COMPARATIVE STUDIES AND RESEARCH ON OPTIMIZING ELECTRIC CONSUMPTION OF WATER SUPPLY SYSTEMS

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ABSTRACT:

Water Supply Systems (WSS) can very well be dubbed as the backbone of every major human settlement for thousands of years at this point as every major human settlement throughout history has, regardless of time period or rural/urban erection or evolution has had its emplacement close to if not dead center over a significant water source that can provide this valuable and desperately needed resource to the populace. Of course, with the passage of time and the ever increasing number of the population and their life style, new techniques and technologies were incorporated within the grand design of the water supply pipeline, mainly automation and operation reliability boosts by means of electricity. It is a given that electrical current is not cheap to produce and maintain, although it is a field of ongoing study and research when it comes to optimizing the energy consumption of any system that runs on this costly resource, both for making the overall operation of the entire system more reliable but also more economical, all the while taking inspiration of multiple specialty works published within this field and, of course, already established local and European Union standards within Romania.

1. INTRODUCTION

1.1 Considerations regarding the operational reliability of the equipment in the structure of water supply systems

Regardless of the accuracy or complexity of the used reliability analysis method, the quantitative evaluation of the reliability of a system requires the knowledge of the reliability indicator values of the components. Obtaining realistic results for the reliability of the system is conditioned by the credibility of the values of the reliability indicators of the elements. Information on the reliability of the elements is useful both for the beneficiaries (for the purpose of optimizing maintenance) and for the manufacturers (for the purpose of applying corrections in design and manufacturing).

In order to estimate the reliability indicators of the elements, two ways of analysis are used, namely: ***Experimental reliability and Operational reliability*.**

Operational reliability corresponds to the situation in which the reliability indicators are determined based on the observations made in real conditions of operation of the equipment. According to research, there is a range of equipment for which reliability testing in laboratory conditions is not economical and the only source of information on reliability remains in-service tracking (Ionescu Gh. C. et al., 2000).

The variant of evaluating the reliability indicators is clearly advantageous from the economic point of view, in relation to the experimental reliability, requiring minimum expenses for the registration and processing of statistical data. The disadvantage of this method of analysis consists in the long duration in which the necessary observations and the encountered difficulties emerge, regarding the assurance of a minimum necessary number of observed elements.

Operational reliability studies of the equipment in the structure of water supply systems are indispensable in order to obtain adequate statistical data of volume and credibility, on the basis of which to establish the values of the reliability indicators and an optimal maintenance policy.

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Unfortunately, these studies in the field of water supply are at a pioneering stage, which is why they must be established on the basis of incident records and records of existing events at the level of water pumping stations (key point in a water supply installation) and analyzes performed on water samples taken from different treatment phases.

These studies mainly highlight the following aspects:

- the number of incidents at the level of the pumping station and their distribution on subsystems (pump drive motors, the pumps themselves);
- the cost of corrective maintenance work performed after incidents;
- energy unavailable due to incidents and distribution by subsystems;
- the causes of the incidents and the damaged elements.

The comments that can be made regarding these studies are as follows:

- ✓ they are not sufficiently detailed and in-depth, as they are limited to some of the subsystems of a water supply installation;
- ✓ they prove useful, because they provide a first image on the condition of the equipment, on their behavior in operation and on the management of their maintenance;
- ✓ the data obtained are not processed in all respects and, as a result, not all possible information is used;
- ✓ despite all the efforts made to correctly report incidents and their parameters, there may still be errors.

Through this, we have considered the overcoming of these aspects, on the one hand by a closer and more detailed follow-up of the equipment, and on the other hand, by a wider processing and at an adequate scientific level of the obtained data, with in order to obtain more useful information in the operation of the hydraulic installations within the water supply systems of the urban centers (Ionescu Gh. C. et al., 2008, 2000).

Based on statistical data, obtained from the in-service monitoring of the equipment, three random variables can be studied, namely:

- ❑ ***proper running time (PRT)***, representing the running time between two successive falls;
- ❑ ***corrective maintenance time (CMT)***, representing the fault time;
- ❑ ***annual number of fails (FT).***

The first two random variables are continuous, and the third is discrete.

It is well known that conducting operational reliability studies for a sample (batch) of a population of a product involves risk (Ionescu Gh. C. et al., 2008, 2000). When conducting operational reliability studies, in order to ensure the premises of risk minimization, when the research results extend from the level of the group to the population, it is necessary to ensure compatible working hypotheses in the two cases. Given this desideratum, a study of operational reliability with a certain degree of scientific rigor, involves the indication of technical characteristics and factors that may influence the reliability indicators, such as: the level of long-term demands, the level and frequency of overloads, environmental factors, maintenance conditions etc. Without carrying out a complete characterization under the aspects mentioned above, I will specify, in the case study, most of the influencing factors.

