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ICT systems supporting sustainable operation and development of municipal waterworks

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Contents

1. INTRODUCTION

Communal waterworks usually consist of four independently working subsystems: pumping unit and a water clarification plant, water distribution network, wastewater network and finally a wastewater treatment plant. A computer aided support of a waterworks is commonly related to independent support of the above listed subsystems. The main difficulties might lie in technical development: separate computer programs are bought for these subsystems. It results in overlapping many operational tasks by different enterprise divisions. This type of approach might lead also to so called "information chaos" which in fact makes the management of the company more complex. Hence, the management team of the waterworks are discouraged to invest in modern, innovative IT systems. Moreover, the capabilities of integration of different programs distributed by different vendors are difficult and time consuming.

On the other hand, the real structure of the waterworks consists of the in rows structure of the above listed subsystems and should be reflected in an IT software which supports as a composite unity the water company. Unfortunately this type of management is commonly not implemented. Hence it is crucial to develop integrated ICT systems taking into account a holistic view of the waterworks and corresponding technological processes. The implementation of such the systems in waterworks secures their sustainable operation and development and such the kind of operation could be called as waterworks smart management. Such systems are under development in System Research Institute (IBS PAN) for over 15 years.

In this report the design of the last, most advanced ICT systems called MOSKAN-W and MOSKAN will be presented. Furthermore the main use cases, functions and capabilities of the both systems will be described.

Currently the ICT systems support the management of the following working subsystems: pumping unit and water clarification plant, water distribution network and wastewater network. The results of implementation of the systems in some Polish waterworks will be also discussed.

2. THE MAIN COMPONENTS OF THE ICT SYSTEM FOR WATERWORKS MANAGEMENT

According to the mentioned idea in development of integrated ICT systems a concept of a system for joined solution of many management tasks in waterworks scale has been developed at IBS PAN (Fig. 1).

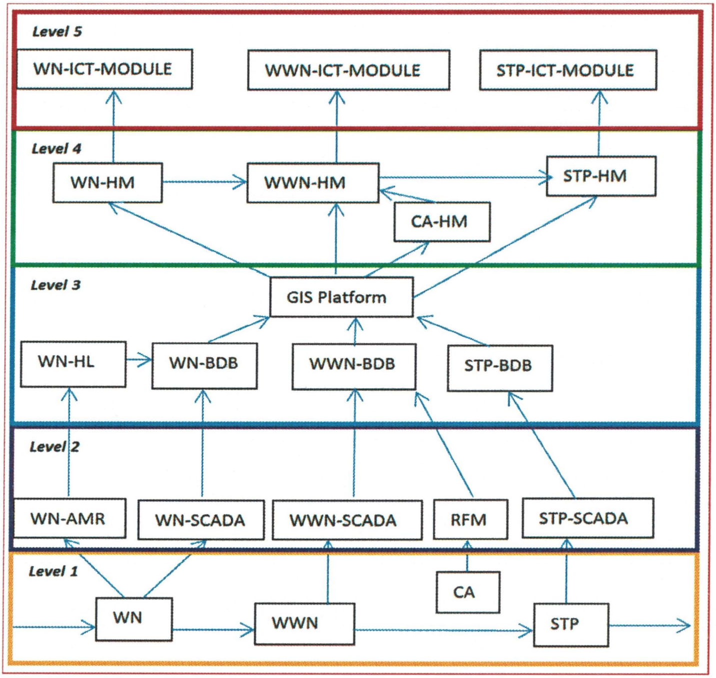

Figure 1. Block diagram of the ICT system for smart management of a waterworks; WN – WaterNet, WWN – WasteWaterNet, CA – CatchmentArea, STP – SewageTreatmentPlant, AMR – Automatic Meter Reading, RFM – RainFallMonitoring, HL – HydraulicLoad, HM – HydraulicModel.

In this system 5 structural levels consisting of 4 waterworks objects and several program modules are foreseen and the key module of the system is the GIS platform with its central data base divided into 4 object oriented branch data bases (BDB).

