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# The Impact of Modernization of the Water Treatment Plant on Improving the Quality of Water Directed to Recipients

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**ABSTRACT**

The work concerns the modernization of the Water Treatment Plant, the objective of which was to improve the quality of recipients; life by counteracting water deficits and ensuring a stable supply of water with appropriate pressure and quality, in accordance with the requirements of applicable regulations. Installing modern control and measuring equipment, as well as modern devices during the modernization of the facility, will significantly reduce electricity consumption, which will realistically minimize the operating costs. The article describes in detail what the modernization of the water treatment plant was like and what effects of water treatment from the quaternary aquifer were obtained. After the completed modernization of the plant, the County Sanitary and Epidemiological Station gave a positive opinion on all materials and devices used in the modernization of the WTP and agreed to supply the existing water supply with purified water.

**Keywords:** water treatment plant (WTP), modernization of the WTP, water quality.

## INTRODUCTION

The increase in the number of people and the dynamically developing agglomerations, both rural and urban, contribute to the increase in water demand. This creates the need to increase the capacity of the nearby Water Treatment Plant. An important aspect is the fact that the water level may change over time, which is documented in periodic tests of raw water quality parameters. In the face of changing legal regulations [WHO, 2017; EU, 2020], growing consumer requirements and high water production costs, water utilities intending to build or modernize the Water Treatment Plant need effective support that allows one to safely define the directions of design and investment activities. It is particularly important in the context of progressive climate change, as water companies are required to optimize the operation of existing technological water treatment systems as well as to search for and use alternative water sources [Gwoździej-Mazur et al., 2022]. One of such water sources can be, e.g. rainwater. Recent studies indicate that their physicochemical quality, depending on the place of collection, is comparable to the quality of the water intended for human consumption, while the microbiological quality is a problem [Mazurkiewicz et al., 2022]. It should also be remembered that the Water Treatment Plants producing water for consumers are sensitive to the periods of high and low temperatures, because on hot and dry days the demand for treated water increases significantly [Rak et al., 2021].

There are many factors that influence the decision of the local waterworks to modernize the WTP that supplies the inhabitants with drinking water. It is influenced by both the technical condition of the equipment, the efficiency of the facility and the quality of the abstracted water in terms of physicochemical and microbiological properties. In 2018, water production by waterworks was based mainly on groundwater resources (73%, that is, 1,552.2 $hm^3$). Although in the years 2000–2018, according to the water balance in Poland, water consumption for the purposes of the economy and population decreased by 11%, a gradual increase in exploitation resources and water intake from underground intakes was observed. Compared to 2017, water consumption in households, both in rural and urban areas, increased by 4.7% [Michałkiewicz et al., 2020]. To meet the requirements, it is necessary to increase the efficiency of the WTP, defined in the study of the water law as Qavrh for continuous operation of the intakes operating continuously [Rasała et al., 2017]. Often, in the water permit, the abundance given for a specific depression is greater accounting for the possible expansion in the future. Increasing the volume of water taken in is related to the exploitation resources of individual intakes. If it is exceeded, it may be necessary to drill new wells. It is also possible to regenerate an existing well. However, it should be remembered that the decision to update the resources, renovate, reconstruct or withdraw the existing water intake and related elements depends on numerous factors, which include the issues of exploitation, environmental protection and ensuring water consumption when changing the hydrogeological conditions in the intake area or its parameters [Hurynovich, Sycziowa, 2016]. An important aspect, which also affects the possible efficiency, corresponds to the output characteristics of the pump set, which determine the amount of consumption from the technical point of view. Increasing the efficiency of WTP often requires the replacement of technological equipment and the increase in the diameter of the pipelines. Therefore, during the initial design of the facility, the designer should consider the potential development of the facility in the future and the possibility of extending the plant or increasing the efficiency of the operated devices.

