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OPERATIONAL CONTROL SCENARIOS FOR A WATER INTAKE SYSTEM WITH AN ARTIFICIAL RECHARGE

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Abstract

In the management of modern water supply facilities, it is essential to achieve the objectives of sustainable development. Recent monitoring devices, together with Information and Communication Technology tools, enable the design and use of methods ensuring that a variety of requirements will be met. This paper presents an original methodology for creating control scenarios for a water intake with managed aquifer recharge while meeting a set of operational criteria. An operational scenario is understood as the control of pump operation in the process of water intake from wells in barriers consisting of several dozen pumps each. The most important criterion is the need to collect infiltrated water from the aquifer evenly over the entire length of the wells in barriers; this is enabled by the introduction of the Sum of Neighborhood Factors. The development of the method was preceded by the identification of objects and processes together with the determination of control and controlled parameters to establish limitations and criteria. The proposed solution was implemented in the form of an algorithm that takes into account the current state of the facility and uses an established knowledge base as a function of a Decision Support System. The proposed methodology was applied to an exemplary water intake facility with an artificial recharge system. The topic of this paper refers to the problem of applying expert systems in the management of water supply systems.

Key words: artificial infiltration, control system, decision support, water intake, water management

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1. Introduction

Modern water intakes can be equipped with monitoring, data acquisition and process control systems. They allow the operator to obtain information about the state of the facility and to interact with it (Dobriceanu et al., 2008; Whittle et al., 2013). Current knowledge and tools in the field of automation - in terms of implementing and monitoring devices and computer data processing - nowadays enable the operation of processes of water supply systems in a way that several years ago was not feasible (Brodziak and Bylka, 2014; Cetinkaya et al., 2008; Koo et al., 2015; Rodney et al., 2018; Stancel et al., 2008).

The amount of information and variety of types of data collected for a complex facility may be large. Variable operational conditions can cause difficulties in the control of facilities based solely on the knowledge and experience of the facility operator. In control systems, hierarchical and distributed approach can be used, as well as various types of algorithms for determining the operating parameters of the devices (Kozłowski et al., 2017; Ormsbee and Lansey, 1994). Water supply systems, due to their complex structure and the multitude of requirements that are expected to be met, can be improved by means of advanced control systems that use smart control algorithms (Mala-Jetmarova et al., 2017; Tatjewski, 2007; Tayfur, 2017). Therefore, to provide support to operators, it is necessary to use modern IT tools, including both hardware and software (Eusuff and Lansey, 2004; Hadžiosmanović et al., 2012; Walski et al., 2013). The combination of automation hardware tools together with IT technologies and the ability to process large amounts of data in complex systems leads to the emergence of a new engineering area called Smart Water Systems (Li et al., 2020; Public Utilities Board Singapore, 2016).

This work aims at presenting a methodology for creating control scenarios for a system that captures infiltrated water under operating conditions that refer to sustainability criteria. To achieve the objectives of sustainable management (Europa EU, 2000; United Nations, 2015; WCED, 1987) in water intakes, it is necessary, first, to determine requirements, and then to take into account the relevant criteria and limitations in the decision-making process (Bohórquez et al., 2015; Marchi et al., 2017; Price and Ostfeld, 2014).

The primary task of control in an infiltration water intake facility is to achieve the expected water production volume determined by the operator and to transfer it to the next stages in the water production process. Proper task assignment in a control scenario should make it possible to achieve a certain capacity of the wells-barrier, taking into account defined constraints and criteria. The proposed methodology was established in line with the principles of Decision Support Systems, which are based on knowledge representation, reasoning system modules, and available information on the state of the object and defined requirements (Ahlemeyer-Stubbe and Coleman, 2014; Bubnicki, 2003; Sriram, 1997). The methodology for synthesizing scenarios for a water supply operation was implemented as an expert system (Fig. 1). The artificial infiltration process aims at enriching the natural water resources and improving the quality of surface water infiltrated through a natural filtrating layer in the ground. In a typical artificial infiltration facility, surface water from a river, lake or other reservoir is collected by pumping stations, from which it is transported to the aquifer recharge site. Raw water is distributed over a large area by the use of drainage systems, ponds and infiltration ditches, from where it infiltrates into the ground. Pre-purified water is captured by a system of wells (grouped in barriers) with different spatial configurations and transported to a water treatment station for final treatment (Asano, 1985; Bouwer, 2002; Dillon, 2005; Eker and Kara, 2003; Tuinhof and Heederik, 2002).