The results obtained for the water supply system of Oradea are briefly presented in this chapter, the working methodology being valid for any other water supply system of urban centers.

1.1 Presentation of the water supply system of Oradea municipality

The drinking water supply of Oradea municipality is made through 5 pumping stations (SPO) located on both banks of the Crişul Repede River in the N-E part of the municipality (table 1) (Ionescu Gh. C. et al., 2008, 2000).

For this purpose, groundwater, water captured from the underground with the help of drains, and surface water, captured from the Crişul Repede River, are used.

Station	Group number x pump type	Group characteristics			Normal operating configuration
		Q (mc/h)	H (m)	P_i (Kw)	
PS 1	6 x SIGMA	435	55	145	4+2
PS 2	1 x SIGMA	500	59	160	5+1(NDS)
	2 x GAZ	300	50	145	
	3 x NDS	400	53	160	
PS 3	3 X 8 NDS	350	80	110	2+1
PS 4	6 x 12 NDS	300	50	250	5+1
	3 x 8 NDS	400	83	160	2+1
PS 5	3 x BRATEŞ 2200 (TR. I)	1200	12	90	2+1
	3 x BRATEŞ 350 (TR. II)	1400	11	75	2+1
	5 x 12 NDS (TR. III)	900	60	200	4+1

Table 1. The structure of the Pumping Stations

On the right bank, the surface water is captured by means of two pipes of Φ 1000 mm. Following the passage through two horizontal settlers, the water enters the 13 basins with the role of enriching the underground water table, located parallel (8 +5) with the Criş riverbed. Between the two rows of basins and Criş there are 2 drains for capturing groundwater, in order to supply the pumping station1 (P.S. 1). To the extent that this amount of water does not meet the requirements for P.S. 1, the surface water from the enrichment basins is also used, filtered with the help of the 10 slow filters. The filters are supplied directly from the raw water, through a pipe of Φ 600 mm^2, when the turbidity is reduced in the water of the Criş River and respectively from the last enrichment basin if the water from the Criş has high turbidity (table 2).

	P.S.1	P.S.2	P.S.3	P.S.4	P.S.5	Total
Total pumped water	11.039.600	5.134.120	4.272.020	17.050.700	17.724.300	55.221.500
Surface water	10.847.800	5.134.120	1.071.200	17.050.700	-	34.103.700
Groundwater	191.800	-	3.201.700	-	17.724.300	21.117.800
Power installed in pumping units (kW)	882	670	330	1850	1870	5602
Power installed in the operating technology (kW)	950	680	330	2012	2340	6300
Electricity consumption (kWh)	4.243.830	1.690.770	1.022.220	4.647.620	4.106.460	17.470.020
Specific consumption kWh/m^3	0,384	0,329	0,445	0,272	0,281	0,316

Table 2. Global energy indicators of PES (values in one year)

Pumping station no. 3 (P.S. 3) is also located on the right bank and pumps water into the compensation tanks (total capacity 22012 m^3).

Pumping station no. 2 (P.S. 2) is located on the right bank and pumps groundwater into the network on the left bank. By means of two enrichment basins, the groundwater supply of the drain is fed.

On the left bank, the captured water reaches gravitationally through two pipes (Φ 1200 mm - Φ 1000 mm) in the 8 enrichment basins located perpendicular to the Criş riverbed. Among these basins are located the secondary drains that supply the main drain, arranged between the Criş riverbed and the 8 basins, fully providing the necessary water for P.S. 4.

P.S.5 only surface water decanted with the two radial decanters and filtered through the 8 fast filters inside the plant is used.

The structure of the pumping stations was presented in Table 1., and the values of some significant indicators regarding the operation of the stations, in one year (2020), are mentioned in Table 2.

1.2 Particularities of pumping stations

In the exploitation activity it is necessary to follow:

- periodic checking of the degree of clogging by reading carefully the level difference between raw water and filtered water;
- that captured flows be constant (by drainage);
- operation of decanters in parallel or in series, depending on the degree of turbidity, respectively their level of clogging;
- that the Parshall flowmeter is working properly;
- the discharge of the deposits should be done periodically depending on the loading of the raw water - once every 60 days;
- checking and maintenance of shunting seals;
- washing the filter to form the biological membrane;
- emptying the decanter in order to wash the concrete screed;
- maintaining a constant water level on the slow filters by adjusting the supply valve;
- emptying the clogged filter, respectively cleaning it by removing the 2-3 cm thick state, from the sand surface;
- disinfection of the sand with a solution of lime chloride in the amount of 0.5 kg/sqm;
- periodic reading of the flows on the two trapezoidal flow meters.

