https://doi.org/10.1051/bioconf/202414103018

Simulation of water supply control on water intakes facilities from underground sources

Irina Purusova[1], *Konstantin* Chizhik[2*], *Mikhail* Tolstoy[3], and *Ekaterina* Popova[3]

[1]Voronezh State Technical University, Russian Federation, 84, 20-letiya Oktyabrya Street, Voronezh, 394006, Russia
[2]National Research Moscow State University of Civil Engineering, 26, Yaroslavskoe Highway, Moscow, 129337, Russia
[3]National Research Irkutsk State Technical University, 83, I-203, Lermontov Street, Irkutsk, 664074, Russia

Abstract. Consideration is given to the enhancement of mathematical modeling of water supply regulation by subterranean water intake structures. The examination of publications using a mathematical model of how subterranean water intake structures function revealed that there hasn't been enough research done on how to solve problems when there is ambiguity and incompleteness of the initial data. A mathematical model of the functioning of the existing water intake facilities from Voronezh's underground sources was constructed using the actual characteristics of the interacting system parts. The distribution of water flows is described by a system of linear equations that include chain, nodal balance, and normal equations that create a balance between the inflow and flow of water at each node. A functional restriction is the balanced flow of water through the collecting duct and into the clean water tank. A control model using linear equations is proposed to forecast the submersible pump supply and to realistically assess the optimal joint functioning of the system comprising the well, submersible pump, collecting conduit, and clean water reservoir. An approach is proposed to solve a system of equations for controlling the water flow from wells to a clean water reservoir.

1 Introduction

For subsurface water intakes to comply with technical and regulatory regulations, reliability standards are always increasing. Automated control systems are typically absent from water intake facilities that provide water from wells to the RFV (clean water reservoir). The stationary difficulties of water flow distribution in hydraulics have been thoroughly studied by both domestic and international specialists. A survey of the literature on mathematical modeling of underground water intakes found a lack of studies on how to deal with issues of uncertainty and incompleteness of original data. There have not been the expected financial gains from the hydraulic models now in use to control the operation of subsurface water intake systems [1-4].

---

[*] Corresponding author: andreicelonenco@mail.ru

2 Methods and materials

The modeling of water supply control at the RFV's well intakes, where the direction of the water flows through the collecting duct is utilized as functional constraint, is unquestionably interesting. Measurements made at water intake facilities revealed that the information provided in the pump passports did not match how the pumping equipment operates in changeable supply and pressure conditions. This is inconsistent with the necessary passport values and results in a reduction in the amount of water provided in the RF [5-9].

Figure 1 shows a diagram of existing water intake structures from underground sources in the Voronezh Region, where measurements were carried out.

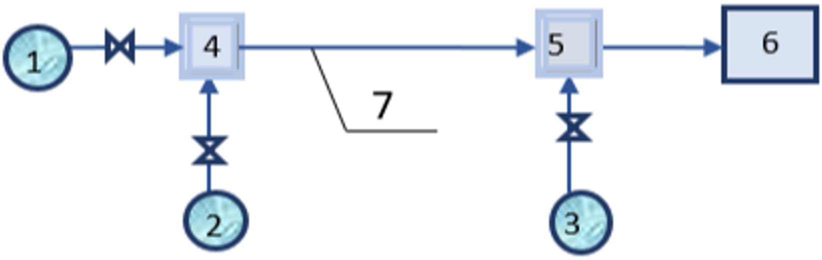

Fig. 1. Water distribution scheme from wells to a clean water reservoir: 1-3 wells with submersible pumps, 4-5 – prefabricated nodes, 6 – clean water reservoir, 7 – prefabricated water conduit.

At the water intake, measurements of the water supply from wells to the collecting duct and the heads of submersible pumps were carried out twice a day throughout the year. The obtained results of field studies have shown that pumping equipment is often overpressure.

Since a transmission link between two wells is what a collecting conduit serves. The collecting duct's resistance rises in response to an increase in water supply from one of the wells, which slows down the increase in water supply from the other wells and puts the system in an aroused condition.

A system of linear equations made up of chain equations, nodal balance equations, and normal equations is given [6-7] as a solution to the problem of managing the water supply (Figure 1) from wells in the RF.