The structure of the actuators was analyzed for a typical artificial recharge facility, taking into account the hydraulic and hydrogeological requirements and system boundaries. The management of artificial infiltration facilities can be the subject of two separate subsystems: the Raw Water Supply System (RWSS) and the Infiltration Water Intake System (IWIS). The RWSS supplies the aquifer, distributing water from the river (or lake) through a drainage system and infiltration ponds. The goal of the IWIS is to deliver water from the aquifer, with the use of pumps organized in wells in barriers, to the Water Treatment Plant (WTP). The RWSS and IWIS systems affect directly the aquifer, and therefore strongly influence each other (Sanz, 1997; Sendil et al., 1990).

To determine the current operational control scenario, it is necessary to define the task and basic data describing the state of the objects, such as:

- the water volume required for the water supply system and water treatment station;
- the efficiency and readiness of pumping equipment (to determine the operating water intake capacity);
- the height of the water table in the wells (to determine locations where water intake is possible or necessary, or where intake is inadvisable).

To ensure safe operation, the control process should take into account the basic constraints (Foxon et al., 2002). The aim is to eliminate the possibility of failure or damage to the equipment, and above all to ensure fulfillment of the control objective. Some limitations are often embedded directly in the equipment, such as the minimum water level in the well, below which the pump will not work. At the same time, these limitations also need to be included at higher levels of control, such as, in production planning systems.

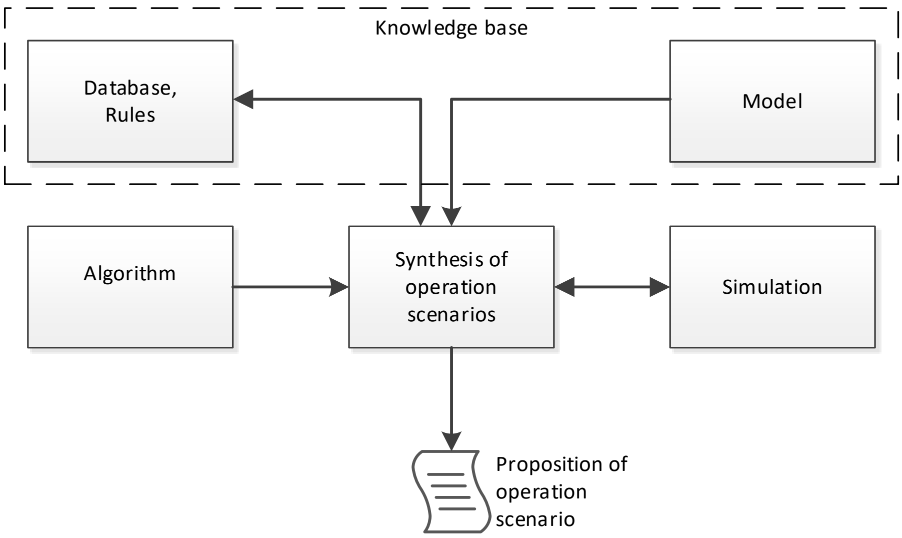

Fig. 1. Diagram of data flow in the system for synthesis of operational scenarios

Control of the water intake system is subject to limitations that include:

- the capacities of the actuators resulting from the construction and specification of the equipment (e.g., pump performance or pipeline throughput);
- limitations built into the actuators in order to avoid operating under conditions likely to cause damage (e.g., thermal protection of the pump when running dry);
- decisions taken by the facility manager to ensure that certain threshold values (resulting from the technological conditions of the facility) are not exceeded.

Additionally, it is recommended for operational scenarios for water intake with an artificial method to take into account the following assumptions that may serve as control criteria:

- Priority water intake from wells with a high static water table.
- Even exploitation of the aquifer, meaning that selections of pumps to be turned on are distributed evenly over the entire length of the wells-barrier. It will ensure avoiding situations, in which pumps in the same vicinity are switched on, while conditions exist (for example, the height of the water table in the well is sufficient) to allow the running of more distant pumps.
- Even pump operation time. It is preferable to switch on a pump with a lower total operating time. This will allow economic criteria to be achieved, as it ensures more uniform use of the equipment, reducing the failure rate and minimizing operating costs.