The defense of the pumping stations in different phases and defense hypotheses is done according to the defense plan, as follows:

a) upon reaching the level of attention communicated by the County Commission for Defense against floods, the activity of observation-alarming and surveillance of the defense dams will be organized, the verification of the existence in stock of the materials necessary for the interventions;
b) upon reaching the flood level communicated by the County Commission of Defense against floods, the local defense of the basic objectives will be organized with the help of the intervention teams and the equipment, thus:

- the dams from the raw water catchments will be closed and strengthened;
- the materials stored in the area of the basic and dangerous objectives will be transported;
- the defense of the pumping stations and of the slow filters will be organized by executing some local dams using own materials and means;
- small infiltrations will be eliminated through the defense dams;
- the additional jute bags and the sand stocks necessary for the elevation of the defense dams and of the drainage manholes at the danger level will be ensured;
- the County Commission for Flood Defense will be asked to allocate additional forces, materials and equipment, will mobilize and organize the entire workforce and its own equipment for interventions, in case of reaching the danger level or breaches in the defense dams.

c) when the danger level is reached or large local erosions appear in the defense dam, with the support of the additional forces and means allocated by the County Commission of Defense against floods, it will proceed to:

- evacuation of the stock of coagulants;
- raising the dams with sandbags and strengthening the eroded areas;
- the announcement through the County Commission of Defense against floods of the units that are located in the area.

If the intervention works cannot prevent the flooding of the territory of the water plants, until the failure of the temporary local dams, the pumping of the pumping stations will be ensured, the dismantling and evacuation of the electric pumps and chlorine cylinders (Ionescu Gh. C., 2007, 2008).

The operation of the pumping stations according to the periods of the year is carried out as follows:

- *In periods of average flows*

It operates in normal mode: 4 groups at P.S. 1, 2 groups at P.S. 3, 2 groups at P.S. 2, 3 groups at P.S. 4, 1 or 2 groups at P.S. 5, depending on the network pressure. The catchments are open depending on the water level in the enrichment basins.

- *During periods of high water*

The water from Crişul Repede is dirty (high turbidity) and the catchments are closed to avoid clogging the pools. The P.S. 5, where surface water is used, the dose of aluminum sulphate is increased to accelerate the settling of solid suspensions in water.

- *In times of frost (ice slopes, ice bridge)*

There are shifts of 2 people each, who will constantly monitor the catchments and will act with specific tools to avoid frost in the catchment area and block the pipes.

- *In periods of low water (drought)*

Captures will be permanently open. The flow of pumped water will be reduced depending on the water level in the caisson.

Functional diagrams of pumping stations no. 1 and 3 are shown in figures 1 and 2.

Since the structure of the P.S. 1 and P.S. 3 is more homogeneous, following the behavior of these P.S. it is more rigorous. As the specific electricity consumption is higher, the operational reliability study focused on these stations. The conclusions of the study are valid, for the most part, for the other P.S.

