# SEWERAGE PUMPING STATION OPTIMIZATION UNDER REAL CONDITIONS

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**Abstract**

Construction of a sewer system on a flat area is characterized by a large number of pumping stations (PS), which implies the probability of occurrence of technical problems and increases operational costs. The article focuses on drainage methods for municipalities situated on a flat area where it is necessary to build up a large number of pumping stations. Problems occur in case of multiple serial, parallel or combined connections of PSs. Energy costs can outweigh other costs, especially if the PS runs more than 2000 hours per year (Wilson et al., 2010). It has been shown that there is a large technical and economic potential for energy savings in sewage pumping. The pumping of waste waters in Slovakia is mostly based on the START-STOP method. This means that the pumps operate at all times at full power. In practice, we can also meet with oversizing of pumps. These and other facts lead to increased power consumption.

Also rainwater infiltration and "black" stormwater connections belong to significant present problems in sewer system operation. Large amounts of storm water in a sewerage PS lead to increasing intensity of waste-water pumping, which is reflected in increasing operational costs.

Optimization of such sewer system is based on mathematical modelling and was implemented in the "Ivanka pri Dunaji" municipality, close to Bratislava – the capital of Slovakia where the above mentioned problems in wastewater discharge cause considerable operating costs and inefficient performance of the system as a whole for a long time. Due to the enormous houses development, the system is inadequately loaded by rain waters as well. Also poor discipline of property owners contributes to the inauspicious situation to a great extent. Despite a ban of connections, paved areas are drained into the sewage system very often. The identification of such connections is very problematic with regard to ownership rights. Rain waters in sewages can degrade the quality of wastewaters, increase operating costs of pumping and reduce system life cycle. It was demonstrated by mathematical modelling that with the use of information technologies, it is possible to make the existing sewerage systems more effective or propose a new system of pumping and discharging waste waters.

**Abstrakt**

Pre výstavbu stokovej siete v rovinatom území je typické značné množstvo čerpacích staníc (ČS), čo implikuje pravdepodobnosť vzniku technických problémov a zvyšuje náklady na prevádzku. Príspevok je zameraný na spôsoby odkanalizovania obcí situovaných v rovinatom území, kde je potrebné budovať veľký počet čerpacích staníc (ČS). Problémy nastávajú pri niekoľkonásobnom sériovom, paralelnom alebo kombinovanom zapojení ČS. Spotreba energie tvorí často najväčšiu nákladovú položkou celkových nákladov generovaných počas životného cyklu čerpadla. Náklady na energiu môžu dominovať ostatným nákladom, hlavne ak je čerpadlo v chode viac ako 2000 hodín za rok (Wilson et al., 2010).

Bolo dokázané, že existuje veľký technický a ekonomický potenciál úspor energie pri čerpaní splaškových vôd.  V praxi sa môžeme veľmi často stretnúť s predimenzovaním čerpadiel. Tieto a ďalšie skutočnosti vedú k zvýšeniu spotreby elektrickej energie.

Významným problémom pri prevádzke stokových sieti je aj infiltrácia dažďových vôd a nedovolené pripojenie dažďových zvodov do splaškovej kanalizácie. Množstvo dažďových vôd v ČS v značnej miere ovplyvňuje čerpanie OV, čo sa prejavuje zvýšením nákladov na prevádzku ČS.

Optimalizácia takýchto sietí je v značnej miere založená na matematickom modelovaní a bola použitá na kanalizácií obce Ivanka pri Dunaji, kde vyššie uvedené problémy v odvádzaní odpadových vôd už dlhší čas

spôsobujú nemalé prevádzkové problémy - zvýšenie prevádzkových nákladov a neefektívny výkon systému ako celku. Systém je v dôsledku enormnej výstavby rodinných domov neprimerane zaťažovaný aj vodami, ktoré zaťažujú systém v čase dažďa. Nemalou mierou k tomu prispieva zlá disciplína majiteľov nehnuteľností v zmysle napojenia spevnených plôch na kanalizáciu. Tieto plochy sú aj napriek zákazu pripojenia mnohokrát zvedené práve do systému splaškovej kanalizácie. Identifikácia takýchto napojení je problematická vzhľadom na vlastnícke práva majiteľov nehnuteľností a tieto napojenia nielenže zhoršujú kvalitu odpadovej vody, ale implikujú zvýšené prevádzkové náklady na čerpanie a znižujú životnosť systému.

Matematickým modelovaním bolo preukázané, že pri využití informačných technológii môžeme zefektívniť prevádzku už jestvujúcich sieti alebo navrhnúť nový systém odvádzania a prečerpávania odpadových vôd.

**Key words:** waste water, sewage pumping stations, rainwater infiltration

## 1 INTRODUCTION

Within Eastern Europe, it is very difficult to encounter any publications describing a solution how to optimize existing sanitary sewer networks with a combination of several pumping stations (PSs). Most of the literature with similar issues focuses on optimization only. Due to the fact, it was necessary to combine several studies and expert articles dedicated to the optimization such as the “Optimization Guidance Manual for Sewage Works” (Nutt, Ross, 2010) dealing with energy savings and efficiency, saying also that pumping is one of the processes, for which it has been shown that it has a great technical and economic potential in energy savings. To achieve energy savings, it is necessary to develop new energy-saving devices and systems.