The waterworks objects located on the *Level 1* of the ICT system are Water Network (WN), Waste Water Network (WWN), Water Catchment Area (CA) on which the waste water network is located and Sewage Treatment Plant (STP). On *Level 2* the programs of monitoring of water net (WN-SCADA and WN-AMR), wastewater net (WWN-SCADA), catchment area (RFM) and the sewage treatment plant (STP-SCADA) are collected. These programs are *on line* measuring and recording in their data bases the data concerning the water production and selling, water flows and pressures in the water net, rain falls, canal filling heights and sewage flows in the wastewater net and the raw sewage inflow to as well as clarified sewage outflow from the sewage treatment plant. These data are exported to the GIS branch data bases which are parts of the central data base of the GIS system situated on *Level 3* of the ICT system. There from all the data some special data tables are prepared including the information enabling hydraulic modelling of the waterworks objects and in form of so called *views* they are transferred to *Level 4* where the programs for modelling the water net, wastewater net, catchment area and the sewage treatment plant are assembled. On *Level 5* are the programs solving the waterworks management tasks with the use of algorithms of approximation, mathematical modelling and optimization. In this way each level of the ICT system is a kind of data source for the successive level programs and the programs of the last *Level 5* are these ones which realize the actual computer support for the water works management. These programs are collected in 3 computing modules dedicated for water net (WN-ICT-MODULE), waste water net (WWN-ICT-MODULE) and sewage treatment plant (STP-ICT-MODULE) (Fig. 1).

Each computing module of the ICT system is autonomous and can run independently from each other but at the same time all modules cooperate via their hydraulic models with the GIS system using for their runs the data gained from the

GIS central data base. Each module and also each hydraulic model has got its own interface and its own database and these bases exchange the data with the GIS data base or with each other via SQL tables. In the following the short descriptions of the system modules are given [4, 5, 7, 9].

Water Net ICT Module

The ICT Module for water net developed in IBS PAN is most extensive and best tested in the practice in several Polish waterworks. Its structure and functionality is shown in Figure 2. It consists currently of ca. 20 programs realizing the main water net management tasks by means of algorithms of multi objects optimization, kriging approximation and mathematical modelling. These tasks are for example [8]: water net hydraulic optimization when with the exchange of some selected pipes the water pressure is regulated on the end user nodes of the network; energy saving pumps control in the pump works located at the network and serving for supplying it with the water or for raising the pressure inside the net; planning the water net revitalization what means the selection of pipes to be repaired or exchanged because of the risk of their failure; planning the network extension in case of a city development or of attaching some neighbour nets to the municipal one; valves control for raising the water flow velocities and improving as the result the water quality; detection and localization of the hidden water leaks to eliminate or reduce the water losses resulted from the leaks.

To realise these tasks a water net hydraulic model correctly calibrated and also a SCADA system appropriately planned have to be available. Because of that also some programs for calibration or temporal recalibration of the water net hydraulic model and for relevant planning of SCADA system are included into the ICT Module.

More detailed descriptions of the algorithms used in the ICT Module and of their ideas are in [2] regarding the planning of the water net revitalization, in [6] regarding the SCADA planning, in [10] regarding the localization of hidden water leaks and in

[12] regarding the pumps control. For water leaks detection the neuronal nets and for multi objects optimization some heuristic and genetic algorithms are applied.

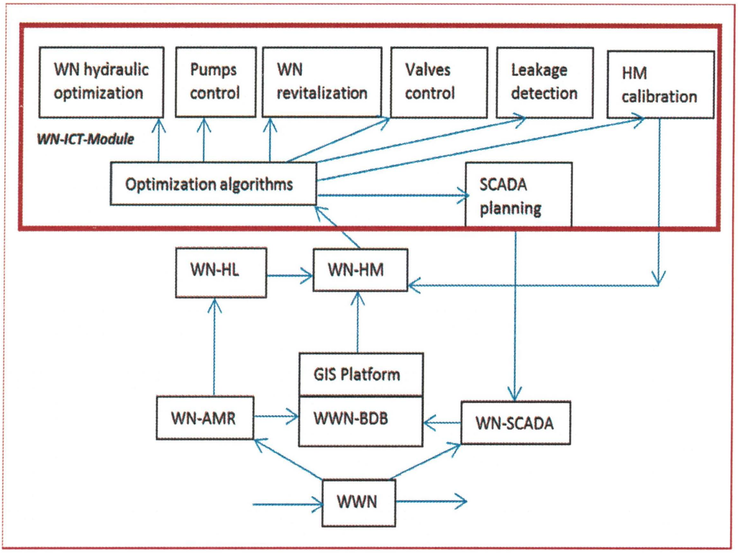

Figure 2. Structure and functionality of the WN-ICT Module.

A preliminary version of the Watern Net ICT Module has been presented in [9] and a possibility to use it as one of the main modules of an ICT system planned for smart city management of a Polish city was discussed in [1].