Data obtained from the measuring devices during operation of the actuators constitute the basis for making further decisions in the algorithm (Duzinkiewicz et al., 2005; Hellström et al., 2000; Sechi and Sulis, 2009; Urbaniak, 2013). Necessary input data may come from various equipment and monitoring subsystems that operate using different technologies. Therefore, to enable them to be synthesized for the scheduling of pump selection, they need to be available in one consistent database system.

A review of the literature did not reveal any reports of algorithmic methods for the control of water intake systems in this type of facility. This may result from the fact that many existing facilities do not possess complete information on processes carried out, because they were constructed at a time when capabilities of automation were limited. Another factor that may play a role, is that such systems are used, but the operating methods have not been publicly disclosed, being treated as part of the operating company's know-how.

2. Methodology

The basic objective of water intake is to provide the appropriate volume of water infiltrated into the WTP, taking into account the defined technological constraints and sustainability criteria. The goal of the proposed method of controlling the water intake system is to determine the operational scenario by indicating the pumps to be turned on for each wells-barrier for a defined task. The control operation of the pump system involves achieving the expected water flow in each well in barriers by turning on suitable pumps while taking into account the constraints and assumptions resulting from the changing operating conditions.

2.1. Object state description

The process of indicating pumps to be turned on requires basic knowledge of the conditions of the facility. Each current state of the facility causes a situation in which the decision-maker must take specific actions. The first stage of decision-making - just after analyzing and identifying the problem – is gathering data. The structure of data suggested below forms the knowledge base for the expert system:

- well readiness state G_i, determined for each well in the barrier (Eq. 1):

$$G_i = \begin{bmatrix} g_{i1} \\ \dots \\ g_{ij} \end{bmatrix} \tag{1}$$

where g_{ij} is the readiness state of the *j*-th pump in the *j*-th well in the *i*-th barrier, taking the value 1 when ready for operation, and 0 in case of failure;

- water table level H_i, determined for each well in the barrier (Eq. 2),

$$H_i = \begin{bmatrix} h_{i1} \\ \dots \\ h_{ij} \end{bmatrix} \tag{2}$$

where: h_{ij} is the water table level in the *j*-th well in the *i*-th barrier [m];

- pump capacity Q_i, determined for each pump in the barrier (Eq. 3),

$$Q_i = \begin{bmatrix} q_{i1} \\ \dots \\ q_{ij} \end{bmatrix} \tag{3}$$

where q_{ij} is the pump capacity in the *j*-th well in the *i*-th barrier [m^3/h];

- pump operational time T_i for each pump in the barrier (Eq. 4),

$$T_i = \begin{bmatrix} t_{i1} \\ \dots \\ t_{ij} \end{bmatrix} \tag{4}$$

where t_{ij} is the total operational time of the *j*-th pump in the i-th barrier [s];

- threshold values of the water table level uH_i specified for each well in the barrier (Eq. 5):

$$uH_i = \begin{bmatrix} uh_{\min,i1}\ uh_{\max,i1} \\ \dots \quad \dots \\ uh_{\min,ij}\ uh_{\max,ij} \end{bmatrix} \tag{5}$$

where $uh_{min,ij}$ is the minimum level of water in the j-th well in the i-th barrier [m], and $uh_{max,ij}$ is the maximum level of water in the j-th well in the i-th barrier [m].

2.2. Objective, criteria and limitations

Data obtained from the monitoring of the facility, together with the hydraulic model, make it possible to simulate control algorithms and analyze the results of changes in wells in barriers. The following symbols are used in the description of the method:

- assumed values $'q$ (grave accent), which represent set value points, e.g., the *assumed water intake volume* entered by the system operator;
- calculated values $\wedge q$ (circumflex), which represent values calculated as a result of the executed algorithm, e.g., the *calculated water intake volume* derived from the use of historical values from the monitoring database;
- obtained values q (no sign), which represent values obtained using the model, e.g., the *obtained water intake volume* resulting from hydraulic analysis of the network.

The *assumed water intake volume* $`Q_B$ determines the productivity of each $i$–barrier. $`Q_B$ is the control objective of the operator, and its values are defined by Eq. (6):

$$'Q_i = \begin{bmatrix} 'q_1 \\ \dots \\ 'q_i \end{bmatrix} \tag{6}$$

where $`q_i$ is the assumed water intake volume in the i-th barrier [m^3/h].

