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**Dorota Mirosław-Świątek, DSc, associate professor**
Institute of Environmental Engineering, WULS-SGGW
e-mail: dorota_miroslaw_swiatek@sggw.edu.pl
**ORCID:** 0000-0003-3920-8215

**Dariusz Morawski, MSc**
Institute of Environmental Engineering, WULS-SGGW
e-mail: dorota_miroslaw_swiatek@sggw.edu.pl

**Łukasz Pieniak, MSc**
HBM Prenscia
e-mail: lukasz.pieniak@hbkworld.com

**Bartłomiej Świątek, MSc**
HBM Prenscia
e-mail: bartlomiej.swiatek@hbkworld.com

**Przemysław Czapski, MSc**
HBM Prenscia
e-mail: przemyslaw.czapski@hbkworld.com

**prof. Tadeusz Siwiec, DSc Eng.**
Department of Environmental Engineering and Geodesy,
University of Life Sciences in Lublin
e-mail: tadeusz.siwiec@up.lublin.pl
**ORCID:** 0000-0002-4671-4602

# RELIABILITY ASSESSMENT OF WATER TREATMENT PLANT WITH APPLICATION OF THE MONTE CARLO SIMULATION

## Abstract

The paper presents a comprehensive Reliability, Availability and Maintainability (RAM) assessment of the Water Supply Plant WULS-SGGW (WSP). The Monte Carlo method was used to simulate failure events of components in the technological process of the water treatment system. BlockSim application was used to perform an analysis. The reliability block diagram was used as a system modeling method. Reliability metrics were estimated based on 1000 simulations of 15 years of operation of the station. Simulations allowed the estimation of reliability metrics for the WSP, its subsystems, sections as well as basic elements included in the model. They also made it possible to determine which components are most critical to reliability.

**Keywords:** reliability, Monte Carlo simulation, RAM analysis, water supply system, BlockSim

# OCENA NIEZAWODNOŚCI STACJI UZDATNIANIA WODY Z ZASTOSOWANIEM SYMULACJI MONTE CARLO


## Abstrakt

W artykule przedstawiono kompleksową ocenę niezawodności, dostępności i utrzymywalności (RAM) Zakładu Wodociągowego WULS-SGGW (WSP). Do symulacji zdarzeń awaryjnych obiektów w procesie technologicznym systemu uzdatniania wody wykorzystano metodę Monte Carlo. Do przeprowadzenia analizy wykorzystano aplikację BlockSim. Jako metodę modelowania systemu zastosowano niezawodnościowy schemat blokowy. Metryki niezawodnościowe oszacowano na podstawie 1000 symulacji 15-letniej eksploatacji stacji. Symulacje pozwoliły na oszacowanie metryk niezawodnościowych dla WSP, jej podsystemów, sekcji, a także podstawowych elementów wchodzących w skład modelu. Pozwoliły również na określenie, które elementy są najbardziej krytyczne dla niezawodności.


**Słowa kluczowe:** niezawodność, symulacja Monte Carlo, analiza RAM, system wodociągowy, BlockSim

## 1. Introduction

Reliable water supply is one of the basic priorities for local authorities. Among the other requirements, water supply should meet quantitative and qualitative objectives as well as physical properties like standard pressure value [1]. To face these challenges water supply systems with pumping stations and pipelines supported by storage tanks are commonly in use and continuously developed. Standard water supply systems infrastructure is presented in Figure 1.

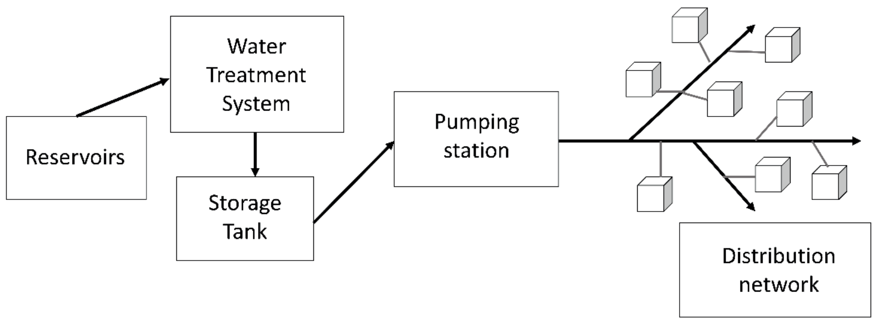


Fig. 1. Key elements of a standard water supply system

Source: own study

Water reservoirs are the first element of each water supply system. Water can be drawn from deep well, from a surface water source or infiltration water intakes. Commonly, raw water from reservoirs will not meet the requirements of strict sanitary standards. Water treatment with chemical and physical processes is used to provide water with proper characteristics for safe daily usage by humans.

A significant amount of water is stored in a storage tank to cover the increased demand for water consumption. Such an increased demand is usually observed during daily peaks – morning and evening, hot summer days, fires. Main pump stations with pipelines network, usually concealed under the ground alongside roads, provide potable water to local substations and then water is taken farther to water piping systems inside buildings to reach finally draw-off valves. Water supply will be uninterrupted and safe only if each element and equipment of the water supply system meets specified reliability requirements.

The reliability of the item is commonly defined as an ability to perform an intended function for a designated period without failure and under specified conditions. For repairable systems, this ability is described with additional stress on availability and maintainability (RAM) [2–5] and is commonly used in various industry sectors [6]. Quantitative RAM analysis of technical systems is an important process during the design stage (Design For Reliability). The RAM analysis helps to decide on the required redundancy, selection of proper system elements, system configuration and optimum maintenance strategy. System reliability is estimated with the use of a mathematical model implementation. Based on this model numerical and functional reliability metrics are obtained [7-8]. Nowadays, calculation methods for a RAM analysis are dynamically developed. All of these methods can be classified into 3 main categories: analytical, the Monte Carlo simulation and heuristic techniques [9]. An analytical approach is widely applied to quantify reliability of the water station. With this approach reliability models for parameters of station subsystems are estimated based on empirical and literature data. Further on the entire system model parameters are calculated based on system architecture and analytical methods [10–14]. There are several successful implementations of the Monte Carlo method for availability metrics calculation. This method adopts repeated random sampling of discrete events from failure distribution [15–16, 8]. Optimum maintenance interval and the number of maintenance tasks with availability and cost optimization were quantified for chemical plant analysis [9]. A discrete events simulation using the Fault Tree methods was also successfully implemented for the wastewater treatment system [17]. Software implementations of described RAM analysis methods are available [18, 8] and commonly used, like BlockSim application [19–20]. BlockSim provides both Reliability Block Diagrams (RBD) and Fault Tree Analysis (FTA) for RAM calculation. BlockSim's RBD and FTA were used in Tchórzewska – Cieślak & Boryczko paper [21] to analyze the downtime of the water supply subsystem. Reliasoft BlockSim was also used to analyze risk in a nuclear power plant [22].