Wastewater Net ICT Module

The ICT module for wastewater net is sparser in its functionality and also less tested in the practice than the Water Net ICT Module The ground for it is that the modelling and optimization of communal sewage networks are more complex and complicated than in case of water nets and especially the development of wastewater net models is a very difficult problem. By a water net only 1 hydraulic model of the object is to formulate and calibrate and it consists of relatively simple linear and nonlinear algebraic equations. Contrary to this by a wastewater net 3 different models are to develop and they are the hydraulic of the network, the model of the catchment area on which the wastewater net is located and some rain fall models that generate beside the communal sewage the additional wastewater inputs to the net. Also the hydraulic model of the wastewater net is much more complicated than a water net model for it consists of partial difference equations more complex by their solution and more time consuming by their calculation than the algebraic relations. Because of that also the implementation of wastewater net models in the waterworks is very rare and hardly to notice in their operational practice.

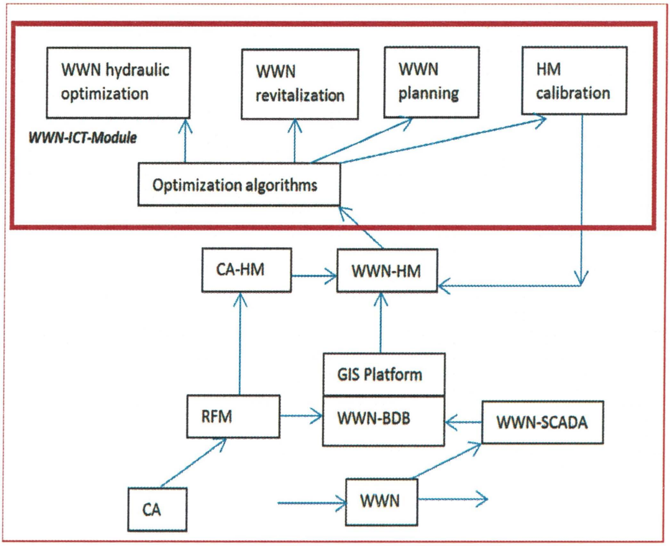

Figure 3. Structure and functionality of the WWN-ICT Module.

The structure and functionality of the ICT Module for wastewater net developed in IBS PAN is shown in Fig. 3. It consists currently of 4 programs realizing the main wastewater net management tasks by means of algorithms of multi objects optimization, mathematical modelling and fuzzy sets. These tasks are [4]: wastewater net hydraulic optimization when with the exchange of appropriate canals their filling with the sewage is regulated; planning the wastewater net revitalization what means the selection of canals to be repaired or exchanged because of the risk of their failure; planning the network extension in case of a city development or of attaching some neighbour nets to the municipal one. To realise these tasks a wastewater net hydraulic model correctly calibrated and also the catchment area model and the rain fall models have to be available. Because of that also some programs for calibration or temporal recalibration of the wastewater net hydraulic model and for making automatically the reliable models of the catchment and rain falls are included into the ICT Module.

More detailed descriptions of the algorithms used in the ICT Module and of their ideas are in [5] regarding the planning of the wastewater net revitalization and in [4, 11] regarding the wastewater net hydraulic optimization and planning and the calibration and temporal recalibration of the network hydraulic model. For wastewater net revitalization the fuzzy sets algorithms and for multi objects optimization the heuristic and genetic algorithms are applied. The results of testing a preliminary version of the Waste Water Net ICT Module has been described in [11] and a possibility to use it as one of the main modules of an ICT system planned for smart city management of a Polish city was discussed in [1].

Sewage Treatment Plant ICT Module

The ICT Module for sewage treatment plant is currently least worked out and it consists of smallest number of the programs included. The reason for it is the most complicated mathematical description of the object in comparison with other objects of the waterworks. In the sewage treatment plant model beside the object hydraulics also the biological and chemical processes occurring in the biomass flowing through the plant tanks have to be considered. Bacteria and microorganisms creating the biomass are responsible for reducing the sewage pollution and the modelling of these processes described by means of ordinary difference equations and afterwards the calibration of the model including hundreds of unknown parameters is a really hard task. The model including in its structure the object hydraulics and the biomass processes is called as the physical model. By the calibration of this model many calculation runs must be done and in case of the model consisting of hundreds differential equations this process is very time consuming.

To go around this problem an operational model of the plant in form of neuronal nets is formulated and this model that is rapider regarding the computing time serves for modelling the physical model that models the real object. In this way the sewage treatment plant modelling occurs in two phases and the operational model is used for elaborating the object control algorithms which are then tested by simulation runs of the physical model.