The value of the assumed water intake volume for the i-th barrier should correspond with the water resources in the i-th barrier area. When defining the water resources accessible for wells in barriers, one should consider hydrogeological processes - the movement of water in the ground - as well as other factors such as the assumed losses (the escape of water from the intake ground), water retention, and the season (weather conditions). Data on the capacity of a pump in a well barrier may be obtained by the means of research - analysis of historical data on the facility's operation - or can be derived from the hydrogeological model of the site.

The method uses two assumptions. In the initial steps of the algorithm, the first assumption is that, $\wedge q_i$ (the calculated water intake volume) for each barrier i does not have to be exactly equal to $`q_i$ (the assumed water intake volume), but can be greater or equal to it. It is assumed that for each barrier i, Eq. (7) is true.

$$\wedge q_i \geq 'q_i \tag{7}$$

According to the second assumption, the completed algorithm should result in a *calculated total water intake volume* defined by Eq. (8).

$$\wedge Q_{out} = \sum_{i=1}^{I} \wedge q_i \tag{8}$$

where:

$$\wedge Q_{out} \in <'Q_{out} - 'Q_{out} \cdot e_U, 'Q_{out} + 'Q_{out} \cdot e_U>$$

$$e_U = \frac{\wedge Q_{out} - 'Q_{out}}{'Q_{out}} \cdot 100 \text{ [\%]}.$$

The derivation of the dependencies (Eq. 8), the introduction of the *coefficient of accuracy of the intake volume* e_U, results from limitations on the adjustment of the water flow in individual pumps in the barriers. The acceptable value of e_U should be determined by an expert appointed by the operator.

The constraints and criteria for controlling the operational process of the pump system are contained in a strict hierarchy of objectives. The objectives correspond to the defined control criteria (Brodziak et al., 2014; Brodziak, 2021), and may be presented as follows:

priority <0> Exclusion of pumps in a state of failure and pumps in wells with water level h_{ij} below the minimum state defined by $uh_{min,ij}$.

priority <1> Selection of pumps for which the water level is above the state defined by

priority <2> Selection of pumps in the well barrier over its entire length to ensure even exploitation of the aquifer.

priority <3> Selection of pumps on the basis pump operational time t_{il}.

Priority <0> and priority <1> address emergency situations, when water levels in wells are too high or too low. When the Raw Water Supply System on the aquifer is properly managed, water levels in the wells will remain between the minimum and maximum values. Therefore, most pumps will be ready to operate, making the task of choosing specific objects from many available a non-trivial problem.

The solution of objective, criteria and limitations is a group of vectors s_i (Eq. 9) determining the state of the pumps for each barrier i. The set of s_i for all barriers determines the operational scenario for the Infiltration Water Intake System.

$$S_i = \begin{bmatrix} s_{i1} \\ \dots \\ s_{ij} \end{bmatrix} \tag{9}$$

where is the pump status in well j in barrier i, taking the value 1 if the pump is to be turned on, and 0 if it is to be turned off.

Methodology of creating the Operational Control Scenarios is presented below.

2.3. Sum of Neighborhood Factors (SoNF methodology)

Implementation of the criteria resulting from priority <0> and priority <1> in the pump selection algorithm is relatively straightforward, but a more complex solution needs to be applied for priority <2>. The purpose of priority <2> is to select pumps to take up water from the aquifer evenly over the entire length of the well in barriers. This is to avoid a situation when, for example, in a hypothetical well barrier consisting of 20 pumps, a series of 10 consecutive pumps located very close to each other are selected to operate, while 10 other pumps distant from those selected are not operational; this would result in uneven use of the aquifer. Therefore, there is a need for a method which, depending on the current conditions in the wells, will allow this type of situation to be avoided. To satisfy the criterion of priority <2>, use of the method of Sum of Neighborhood Factors (SoNF) is proposed. The method is based on a ranking approach, where each pump in the barriers considered for selection is evaluated on the basis of an accumulated number of points determined by the coefficient *SoNF*.

SoNF is calculated for each pump considered for selection in a given iteration of the scenario. Calculation of the *SoNF* coefficient requires analysis of the operating status of the other pumps in the same well barrier (neighboring pumps). This analysis involves calculating Neighborhood Factor (*NF*) for all pumps considered fit to operate. *NF* value of the pump being analyzed depends on the condition of the neighboring pumps. Neighborhood Degree (*ND*) is introduced to determine the number of neighboring pumps, the operational status of which should be analyzed in the calculation of *NF*. For example: when *ND* = 1 the status of the first preceding pump and the first following pump will be analyzed; when *ND* = 2 the states of two preceding pumps and two following pumps will be analyzed. This is illustrated in Fig. 2.

