21.4 %

ni: u Master planu Požarevca prikazano je oko 100 km distributivnih cevovoda, a interni podaci u vodovodskom preduzeću bili su krajnje nepouzdanii. Prema tada raspoloživim informacijama najzastupljeniji cevni materijali su azbest cement (53,5%) i plastika (35,0%).

3.2 Dobijeni rezultati

Na osnovu raspoloživih podataka na početku projekta (podaci na godišnjem nivou za 2008. godinu) izračunate su komponente vodnog bilansa i indeksa ILI, kao i njihova neodređenost (tabela 1). Rezultati su prikazani u skladu sa standardnom IWA terminologijom.

Neizbežni godišnji stvarni gubici vode UARL iznose 231.100 m³/god, a njihova neodređenost 29,6%. Dobijeni rezultati imaju veliku neodređenost i nisu upotrebljivi za donošnje ispravnih upravljačkih odluka.

Nakon sprovedene aktivnosti 2 (ugradnja merača protoka velike pouzdanosti na izvorištu), smanjena je neodređenost NRW sa 54% na 22% i indikatora ILI sa 87% na 49%.

Tabela 4. Procena vrednosti kompionenti vodnog bilansa i ILI na kraju projekta
Table 4 Valuation of the components of the water balance and ILI at the end of the project

Ulazni podatak / Input data	Najbolje procenjena vrednost / Best estimated value	95% CL (±)
Dotok vode sa izvorišta u VDS (m³/god) / Inflow of water from springs in the WDS (m³/year)- $V_{inp,i}$	6.690.000	± 2 %
Fakturisana izmerena legalna potrošnja vode (m³/god) / Billed measured legal water consumption (m³/year)- $V_{BMAC,i.}$	3.351.314	± 2 %
Fakturisana neizmerena legalna potrošnja vode (m³/god) / Billed unmetered legal water consumption (m³/year) - $V_{BUMC,i}$ - (5 % od $V_{BMAC,i.}$)	167.566	± 20 %
Nefakturisana legalna potrošnja vode (m³/god) / Legal unbilled water consumption (m³/year)- V_{UAC} - (1 % od $V_{inp,i}$)	66.900	± 80 %
Ukupna fakturisana legalna potrošnja vode (m³/god) / Total invoiced legal water consumption (m³/year) - V_{AC}	3.518.879	*računa se* ± 1,6 %
Nelegalna potrošnja vode (m³/god) / Illegal water consumption (m³/year) - V_{UC} - (0.1% od $V_{inp,i}$)	6.690	± 80 %
Zapremina vode usled greški na vodomerima (m³/god) / Volume of water due to errors on water meters (m³/year) - V_{CME} - (10 % od $V_{BMAC,i.}$)	335.131	± 50 %
Dužina glavnih cevi (km) / Length of connecting pipes (km) - L_m	175	± 1 %
Broj priključaka / Number of connections (-) - N_{conn}	13.190	± 2 %
Dužina priključnih cevi (km) / Length of connecting pipes (km) - L_{conn}	131,9	± 10 %
Prosečan pritisak u VDS (m) / Average pressure in the WDS (m) - P_{aver}	42,5	± 5 %
Non Revenue Water (m³/god) / (m³/year)	3,171,120	± 4,6 %
ILI	10.5	± 9,1 %

Nakon toga sprovedene su aktivnosti 3 i 4 i dobijeni su sledeći rezultati, prikazani u tabeli 2.

Nakon završetka aktivnosti 5, dobijeni su sledeći rezultati, prikazani u tabeli 3.

Nakon sprovedenih svih aktivnosti od 1 do 6, navedenih u delu 2.2, izračunate su konačne vrednosti komponenti vodnog bilansa VDS Pozarevca i indeksa ILI, kao i njihova neodređenost, i prikazane u tabeli 4.

Procenjena vrednost UARL iznosi 263.700 m³/god, a njegova neodređenost 5,5%. Dobijeni rezultati ukazuju na znatno veću pouzdanost izračunatih komponenti vodnog bilansa i indeksa ILI.

Kao rezultat svih pomenutih aktivnosti, detektovano je da ukupna dužina vodovodne mreže iznosi oko 175 km. Cevni materijali su plastika (PE100, PE80 i PVC) ukupne dužine oko 99 km (56,4 %) i azbest cement ukupne dužine 55,5 km (31,7 %). Cevi prečnika manjeg od 100 mm su ukupne dužine 112,8 km (64,5 %).

were obtained, shown in Table 3.

After carrying out all activities from 1 to 6, listed in section 2.2, calculation was done for the final value of components of the WDS Pozarevac water balance and ILI index, as well as their uncertainty, shown in Table 4.