The structure and functionality of the ICT Module for sewage treatment plant developed in IBS PAN is shown in Figure 4. It consists currently of 2 programs realizing the main wastewater net management tasks by means of algorithms of multi objects optimization neuronal nets. These tasks are [7]: development of control algorithms regulating the rates of recirculation flows of biomass between the tanks from which the object is consisted; calibration and temporal recalibration of the physical and operational models of the plant. The physical model consists of separated models which are connected in rows and that describe the individual tanks of the whole object and which are: primary clarifies reducing the organic components from the sewage; activated sludge basins in which nitrogen and phosphor pollution are reduced by the bacteria being in the biomass; secondary clarifiers where the sludge is separated from the treated sewage by means of gravitational settling of the sludge particles. The calibration of the physical models consist then in successively followed calibration of each of these individual models. In case of the operational model it describes the object as a whole and also its calibration is a one-off process.

The results of testing a preliminary version of the Sewage Treatment Plant ICT Module has been described in [7] and a possibility to use it as one of the main modules of an ICT system planned for smart city management of a Polish city was discussed in [1].

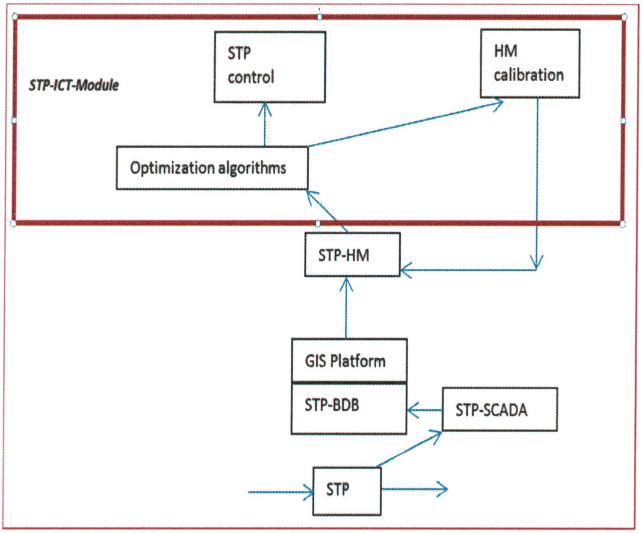

Figure 4. Structure and functionality of the STP-ICT Module.

Waterworks Management

In frame of the smart and sustainable management of waterworks an integrated ICT system supporting the solution of many management tasks has been developed in IBS PAN and partially implemented and tested in several Polish waterworks. In this ICT system the computer aided management of the water network, wastewater network and the sewage treatment plant basing on the hydraulic models of the objects investigated and on some algorithms of optimization and mathematical modelling is realized. To do it the monitoring systems supervising the water and wastewater nets and the sewage treatment plant must be implemented in the waterworks and with the hydraulic models and optimization algorithms together they are integrated with the GIS system being the computing platform for all programs and forming in this way an united ICT system.

An IT system for computer aided management of communal water networks by means of GIS, SCADA, mathematical models and optimization algorithms has been already presented on the ICT4S'2013 in Zurich [9]. In the ICT system for the management of the whole waterworks the IT system developed for water nets has been extended about new systems dedicated for the wastewater network and sewage treatment plant. These three IT systems are internal integrated based on the data base communication via SQL tables.

The main goals of the ICT system proposed and already constructed are minimization of the operational costs of the whole enterprise and securing the accident-less functioning of its key objects. Some other main goals that are to be achieved with the ICT system are the improvement of the quality of the drink water produced by the water network, generation of scenarios of planning the water and wastewater nets revitalization, control of pump works installed in the water net, hydraulic optimization of water and wastewater nets, reducing the water losses by the early detection and localization of the hidden water leaks in the water net and the environment protection by minimizing the amount of pollutions introduced to the city river by the sewage treatment plant. The innovation features of the ICT system developed are the integration of all programs supporting the waterworks management in form of an united and centrally operated system, the simultaneous management of all objects being the elements of the waterworks and the use of mathematical algorithms of optimization and modelling for the solution of all management tasks.

The integration between individual modules of the ICT system is implemented on the database level which means sharing the information (tables, views) directly between specialized local databases. E.g. the database of the water network module will read the data describing the network and its parameters from surveying GIS branch database and after this transfer the module programs will use the data for water net hydraulic calculation or optimization. That approach makes modules communication simple, reliable and seamless executable. This is in contrary to the currently practice of waterworks management when the enterprise objects are operated separately with the use of several programs running autonomously and without any cooperation. As a result the quality of the management of different enterprise objects and either their development and modernization is also unalike and very differentiating. The development and introducing into practice of the ICT system described can secure the sustainable development of the waterworks as well as their smart management.

In the following two examples of implementation of the ICT systems in a water network and wastewater network in Poland still as separated and not integrated systems are presented.