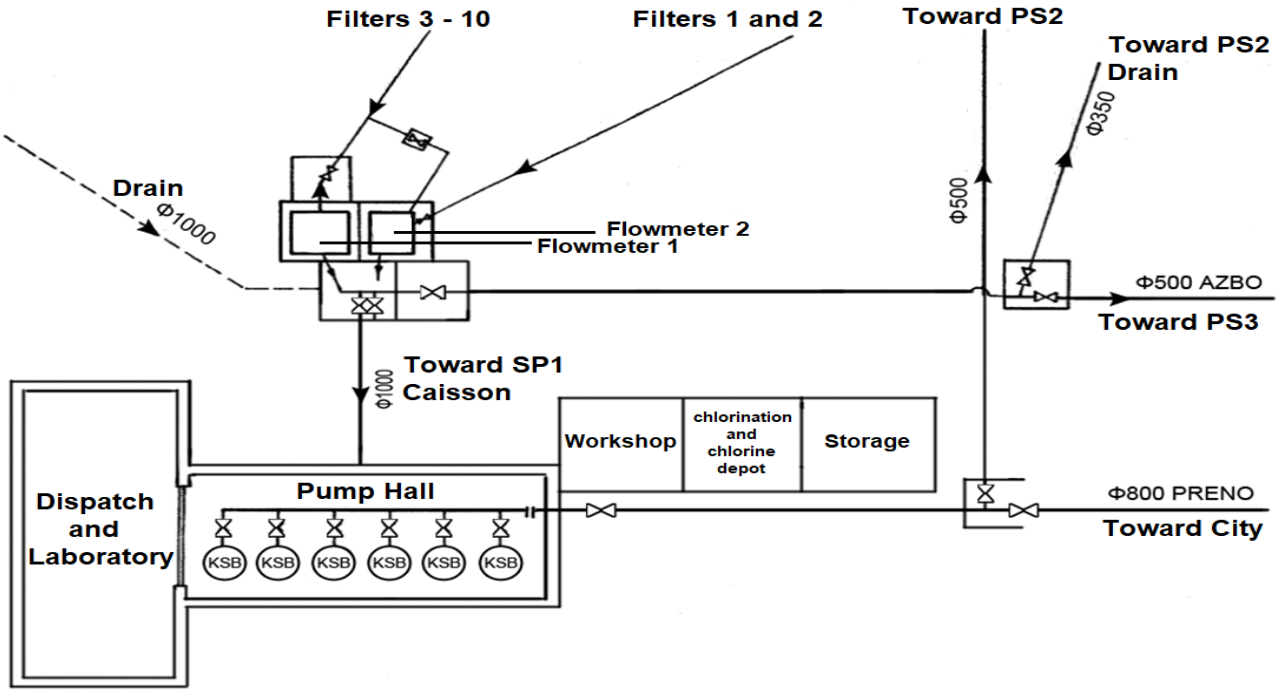


Figure 1. Functional diagram of the Pumping station no. 1 – ORADEA

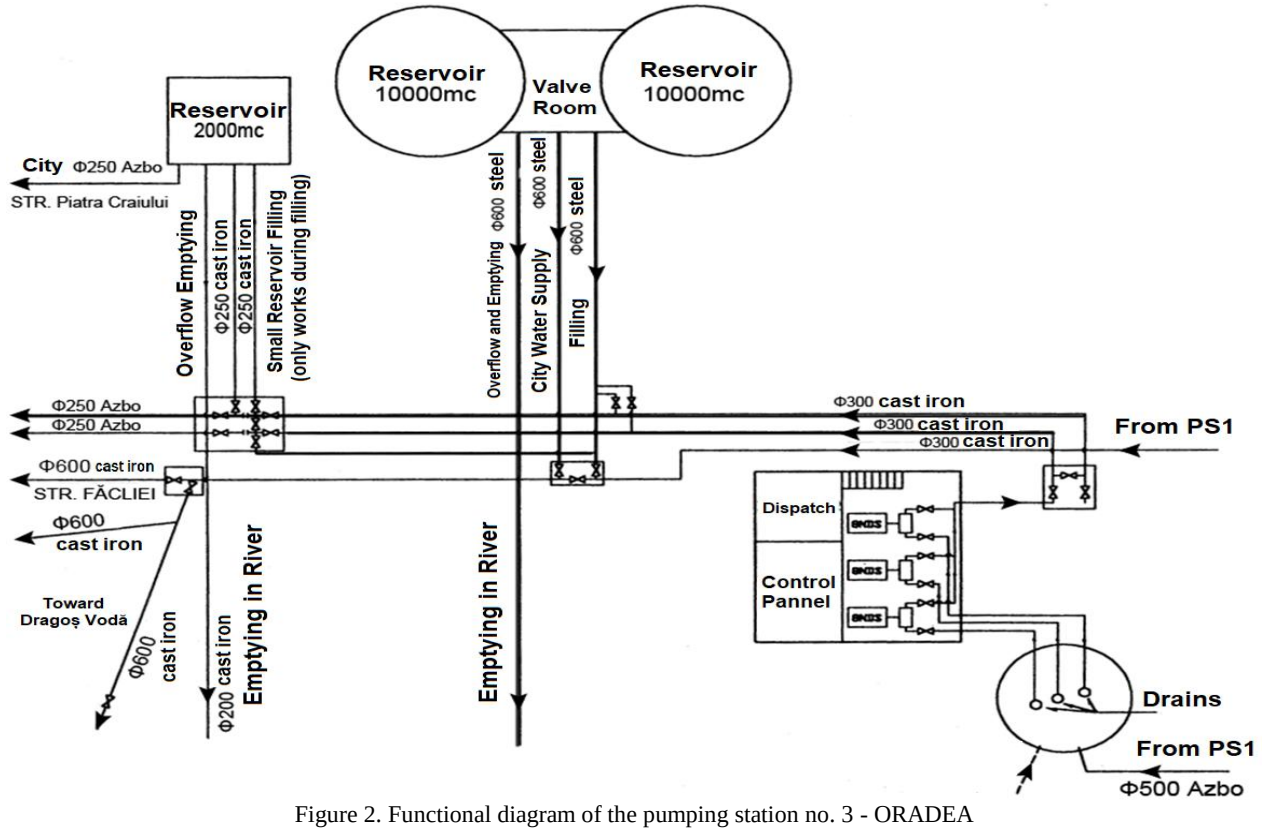


Figure 2. Functional diagram of the pumping station no. 3 - ORADEA

To exemplify the degree of load of the SP, in figure 3. and 4. the monthly load curves are shown.