The article shows that by linking of individual water infrastructure systems, such as CTD, GIS and mathematical modelling a powerful tool can be obtained to reduce operating costs and predict negative events which could cause significant financial losses.

This article also shows the possibility of using hydroinformatics systems to optimize existing sewage systems. Hydroinformatics, as a relatively new discipline, combines elements of latest information technologies and hydraulics. Created hydroinformatic tools, such as Mike Urban, have a great capability to realistically view operational and emergency situations in water and wastewater related systems. They enable to answer not only basic questions about hydraulic system behaviour, but also questions related to forecasts of quantitative and sometimes also qualitative parameters and their simulations for specific events as in the article “Utilization of Hydroinformatic Tools in Slovakia” (Kučera, Gibala, 2006).

At present, we can meet with designs of sewerage and collecting wastewater into one central waste water treatment plant for large conurbations. In case of talking about gravitation drainage, we can talk about a preferred solution, but if it is necessary to pump wastewaters with a greater number of PSs, we can encounter many problems in design and operation (Sousa et al., 2002). Several unusual operating conditions were simulated there that were discussed with operating staff of Bratislava Water Company. It is also aimed at using hydroinformatics methods in safe sewerage disposal and demonstrating potential benefits of using them. On the basis of supporting documents of operating order and GIS and their proper calibration with supporting data from SCADA, it is possible to assess the current state. This enables to calculate basic hydraulic parameters such as flow capacity of each pipe, speed of sewages, and optimum diameter of sewer pipes and synergies of PSs.

Also infiltration of rainwater represents an enormous problem in operation of a sewer network. When developing wastewater planning strategies, water utilities face one of the greatest challenges that is to find such solutions that are not only cost effective in the short term, but also provide a desired level of service over the life of the infrastructure. Uncertainties in predictions of future population size, climate change impacts, rates of system deterioration and accuracy of hydraulic model calibration can have a significant impact on planning solutions. (Wilson et al., 2010). In the course of nonlinear climate processes in nature where extreme events occur increasingly, solving the problem is indispensable. Rainwater can infiltrate through pipe joints and leak through holes in manhole shafts. Leaks can occur due to the use of low-quality materials in the network construction. Large amounts of storm water in a drainage system lead to increasing intensity of pumping, which is reflected in increasing operating costs.

Nowadays, the operation of pumping stations needs to use computing technologies. To better understand a pumping system, relevant data must be processed depending on their importance and used to solve the problem. Proper system design, installation and possibly operation are the first important step. The achieved goals of simulations will be incorporated into the security plan of the sewerage system, which can also be applied to other similar systems. The article may serve as an analysis of current situation and also help predict and accurately identify weak points of the system and optimize effectiveness of operation and performance. The contribution of this work consists in an innovative approach to understanding a sewerage network and can serve as a guide for water companies in their reconstruction.

## 2 DESCRIPTION OF THEORETICAL METHOD AND CHOSEN AREA

The village of Ivanka pri Dunaji is located near the Danube River eastward from the capital city of Slovakia – Bratislava. The total population amounts to 5531. At present, it has 2910 inhabitants. In the simulation, connections with all residents were considered. The territory of the municipality is flat terrain with moderate waves. The terrain slightly declines to the Sursky channel. The municipal sewerage system is designed as a separate sewer. Rain waters and other waters are disposed at the source and they are excluded from the sewer system.

The Sursky channel as a man-made stream with the function of a trapping channel is the main recipient of the village.

There is no large industrial plant running in the village of Ivanka pri Dunaji. In this region, there are only minor operations, restaurants, cafes, further shops, schools and medical facilities. Waste water produced in these facilities has a municipal wastewater character.

The technological process of the village sewer consists of the following operations:

- collecting wastewaters discharged through household connections in sewer system
- wastewater transport through gravity pipeline to pumping stations,
- pumping wastewater to WWTP in Bratislava-Vrakuna

The sewer system consists of 14 PS. The wastewaters are several-fold pumped to the biggest and main PS5 which is located at the end of the village.

Profiles of house connections are DN 150 or DN 200 PVC, main sewer network from DN 300 to DN 600. The bulk of the gravity sewer system in the village is DN 300 with minimum slope 3.5 ‰.

On the main collector system, PSs are built. On the collector A, there are 3 PSs. On the collector B, 1 PS, on the collector D, there are 2 PSs. The collector E includes 4 PSs and the sewerage system F then 1 PS.

On the collector system A, PS5 is placed, from which sewages are pumped through a pressure pipe DN 600, 4673 m in length to the WWTP in Vrakuna (Fig.1).

## 3 MATHEMATICAL MODELLING OF SEWER NETWORK

In times of rising energy prices in transport of fluids, effectiveness should be considered. On the foreign market, software applications are available that help us reconcile the system utilization in order to avoid excessive spending, whether in the procurement, construction, operation or maintenance of the network.

This chapter describes the formation of a strategic mathematical model of shared sewage drains stated in the report of Bratislava Water Company (BVS) using the simulation software Mike Urban followed by computing a building simulation model of the sewerage network comprising pipelines retrieved from GIS and sewer PSs. The resulting model is then calibrated according to the data obtained from the CTD (central technology dispatching) such as information about course levels in PSs, inflows and consumption.