3. CASE STUDIES OF IMPLEMENTATION OF ICT SYSTEMS

3.1. ICT for water networks

Software MOSKAN-W dedicated only for communal water nets has been implemented in the Polish waterworks in Mikołów being the city with the population of 40.000 inhabitants. The network investigated is of the length of 310 km with the number of the end users equal to 7.600 objects and with the daily water production equal to 7.500 m^3. The hydraulic graph of the network exported by a GIS system to the hydraulic model consists of ca. 3.500 pipes and 3.500 nodes (Fig. 5).

On the water net a SCADA system consisting of 100 measuring instruments for water pressure and of 50 instruments for water flow is installed. The water sale is measured by an AMR system and the data are sending on line via radio transmission to SQL database of the monitoring system.

From there they are imported by the GIS system and prepared as input data for the hydraulic model. To the AMR system all end users of the water net are attached. In this way the calibration of the water net hydraulic model can be done automatically and for the data concerning the water selling and water production in form of hourly curves with the time horizon of 24 hours. In Fig. 6 the localization of the monitoring points for flow and pressure measurements on the water net is shown.

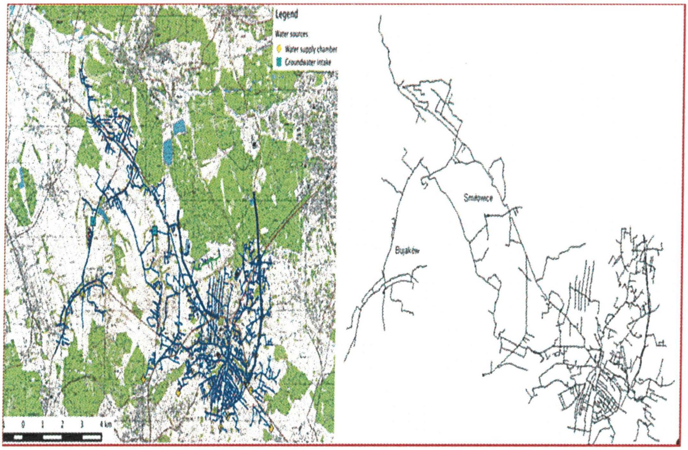

Figure 5. Water network investigated on the geodesy card (*left*) and as graph exported to the hydraulic model.

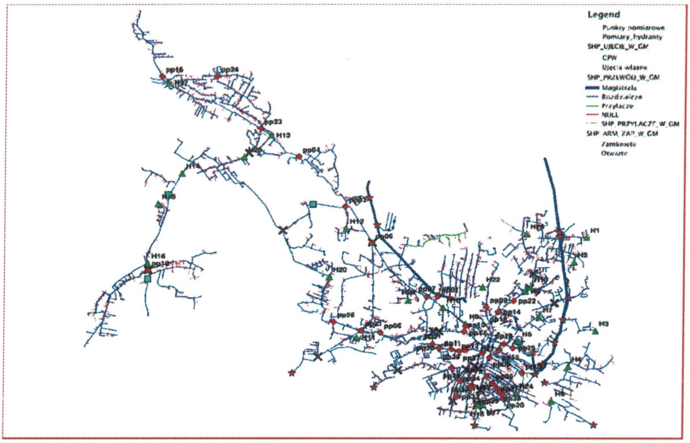

Figure 6. Graph of the water network modelled with the measurement points marked.

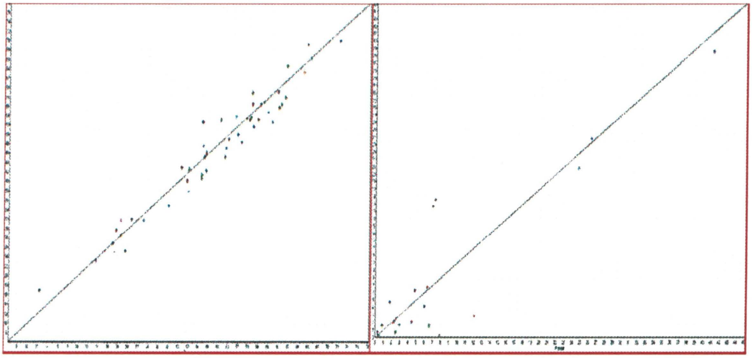

Figure 7. Calibration results for water pressures (*left*) and water flows as differences between measurements and calculations in monitoring points.