Estimated UARL value is 263.700 m³/year and its uncertainty 5.5%. Results indicate a significantly higher reliability of the calculated components of the water balance and the ILI index.

As a result of all the above mentioned activities, it was detected that the total length of the water supply network is about 175 km. Pipe materials were plastic (PE100, PE80 and PVC) with a total length of about 99 km (56.4%) and asbestos cement with the total length of 55.5 km (31.7%). Pipes of diameter smaller than 100 mm are in total length of 112.8 km (64.5%).

Also, significantly increased is the average number of monthly bills (invoices) and is approximately 17.730, of which 10% of the economy and 90% of the population (54% of individual houses and 36% of the buil-

Takođe, značajno je povećan prosečan broj mesečnih računa (faktura) i iznosi oko 17.730, od toga 10 % za privredu a 90 % za stanovništvo (54 % individualne kuće i 36 % stambene zgrade).

Prosečan pritisak u VDS dobijen je na osnovu kalibrisanog matematičkog modela.

Treba napomenuti da nije izvršena procena tačnosti različitih kategorija vodomera kod potrošača na statističkom uzorku vodomera, ali je prilikom zamene dotrajalih vodomera novim, veće tačnosti, primećeno da je fakturisana količina vode veća i do 20% u odnosu na ranije fakturisane količine.

4. DISKUSIJA REZULTATA

Iz priloženih rezultata može se videti da je na početku realizacije projekta, neodređenost ulaznih veličina bila izuzetno velika, što je uticalo na neodređenost komponenti vodnog bilansa i indeksa ILI. Najveći izvor greške, odnosno neodređenosti, bilo je merenje dotoka vode u sistem. Ugradnja novog merača protoka, veće pouzdanosti, značajno je uticala i na smanjenje neodređenosti rezultata. Povećanje pouzdanosti merenja dotoka vode je bila prioritetna, obzirom da se VDS Požarevca snabdeva samo iz jednog izvorišta. Njegovom ugradnjom smanjila se neodređenost zapremine koja ne donosi prihode sa 54% na 22% i indikatora ILI sa 87% na 49%.

Nakon povećanja pouzdanosti merača protoka vode sprovedene su aktivnosti vezane za smanjenje neodređenosti potrošnje vode u VDS, pa se neodređenost NRW smanjila na ±4.6 %, ali neodređenost indeksa ILI je još uvek velika, i iznosi ±30.5 %.

Nakon smanjenja neodređenosti i fizičkih veličina VDS, neodređenost NRW ostaje ista, a neodređenost indeksa ILI se smanjuje na 21.4 %.

Tek nakon kalibracije matematičkog modela, smanjuje se i neodređenost prosečnog pritiska u VDS, pa i indeks ILI ima prihvatljivu neodređenost od ±9%.

Iz dobijenih rezultata, nakon sprovođenja svih aktivnosti od 1 do 7, može se zaključiti da je lociranje svih potrošača i njihovo unošenje u bazu i GIS značajno uticalo na smanjenje neodređenosti. Formiranjem nove baze značajno se povećao broj mesečnih faktura (skoro za 50%) i broj registrovanih vodomera (za oko 20%). Međutim, zapremina vode koja donosi prihod je smanjena za oko 10%. Razlog za smanjenje zapremine vode koja donosi prihod leže u eksternim faktorima na koje projekt nije mogao da utiče: povećanje cene vode i ekonomska kriza koja je započela krajem 2008. godine, što je uticalo na značajno smanjenje zapremine vode koja donosi prihod kod privrednih korisnika (za oko 22%).

Evidentiranje svih objekata VDS značajno je doprinelo povećanju pouzdanosti podatka o dužini cevi.

ding).

Average pressure obtained in the WDS is calibrated on the basis of the mathematical model.

It should be noted that there was no assessment of the accuracy of various categories of consumer's water meters on the statistical water meter sample, but during the replacement of worn-out water meters with new, with higher accuracy, it is observed that the billed amount is greater by 20% compared to the previously billed amount.

4. DISCUSSION OF RESULTS

From the above results, it can be seen that at the beginning of the project, the uncertainty of input was extremely high, which contributed to the uncertainty of the components of the water balance and the ILI index. The largest source of error or uncertainty was the measuring of the water flow into the system. Installation of new flow meters, with higher reliability, significantly affected the reduction of uncertainty of results. Increase of the reliability of the water flow measurement was a priority, given that the WDS Pozarevac is supplied from one source. Its installation has decreased the volume uncertainty which brings revenue from 54% to 22% and ILI indicator from 87% to 49%.