A popular factor influencing the decision to modernize the WTP is the change in the quality of the abstracted water. Groundwater resources in most regions of Poland and the world constitute a raw material that is the basic condition for the development of the economy. The chemical composition and the degree of mineralization of the water are influenced by the lithology, depth, and time of water staying in the rock environment. Groundwater resources depend on the hydrogeological and climatic conditions. The progress of civilization adversely affects the environment. This results in noticeable traces of anthropogenic pollution, not only in surface waters, but also in groundwater. After some time of exploitation of the intake and analysis of the results obtained from the research on the parameters of the abstracted water, it may turn out that the composition of the raw water has changed and the concentration of pollutants has increased or decreased. The pollutants that change the chemical composition of groundwater are direct or indirect causes of human activities. It is influenced by factors such as increased water abstraction, spread of settlements, dynamically developing industry, and logging; however, agriculture, which causes nitrogen compounds pollution, is also of particular importance [https://blog.retencja.pl/2017/06/17/water underground pollution]. Taking into account the possibility of changing the composition of the water intake during the modernization of the WTP, the technological system should be selected in such a way that it is possible to change it in the event of the necessity to change it.

One of the most important issues constituting the basis for the decision to modernize the entire system or a single process is the quality of the water reaching the recipients in terms of bacteriology, physicochemistry and organoleptics. Microbiological, chemical, indicator parameters and additional chemical requirements are specified in the currently applicable Regulation of the Minister of Health of December 7, 2017 on the quality of water intended for human consumption [RMH, 2017]. In addition to the national regulation, water should also meet the World Health Organization's Drinking Water Quality Guidelines [WHO, 2017]. In connection with periodic epidemics, WHO introduces the guidelines relating to the prevention and safety of water supply systems related to the prevailing virus, e.g. WHO Water, sanitation, hygiene and waste management guidelines for the COVID-19 virus. Technical brief issued on March 3, 2020. The regulations concerning the monitoring of drinking water quality, made more stringent in 2010, oblige the sanitary and epidemiological services and waterworks to systematically control the quality, which significantly influences the assessment of the plant's work quality [Juraszka, Braun, 2011]. The new regulations entail the need to adapt to the changes contained therein and to modernize the processes and the entire technological system so that the quality of the treated water meets the current requirements.

The devices used in individual treatment processes are of great importance for the previously described parameters, such as the efficiency of the WTP and the quality of the treated water. It is due to their reliability that the WTP is able to supply consumers with the water that meets the quality requirements efficiently and without failure. Due to the lower contamination of the intake water than in the case of surface waters, the designed groundwater treatment technology is, in most cases, less complicated and is based mainly on the removal of excess iron and manganese. Therefore, it is very important that rapid filters are operated in an appropriate and monitored manner. The permissible filtration speed should not be exceeded as a result of large peak sections or sludge breaking from the bed caused by the activation of the submersible pump and the dynamic increase in flow [Juraszka, Braun, 2011]. Exhausted devices reduce both the efficiency of the WTP and the quality of the treated water. Additionally, lack of automation of processes has a negative impact and enforces 24-hour service control, which is the main reason for numerous failures. The modernized self-service system does not exclude the need to control the filtration process, but significantly facilitates quick response to the anomalies leading to work disturbances.

Before the decision on the WTP modernization, the appropriate approach to the subject is to perform pre-project technological research enabling to determine the water treatment technology, parameters of unit processes, and the necessary scope of investment. The result of such technological research is the knowledge of the proper technological system, approximate investment and operating costs. Designers receive the guidelines that allow for the proper preparation of technical documentation. A well-thought-out construction and executive design enables the proper implementation of the investment, the completion of which will be the launch and acceptance of the investment and the achievement of the intended technological effect [Szerzyna and others 2016; Sawiniak et al. 2016; Pruss et al. 2018, 2021].

The article presents the impact of the WTP modernization on counteracting water shortages and ensuring a stable supply of water with appropriate pressure and quality in accordance with the requirements of the applicable regulations. It was shown that the installation of modern control, measurement and control equipment, as well as modern devices will save electricity consumption and minimize operating costs.

## METHODOLOGY

### Characteristics of the water treatment plant and water quality

The selected Water Treatment Plant is a strategic facility for the Commune. The task of the facility is to treat underground water as well as to secure the living partitions and fire protection. There is a WTP technological building on the plot, where all the devices involved in the water treatment process are located. These include three underground water wells, a storage shelter, a fuel feed, a rinse water decanter, a chlorine store, underground infrastructure (inter-facility networks), internal roads, an area fence with an entrance gate and a wicket, trees and low greenery. The water is drawn from three wells in the quaternary aquifer, which is located at a depth of 80.0 m below sea level. Figure 1 shows the average quality of the abstracted groundwater.