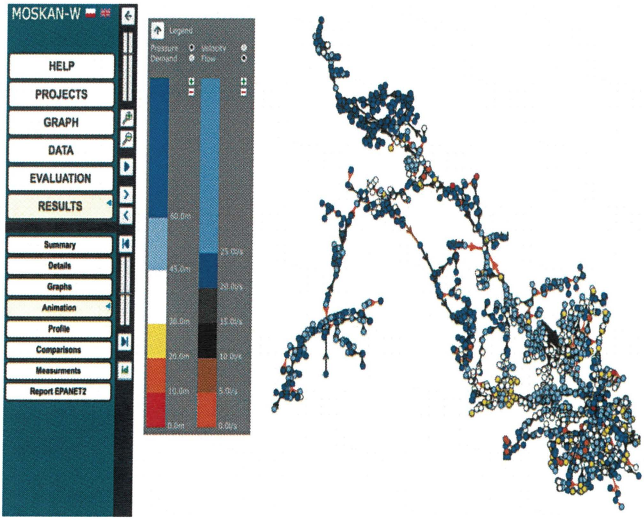

Figure 8. Results of hydraulic model calibration on the MOSKAN-W screen.

The calibration of the water net model was realized using the MOSKAN-W system and an algorithm of multi objects optimization with two criteria of quality defined for the deviations between the calculated and measured values of pressure and of flow. The results obtained are very satisfied for the correlation coefficient calculated for pressures equals to 97% and this one calculated for the flows equals to 90% (Fig. 7). In Fig. 7 the screen of MOSKAN-W assigned for water networks with the calibration results is shown; with different colours the flows and pressures with the values belonging to different value ranges are marked.

3.2. ICT for wastewater networks

Software MOSKAN dedicated for communal wastewater nets has been implemented in the Polish waterworks in Poznań on a selected reference catchment (Fig. 9).

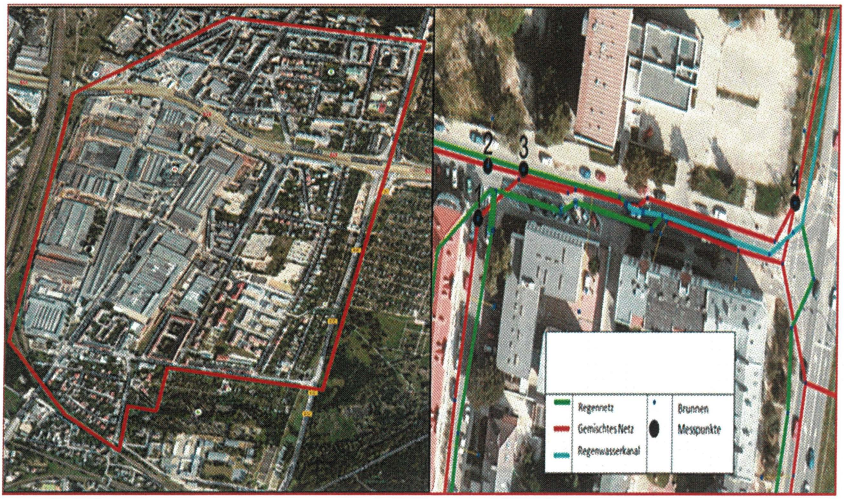

Figure 9. Catchment investigated (*left*) and SCADA point on the network.

Modelling of wastewater nets is more complicated than in case of water nets when only the hydraulic model for the network has to be formulated. By the wastewater nets three separated models for the network, the catchment and for the rainfalls are to make and the data generated by the catchment and rainfall models are then used as inputs for the network model. Also the network model for sewage systems is more complex than the model for water nets for it consists of differential equations which are more difficult to solve than the algebraic ones. The wastewater net given off for the modelling consists of 275 nodes and 285 canals. On this network a monitoring system is installed consisted of 4 measurement points assigned to measure the heights of canal fillings with the sewage and of 1 measurement point to measure the rainfalls (Fig. 9). Unfortunately 2 of 4 monitoring points for canal filling measurements were out of order during the time of the network modelling and the measurement data from only 2 points P1 and P2 could be used to calibrate the network model.