To determine the value of *ND* for which *SoNF* should be calculated, the maximum value from the set ***M*** needs to be found. Set ***M*** consists of numbers specifying how many non-working pumps, directly adjacent to each other, lie between working pumps (Fig. 3).

The value of *ND* is an integer equal to half of *max(**M**)* calculated for every iteration (Eq. 10).

$$ND = Ent\left(\frac{\max(M)}{2}\right) \tag{10}$$

The values of *NF* denote the following situations:

- NF = 0 when the neighboring pump is indicated for operation (the aquifer is already in use);
- NF = 0.5 when the neighboring pump does not exist (the pump is at the end of the barrier);
- NF = 1.0 when the neighboring pump is not indicated for operation (the aquifer is not in use);
- NF = 1.5 when the pump is out of service (the capacity for water intake from the aquifer in this place is reduced; the pump is not working and cannot be switched on in the nearest iteration).

When knowing *ND* and *NF*, it is possible to calculate *SoNF* for the analyzed pump. For the selected pump two *NF* values are determined: for the preceding pump NF_{ND}^{-} and for the following pump NF_{ND}^{+}. The coefficient $SoNF_{ND}$ is then defined as Eq. (11).

$$SoNF_{ND} = \sum_{n=1}^{ND} NF_{ND}^{-} + NF_{ND}^{+} \tag{11}$$

$SoNF_{ND}$ needs to be calculated for all pumps in the well barrier. The pump in the *i*-th barrier with highest $SoNF_{ND}$ value is selected to be turned on. For example, if it is *j*-th pump in that *i*-th barrier; then the selection is indicated by changing the s_{ij} to the value 1 in vector S_i .

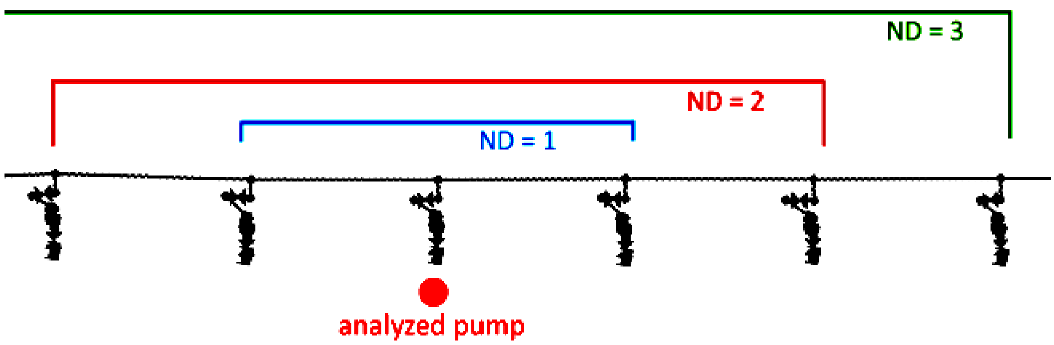

Fig. 2. The range of the analyzed neighborhood based on *ND* values, with the pump being analyzed marked

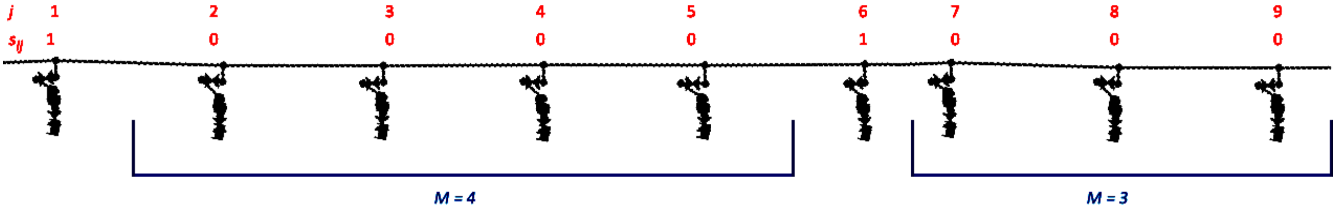

Fig. 3. Example illustrating values in ***M*** for an analyzed well barrier

Calculations of *SoNF* should be performed when the algorithm is searching for a pump to turn on in a given barrier. *SoNF* is calculated for those pumps that meet the following conditions:

- s_{ij} = 0, the pump is not currently selected to be turned on;
- g_{ij} = 1, the pump is not in a state of failure;
- $h_{ij} > uh_{min,ij}$ the water level in the well is above the minimum.