When analyzing the quality of the abstracted water, it can be seen that groundwater is characterized by exceeded concentrations of iron and manganese, which is characteristic of groundwater. The manganese concentration is 0.14–0.21 mgMn/l, while the iron concentration is 1.63–2.31 mg/l. According to the regulation of the Minister of Health of 7 December 2017 on the quality of water intended for human consumption, the permissible concentration of manganese in water is 0.05 mgMn/l, and for iron it is 0.2 mgFe/l. The removal of these compounds from water is the main technological problem for the analyzed WTP. The current technological system was based on the intake of underground water from wells that are not subject to modernization. The water taken is transported to the sprinkler, where there are 3 aeration towers (cascades). The water is aerated in open cascades; the process is supported by the splash water fall. Then, the water flows through filters filled with quartz sand to the treated water tank with a capacity of 35 $m^3$, from where the hydrophore set pumps the water to the municipal network and to the tank located in a nearby town.

### Purpose and scope of the water treatment plant modernization

The main objective of the modernization of the WTP was to improve the quality of life of recipients by counteracting water deficits and

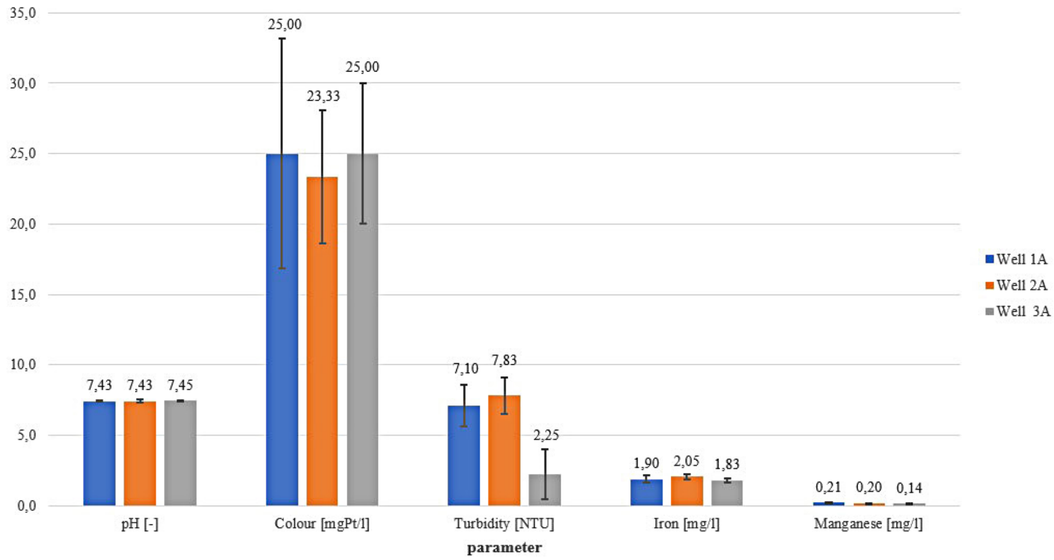


**Figure 1.** Average quality of the groundwater intake

ensuring a stable supply of water with appropriate pressure and quality according to the requirements of applicable regulations. Installation of modern measuring and control equipment, modern devices that will reduce electricity consumption, will save energy and minimize operating costs.

## Modernized water treatment plant system and technological devices

### *Aeration*

The existing cascades are not used up and due to their good technical condition it was decided not to replace them. However, the technological process for which they are responsible has been modernized. In order to increase the efficiency of the oxidation of Fe II to Fe III from about 20% to about 50% on the basis of pre-design technological tests carried out at the pilot station, the supporting structure was raised by about 1 m and three reaction tanks were designed under each of the three devices. The tanks have the shape of cuboids with dimensions of 2000x1000x1000 mm and a capacity of approx. 2.00 $m^3$ each. They will ensure better oxygenation of the water, 6.6–8.5 $mgO_2/l$, and will allow water retention for 15–20 minutes after aeration. The work was carried out in stages to maintain the continuity of the WTP operation.

All pipelines were dismantled and replaced with new ones, made of 1.4307 acid resistant steel. A dissolved oxygen concentration sensor was also installed in the aerated water pipeline to monitor the oxygenation of the water.

### *Filtration*

Taking into account the guidelines from technological research, a two-layer bed was designed, consisting of a catalytic layer (braunstein with a grain size of 1–3 mm and a layer thickness of 50 cm) and quartz sand (granulation 0.8–1.4 mm and a layer thickness of 100 cm). No gravel bed supporting layer is required to replace drainage with slot drainage. The optimal filtration speed should be 8 m /h. The filters are first backwashed first with air for 3 minutes at an intensity of 5.76 $m^3$ / min, and then with water for 7 minutes at an intensity of 13–15 l / $m^2$s.