When compiling the mathematical model, the following was made:

- Identification of problems, or questions to be solved by the model,
- Defining real elements of the sewage network in terms of the mathematical model,
- Operating system characterization during the examined time periods,
- Model calibration based on the data from CTD,
- Launch of calculating the mathematical model and solving the issues mentioned above.


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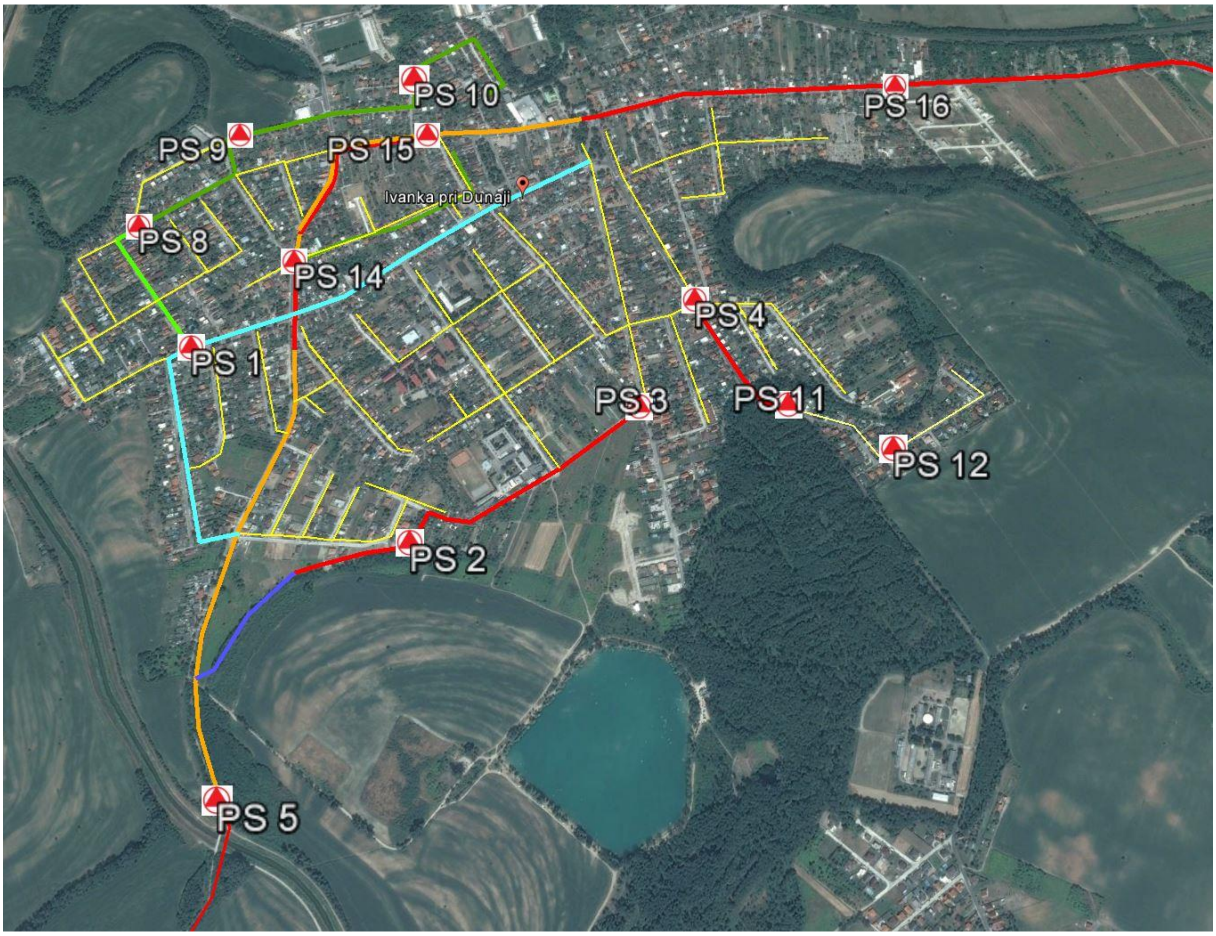


**Fig. 1 Site layout of sewer system in Ivanka pri Dunaji**

## 3.1 Unusual cases in network modelling

This chapter is focused on the assessment of non-standard conditions, for example during a power failure. The question was how long it would take before all PSs in the village stop pumping and the system collapses. The information is very important for the attended operation in order to act quickly in similar situations to prevent damage of property.

In this simulation, we considered only sewage waters without rain waters. The simulation time was set to 7 hours per day during 5 working days and 2 weekend days. For each type, separate curves of daily irregularities during the day were used.

It should be said that when the simulation was set to the existing conditions, no defects of PSs and electrical outages occurred; the current system works properly. The collecting system appeared to be slightly oversized because it was designed for prospective conditions that are not currently met.

The simulation started at 00.00 a.m. on 05/19/2014. After running the simulation, flooding at the edge inspection chamber occurred. It should be noted that these conditions became evident after 8 hours of simulation in PS16. The simulation shows other problematic parts upstream PS7, PS10, PS11 and PS16. The sewer part before PS16 was flooded first. The discharge of wastewaters to landscape occurred on 19/05/2014 at 8:21 p.m. followed by PS7 at 19:17 p.m. PS11 was flooded at 19:38 p.m. that day (Fig. 2). PS10 was flooded after the last 4 days of simulation time on 23/05/2014 at 01:38 p.m. It was due to the low population density in the area.