Chain equations:

$$\mathrm{H}_1^{(\text{к}-1)}\delta\overline{\mathrm{H}}_1^{(k-1)} = 2h_{1-4}^{(k-1)}\delta\,\bar{Q}_{1-4}^{(k)} + 2h_{4-5}^{(k-1)}\delta\,\bar{Q}_{4-5}^{(k)} + 2h_{5-6}^{(k-1)}\delta\,\bar{Q}_{5-6}^{(k)} + h_{1-4}^{(k-1)}\delta\,\overline{\mathrm{S}}_{1-4}^{(k)} \tag{1}$$

$$\mathrm{H}_2^{(\text{к}-1)}\delta\overline{\mathrm{H}}_2^{(k-1)} = 2h_{2-4}^{(\text{к}-1)}\delta\bar{Q}_{2-4}^{(k)} + 2h_{4-5}^{(\text{к}-1)}\delta\bar{Q}_{4-5}^{(k)} + 2h_{5-6}^{(\text{к}-1)}\delta\bar{Q}_{5-6}^{(k)} + h_{2-4}^{(k-1)}\delta\,\overline{\mathrm{S}}_{2-4}^{(k)} \tag{2}$$

$$\mathrm{H}_3^{(\text{к}-1)}\delta\overline{\mathrm{H}}_3^{(k-1)} = 2h_{3-5}^{(\text{к}-1)}\delta\bar{Q}_{3-5}^{(k)} + 2h_{5-6}^{(\text{к}-1)}\delta\bar{Q}_{5-6}^{(k)} + h_{3-5}^{(k-1)}\delta\overline{\mathrm{S}}_{3-5}^{(k)} \tag{3}$$

Nodal balance equations:

$$Q_{1-4}^{(k-1)}\delta\,\bar{Q}_{1-4}^{(k)} - Q_{4-5}^{(k-1)}\delta\,\bar{Q}_{4-5}^{(k)} + Q_{2-4}^{(\text{к}-1)}\delta\bar{Q}_{2-4}^{(k)} = 0 \tag{4}$$

$$Q_{4-5}^{(\text{к}-1)}\delta\bar{Q}_{4-5}^{(k)} + Q_{3-5}^{(\text{к}-1)}\delta\bar{Q}_{3-5}^{(k)} - Q_{5-6}^{(\text{к}-1)}\delta\bar{Q}_{5-6}^{(k)} = 0 \tag{5}$$

Normal equations:

$$Q_{1-4}^{(k-1)}\delta\,\bar{Q}_{1-4}^{(k)} - Q_{2-4}^{(\text{к}-1)}\delta\bar{Q}_{2-4}^{(k)} = Q_{1-4}^{z(k-1)}\delta\,\bar{Q}_{1-4}^{z(k)} - Q_{2-4}^{(\text{к}-1)}\delta\bar{Q}_{2-4}^{(k-1)} \tag{6}$$

$$Q_{1-4}^{(k-1)}\delta\,\bar{Q}_{1-4}^{(k)} - Q_{3-5}^{(\text{к}-1)}\delta\bar{Q}_{3-5}^{(k)} = Q_{1-4}^{z(k-1)}\,\delta\bar{Q}_{1-4}^{z(k)} - Q_{3-5}^{z(\text{к}-1)}\delta\bar{Q}_{3-5}^{z(k)} \tag{7}$$

where H_1, H_2 и H_3 – required head of submersible pumps in wells 1, 2, and 3;

$\delta\bar{H}$ – the relative variation, during a specified duration, of the submersible pump's necessary pressure;

h – pressure reductions in the pipeline segment;

Q – the pipeline section's projected flow rate;

$\delta\bar{Q_i}$– the percentage change over a given time interval between the average values of the section i flow rate calculation of the associated node;

$\overline{Q^z}$ – pump supply, for the duration of the stated timeframe;

$\delta\overline{Q^z}$– the pump supply's relative deviation during a certain time period;

$\delta\bar{S_i}$– the pipeline section's coefficient of hydraulic resistance's relative variation over a certain time period;

k - the number of iterations.

Pump pressure characteristics are the format in which the chain equations (1) through (3) are displayed. The water mark in the RF, the pump's pressure losses, the pressure line, the collecting duct, and the well's dynamic water level all affect the necessary pump pressure. The pumps operate around the clock, therefore the well's static water level is not taken into consideration.

Nodal balancing equations (4) through (5) determine the equilibrium of water flows from wells through constructed units, according to Kirchhoff's first law. Water flow from the prefabricated units 4 and 5 is shown in this case by a negative indication. These equations are based on the concept of perturbation control on a dead-end network, in which there is a disturbance in every well.

The hydraulic model of the operation of water intake structures is a planar non-looped graph from the perspective of modeling the perturbed state of the SPRW (water supply and distribution systems), as shown in Figure 1. It has first-kind boundary conditions in node number six and second-kind boundary conditions in nodes 1-3. The controlled water supply from wells in the RFV and the relationship between the second-lift SPRV's operation and the water intake operating mode are not included in the suggested modeling.

The RF's water level is steady. The designated types of boundary conditions are established based on the water intake structure scheme: wells - RFV. This facilitates the simulation of water extraction from subsurface sources as a discrete entity.

3 Results

The provided linear equations are solved by adding pump feed readings at the current water intake facilities. The water consumption value in the collecting duct sections can be computed thanks to this. It is impossible to solve the system of linear equations with many iterations, like k = 1,06, without automating the control of the water supply mode from wells in the RF.