In most papers in analyses of the reliability of water supply systems only the availability metric was assessed (among others [23, 24]). In this paper a complex RAM analysis of the Water Supply Plant WULS-SGGW was performed with the Monte Carlo simulation method implemented in BlockSim application.

## 2. Water Supply Plant description

The Water Supply Plant WULS-SGGW [25] is a system, which supplies water to the campus of the Warsaw University of Life Science. The campus consists of university buildings, greenhouses and experimental plots, laboratories, administration buildings and technical services, dormitories, libraries, etc. What makes this water supply system unique is the scientific and research character. The system is used for several student classes and research projects [26]. Key performance characteristics of technological process are: daily average flow – Qavday = 950 $m^3$/day; daily maximum flow – Qmaxday = 1034 $m^3$/day and maximum hourly flow – Qmaxh = 150 $m^3$/h. Taking into consideration Qavday and the standard daily water demand of 0.1 $m^3/(M \cdot day)$, WSP production capacity can fulfil the demand for water consumption of 9500 people. The water supply system flow diagram is presented in Figure 2.

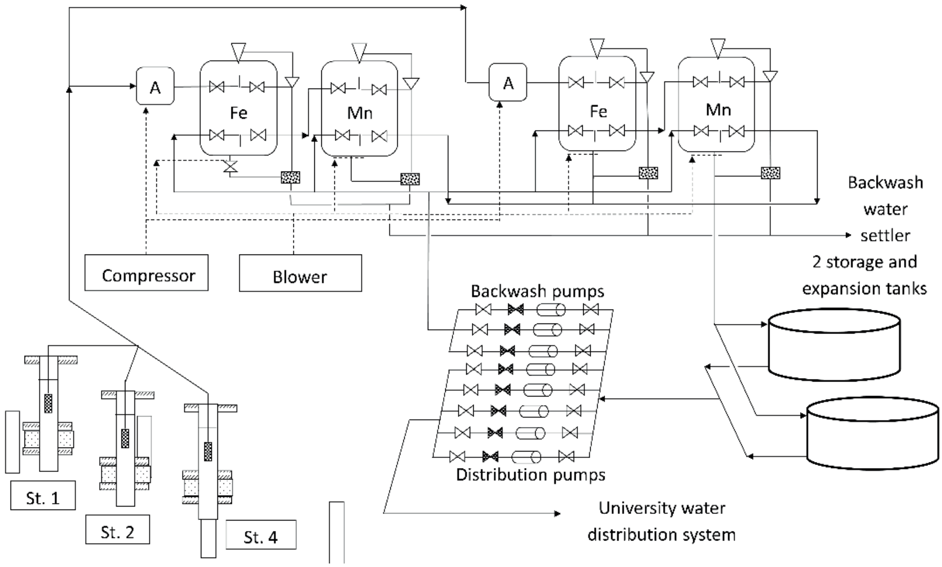


Fig. 2. The Water Supply Plant WULS-SGGW flow diagram

Source: own study

The water station in question draws water from 3 deep wells St 1, St 2 and St 4. Next the water goes through two parallel technological sections. Each of them starts with aerators *(A)*, and compressed air for aerators is prepared in the air compressor unit. Aerated water is then filtered in the de-ironing and the de-manganese filters. Subsequent to this process water is stored in the two storage-expansion tanks. Water from storage tanks is distributed via distribution pumps directly to the university water distribution system. The water distribution system is connected with all campus buildings. If de-ironing and de-manganese process is used, there is a need for backwash filtering of the filter bed. Treated water from clean water storage tanks is used for backwash. An additional unit of backwash pumps is required for this process. Backwash water flows from top to bottom of the filters, then water with released contamination is directed to the backwash settling tank.

The compressed air unit is divided into two subsystems. The first one of them is a compressor with air pipelines connected to aerators. The second low-pressure part is a blower with pipelines connected to lower parts of filters. Such a connection helps to intensify the backwash of filters.

## 3. Methods

### 3.1. Reliability Assessment

Reliability is defined as the likelihood that the item will perform its intended function during a specified period of time and in the defined environment conditions without failure. Mathematically this can be described with special functions and finally quantified with reliability metrics. It takes into consideration the characteristics of the item and the stochastic process that affects its performance.

*R(t)* known as reliability function is defined as probability, *P* of failure less performance till t point of time with operation under defined environment condition [27]:

$$R(t) = P(T \geq t) \qquad t \geq 0 \tag{1}$$

where:
$T$ – is a continuous random variable as the time of proper operation.

As the water supply system is repairable, performance characteristic based only on function *R(t)* is insufficient and so the system renewal theory should be used. The influence of maintenance factors should be considered for needs of a complex analysis. In such a case use would be made of the methodology of analysis commonly known as RAM assessment [9, 19]:

- Reliability, as it has been mentioned before, is the ability of the item to perform its intended function during a defined time under specified conditions.
- Availability is defined as the ability of the system to be in a state that allows performing an intended function under specified condition, during a specified point of time or period of time. Keeping the system in this state requires the assurance of external resources.
- Maintainability measures system ability to be restored (with required resources and methods) to operational status after a failure has occurred.