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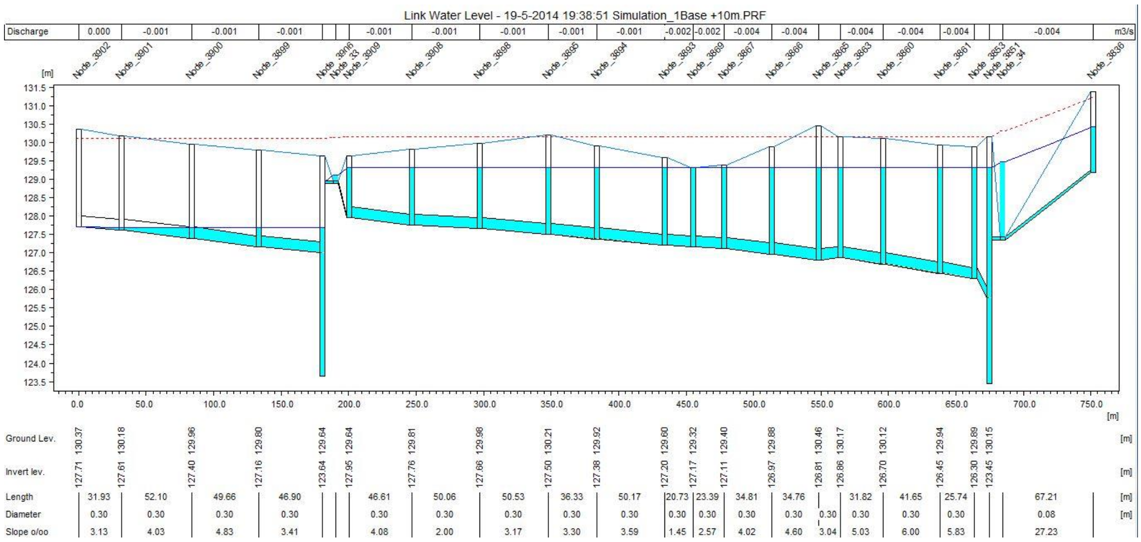


**Fig. 2 Flooded sewerage pipes and pumping station PS11**

## 3.2 Illegal connections of rain waters from roofs to sewage system

In the next step of simulation, we focused on illegal connections from roofs to the sewage system. Due to the insufficient solution of rainwater drainage in the village, property owners are often forced to discharge the water into the separate sewerage system. Residents do so in contradiction to the contract on connection to the public sewer system. There was a number of cases where the people have been connected from roofs into the sewer house connections already during the house construction, either directly or through an overflow edge of the rain water basin. Residents, however, do not realize that the inflow of rainwater from few roofs could exceed the designed capacity of a PS.

The operator can defend against such cases as follows:

- Do not allow any new inhabitancy without resolving and testing the rainwater drainage system, despite the fact that the newly built sanitary sewer will be finally approved.
- Increase the awareness of the population of possible financial penalties. Smoke tests together with camera monitoring should demonstrate who has a "black" connection. It should be in the interests of the village council and the sewer operator so the confirmation of such suspicions should be the priority.
- An expensive, but permanent solution consists in building storm sewers, or constructing an accumulation "rain" tank near a PS where the mixed water can be accumulated during the rainfall and then, after the rainfall end, pumped back to the system.

To simulate these conditions, 15 minute rainfall with a frequency of 0.5 was used for the territory of Bratislava subsequently divided into the simulated zones through each catchment area of PSs. The simulation was carried out in three variants with a share of 10%, 15% and 30% connection from roofs of the total interested area. Within each simulation of illegal connections, there were significant operational states.

For each alternative, we focused on the rate of flooding each particular boundary part of the sewer network. In these places, along the longitudinal profiles, the sewer lays in a smaller depth. Right here, there was the assumption that flooding inspection chambers would happen sooner and gravitational flow be pressurized. We considered only the PSs that demonstrated the greatest impact of rain runoff from roofs as PS16, PS11, PS1, PS7 and PS5. In the individual situations, we can see the places highlighted in blue colour which were loaded by the runoff from roofs (Fig.3, Fig.4, and Fig.5). The points, or the shafts which occurred during the simulation discharge of mixed wastewaters over the landscape are highlighted in red.


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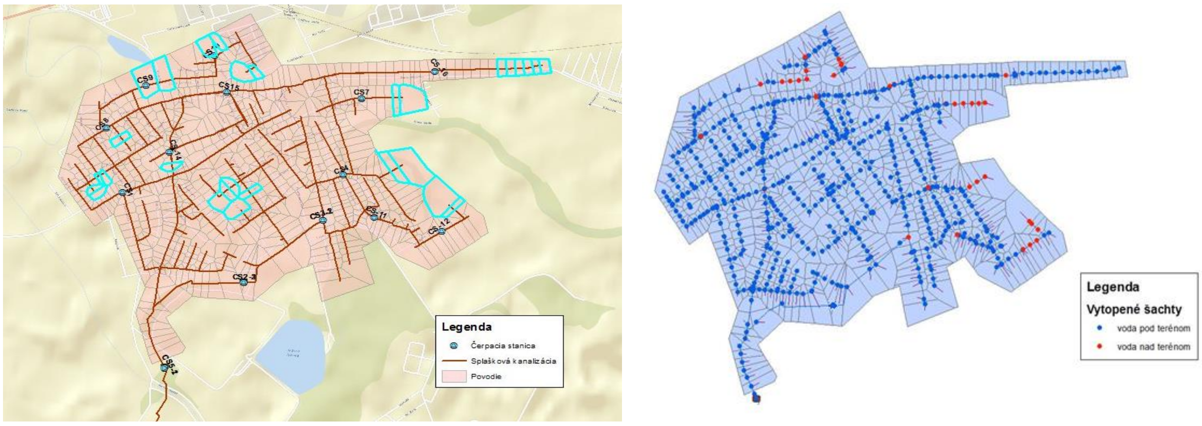