During the modernization of the WTP, TETRA filtration drainages were used, which can be used not only in new but also in modernized open filters. They ensure an even distribution of air and water, as well as low operating costs. These blocks are made of high-density polyethylene, which ensures durability and a longer service life without maintenance. This system uses central anchoring, increasing the stability and certainty of the foundation.

Filters were equipped with on / off electric dampers, electric regulating dampers, manually operated dampers and electromagnetic flow meters on the outflow of water treated from the filters. All pipelines were dismantled and replaced with new ones, made of 1.4307 acid resistant steel. Their diameters were selected to maintain the appropriate velocities in the pipelines.

The existing tank was converted into an intermediate treated water tank with a capacity of 35

$m^3$. Due to insufficient capacity, a second degree intermediate pumping station (shunt) was designed to pump treated water from the intermediate reservoir to two new retention reservoirs. The capacity of the indirect pumping station is equal to the maximum production of water at the Water Treatment Plant, that is 120 $m^3$ / h. Intermediate pumps, like backwashing pumps, work in the 1 + 1 system (1 working + 1 standby). Due to the increased efficiency of the WTP, two new storage reservoirs were added. The tanks have a capacity of 250 $m^3$ each. In the valve chamber, there are wedge gate valves for the pipelines supplying and discharging treated water, as well as the discharge and overflow pipelines.

### *Disinfection*

The treated water is disinfected with chlorine in the form of a sodium hypochlorite solution. The dose was determined during the WTP start-up so that the concentration in the pumped water was 0.3 $mgCl_2/dm^3$. To effectively mix water with disinfectant, a 1:3 sodium hypochlorite dilution was used. Then, the concentration of active chlorine in the working solution is 50 $gCl_2/dm^3$. Two dosing sets have been designed that work in an alternating system (primary and backup). The measurement of the free chlorine content has been designed on the discharge line. The devices intended for dosing can work in both automatic and manual systems. Dosing takes place on the pipeline transporting treated water to the network (after the UV lamp, but before free chlorine measurement) and to the retention reservoirs. Dosing takes place inside the WTP room and the dose depends on the current water flow rate. The determined dose of sodium hypochlorite solution is distributed by the controller to each dosing system for a given dosing point. The installation is made of unplasticized polyvinyl chloride PVC-U (Figure 2).

The lamp is located in the discharge pipeline, behind the III$^o$ pumping station, but before the sodium hypochlorite dosing point. The radiation in the UVC range deactivates many microorganisms in the water. When modernizing a high capacity Water Treatment Plant, a combination of disinfection using both chemicals and UV lamps is often used. This increases the microbiological safety and allows the removal of chlorine-resistant microorganisms; moreover, it increases the functional value by reducing the dose of sodium hypochlorite.

The wastewater generated in the chlorine station is discharged to a designed outflow neutralization tank. After flowing into the tank, they are neutralized with a 3% aqueous solution of sodium thiosulfate in the amount of 3.5 kg per 1 kg of $Cl_2$.