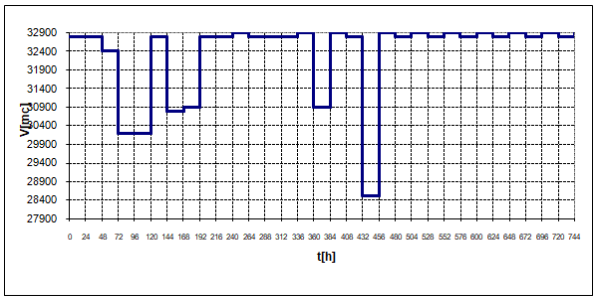


Figure 3. PS1 Monthly Load Curve (January 2012)

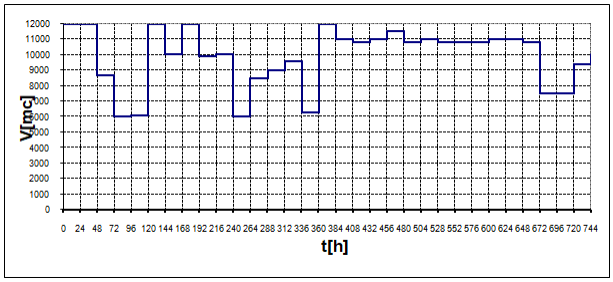


Figure 4. P.S.3 Monthly Load Curve (January 2012)

2. CONCLUSIONS

The bibliographic research, Case study performed on the operational reliability of the Pumping Station no. 1 (P.S.1) and of the Pumping Station no. 3 (P.S.3) from Oradea (located on the right bank of Crişul Repede River), which extended over a period T = 10.5 years, using the data obtained from 01.01.2011 ÷ 30.06.2021 and the results obtained by the authors regarding the optimization of the energetic functioning of the water supply systems and of the subsystems in their structure, led to the formulation of the following conclusions:

1. *Establishing the economic criteria for optimizing the structural reliability of a water supply system is a first aspect of assessing the energy performance of water supply systems and subsystems in their structure.*

The feasibility criteria for the solutions lead to the identification of the elements in the system that can have a great impact on the life, in general, and on the health of the population, by providing information on the security level of the technological processes.

The typical WSS structure of urban centers generally includes, as components, constructions and installations for: water abstraction, correction (improvement) of water quality (or water treatment), transport, pumping, storage and distribution of water (Ionescu, Daniela-Smaranda et al., 2007; Ionescu Gh. C., 2003; Ionescu Gh. C. et al., 2011).

The current trend in this field is to ensure drinking water, in accordance with current regulations, respecting the conditions of quality, quantity and pressure to the consumer.

The object of study of water supply is water, with its physical - chemical characteristics, biological and bacteriological indicators, together with all the processes and processes of capture, treatment, transport and distribution to consumers. It is necessary to take into account the fact that the accumulations of microelements, contained in drinking water, per kg-body differ from one organism to another, due to age, metabolism, certain diseases, etc. and can cause illness.

Studies and research to improve water treatment and clarification should focus in particular on reducing existing suspensions, chemicals and minerals in raw water, below the concentrations allowed for each indicator, with the highest possible technical and economic efficiency.

Mathematical modeling, process simulation and experimental study on the principles of similarity are essential ways of investigating in the field of WSS of urban centers.

2. *The complexity of the problems regarding the quality conditions requested by the beneficiary of the different categories of water supply, in correlation with the quality of the water source, determines the water cost, the treatment technology, the composition of the water supply system and, finally, the development of the water supply technique water (Ionescu Gh. C. 2003,2007, 2004).*

The magnitude of the water quality problems is also given by the ratio between the quantities requested by different consumers. This ratio depends on the development of the country, the specifics of its economy. In the Bihor area, the main sources of pollution on the Crişul Repede River that discharges wastewater (industrial) are: R.A.G.C.L. - Aleşd and S.C. Romcim S.A. - Aleşd. The Crişul Repede River is the main source of water supply for the riparian localities, which is why the control of the discharged wastewater must be carried out rigorously, offering optimal treatment solutions. The quality problems of the water sources and of the water delivered to the consumers catch more and more the attention of the specialists in the field, in order to solve all the aspects that arise;

Comparatively analyzing the C.E.E. and Romanian regulations, we find that a number of quality indicators still show significant differences both between the maximum recommended concentrations and between the maximum allowable concentrations, which is why the quality of drinking water in our country leaves much to be desired (Gligor, E., Dan Florin, 2009; Ionescu, G. L., 2009; Ionescu Gh. C., 2007).

3. *The study of the predictive reliability of water supply systems (WSS) involves a series of specificities that derive from the structural features and the social and economic implications of water quality. The problem is not adequately reflected in the profile literature.*

The study of the reliability of the WSS first involves the structural representation and functional analysis of the WSS and its subsystems. For the structural representation it is recommended to use the equivalent reliability diagrams, and for the functional analysis on different levels we will use event trees and state graphs;

The most significant indicators for characterizing the reliability of the WSS and its subsystems are: time security, time availability and flow availability, with reference to a certain

level of water quality and quantity (Ionescu Gh. C., 2003; Ionescu Gh. C. et al., 2011).