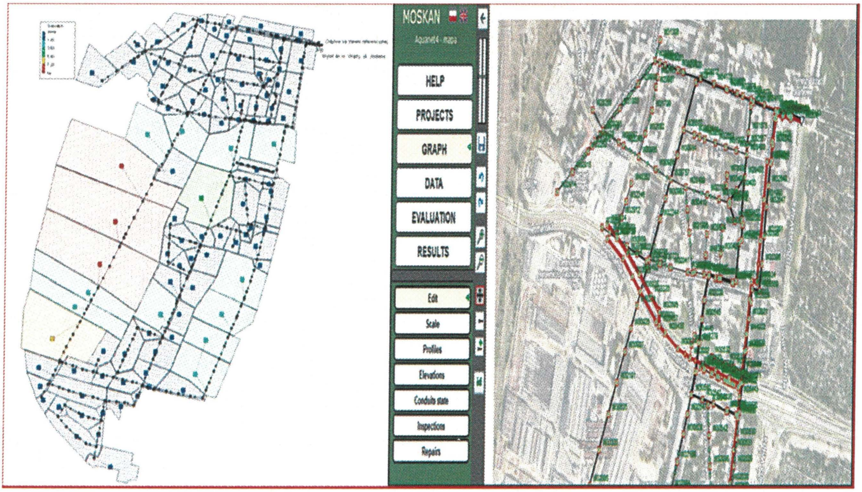

Figure 10. Catchment model (*left*) and network graph on the MOSKAN screen.

While modelling the catchment it has been divided manually in 110 singular catchments for which the individual surface and slope values were calculated automatically using the tools of a GIS system. The catchment divided into singular catchments as well as its depiction on the screen of MOSKAN are designed in Fig. 10.

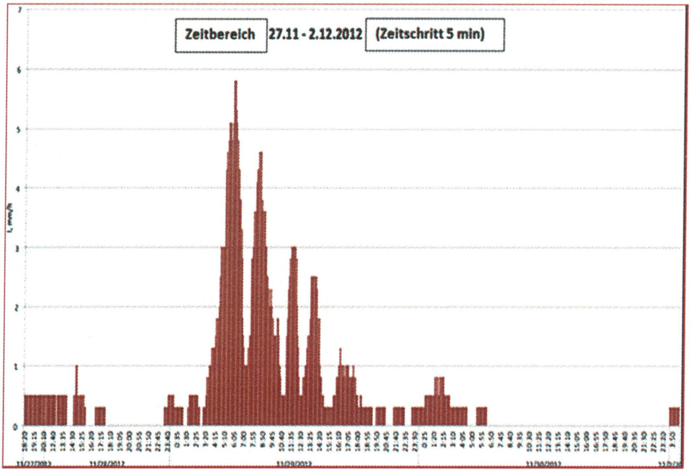

Figure 11. Rainfall model for the sewage network modelling.

The data won from the monitoring devices are shown in Figures 11 and 12 and they concern the rainfall measurements and the canal filling heights measurements in the measurement points P1 and P2.

The calibration of the wastewater net model has been done by means of a multi object optimization algorithm and the model parameters that were optimized are roughness and dimension values of the canals. By the calibration of the whole sewage system consisted of the network, catchment and rainfall models also the catchment model was calibrated but it has been done by hand and the catchment parameters optimized are the soil porosity values changed individually for each singular catchment.

In Fig. 13 the calibration results are shown while the measuring data with red colour and the calculation results with green one are marked. In general are the results satisfied as for the both monitoring points P1 and P2 the measurement and calculation data show a quite good accordance.

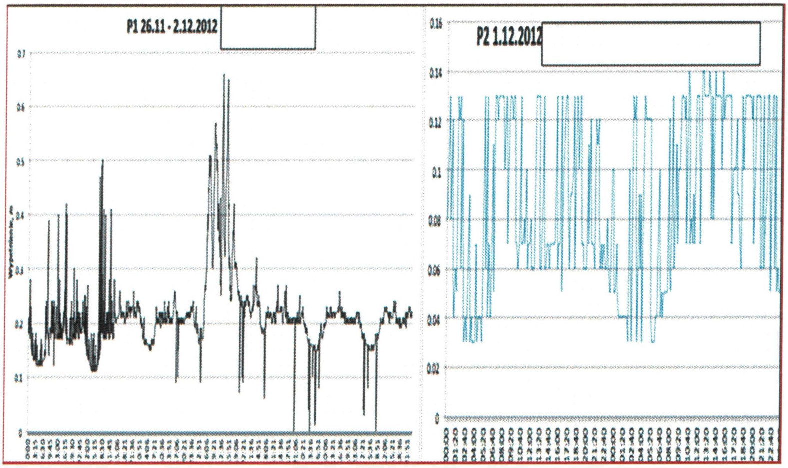

Figure 12. Measurements data from monitoring points P1 and P2.