**Fig. 3 Alternative with 10% connection of rainwaters from roofs**

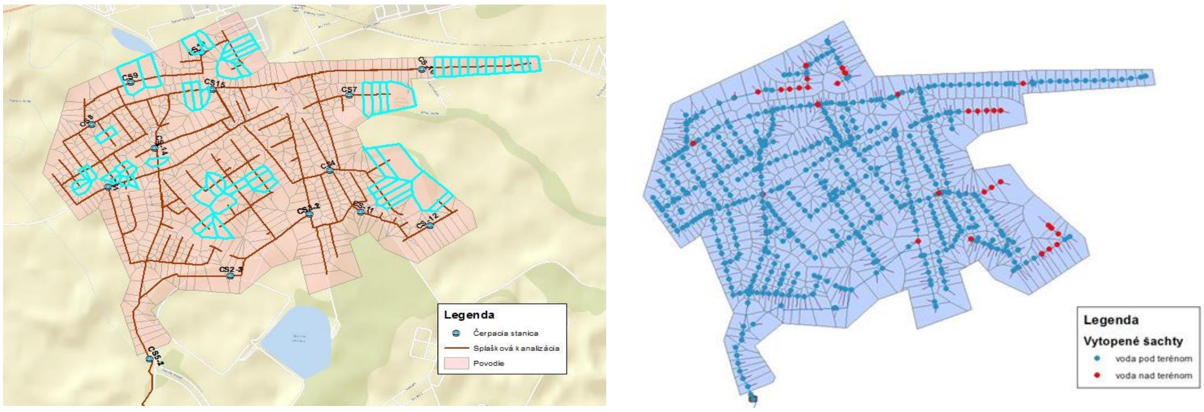


**Fig. 4 Alternative with 15% connection of rainwaters from roofs**

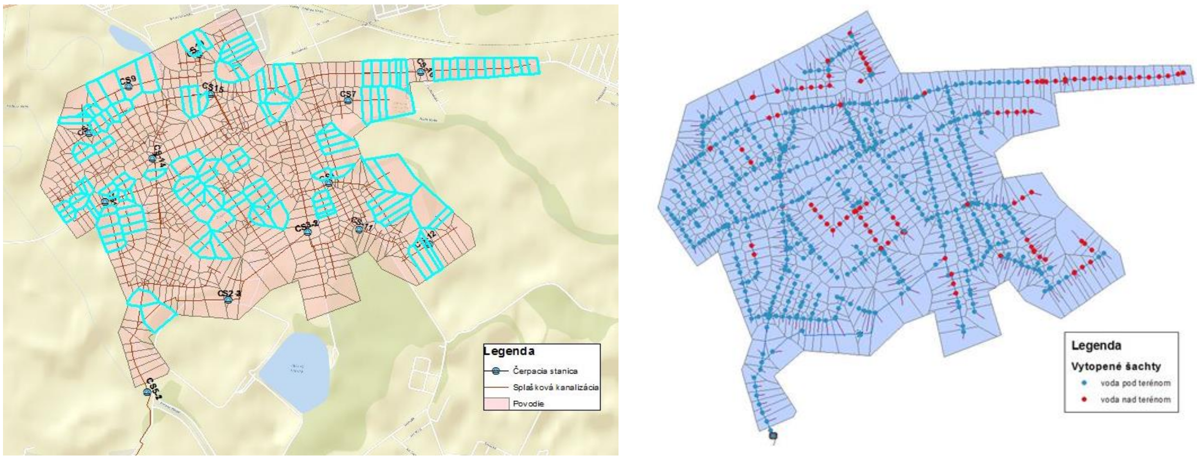


**Fig. 5 Alternative with 30% connection of rainwaters from roofs**

All three alternatives showed the danger of connecting rain waters to the separate sewage system. Mostly edge areas were flooded, and it was confirmed that the larger proportion of the connections has a significant impact such as the size of the flooded area as well as the speed of flooding. Already in the first alternative, there was a pressure flow instead of gravity flow in places with a pure gravity sewer, which has an adverse effect on the operation as well as shortens operating lifetime of pipes and joints. The worst results showed the option of 30%. The simulation leads to the pressure flow and backflow water nearly at 95% of the network.