The method of parametric investigation and evaluation of the level of reliability by simulation is suitable for evaluations regarding water quality but also with reference to the reliability of some equipment with parameter drift.

- WSS is a serialized reliability system as a whole;
- There are subsystems in the composition of WSS, which through their technological structure, require a specific treatment of parallel systems, so:
  - Pumping subsystems are of the type „k of n";
  - The structures of the capture and distribution subsystems are of the type 2×100% or 3×50%;
  - The water treatment subsystem requires a special analysis, on the one hand in terms of water quality indicators (parametric reliability - mentioned above), on the other hand due to the existence, in some cases, of several treatment paths, parallel in technological appearance, designed to generate water with different levels of quality, in accordance with its destination.
- With reference to the WSS and the subsystems in its structure, predictive reliability analyzes should cover: time safety, flow safety, time availability, flow availability.

The subsystem with the greatest impact on WSS reliability is the pumping subsystem (WSPS), which, having a "k of n" type structure, involves relatively elaborate analyzes regarding the evaluation and optimization of the reliability level. To assess the level of reliability of the WSPS, it is recommended to apply, as appropriate, the models described in the paper:

- the general binominal model „n + k";
- the markovian model, for structures of „n + k" type which are relatively simple („1+1", „2+1", „3+1", „3+2" etc.), highlighting the type of reserve;
- evaluation of time and flow availability and unavailability, by combining the binomial method with the flow-time diagram.

4. Assessing the level of reliability of a water supply system involves knowing the reliability indicators of the component equipment, which requires an analysis of their operational reliability. In order for the results of the analysis to have the highest possible degree of credibility, it is necessary that the analysis interval be extended for as long as possible (in the order of years), respectively, the number of observed equipment should be as long as possible (Ionescu, G. L., 2009).

In order to evaluate the reliability indicators of the equipment within the water supply systems, I recommend that the statistical estimation be done by the linearization method, combined with the least squares method, and the verification of the statistical hypotheses with the Kolmogorov test (Ionescu Gh. C., 2003);

Following the analysis of the wear phenomena and the defects found in the elements of the studied system, the following methods of conservation and increase of reliability resulted:

- Oversizing elements in the design phase:
  - ⇒ The performance of the element increases;
  - ⇒ Additional investment costs.
- Reducing performance dispersion:
  - ⇒ The need to reduce the tolerance limits of the rated performance guaranteed by the manufacturer.
- Reduce element overload:
  - ⇒ Adoption of adequate means of protection;
  - ⇒ Increasing the number of spare parts.
- Reducing the rate of performance degeneration:
  - ⇒ Use of reliable materials with a slow aging process;
  - ⇒ Proper maintenance, lubrication and maintenance measures;
  - ⇒ Reducing the demand for items whose rate of performance degeneration depends on demand.
- Maintenance operations, especially those based on reliability (10):
  - ⇒ Preventive maintenance (reduction of the probability of failure due to degradation):
    - Maintenance based on reliability, which aims to prevent the entry of the element in an area where the reliability indicators no longer correspond;
    - Maintenance based on the total production, which follow more the production realized by the respective element accepting also the risk related to the postponement of some maintenance for the realization of some conjuncture production requests.
  - ⇒ Corrective maintenance (the set of activities designed to restore a malfunctioning item):
    - Palliative corrective maintenance, which involves putting the fallen element back into operation as soon as possible, using temporary solutions that will be followed by another maintenance activity to bring the item back to its normal state;
    - Curative corrective maintenance, which involves the re-commissioning of the defective element under normal and permanent conditions.

The water supply system of Oradea is sufficiently elastic and covering in terms of flow availability.

Although the system for tracking and recording events regarding the operating behavior of pumping stations needs to be supplemented, the data taken from the current operating and intervention registers allow for the performance of operational reliability studies with an acceptable level of credibility.

The level of operational reliability of the two analyzed pumping stations (P.S.1 and P.S.3) is comparable, (higher at PS3, explainable in terms of the characteristics of the aggregates which are newer and of lower unit powers).

The level of operational reliability of the groups in the pumping stations is comparable (slightly lower in group 1 of P.S. 2 and in group 2 of P.S.3, probably due to the more intense use of these groups).

Exponential distribution (TBF) can be adopted for the random variable "good running time" (TBF), and for the random variable "corrective maintenance time" (TMC) it is recommended to use it in empirical mean estimates (MTMC* = 1/μ*).