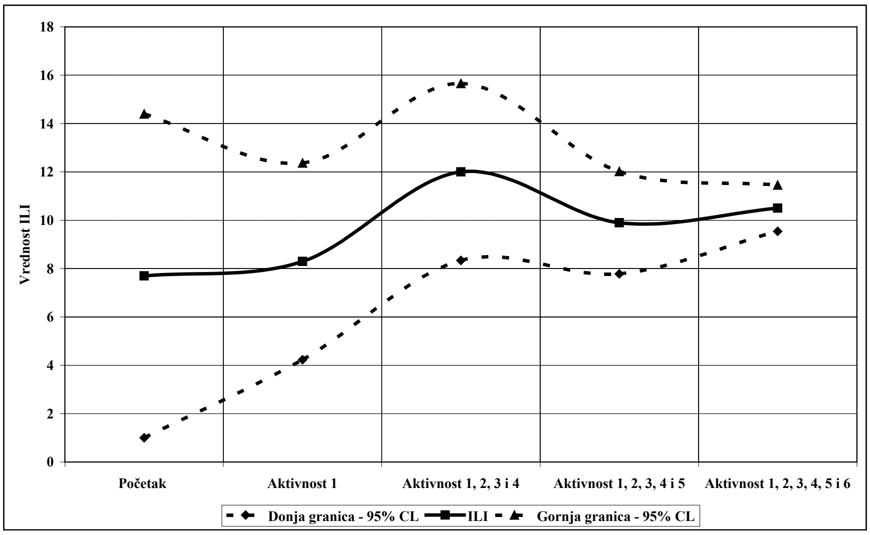
After increasing the reliability of the flow meter have been carried out activities related to the reduction of uncertainty in water consumption in the WDS, and NRW uncertainty is reduced to ± 4.6%, but the ILI index uncertainty is still high, and is ± 30.5%.

After the reduction of uncertainty and the physical size of the WDS, the uncertainty of NRW remains the same and the ILI index uncertainty decreases to 21.4%.

Calibration of the mathematical model reduces the uncertainty of the average pressure in the WDS and the ILI index has an acceptable uncertainty of ± 9%.

From the obtained results, after the implementation of all activities from 1 to 7, it can be concluded that the location of the consumer and its incorporation into a GIS has a significant impact on the reduction of uncertainty. Establishing a new base significantly increased the number of monthly invoices (almost 50%) and the number of registered water meters (about 20%). However, the volume of water that brings revenue was reduced by approximately 10%. The reason for reducing the volume of water that brings revenue lie in external factors that the project could not affect: increasing water prices and the economic crisis that began in late 2008, which resulted in a significant reduction in the volume of water that generates income for commercial users (for about 22%).

Recording all WDS objects has contributed signifi-



Slika 4. Uticaj sprovedenih aktivnosti na promenu vrednosti ILI i njegove neodređenosti
Figure 4 Impact of activities conducted on the change in ILI value and its uncertainty

Iz rezultata može se zaključiti da zaposleni nisu imali pouzdane informacije o dužini cevi prečnika manjeg od 100 mm. Takođe, značajno se promenila i zastupljenost cevnog materijala.

Obzirom da nije izvršena procena tačnosti različitih kategorija vodomera kod potrošača na statističkom uzorku vodomera, i dalje je ostala velika neodređenost prividnih gubitaka vode. U narednom periodu treba sprovesti aktivnosti kojim bi se povećala njihova pouzdanost, i potom preduzele akcije za njihovo smanjenje.

Kalibracija matematičkog modela je uspešno sprovedena, što je omogućilo i pouzdano određivanje prosečnog pritiska u VDS. Ovo je od naročite važnosti obzirom da je vrednost UARL direktno proporcionalna pritisku. Na ovaj način smanjena je i neodređenost indeksa ILI.

Nakon sprovedenih aktivnosti procenjena vrednost indikatora ILI se povećala sa 7.7 na 10.5, ali se njegova neodređenost značajno smanjila sa 88% na 9%. Na narednoj slici 4 dat je prikaz uticaja sprovedenih aktivnosti na promene vrednosti ILI i njegove neodređenosti.

5. ZAKLJUČAK

U velikom broju vodovodnih sistema, naročito u zemljama u razvoju, podaci o elementima sistema, merenja protoka i potrošnje vode imaju veliku neodređenost. Ova neodređenost se u daljim proračunima propagira na izračunate vrednosti PI. Postoje različite metode za analizu neodređenosti, ali ne postoji metodologija koja može dati tačne razultate na osnovu netačnih ulaznih podataka.