The previously mentioned set of linear equations states that managing the water supply from wells in the RFV makes the following possible:

- to guarantee that the water input and outflow are balanced in every node and section;
- to more accurately determine the installed pumps' performance and pressure, as well as the costs at the sites at any given time, and to forecast the water supply by pumps;

Submersible pump, collecting duct, and RFV in separate sections are used to track changes in system parameters; well, submersible pump, collecting duct, and RFV are used to optimize the system's joint operation mode.

An algorithm for resolving a set of equations governing the water supply from wells in RF, Figure 2, is shown below.

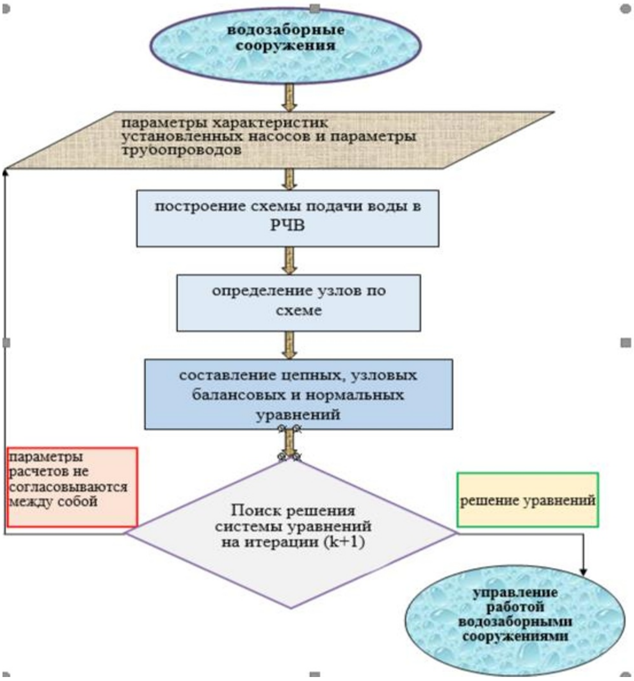

Fig. 2. A system of equations is solved using an algorithm.

In order to automate the control of water intake from subterranean sources, electronic sensors that measure water flow and pressure and send the results to the control room's control panel must be installed.

- tracking of parameter variations throughout all sections, including pipeline hydraulic resistances and flow rates;

Recognizing irregular pump performance; calculating the amount of electricity used by submersible pumps.

The suggested approach can solve a system of equations using the steps provided to automate the water intake's operation:

- model the most cost-effective well operation mode;
- forecast the RF's water supply from pumps.

4 Conclusions

The suggested set of linear equations shows the trajectory of the borehole-RFV system's transition to a new state and specifies the condition of water intake facilities at every point during operation. The most cost-effective way for a water intake to function can be simulated.

The expected economic benefit of using the presented algorithm, Figure 2, for existing water intake facilities amounted to 2,076 thousand rubles, according to the average tariffs of electricity consumed in 2024 in the Voronezh region. This result is obtained by comparing the cost of electricity costs before and after the application of the control algorithm.

References

1. V. L. Elovik, Proceedings of BSTU. Series 2: Chemical technologies, biotechnology, geoecology **1(229)**, 242-248 (2020)
2. I. V. Nikolenko, Construction and Technogenic Safety **18(70)**, 143-148 (2020)
3. V. N. Fisenko, *Evaluation of the energy efficiency of pumps in water supply systems*, Yakovlev readings of the XIII International Scientific and Technical Conference, dedicated to the memory of Academician of the Russian Academy of Sciences S.V. Yakovlev. The Ministry of Education and Science grew. Russian Federation, Moscow State University of Civil Engineering, pp. 116-123 (2018)
4. R. V. Chupin, M. V. Moroz, V. R. Chupin, Water Supply and Sanitary Engineering **11**, 16-25 (2022)
5. I. Y. Purusova, Energy Saving and Water Treatment **4(120)**, 26-28 (2019)
6. I. Y. Purusova, Current Directions of Scientific Research of the XXI Century: Theory and Practice **6**, no. 6(42), 290-293 (2018)
7. I. Yu. Purusova, K. I. Chizhik, V. I. Shcherbakov, *Technological parameters of submersible pumps at water intake facilities from underground sources*, Yakovlev readings. Collection of reports of the XVI International Scientific and Technical Conference, dedicated to the memory of Academician of the Russian Academy of Sciences S.V. Yakovlev, Moscow, pp. 184-188 (2021)
8. K. I. Chizhik, V. I. Shcherbakov, I. Yu. Purusova, *Energy costs for raising water from underground sources*, Yakovlev readings. Collection of reports of the XV International Scientific and Technical Conference dedicated to the memory of Academician S.V. Yakovlev, pp. 208-211 (2020)
9. V. I. Shcherbakov, K. I. Chizhik, N. P. Konovalov, I. Y. Purusova, *Energy efficiency of functioning of water reservoir wells and collecting conduit*, Construction. The formation of living Environement. XXI International Scientific Conference on Advanced in Civil Engineering, p. 022060 (2018)