### 3.2. BlockSim application

BlockSim application is part of the Reliasoft's Synthesis Platform with a complete solution for reliability analysis and reliability management within the organization – Reliability Engineering Enterprise Platform [20]. The BlockSim software helps analyze a system in a context of reliability, availability, and maintainability with additional features to consider and to compare various maintenance strategies. Such a complex RAM analysis can be performed with the use of various tools and methods like Reliability Block Diagrams (RBD), Fault Tree Analysis (FTA), Markov Diagrams and Process Flow Diagrams (PFD). The Fault Tree Analysis module is often used for risk and safety analyses [28, 17, 22, 29]. BlockSim results can be obtained as a solution of exact computation or discrete event simulation. Discrete event simulation internally uses an algorithm based on L'Ecuyer's random number generator with a post Bays-Durham shuffle [20]. RBD and FTA can reflect reliability-wise configuration of the systems with series, parallel, "k out of n", standby and load sharing configuration. In order to simplify the probabilistic model of such a system, it is assumed that the failure of each component of that system is statistically independent of the operation or failure of other components. This approach avoids the need for complex calculations for conditional probabilities. This approach is commonly used in practice.

The definition of reliability policy for each of the system elements is based on the Universal Reliability Definition that defines the reliability model according to a distribution or fixed value, corrective and scheduled maintenance definition with additional emphasize for the event duration, cost and required resources.

As an extension of RBD, the Phase Diagram [30] was introduced to model and analyze the sequence of different operational and/or maintenance phases experienced by the system.

Analysis results are presented as plots, graphics, dashboards, tables and reports. On this basis the right decision can be made for redundancy, reliability allocation, and selection of system components, system configuration, maintenance strategy etc.

## 4. The reliability model of the WSP system

The RAM model includes the most important water supply system elements having the greatest impact on its operation, on system downtime and the quality of treated water. Based on the technological scheme (Figure 2), the reliability block diagram has four components (Block1 – 1st stage pumping station; Block2 – water treatment system; Block3 – Backup and expansion tank; Block4 – 2nd stage network pumps) that operate in a serial configuration (Figure 3). In such a reliability structure, the failure of at least one of the components causes the loss of reliability of the entire system.

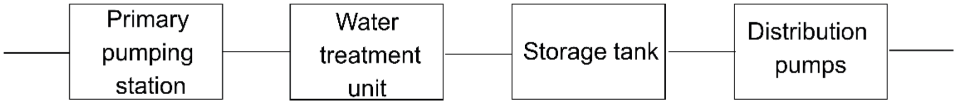


Fig. 3. The WSP system level reliability block diagram
Source: own study

The Primary Pumping Station (Figure 2), with three submersible pumps, operates in "k out of n" (k = 2, n = 3) structure (Figure 4). The Primary Pumping Station works correctly when at least two pumps are available.

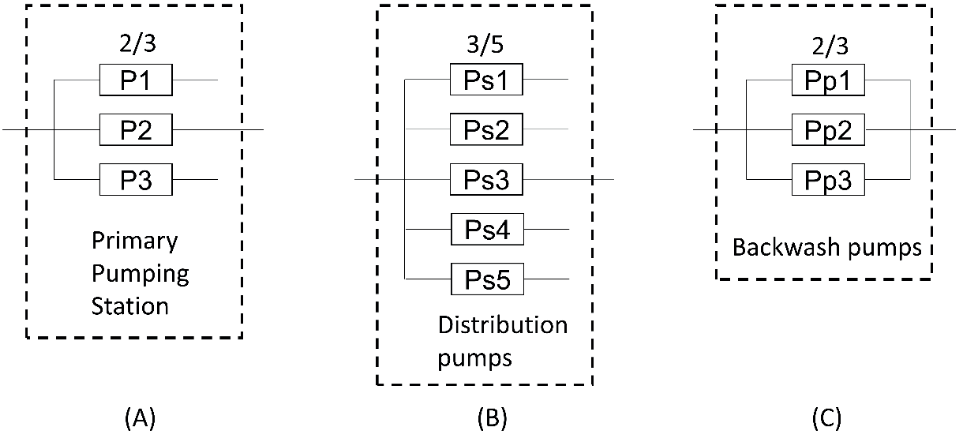


Fig. 4. Reliability-wise configuration of A) Primary pumping station (*P1, P2, P3* – submersible pumps); B) Distribution pumps (*Ps1, Ps2, Ps3, Ps4, Ps5* – Distribution pumps); C) Backwash pump unit (*Pp1, Pp2, Pp3* – Backwash pumps).

The Secondary Pumping Station (Distribution pumps) (Figure 2) with 5 pumps also has a "k out of n" reliability structure (k = 3 n = 5) (Figure 4). In this case, at least 3 pumps should be available to fulfil the technological requirements of water mass flow and its pressure. Also, a reliability structure "k out of n" (k = 2 n = 3) was adopted for the set of flushing pumps (Figure 4).

The basic reliability structures (serial structure, parallel structure or "k out of n") cannot properly model the WSP reliability with consideration to the periodic backwash of the filter bed by a set of backwash pumps (Figure 2) This is explained on Figures 5 and 6. The process of water filtering results in settling of contaminations in the internal pores of the filter bed. This entails clogging of the bed and as an effect a slow but gradual decrease in filter efficiency. As a rule the duration of the clogging process cannot be determined. It depends predominantly on the volume of water consumption by consumers. Restoration of the filters to their original condition is done through the backwash process, which is triggered by the amount of filtered water through a given filter. In case of a short duration of filter backwashing (15 min.) compared to the long filtration cycle and "k = 2 out of n = 3" reliability structure, the assumption of reliable filtering can be made, especially that in the event of an emergency, the filtering time is not significantly extended beyond the assumed limit, resulting in a slow decrease in the filter capacity; considering the operation of the reserve and expansion tanks, this does not pose a threat to the entire system. This additional time helps the operator to eliminate the damage.