Most of the falls of the pumping groups are determined by the inadequate quality of the gaskets (71.46% - PS1 and 56.7% - PS3). At a great distance in terms of unreliability are other components: electric drive motor, valve and damper;

Analyzing from a reliable point of view the components of the electric motor structure, a differentiated hierarchy is found for the motors in the structure of the two pumping stations, as follows:

PS1: lubrication subsystem - bearings - stator and rotor - shaft - windings - bushings;
PS3: bearings and shaft - rotor and windings - stator and bushings - coupling.

The availability characteristics reflect an operational reserve in pumping groups, in the required flow conditions, higher by (10 ÷ 15)% compared to the reserve expected by the project.

We believe that in the future, efforts are needed in the following directions:

- Establishment of a modern management system for actions related to the reliability and maintenance of PES equipment, by practicing informational feedback (Ionescu Gh. C. et al., 2009);
- Rehabilitation of pumping stations (PS1, PS3), in order to increase energy performance and reliability;
- Reconsideration of component suppliers, especially those from which the gaskets are purchased.

Optimizing the energy performance of water supply systems and their subsystems is currently a key issue in the design, design, execution and operation of technical systems. There is a close dependence between the manufacturing cost of a system (product) and the level of reliability assigned to it. It is easy to guess that the higher the cost requirement, the more severe the requirement for reliability. On the other hand, the maintenance activity (maintenance, repair) from the operation phase, imposes costs whose level is inversely related to the level of reliability of the system (product).

The criteria for evaluating the feasibility of solutions, applicable in the field of WSS are (Ionescu Gh. C. et al., 2011):

- Investment payback time;
- Discounted net income;
- Profitability index.

For an optimal sizing, in the perspective of the new strategy regarding the habitat, it is necessary to complete the mentioned criteria with others, just as essential. Determining from a quantitative point of view is the acoustic criterion, according to which, each pipe (material, diameter, length) is associated with its own size in terms of transmission of vibrations and noise and, similarly, local resistance - the next criterion to improve the normative design provisions, according to which the maximum allowable speeds are unique, regardless of the material, the network configuration, etc.

Genetic algorithms (GAs) are adaptive algorithms that determine the optimal solution to an optimization problem based on mechanisms specific to genetics and natural selection..

The advantages of the "Genetic Algorithms" method compared to traditional methods of solving optimization problems are the following:

- It does not require a very rigorous modeling of the analyzed method, because they use representations of potential solutions and not the solutions themselves;
- Unlike gradient methods, which use analytical representations of the analyzed problem, AG does not require the complex calculation of some derivatives;
- Performs a parallel search in the solution space, as opposed to step-by-step searches;
- They can simultaneously analyze an increased number of regions in the solution space, which is why their sensitivity to local minimums is lower.

When designing the WSS, the optimization is related to the nominal (often maximum) operating conditions of the system, the optimization criteria having as probable input quantities the damages caused by the interruptions by failure (D_a) and the deviation of the water quality indices from a certain predetermined level. D_c) during the analysis period (T_A).

During the operation (operation) of SET, operating situations occur at parameters other than those designed (forced or normal load limitation) which require a reassessment of the conditions (strategy) for optimal operation of the system. In this context, aspects of two of the possibilities of action meant to ensure the optimal functioning of the system under the mentioned conditions (optimal conjuncture) are discussed.

5. *There is a need for the widespread adoption of real-time facility control systems, which would lead directly to the economic and technical-environmental reconsideration of all water resources management projects, such as and hydro-urban constructions.*

Two elements are needed to control water distribution networks:

- computer equipment of the distribution network that allows through the automation and control installations, to order, from a dispatcher station, through tele-mechanic channels, stations arranged on the water distribution network. The dispatcher must have a computer-aided programmable machine;
- a program for controlling the state of the distribution network (according to an efficiency criterion),

according to the scheduled hourly consumption schedule.

The main purpose of optimal control is to develop, based on mathematical means, decisions that ensure the optimization of direct operating costs by making better use of existing resources and by minimizing electricity consumption. The purpose of automated tracking is to assemble the three basic algorithms: demand forecasting, pump scheduling, and network simulation into a complete system. The consumption forecast will provide the information, for the adoption of the decisions, both in the issue of the planning of the exploitation regimes, and in the purpose of the optimal design and development of the respective system (Ionescu Daniela-Smaranda et al., 2007; Ionescu G. L., 2009).

Maintenance is the second most important lever (along with equipment quality) that influences the level of availability of equipment and systems. Reliability-based maintenance is a significant example of scientific maintenance management, based on operational reliability studies and technical diagnostic subsystems.

An essential aspect of the management of the maintenance of "k from n" type structures is that of identifying the moment of initiation of the maintenance actions so that the reliability gain is maximum. Such an approach is part of the maintenance strategy based on reliability.

The indicators of interest for the management of the maintenance of "k of n" type systems, according to the stated criterion, are: the value of the time interval after which the reliability gain reaches the maximum value (T_s), the time security ($R(T_s)$) and the reliability gain ($\Delta R(T_s)$) at the time of T_s.