If it is not possible to indicate one pump with the maximum $SoNF_{ND}$ value (i.e. in the case when the same *SoNF* values are obtained for more than one pump), the selection is extended by calculation $SoNF_{ND\ 1}$, i.e. *SoNF* for the neighborhood degree ND-1. Among the pumps with the same maximum values $SoNF_{ND}$, the one for which the $SoNF_{ND\ 1}$ is the greatest is indicated to be turned on.

If the comparison of values still fail to indicate only one pump, the choice is made based on the criterion of priority <3>. Among the set of pumps with the highest value of and , the pump with minimum operational time t_{ij} is selected. Priority <3> applies to the situation when ND = 0, then the pump indication is made on the basis on operational time. If more than one pump has the same minimum value, the selection is made using a randomizing function.

3. Results

A representative water intake facility for the city of Bydgoszcz in Poland was the subject of a case study. The municipal water supply system uses the managed aquifer recharge method. An artificial infiltration water intake facility named Czyżkówko was newly built in 2010. The nominal daily water output was assumed to be 75,000 m3/day. The Raw Water Supply System consists of ponds with a total active area of 20.62 ha, which are quite distant (0.4–1.5 km) from the bank of the Brda river, which supplies the aquifer. The RWSS consists of 13 ponds, 16 ditches and more than 13 km of pipelines, together with river water pumping stations and two intermediate pumping stations. The Infiltration Water Intake System consists of 106 deep-water wells with pumps, 67 wells of six cumulative siphon wells and over 8 km of drainage pipelines, forming a system of i=6 barriers of wells. For an example decision situation represented in the knowledge base and object states, an algorithm based on the proposed methodology was implemented. The facility was also subject of Brodziak (2017) based on simulations performed using a validated hydraulic model of the Czyżkówko water intake provided by the municipal water and sewage company Miejskie Wodociągi i Kanalizacja w Bydgoszczy Sp. z o.o. below chapters presents the most important results.

3.1. Algorithm

The algorithm aims at creating an operational scenario for the Infiltration Water Intake System by selecting pumps according to defined objectives, criteria and limitations. The main steps of the algorithm are described below.

Step || 1 || Loading of the model, structures of wells in barriers and states of the object.

The first step involves the creation of a knowledge base about the system. The network hydraulics model is loaded, along with information on the structure of wells- barriers (the combination of pumps, reservoirs and their ID numbers related to the model). Current values reflecting the object states are also read, including the vectors G_i, H_i , Q_i , T_i , uH_i for each barrier.

Step || 2 || Determination of the objectives of the operational scenario.

This step involves defining the control task, by specifying the *assumed water intake volume* ‘Q_B and the *accuracy coefficient of the intake volume* e_U. To avoid a situation where the objectives are impossible to achieve, estimation of the nominal (maximal) water intake volume of the barriers is performed using the values of the current object states.

Step || 3 || Creation of a proposal for the vectors S_i

The vectors describe which pumps need to operate, and which do not, in a given operational scenario.

Step || 3 || A - Inclusion of priority <0>.

The goal of priority <0> is to identify pumps that cannot be turned on. This occurs for pumps located in wells where the water level h_{ij} is below $uh_{min,ij}$ or the well readiness value g_{ij} indicates failure; in both cases the operation of the pump is impossible. These situations should be identified unambiguously in order to exclude the pump from further consideration in the algorithm. These pumps are assigned the value “–1”, meaning that they are decommissioned in the current scenario. This constraint can be implemented through actions performed on the tables of uH_i, H_i and G_i. As a result, in first iteration pumps status in vector S_i can be updated (Eq. 12).

$$S_i = \begin{bmatrix} s_{i1} \\ \dots \\ s_{ij} \end{bmatrix} \quad (12)$$

where:

$s_{ij} = 0$ for $h_{ij} > uh_{\min,ij} \wedge g_{ij} = 1$

$s_{ij} = -1$ for $h_{ij} \le uh_{\min,ij} \vee g_{ij} = 0$

Step || 3 || B - Inclusion of priority <1>.

Priority <1> indicates the pumps for which the water level h_{ij} in the well is above the defined maximum level $uh_{max,ij}$, as a result of which the vector is updated with the status of pumps which should be selected to be turned on first (Eq. 13):

$$s_{ij} = 1 \text{ for } h_{ij} > uh_{\max,ij} \wedge g_{ij} = 1 \quad (13)$$

Step || 3 || C - Inclusion of priority <2> and priority <3>.