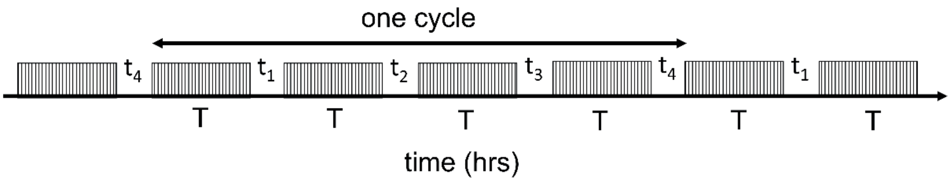


Fig. 5. Backwash pumps operation plan (T=15 hours; t1=t2=t3=t4=15 minutes – backwash filter downtime *F1, F2, F3, F4*

Source: own study

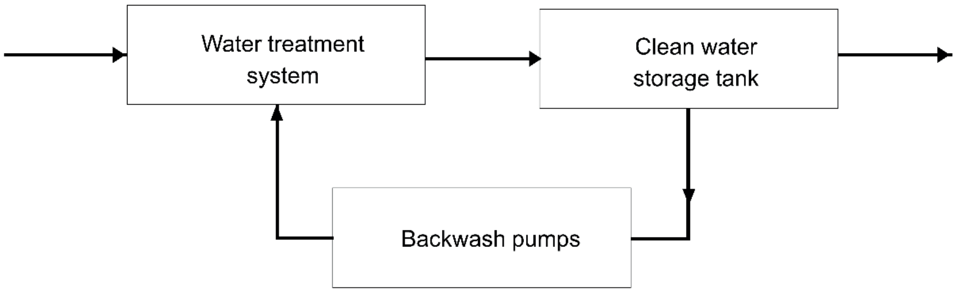


Fig. 6. Water Treatment System – Clean water storage tank – Backwash pumps water flow diagram

Source: own study

The storage tank consists of two chambers (Figure 7). As chambers are in a parallel configuration, at least one of the units must succeed to fulfil the tank's function in the WSP. The Water Treatment System comprises the Water Aeration Unit (WAU) and the Water Treatment Section. Both components operate in a serial reliability structure (Figure 8). The Water Treatment System is represented by a parallel structure consisting of two parallel sections (Section 1, Section 2). The proper operation of any of the sections ensures the reliability of the system.

The elements of each section (Aerator and both Filters) are connected in series. All components must be available to run properly in the water treatment process.

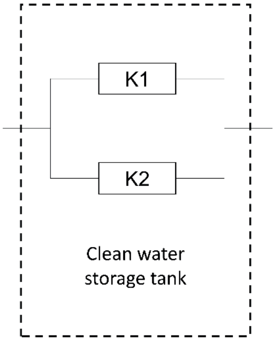


Fig. 7. Clean water storage tank Block diagram (*K1, K2* – Tank chambers)

Source: own study

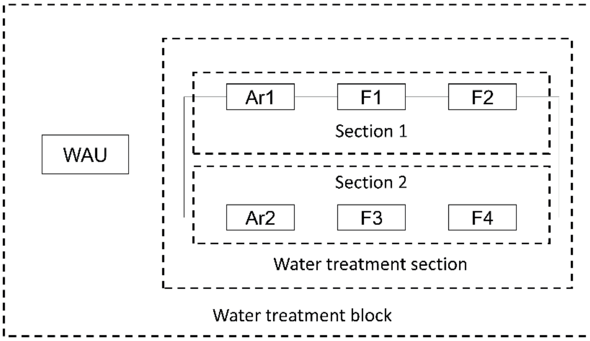


Figure 8. Water treatment system Reliability Block Diagram (WAU – water aeration unit; *Ar1, Ar2* – aerator; *F1, F3* – de-ironing filter; *F2, F4* – de-manganese filter)

Source: own study

Failure logs were reported and documented through 15 years of system operation. Failure logs contain information about the malfunction of the WSP components (type, number, date and time of occurrence and duration of the malfunction, as well as the impact of its effects on the station's operation). Based on this operational data the values of reliability characteristics adopted in the simulations were estimated (Table 1). The failure intensity of components (Figure 4, 7 and 8) was calculated according to the formula (3), in which the MTBF was estimated on the basis of the failure log.

Tab. 1. Reliability parameters for the WSP equipment

| Name | Failure Intensity λ [1/h] | Mean Time To Repair [h] | Planned Maintenance |
|---|---|---|---|
| P1,P2,P3 | 3.04414E-05 | 336 | n.a. |
| K1, K2 | 0.76104E-05 | 252 | n.a. |
| Ps1, Ps2, Ps3, Ps4, Ps5 | 4.56621E-05 | 24 | n.a. |
| Pp1, Pp2, Pp3 | 1.52207E-05 | 12 | n.a. |
| WAU | 1.52207E-05 | 168 | n.a. |
| Ar1, Ar2 | 6.08828E-05 | 8 | 8 hrs of chemical cleaning, once per year |
| | | | Backwash per each 2 hours, once per quarter |
| F1, F2, F3, F4 | 7.61035E-06 | 672 | 72 hrs. of cleaning, once per quarter |

Source: own study

### 4.1. The WSP RAM analysis with BlockSim application

The reliability block diagrams of the water treatment station presented in the diagrams (Figure 3, 4, 7–9) were devised in the BlockSim program. Next the discrete event simulation was performed using an algorithm based on a random number generator [20]. Due to complex reliability structure of the considered system, for each of the technical devices a simple model was adopted with the reliability function R(t) defined by formula (1) with exponential distribution:

$$R(t) = e^{-\lambda t} \tag{2}$$

where:
$\lambda$ – constant failure rate [1/h]

The exponential distribution is commonly used in reliability assessments of complex technical systems and when limited data is available [21, 31, 27, 22]. For exponential distribution, for which the failure rate is constant λ, it can also be calculated based on MTBF parameter:

$$\lambda = \frac{1}{MTBF} \tag{3}$$

where:
*MTBF* – Mean Time Between Failures, [h].