**Figure 2.** Sample photo from WTP after modernization – pump hall

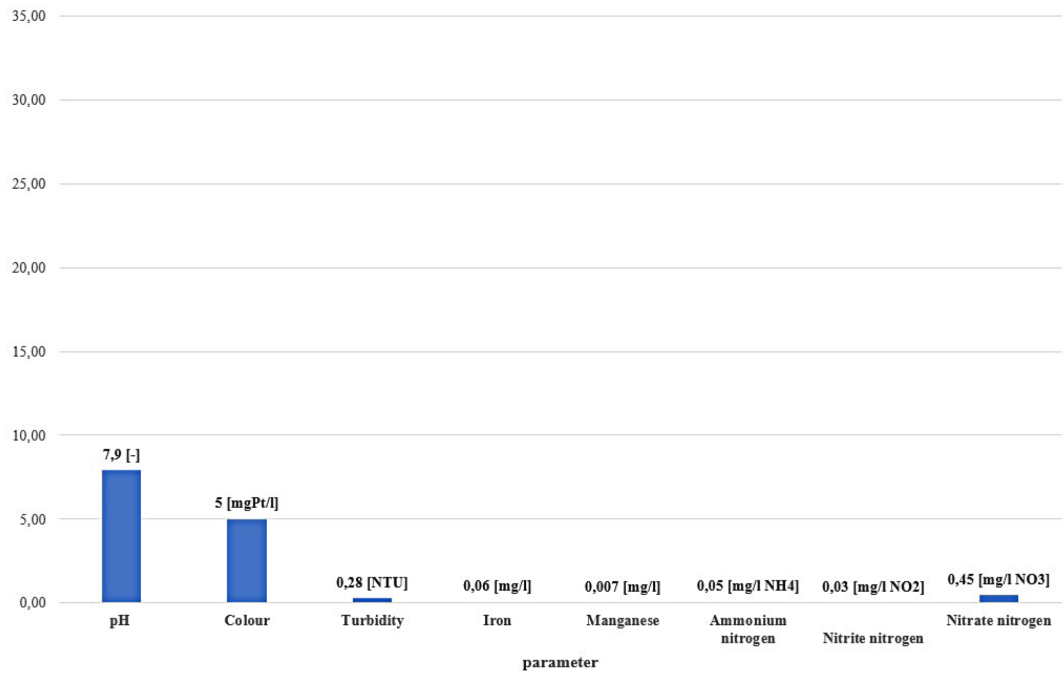


**Figure 3.** Parameters of the quality of treated water after the modernization of the WTP

The pH is then adjusted to pH = 7 with a dose of 13.5 kg /1 kg of $Cl_2$ of hydrated lime. After the desired effects are achieved, the contents of the tank are exported by authorized transport.

After modernization, pumping water into the water supply network is carried out by a new hydrophore set with the capacity of the maximum hourly consumption and maintaining the set pressure in the network. The assumed capacity also takes into account the fire water supply. On the basis of the Functional and Utility Program and after the audit of the existing pumping station, the set was selected to supply the network with the maximum hourly water demand of 300 $m^3$/h and the head 68 m. Compared to the previous pumps, the new pumps ensure a higher total efficiency of the order of 62.5–67.9% and lower values of the energy consumption index of 0.2500.281 kW/$m^3$.

At the connection of the WTP and the retention reservoir in a nearby town, GPRS communication is located, responsible for switching on and off network pumps. It depends on the degree of filling of the tank. When the pumps are turned off, the tank is responsible for maintaining the pressure in the network. Modern SCADA visualization software was used at the modernized Water Treatment Plant. In addition, a telemetry module was used, enabling communication with a field tank of clean water. The new hydrophore set is shown in Figure 2.

### The quality of treated water after modernization

After completion of the modernization and commissioning of the Water Treatment Plant, water pump tests were carried out into the water supply network, the results of which are presented in Figure 3. The County Sanitary and Epidemiological Station gave a positive opinion on all materials and devices used in the modernization of the Water Treatment Plant. On the basis of the inspection report of the Sanitary Supervision, the hygienic assessment with hygienic certificates and the test reports, the Water Treatment plant was connected with the existing water supply network.

## CONCLUSIONS

The developing technology of water treatment helps to achieve better water quality, the organoleptic, microbiological and distribution qualities of which satisfy the recipients. The WTP modernization was carried out with the maximum use of the existing infrastructure and equipment located in the facility, which allowed the reduction of investment costs. The use of 1.4307 stainless steel pipes reduces the likelihood of corrosion. On the other hand, fittings made of ductile iron ensure high resistance to increased pressure, water hammer and other loads of the installation, favorably affecting its long and failure-free operation. Modernized aeration and filtration processes, on the basis of technological research carried out on a pilot scale, allowed reducing the content of undesirable iron and manganese compounds in the water. The replacement of worn-out and energy-consuming devices with new ones allowed for the reduction of electricity costs, which brought not only financial but also ecological benefits. The new hydrophore set enabled to ensure sufficient pressure in the network and transport the required volume of water to recipients, with lower energy consumption and higher efficiency than the originally installed pumps.

The new chlorination rooms designed and constructed ensure that the health safety requirements of the people operating the WTP are met. Full automation of the Water Treatment Plant makes the facility operation, control and prevention of failures easier, and the visualization provided by SCADA software allows monitoring and regulating the processes. All the achieved effects of modernization contributed to the fact that the Water Treatment Plant is easier to operate and control, with fewer emergencies, and provides consumers with the water that meets the quality requirements of water intended for human consumption.


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