Selection of the pumps to be switched on is based on the proposed *SoNF* method. One iteration of the *SoNF* method will select one pump to be turned on. Pump selection is repeated iteratively, for each barrier. After selecting one pump the algorithm updates the vector S_i and checks whether condition Eq. 7 is fulfilled. Once the condition is met, the algorithm ends. If not, to select the next pump, calculations are repeated with the updated S_i. After determining the vectors S_i for all barriers, the *calculated water intake volume* ^Q_{out} is obtained.

Step || 4 || Fine tuning of the vector S_i.

At this point, vector from **Step || 3 ||** fulfills condition (Eq. 7), which means that the pumps in each well barrier will provide a *calculated water intake volume* ^q_i which accounts for at least as much as the *assumed water intake volume*`q_i. If for the given ^Q_{out} satisfied Eq. (8), the algorithm proceeds to step || 5 ||. If not, then a correction algorithm is run to adjust the current vector. Depending on whether ^Q_{out} is larger or smaller than the acceptable values, step || 4 || A or step || 4 || B is performed.

Step || 4 || A - Additional indication of pumps to be turned ON.

The situation, where is below the acceptable range, can occur when the system operator enters an *assumed water intake volume* `q_i higher than the nominal capacity obtainable in the *i*-th barrier in a given decision situation. In this case, the shortage of volume flow in one wells-barrier will be made up by switching on one or more pumps in other barriers, and this step serves to select those pumps.

To handle such a case, all barriers are searched for pumps that can be turned on (also taking into account priority <0>). From the resulting set, based on priority <3>, the *i* pump with the lowest operational time is selected to be turned on. The status s_{ij} of this *i* pump *from j* barrier is updated to "1" in the vector S_i, and the algorithm returns to step || 4 ||.

Step || 4 || B - Additional indication of pumps to be turned OFF.

The situation, where ^Q_{out} is larger than the acceptable range, can occur because the pumps' capacities q_{ij} are different, and turning on one pump can change the `q_i value abruptly.

Selection of pumps to be switched off is based on priority <3>. The procedure is similar to that in step || 4 || A, but here all barriers are searched for pumps that can be turned off (taking into account priority <1>). The pump, the operational time of which, is the greatest is selected to be turned off. The status s_{ij} of this *i* pump *from j* barrier is to "0" in the vector S_i, and the algorithm returns to step || 4 ||.

Step || 5 || Simulation of the created hydraulic scenario.

In this step, the operational scenario determined by the vectors which define the status of the well barrier pumps, is subjected to verification. The pump statuses from S_i are passed on to the model to perform a simulation of the hydraulic system.

Step || 6 || Verification of operational scenario and updating object state.

The simulation returns values of *obtained pump capacity* q_{ij}, which can be summed to calculate Q_{out} , the *obtained water intake volume*. The current data with pump flow rates are saved in the knowledge base as q_{ij}, and will be used in the next iteration of the algorithm control scenario.

If the *obtained water intake volume* from the simulation continues to satisfy the assumption Eq. (8), then the operator may forward the created operational scenario for implementation in the control system. Otherwise, the algorithm returns to step || 3 ||, which creates an operational scenario for the updated values describing the updated object states.

3.2. Implementation of the method

A model of an IWIS transport system was built in EPANET (developed by the United States Environmental Protection Agency, EPA). The shared source code of the program and the Programmer's Toolkit, including a DLL file, allow it to be used with other applications, without the need of limitations of native GUI of EPANET. An IT environment was developed with the use of Matlab program to perform calculations and data operations. Matlab formed the central component which comprised the database with the object states, together with M files consisting of scripts for the algorithm for creating operational scenarios. Calculations and readings obtained in the hydraulic model simulation results were integrated with the script. Functions from the EPANET DLL were called in Matlab using the OpenWaterAnalytics/EPANET-Matlab-Toolkit library (KIOS, 2015). This solution made it possible to perform simulations for the created scenario without the need to run the EPANET GUI graphical interface, enabling fast creation and verification of scenarios. The flow of data between the tools used is shown in Fig. 4.