Failure rate parameters for each system item are presented in Table 1. Parameters were estimated based on operational data. The BlockSim application performed 1000 simulations of fifteen years of water treatment station operation time. Running simulations for this period made it possible to compare the calculated number of failures with the actual number of their occurrences. The final *RBD* model consists of 20 equipment items included in the WSP reliability model. For each j-th simulation (j = 1, ..., 1000) in the scheme of 15 years of operation the value of the random variable T, describing the time of proper functioning of the facility between downtimes related to damage removal or resulting from scheduled service times (Table 1), are drawn according to the adopted exponential distribution (the Monte Carlo simulation) [32]. The operation of the set of backwash pumps in the section of flushing Fe filters and Mn filters are implemented in the BlockSim application by introducing an additional module in the calculations – the Phase Diagram [30]. The Phase Diagram allows modelling and analysis of the sequence of various operating and maintenance phases of the system (Figure 5). The model for each station item assumes that the repair time is fixed and defined by the average repair time (Table 1). Using the adopted reliability structure model, the computational application analyzes the viability and failure times for the entire system and highlighted subsystems. Performing 1000 simulations allows the generation of a population of n = 1000, which consists of operating processes over a given 15-year period of such facilities as the WSP, its subsystems, and their components as well as 20 basic elements of equipment.

## 4.2. Reliability metrics

Below is a description of the metrics that were calculated in the BlockSim application and used in the WSP reliability assessment.

- *UPt* – average uptime (obtained by taking the sum of the uptimes for each simulation and dividing it by the number of simulations).
- *Dt* – average downtime (obtained by taking the sum of the downtimes for each simulation and dividing it by the number of simulations).
- *A* – mean operational availability, defines as the ratio of the system uptime divided by the total simulation time (total time):

$$A = \frac{UP_t}{T_t} \tag{4}$$

  where:
  Tt – total operation (simulation) time.

- *NF* – average number of system downing failures (average from all simulation runs).
- *MTBF* – Mean Time Between Failures:

$$MTBF = \frac{UP_t}{N_F} \tag{5}$$

- *MTTF* – Mean Time To First Failure.
- *MTTR* – Mean Time To Repair.
- *MTTM* – Mean Time To Maintenance.
- *R(t)* – Point Reliability defined as the probability that the system has not failed by time t.
- *RS FCI* – relative index quantifying the percentage of times that a failure of this component caused a system failure.
- *RS DTCI* – relative index quantifying the contribution of the block to the system's downtime.
- *NC* – number of corrective maintenance actions that caused the system to fail.
- *CMt* – average time the system was down for corrective maintenance actions (CM).
- *PMt* – the average time the system was down due to preventive maintenance (PM) actions.
- *NP* – number of PM actions that caused the system to fail.

## 5. Results and discussion

The results of computational simulations (1000 simulations of 15 years of operation), in the form of the analyzed metrics, are summarized in Table 2.

Tab. 2. Reliability metrics

| Metric | Value |
|---|---|
| A | 0.9954 |
| Ut [h] | 130800 |
| Dt [h] | 600 |
| MTTF [h] | 49686 |
| MTBF [h] | 49136 |
| MTTR[h] | 148 |
| MTTM[h] | 7 |
| NF | 2.662 |
| NC | 9.197 |
| CMt [h] | 395 |
| NP | 71.492 |
| PMt [h] | 205 |

Source: own study

The estimated average number of damage in the NF system causing the loss of correct operation of the WSP during the 15-year operation period is 2.662. This means that for 1000 simulations 2662 malfunctions have been recorded. The *NF* specified in the reliability model does not differ significantly from reality. During 15 years of station operation, 4 failures occurred.

The station was found to have a very high mean availability index *A* = 0.9954, which exceeds the requirements in this respect for water supply plants with reliability class [33]. The Mean Time Between Failures *MTBF* reaches the value of about 5.5 years (49136 hours), and the Mean Time To Repair *MTTR* of the water treatment station is 148 hours. The Mean Time To Maintenance *MTTM* is 7 hours. During 15 years of operation, the station did not provide water with the required quantity and quality (*Dt*) for 25 days. The average number of repairs was 9.197, which resulted in 395 station stops and the downtime 71.492 scheduled services were 205 hours.

Figure 9 presents how the reliability function *R(t)* of the station changes over a 15-year operation period. The *R(t)* values were derived from the BlockSim calculation program with a time step of 100 hours (Figure 9). The probability of station failure over 15 years of operation is 0.931, with availability *A*(t=15 years)= 0.996.

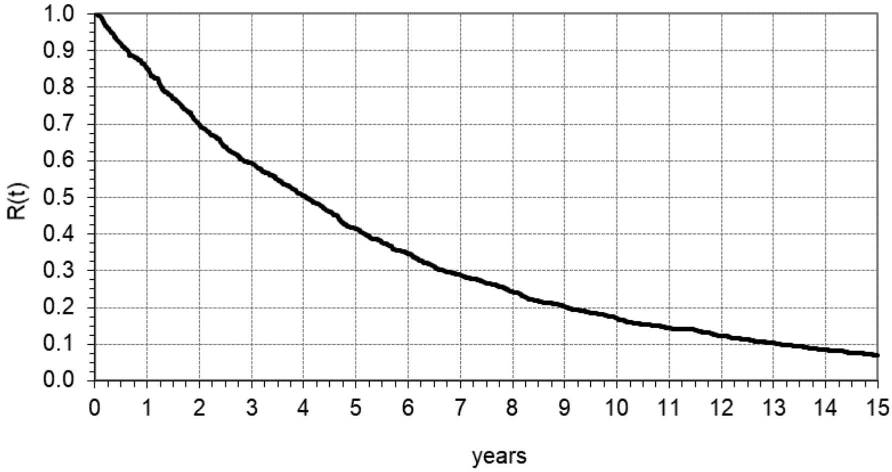


Fig. 9. Calculated system Point Reliability *R(t)*

Source: own study

Computational simulations of the station's operation with the assumed reliability model allowed estimating the operational readiness index for its main components (Figure 10). The secondary tank and distribution pumps were found to have the highest availability ratio (*A*> 0.99999). The Water Treatment block has the lowest value of this metric (*A* = 0.9958). The water aeration unit is characterized by lower availability than the Water treatment section (Figure 11). It should be emphasized that all components have a very high availability ratio *A*> 0.995. In the Suchorab's paper [34] it has been proven that the highest readiness index was obtained for the control and power supply system: 0.999999 and the lowest for the intake: 0.840401.