### 3.3 Use of variable frequency drive

The simulation of using a variable frequency drive can demonstrate potential savings in operating costs, whether electrical energy savings in running pumps, or savings due to a prolonged period of repairs and their life. The simulation required to change the characteristic curves of various pumps offered by manufacturer. It is important to note that it is not recommended to regulate the rotation speed in the whole range from 0% to 100%. Manufacturers recommend the pump regulation ranging from 70% to 100%. Therefore, the simulation was carried out with 100%, 85% and 70% of the characteristic efficiency. The sewerage system in the village of Ivanka pri Dunaji uses four types of pumps: Sigma 80 GFHU; ABS AFP 1035; ABS Piranha M26/2D; ABS Piranha M55-2D pumps. We can mention the pump type ABS AFP 1035 which is installed at the last pump station PS5. The simulation was running in one particular day without rainfalls. The characteristic curve had to be transferred to the simulator program MIKE URBAN (Fig. 6).

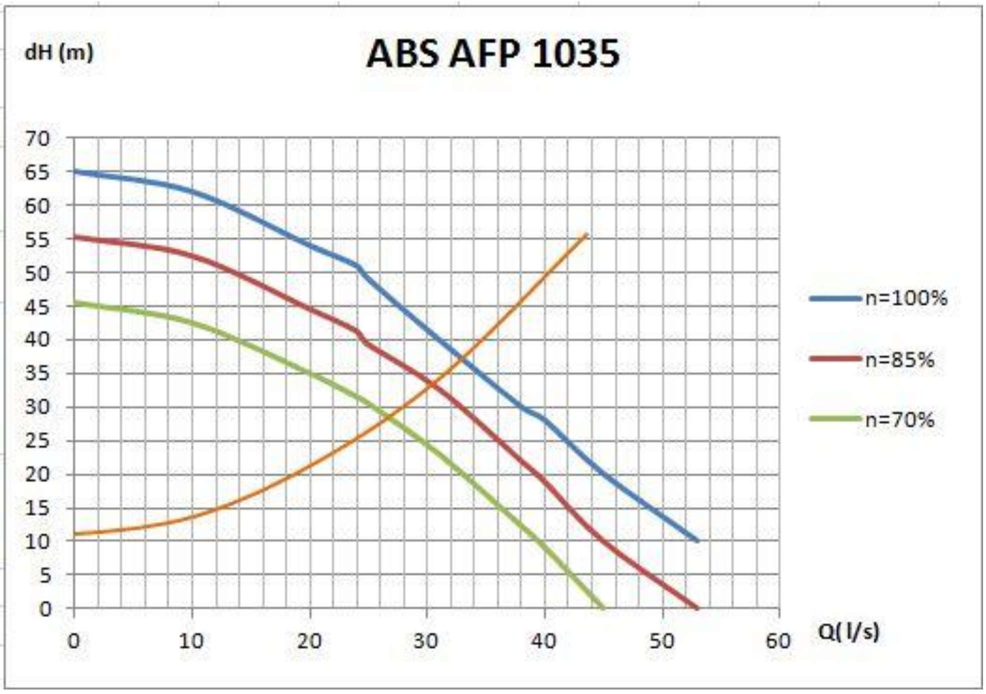


**Fig.6 Characteristic performance curve of ABS AFP 1035 pump**

The graphics drawing of the ABS AFP 1035 pump (PS5) at 100% efficiency shows that the pump started pumping 32 times a day, while the longest pumping time was 40 min from 14:45 to 15:25. The maximum flow rate of the pump was 0.032 $m^3.s^{-1}$, which is 32.0 $l.s^{-1}$ (Fig. 7).

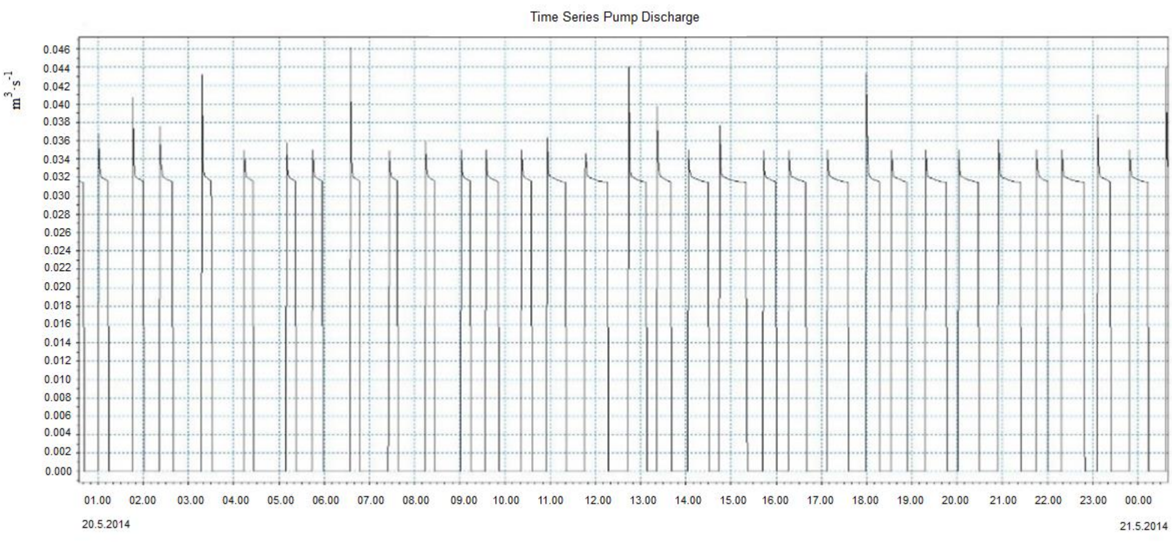


**Fig.7 Graphics pumping performance of ABS AFP 1035 pump at 100%**

The graphics performance shows pumping at 85% efficiency where it is apparent that the pump started pumping 29 times a day, while the longest pumping time was 43 min from 21:05 to 24:48. The maximum flow rate of the pump was 0.03 m3.s-1, which is 30.0 l.s-1 (Fig. 8).