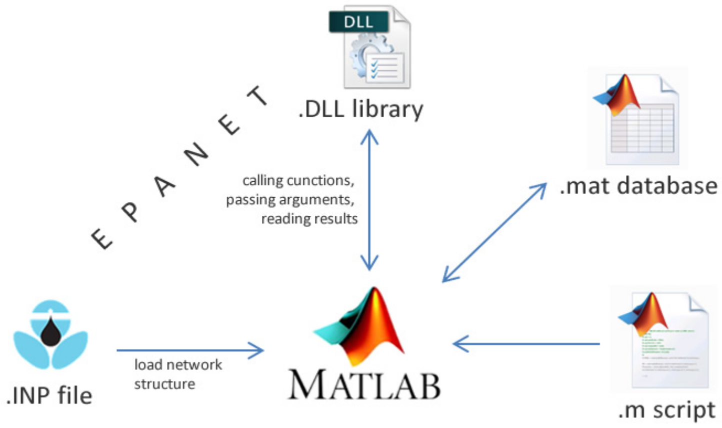

Fig. 4. Data flow between tools creating the simulation environment

The water intake model stored in the EPANET .INP file, along with the database describing the structure of the system and object states, constitutes the knowledge source. After an operational scenario is created, to verify this scenario, the vectors containing pump statuses for particular well in barriers are loaded into the model. The open/closed pump statuses correspond to boolean 1/0 values; hence the vector can be used directly, by assigning the value "1" to the elements with the corresponding pumps ID and setting status closed on pumps ID with s_{ij} "0" and "-1". The model with updated parameters, resulting from the simulation, enables the readings of, among others, flow speed through pipelines and obtained pump flow rates. The obtained values are used to update the database that stores the object states which will be used in the next algorithm iteration to create a new operating scenario. The code implementing the presented algorithm has been published in the Github repository.

3.3. Discussion and perspectives of the study

The proposed algorithm should be triggered to generate new scenarios in the event of further decision situations, such as:

- changes in the obtained water intake volume beyond the scope defined by the accuracy coefficient of the intake volume e_U, which may be caused by: failure of the well and modification of the associated status in G_{ij}, lowering of the water level H_{ij} in the well below $uh_{min,ij}$, or changes in the limit values uH_{ij} beyond the current H_{ij} values;
- changes in the assumed water intake volume, entailing the definition of a new decision scenario by the operator.

The proposed method may be delivered as a Decision Support System. This solution requires the implementation of a master control layer with monitoring devices in a Water Intake with an Artificial Recharge System. A reliable information system and computer model are the main factors ensuring the correct operation of the facility. Account should also be taken of the nature of the model used, its limitations resulting from the simplified representation of reality, and the uncertainty of measurements characterizing the facility. The hydraulic model must be correct and validated in order to ensure reliable results. The created control scenario can be transferred directly for implementation in the SCADA system, then monitoring of the scenario should take place.

Currently, the traditional approach to water intake control is applied, with an implemented layer of automation at the lowest level of actuators, but without the analysis of "global" data. Higher-level analyzes are performed with the involvement of significant human resources and result in obtaining results with a delay, which affects the decision-making process.

It is worth mentioning that, as older facilities lack full-level monitoring, the method can be used for recently built facilities or these that have undergone significant modernization. The use of the SCADA monitoring system allows direct coupling with the scenario generation system, which can be based on current values from monitoring devices and actuators. This enables full verification of scenarios and updating the knowledge base, which can be supplemented by verified data obtained directly from the facility. The implementation of the method on a real site requires performing programming work, which in the case of facilities of this nature cannot be done in an *ad hoc* manner. Analytical work is currently under way to implement the method in the control system of a real water intake with an artificial infiltration system. Implementation of the method will enable a "before" and "after" investigation of the effect on the operations of the evaluated facility, the results of which will be the subject of another publication.

4. Conclusions

The operation of water intakes with the artificial infiltration method is a complex task. The methodology in this paper presents a solution to the problem of the current operation of a water intake facility with managed aquifer recharge. A large structure, the variability of operating conditions and the multitude of information about object states are the factors that cause difficulties in a control system based only on the knowledge of the system operator.

The need to take action in a short time requires the decision-makers to have tools to support their tasks. This paper provides an algorithmic method, which in conjunction with the operator's experience can provide an effective strategy for the management of a water intake.

The proposed expert system may have direct practical application as a part of the operator's Decision Support System. The developed method can shorten the time needed to get acquainted with the current capabilities of the facility. Consequently, it makes it possible to define the proper operational tasks under the changing operating conditions of a water intake facility.

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