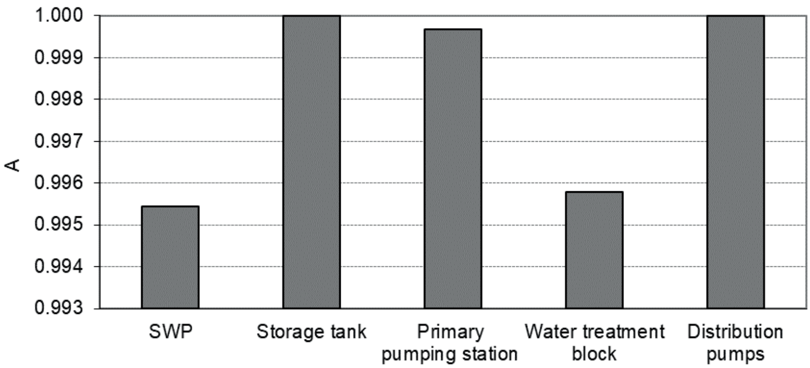


Fig. 10. Mean availability calculated for the WSP subsystems

Source: own study

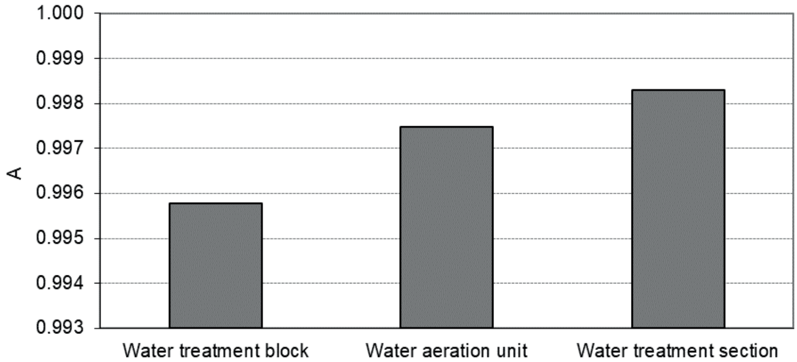


Fig. 11. Mean availability of Water Treatment Subsystem units

Source: own study

The Water Treatment Block has a major impact on the number of WSP downtimes (Figure 12) and is the cause of 89% of its failures.

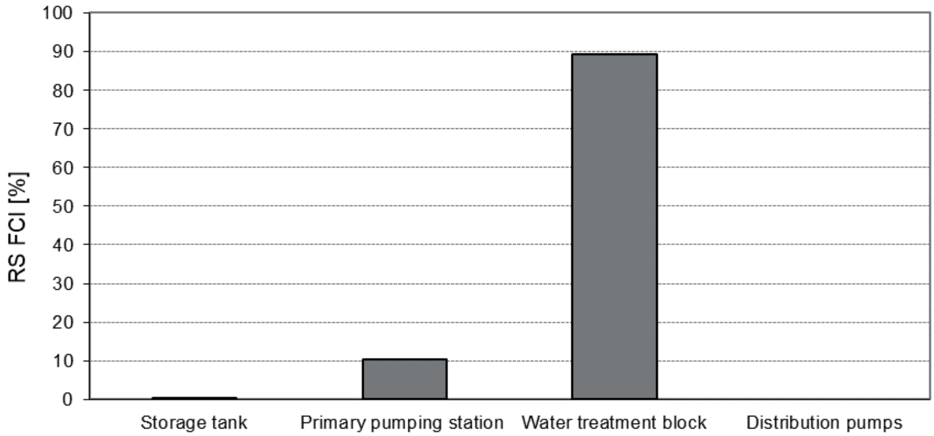


Fig. 12. The calculated RS FCI indicators for WSP subsystems

Source: own study

It should be emphasised that they are mainly related to the unreliability of the water aeration unit (Figure 13), which causes 74% of station failures.

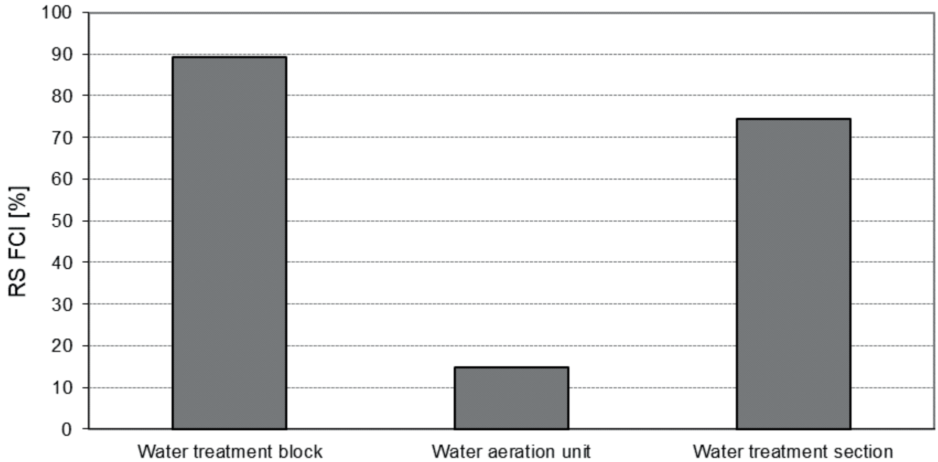


Fig. 13. The calculated RS FCI indicators for the Water treatment unit equipment

Source: own study

The Water Treatment Block has the largest share in the overall station downtime (Figure 14), the RS DCI indicator reaches 92%, of which 55% are associated with the water aeration unit (Figure 15).