The analytical and numerical expression of the indicators (T_s, $R(T_s)$, $\Delta R(T_s)$) for cases of practical interest) and for widely used electrical equipment (tables 1 and 2), highlights the fact that:

- for all the analyzed structures, the indicators $R(T_s)$ and $\Delta R(T_s)$ increase nonlinearly with k (increase with the decrease of the reservation degree);
- for all the structures and equipment analyzed, the indicator T_s decreases nonlinearly by k (decreases with the decrease of the reservation degree);
- the values of the indicators $R(T_s)$ and $\Delta R(T_s)$ are dependent only on the structure and not on the reliability characteristics of the equipment;
- the values of the T_s indicator depend on both the structure and the reliability characteristics of the equipment.

3. AUTHOR CONTRIBUTIONS

The main contributions made by the authors in the studies are:

√ Carrying out a bibliographic synthesis in the fields of water supply, experimental and operational reliability, problems of optimizing the reliability of systems and systematized presentation of the existing informative material in the specialized works;

√ Identifying the problems not treated properly in the specialized works as well as the research directions that are identified with the approached topic, applying in the study of water supply systems, the elements of dimensional analysis;

√ Carrying out a comparative analysis between the O.M.S. norms, the Council of Europe Directive - C.E.E. no. 80/778 and the Romanian regulations (STAS 1342 / 1-1991);

√ Carrying out a new case study on the water quality of the Crişul Repede River (Sampling was done on May 10, 2020 and on July 7, 2020), in order to highlight the changes produced by an increased flow, in conditions of heavy rainfall. The results of the analyzes lead to the establishment of the procedures for treating the captured water in order to make it drinkable;

√ Elaboration of equivalent reliability diagrams and structural diagrams for WSS and its subsystems;

√ Parametric approach to WSS reliability, with reference to the following aspects:

- Water quality, materialized by quality indices that show the content of some substances;
- Water availability to the consumer, quantified by indicators such as: pressure, flow, level, temperature;
- Parameter drift of some equipment from the WSS structure.

√ Elaboration of the mixed technological scheme (series - parallel) of a complex water treatment subsystem;

√ Applying the method of analysis of failure modes and effects (A.M.D.E.) to WSS reliability analysis;

√ Assessing the availability of water pumping subsystems;

√ Evaluation of all the indicators of reliability of the hydraulic installations within the water supply systems;

√ Carrying out a case study, regarding the operational reliability (FO) of the Pumping Station no. 1 (PS1) and of the Pumping Station no. 3 (PS3) from Oradea (located on the right bank of Crişul Repede), which extended over a period T = 10.5 years, using the data obtained from 01.01.2011 ÷ 30.06.2021;

√ Drawing up the load curves of Pumping Stations 1 and 3, during January 2021;

√ Determining the distribution laws and the reliability indicators for the pumping stations 1 and 3, presenting tabularly, on pumping groups, both the distribution functions of the variable time for good operation and corrective maintenance;

√ Elaboration of pareto diagrams of failure rates for groups of pumping stations and for stations as a whole;

- √ Calculating the probabilities of good functioning and failure for groups, respectively stations and successive graphical presentation of the respective indicators;
- √ Assessing the temporary variation of maintainability and availability for groups and stations;
- √ Development of flow-time diagrams for Pumping Stations 1 and 3;
- √ Analyzing two extreme situations for each pumping station and comparing the required flow values with the operational flow values;
- √ Choosing the optimal method for evaluating the reliability indicators for the equipment within the water supply systems, as well as the methods for preserving and increasing the reliability;
- √ Establishing the criteria that are suitable for the analysis of the economic feasibility of the technically plausible solutions for WSS;
- √ Presentation of the usual optimization criteria regarding the dimensioning of the water supply installations and presentation of a proposal regarding the completion of these criteria with a new criterion, the acoustic one, according to which, each pipe will be associated with an individual size regarding the transmission vibration as well as noise and similarly local resistance. This criterion is intended to improve the normative design provisions, based on which the maximum allowable speeds are unique, regardless of the material used, the network configuration, etc.;
- √ Elaboration of a heuristic method for the functional optimization of the WSS and of the subsystems in their structure;
- √ Adapting the use of the real-time control system, used so far to maintain a constant level in the rainwater retention basins, to ensure a constant level in the water storage tanks, within the water supply system;
- √ Elaboration of an own scheme of optimized control of a water supply system, with the indication of the cost techniques necessary for the decision support system;
- √ Indication of the main objectives necessary for the optimal design of the sanitary installations;
- √ Suggesting the need for a judicious management of drinking water, by stimulating the actions of rainwater use;
- √ Scoring the main ways to reduce energy consumption, both in the design phase of a water supply system and in the case of objectives that are already in operation.

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