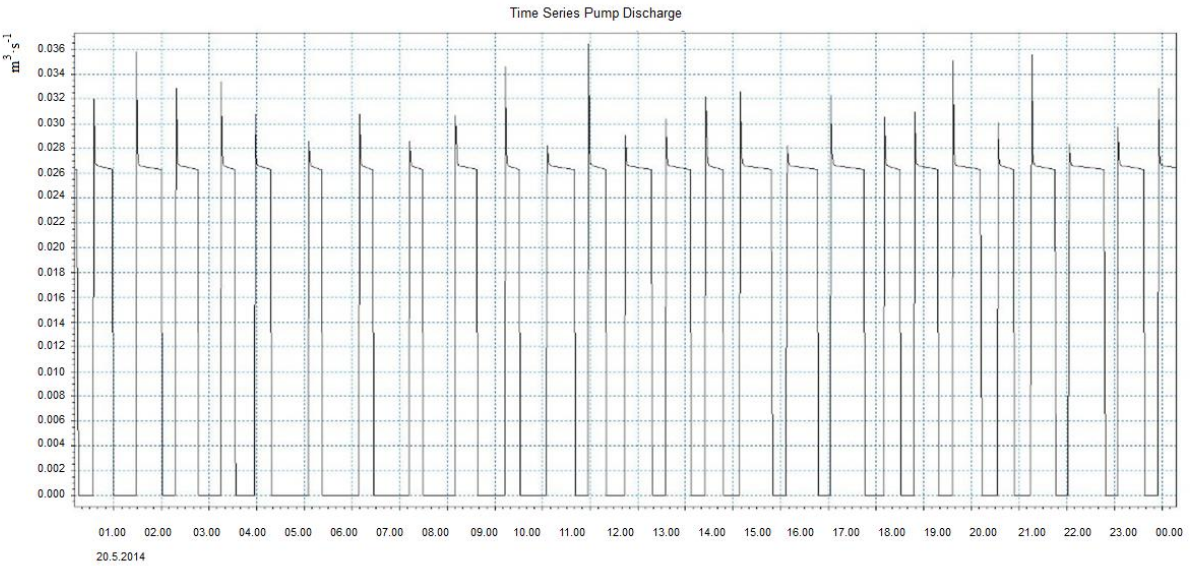


**Fig. 8 Graphics pumping performance of ABS AFP 1035 pump at 85%**

The graphics drawing at 70% efficiency shows that the pump started pumping 26 times a day, while the longest pumping time was 50 min from 21:00 to 21:50. The maximum flow rate of the pump was 0.026 m3.s-1, which is 26.0 l.s-1 (Fig. 9).

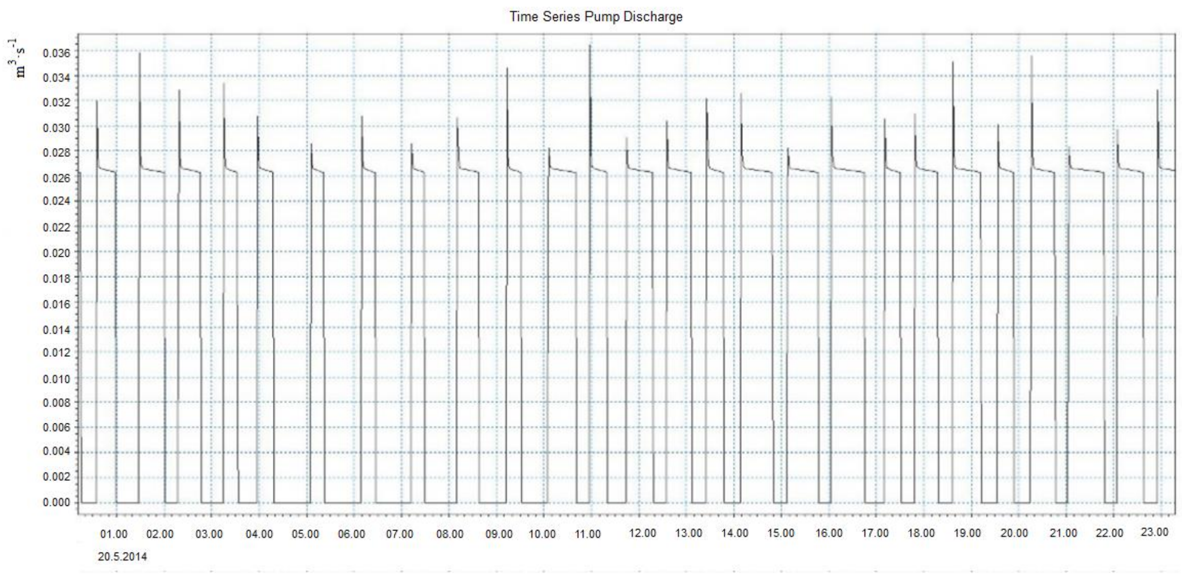


**Fig. 9 Graphics pumping performance of ABS AFP 1035 pump at 70%**

In this case, the simulation showed considerable savings in operating costs. They are induced by the ideal pump design and by that the efficiency points are in the range of pump efficiency, which corresponds to the flow rates for individual efficiency levels. At 70% efficiency, the saving potential is 703 euros/year. When the price of VSD amounts to around 500 Euros, the return on investment is 14 months of operation (Tab. 1).