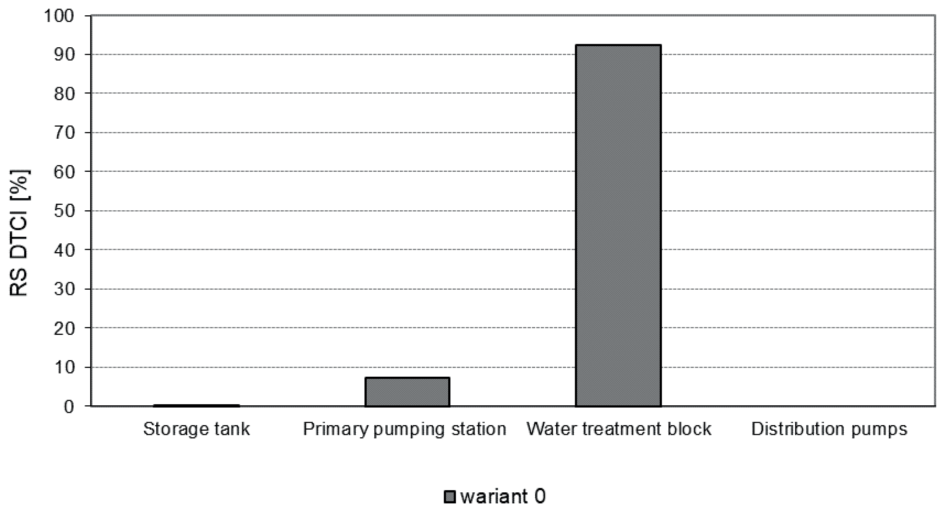


Fig. 14. The calculated RS DTCI indicators for the WSP subsystems

Source: own study

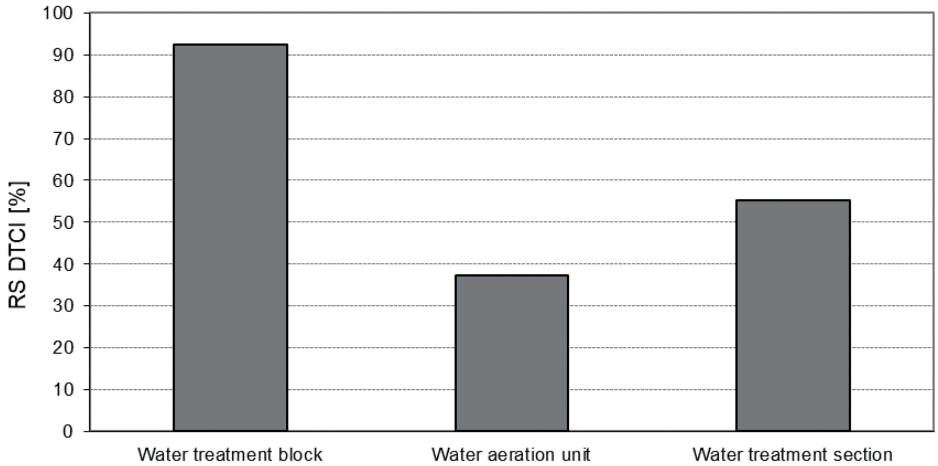


Fig. 15. The calculated RS DTCI indicators for the Water treatment unit equipment

Source: own study

It is worth noting that the RS FCI and RS DTCI index for the Primary pumping station, the Tank and the Secondary pumping station is over 10-fold lower than the values of these indicators for the Water treatment block. These three blocks are characterized by high redundancy (Figure 4, Figure 7) and work in series with the Water Treatment Block and its two sections carrying out the process of iron and manganese removal from water (Figure 8). The calculated RS FCI and RS DTCI indicators for individual equipment items are shown in Figure 16 and Figure 17.

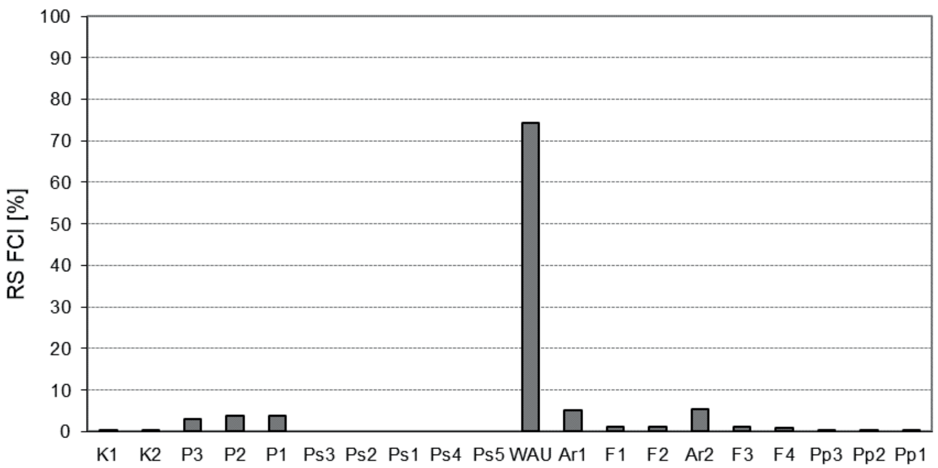


Fig. 16. The calculated RS FCI indicators for WSP elements

Source: own study

Less than 1% of water treatment station failures result from the failure of the following devices: tank chambers, backwash pumps, distribution pumps, as well as *Fe* filters and *Mn* filters. Submersible pumps and aerators have a minor impact on system failures. Additionally, the failure events of tank chambers, filters, backwash pumps and network pumps have a very insignificant impact on the station's downtime (below 1%). The downtime for submersible pumps is below 3% of the downtime of the entire station. Failures of aerators resulted in 17% of the station downtimes. Much higher values of the RS FCI and RS DTCI indicators for the water aeration unit result from the $\lambda$ value adopted for it in the reliability model. These failure rates are high in comparison to other facilities. This also applies to the average repair time and its serial connection in the technological line. Higher values of both indicators for aerators also result from the high value of failure rate $\lambda$ and their operation in series. Submersible pumps are also characterized by low redundancy, high $\lambda$ value and the longest average repair time.