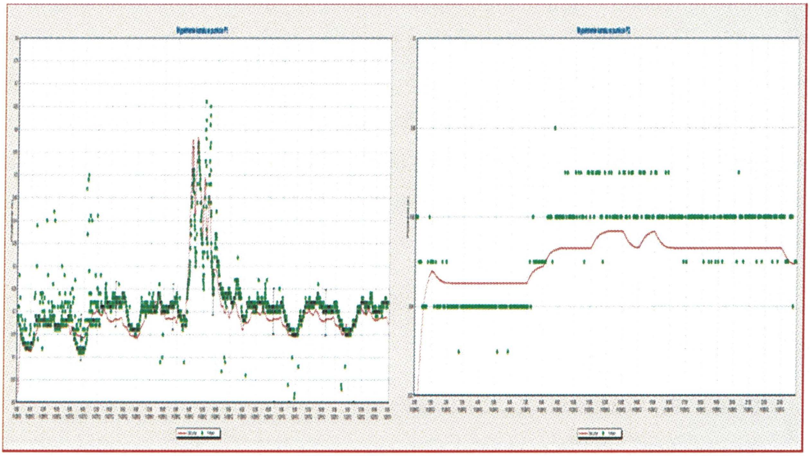

Figure 13. Calibration results for monitoring point P1 (*left*) and P2.

The imitation of the measurements by the calculation results are better and more quantitative for point P1 than for point P2 for which they are of more qualitative kind;

the reason for it is that also the measurements coming from this second monitoring point were of a rather poor quality (Fig. 12).

4. CONCLUSIONS

The report describes a concept of integrated ICT system for supporting municipal waterworks management. The concept is based on the idea that has been developed at the Systems Research Institute (IBS PAN) in Warsaw in cooperation with Intergraph Polska responsible for including into the ICT system a GIS program and its integration with the monitoring and modelling and optimization programs.

Currently tested and also still developed modules support areas of water supplying and wastewater transporting and treatment systems. Water net and wastewater net ICT systems as well as the sewage treatment plant ICT system are enriched by numerous mathematical models and multi objects optimization and approximation algorithms that enable to support with computer technique all management tasks occurring in the waterworks. These tasks concern technical operation of the waterworks that could be called as waterworks *hard management* as well as organizational and administrative actions that could be called as waterworks *soft management*. These both kinds of management tasks are commonly realized in the waterworks separately with different programs what often leads to an information mess instead to cause the improvement of the enterprise management.

5. REFERENCES

1. Bryłka R., Kazubski K., Studzinski J., "ICT system for SMART CITY management". 2nd International Conference on ICT for Sustainability (ICT4S 2014), 24-27 August 2014, Stockholm, Sweden, 258-264.
2. Saegrov, S., "Care-W – Final Report". Research Report, SINTEF, Trondheim 2004.

3. Saegrow, S., "Care-S – Final Report". Research Report, SINTEF, Trondheim 2005.

4. Służalec A., Studzinski J., Ziolkowski A., "Optimization of sewage structure in the integrated system for sewage design, management and revitalization – MOSKAN". In: Simulation in Umwelt- und Geowissenschaften (J. Wittmann, M. Mueller, Hrsg.), ASIM-Mitteilung AM 146, 2013, 203-210.

5. Stachura, M., Fajdek, B. and Studzinski, J., "Model based decision support system for communal water networks". ISC'2012 Conference, Brno, June 4-6, 2012, 19-23.

6. Straubel, R., Holznagel, B., "Mehrkriteriale Optimierung für Planung und Steuerung von Trink- und Abwasser-Verbundsystemen". Wasser Abwasser, Vol. 140, No. 3, 191-196.

7. Studzinski J., "Wastewater treatment plant maintenance using the plant mathematical models". In: Quality, Reliability and maintenance, 4th International Conference QRM'2002 (G.J. McNulty, ed.), PEP London, 137-140.

8. Studzinski, J., "Some algorithms supporting the computer aided management of communal water nets". In: Modelling and Simulation'2009 (Marwan Al-Akaidi, Ed.) EUROSIS-ETI Publication, Leicester, UK, 2009, 345-349.

9. Studzinski J., "IT system for computer aided management of communal water networks by means of GIS, SCADA, mathematical models and optimization algorithms". In: Proceedings of the ICT for Sustainability Conference: ICT4S, Zurich, February 14-16, 2013, 123-127.

10. Studzinski J., Rojek I., "Failures localization within water networks by means of neuronal nets". In: European Simulation and Modeling Conference: ESM 2012, Essen, October 22-24, 2012, 64-68.

11. Studzinski J., Wójtowicz P., "Simulation von Abwassersystemen mit der MOSKAN Software". ASIM 2014, 22. Symposium Simulationstechnik,

Tagungsband, ASIM Mitteilung AM 151 (Jochen Wittmann, Christina Deatcu, Hrsg.), HTW Berlin, 03-05.09.2014, 181-185.

12. Waterworth G., „Efficiency modeling in the cost reduction of water pump maintenance". In: Proceedings of QRM'2002, Ed. G. J. McNulty, PEP London, pp. 141-144.