**Tab. 1 Calculation of electric energy consumption for the ABS AFP 1035 pump at various efficiencies**

| PS5 - ABS AFP 1035 | 100% | 85% | 70% |
|---|---|---|---|
| Pumping time (hr.) | 11,0 | 11,5 | 12,6 |
| Pump power (kW/h) | 26,0 | 24,0 | 21,0 |
| EUR/day | 25,7 | 24,8 | 23,8 |
| EUR/year | 9395,0 | 9067,0 | 8692,0 |

## 4 CONCLUSIONS

The article shows the possibility of using hydroinformatics systems to optimize existing sewage systems. Several unusual operating conditions were simulated that were discussed with the attended operation of Bratislava Water Company.

The first simulation was focused on power failure during pumping in PSs and the ability of the sewer system to accumulate sewages. The simulation showed that it took about eight and a half hours, until sewages sprained above the surface. The water company operations need to ensure the removal of faeces car first from PS16, PS11 and PS7. Due to the low built up area density in the peripheral parts of the sewer network, the sewers can be accumulated for few days.

The next step of simulations included illegal connections from roofs to the sewage system. Three variants of the simulation were carried out with a 10%, 15% and 30% share of connections from roofs of the total area in question. On peripheral edges of sewer, where pipes of smaller diameters in smaller depths were designed, the 10% simulation showed a problem with flooding as first. Also PS16 was the most problematic as it was flooded in 15 minutes before the start of the simulation. In the alternative of 15% connection, sewages sprained above the surface in the 14-th minute and in the case of 30% connection already in the 10-th minute. Flooding of PS7, PS12 and PS10 occurred with less time differences. The strategic PS5 drained sewages reliably in all three alternatives.

The application of a variable frequency drive was the third part of the simulations. It aimed at demonstrating potential savings in operating costs and due to a prolonged period of repairs and life cycle. The simulations were conducted with 100%, 85% and 70% characteristic efficiency. The possibility of savings in operating costs was demonstrated in two cases: for PS1 and PS5. For PS5, the return of investments was within 14 months of operation and for PS1 up to 15 months. It is important to note that the reduction in efficiency also reduces the pump flow, which may negatively affect the function of macerator pumps. Result may be the clogging of the pump by stiff particles.

The achieved goals of simulations will be incorporated into a security plan of the sewerage system which can also be applied to other similar systems. The article may be used as an analysis of current situation and also help predict and accurately identify weak points of the system and can optimize effectiveness of operation and performance. It has been shown that by linking of individual water infrastructure systems, such as CTD, GIS and mathematical modelling, a powerful tool can be obtained to reduce operating costs and possibly predict negative events which could cause significant financial losses.

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**RESUMÉ**

Cieľom príspevku bolo vytvoriť metodiku využitia prostriedkov hydroinformatiky v oblasti bezpečného odvádzania odpadových vôd a preukázanie možných výhod ich využitia. V rámci východnej Európy sa len veľmi ťažko stretneme s publikáciami, ktoré by opisovali riešenie optimalizácie jestvujúcej splaškovej kanalizačnej siete s kombináciou niekoľkých čerpacích staníc. S realizovanými pokusmi optimalizovať systémy odvádzania OV sa môžeme stretnúť hlavne v zahraničí. Z tohto dôvodu bolo množstvo informácií čerpaných zo zahraničnej literatúry a vedeckých štúdií.

Pre splnenie zadefinovaných cieľov bola spravená analýza implementácie informačných technológií v podobe matematického modelu v prepojení na dátové zdroje BVS. Dôležitou súčasťou príprav a stavby matematického modelu sústavy bol transfer dát. Pre správne fungovanie bolo nutné model nakalibrovať s využitím dát s centrálneho technického dispečingu. Nakalibrovaný model charakterizoval súčasné prevádzkové pomery na sieti, vďaka čomu mohol byť aplikovaný pri riešení predpokladaných reálnych neštandardných stavov. Zároveň sa preukázalo jeho možné využitie na iné sústavy.

Dosiahnuté výsledky bude možné zapracovať do plánu bezpečnosti odvádzania OV, ktorý sa bude môcť aplikovať aj na iné, podobné sústavy. Práca môže slúžiť, ako analýza súčasného stavu a tiež pomôže predpovedať a presnejšie identifikovať slabé miesta systému, môže optimalizovať z cieľom zefektívnenia prevádzky a hospodárnosti systému. Bolo preukázané, že prepojením jednotlivých sústav vodárenskej infraštruktúry, ako CTD, ZIS, GIS a matematického modelovania získame silný nástroj pre zníženie prevádzkových nákladov a možnú predikciu nepriaznivých udalostí, ktoré môžu spôsobiť značné finančné škody na majetkoch.