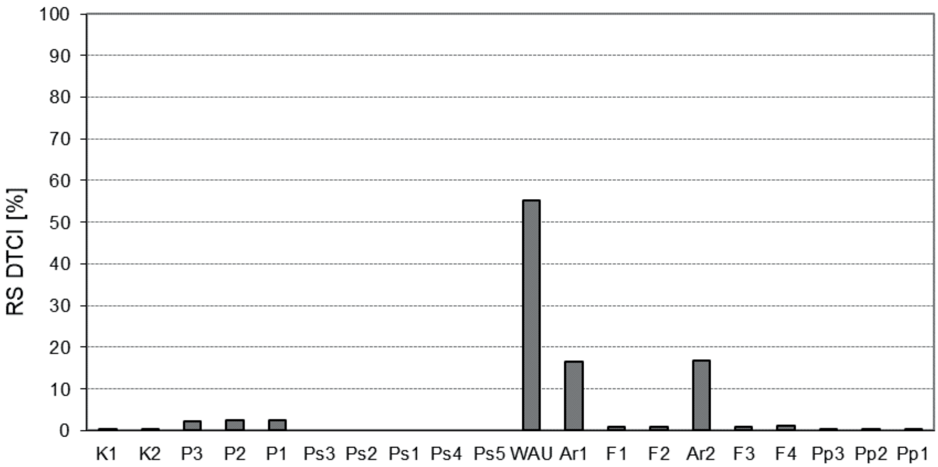


Fig. 17. The calculated RS DTCI indicators for the WSP elements

Source: own study

The availability *A* values of the station, its components and equipment obtained in the analysis are comparable with values specified in literature [33, 35]. A comprehensive analysis of many indicators describing the reliability of the WSP was carried out using computational simulations performed in the BlockSim. The adopted approach uses a simulation of the object's operation for the adopted period of operation with the random generation of damage to individual devices according to the theoretical distribution. This is different from analyses of the reliability of water supply stations presented in the literature. They mainly calculate the reliability model for which, based on literature or operational data, static availability of the main equipment or station components is estimated. Then analytical methods are used to calculate the availability of the water supply plant or its components [13, 23, 11]. Reliability analyses based on analytical equations applied to objects with a complicated reliability structure can generate erroneous results as compared to calculations generated by random simulation for a repairable system. Such a result difference can be the most critical for the simple parallel structure that connects two devices. After the failure of one of the elements and not taking into account its repair in the analysis, the object goes into a state of failure after the failure of the other element. In fact, if the first element is repaired before the second element becomes damaged, the object will not lose its reliability. This type of system behaviour is particularly visible when analyzing the NF indicator for the WSP and its components (Fig. 18). The indicator *NF* = 2.349 for the Water Treatment Block has a value close to the *NF* value for the WSP. Other components have a significantly lower number of damages that not exceeding 0.273 for the first stage pumping station. During the simulation, there is no significant damage to the 2nd stage network Pumps set (*NF* = 0.01). Very low values of *NF* = 0.04 for mud pumps are connected not only with their parallel connection and short repair time but also with their operating conditions (Figure 5) - they work every 15 hours for 15 minutes.

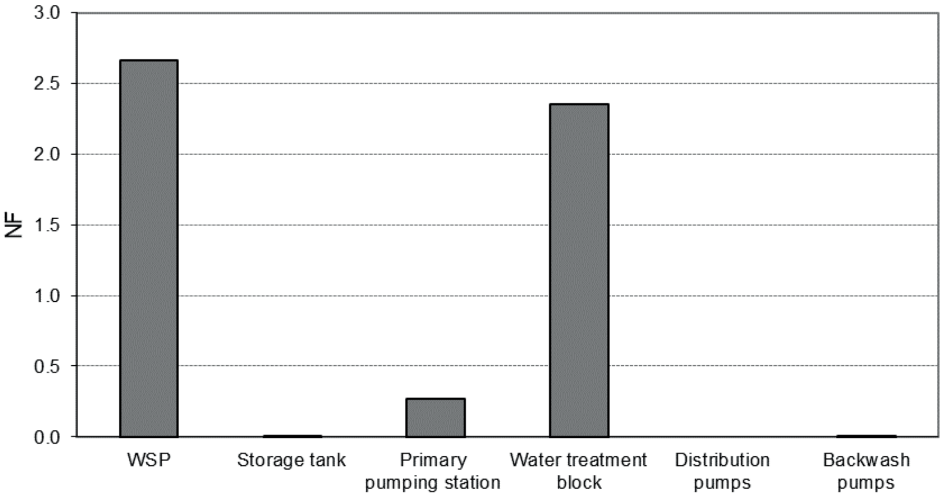


Fig. 18. WSP subsystems – Average Number of System Downing Failures (operating time 15 years)

Source: own study

## 6. Conclusions

The proposed model of the complex reliability structure of the WSP and the use of the Monte Carlo method to simulate failures in basic objects in a technological line allowed performing a comprehensive reliability assessment based on indicators related to the reliability, availability and maintainability of the system.

The results of computational simulations (1000 simulations of 15 years of Operation) obtained with BlockSim application allow the formulation of the below presented quantitative conclusions regarding the analyzed reliability indicators.

Adopting a simple model of the reliability function for individual devices based on exponential distribution gives satisfactory calculation results. The estimated average number of damages of the NF system resulting in the loss of correct operation of the WSP during the 15-year service life is 2.662 and does not differ significantly from reality.

The water treatment station has a very high operational readiness index A = 0.9954, which exceeds the requirements in this respect for water supply stations of reliability class I. Based on the model the probability of station failure over 15 years is 0.931. All system components have a very high availability A> 0.995.

The mean time between failure MTBF reaches the value of ca. 5.5 years (49136 hours) and the mean repair time to repair MTTR of the station is 148 hours. The mean time to maintenance MTTM of the station is 7 hours. The average number of repairs was 9.197 that resulted in 395 hours of station shutdowns, and the unavailability time for 71492 scheduled service hours was 205 hours.

The water aeration unit is the most critical one for the reliability of water supply plant. It is responsible for 74% of its failures, and 55% of the time it remains unavailable.

The analyzed water line shows quite good reliability indicators resulting from the correctness of the selected structure and the precise selection of devices. The process of modernization designing of the station was carried out in constant contact of the design company with the employees of the station and the Plant. This is not the case at all water supply stations, and therefore breakdowns may occur more frequently. This applies in particular to the wrong selection of filter beds, the number of filters, and the precision of selection of network pumps and above all pumps in wells.

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