Podaci velike neodređenosti mogu da navedu na pogrešne zaključke i samim tim dovedu do pogrešnih upravljačkih odluka. Njihovom kvanitifikacijom omogućava se vodovodnom preduzeću da odredi prioritete gde treba koncentrisati aktivnosti kontrole

cantly to increasing the reliability of the data on the length of the pipe. From the results it can be concluded that the employee did not have reliable information on the length of pipe with a diameter of less than 100 mm. Also, significantly was changed the representation of pipe material.

Given that there was no assessment of the accuracy of various categories of consumer's water meters on the statistical sample, it still remains a large uncertainty of the apparent water losses. In the future there should be activities that would increase their reliability, and then take action to reduce them.

Calibration of the mathematical model has been successfully implemented, which allowed the reliable determination of the average pressure in the WDS. This is of particular importance since it is directly proportional to the value of UARL pressure. In this way, the uncertainty of ILI index is reduced.

After conducted activities estimated value of the ILI indicator increased from 7.7 to 10.5, but its uncertainty was significantly reduced from 88% to 9%. In the following, Figure 4 gives an overview of the impact of activities conducted on the change in value ILI and its uncertainty.

5. CONCLUSION

In many water supply systems, especially in developing countries, data on the elements of the system, measurements of flow and water consumption have great uncertainty. This uncertainty in the further calculations is propagated to the calculated value of PI. There are different methods for the analysis of uncertainty, but there is no methodology that can provide accurate results on the basis of incorrect input data.

Large data uncertainty may lead to wrong conclusions and thus lead to incorrect management decisions. Their quantification enables Water Company to prioritize where to focus the activities of data quality kvaliteta podataka.

Na primeru VDS Požarevca prikazano je kako se sprovođenjem aktivnosti od 1 do 7, navedenih u delu 2.2, može smanjiti neodređenost proračuna komponenti vodnog bilansa i PI. Samo na osnovu takvih PI mogu da se donese racionalne upravljačke odluke.

control.

Example of the WDS Pozarevac shown how the implementation of activities from 1 to 7, listed in section 2.2, can reduce the uncertainty of the components of the water balance and PI. Only on the basis of such PI can make rational management decisions.

ZAHVALNOST

Autori se zahvaljuju “Ehting” d.o.o. iz Beograda i JKP “Vodovod” Požarevac za ustupanje svih potrebnih podataka i kalibrisanog matematičkog modela VDS, kao i Ministarstvu prosvete i nauke Republike Srbije koja je finansirala projekat broj TR 37010 “Sistemi za odvođenje kišnih voda kao deo urbane i saobraćajne infrastrukture”.

ACKNOWLEDGEMENTS

Authors would like to thank “Ehting” Ltd. from Belgrade, the PUC “Water Works” Pozarevac for the transfer of all relevant data and calibrated mathematical model of WDS, and the Ministry of Education and Science of the Republic of Serbia, which funded the project number TR 37010 “Systems for drainage of rain water as part of urban and transportation infrastructure.”

LITERATURA / LITERATURE

1. ISO/IEC Guide 98-3:2008. “Uncertainty of measurement Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)
2. Alegre, H., Baptista, J.M., Cabrera, E., Cubillo, F., Duarte, P., Hirner, W., Merkel, W. & R. Parena (2006): Performance Indicators for Water Supply Services. - Second Edition, Manual of Best Practice, IWA Publishing, London, UK.
3. AWWA. (2009). “Water Audits and Loss Control Programs: AWWA Manual M36.” American Water Works Association, Denver, USA.
4. JKP “Vodovod” Pozarevac (2013). Godišnji izveštaj službe naplate, uporedni pregled za period 2007-2012. god.
5. Lambert A, Taylor R (2010). Water Loss Guidelines, Prepared for: Water New Zealand.
6. Thornton, J., Sturm, R., and Kunkel, G. (2008). Water Loss Control, McGraw-Hill, New York.
7. Sattary, J., Boam, D., Judeh, W. A., and Warren, S. (2002). “The Impact of Measurement Uncertainty on the Water Balance.” *Water and Environment Journal*, 16(3), 218-222.
8. Herrero, M., Cabrera Jr, E., and Valero, F. J. (2003). “A New Approach to Assess Performance Indicators’ Data Quality.” Pumps, Electromechanical Devices and Systems Applied to Urban Water Management Systems, E. Cabrera and E. Cabrera Jr., eds., Swets & Zeitlinger, Lisse, The Netherlands, 69-78.
9. Ehting (2013). “Program za povećanje efikasnosti smanjenja gubitaka vode u vodovodnom sistemu Požarevca”.
10. Pregled novih metoda za smanjenje gubitaka u vodovodnim mrežama, D. Kostić, M. Ivetić, Voda i sanitarna tehnika, Beograd