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PILOT PROJECT TO INCREASE THE ECONOMIC EFFICIENCY OF SURFACE WATER PUMPING STATIONS

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Purpose: The most common effects of surface subsidence are flooding and waterlogging of the most depressed areas, and a change in the direction and intensity of surface water runoff. Stopping drainage would result in flooding of depressed areas on the surface and contamination of near-surface aquifers, which are also a source of drinking water.
Design/methodology/approach: The research was carried out based on geodetic measurements carried out by surveying services in the vicinity of the analyzed watercourse. From the prepared database of functional scenarios for pumping stations, the optimal variant was selected based on a panel study of experts.
Findings: The publication analyses the possibilities of reducing the costs of the functioning system of storm water drainage from drainless basin in the area of an abandoned mine. A technically feasible and economically viable design solution was presented.
Research limitations/implications: Due to the limited area of available land, the pumping station modernization project envisages generating electricity only for own needs. When making investment decisions, all investment attractiveness factors indicated in the study should be taken into account.
Practical implications: The process of draining drainless basins is energy-intensive. Reducing expenditure on the purchase of electricity will improve the security of energy supplies. The pumping station has some retention, but a longer shutdown time could lead to environmental problems. Removing the damage would require financial outlays and would take many years.
Social implications: Planned energy supply security projects may have a positive impact on the local community and economy. The project in question will create new markets related to "green energy".
Originality/value: The combination of drainage problems in drainless basin and the use of renewable energy sources to improve power supply security has not been the subject of scientific research so far.
Keywords: drainless basins, flood risk, RES, elements of the circular economy; mine closure.
Category of the paper: Research paper, conceptual paper, case study.

1. Introduction

Underground mining operations affect the environment both during the period of active mining and after the liquidation of the Mining Plant. The provisions of the Geological and Mining Law extensively take into account environmental protection and, among other things, oblige the entrepreneur to repair any damage caused by the mining plant's operation. The legislator obliges the mining entrepreneur, or its successor in title, to identify any environmental hazards associated with past mine operations. The entrepreneur is obliged to present the areas of shallow mining operations as places potentially at risk of surface-type discontinuous deformations, specify the locations of discontinuous deformations coinciding with the edges of mining operations, the occurrence of tectonic disturbances, and determine the category of suitability of the area for development after the end of mining operations. The entrepreneur, and the Mine Restructuring Company S.A. (SRK S.A.), as the legal successor to the previous mining operation, is obliged to restore any property located in the mining area where damage has occurred due to the previous mining activity. The impact of mining on the environment covers a wide spectrum of factors (Prusek, Turek, 2018).

2. Materials and methods

The mining activity carried out in various forms affects the atmosphere, hydrosphere and lithosphere, and the pits that occur in the rock mass can pose a threat to the surface. Continuous and discontinuous deformations always accompany the extraction of deposits, regardless of the method of mining, and these affect changes in water relations (Bondaruk et al., 2015; Chmielewska et al., 2020; Łabaj et al., 2020). Impacts on the lithosphere are associated with the storage of wastes from previous mining activities and land transformations in the form of continuous and discontinuous deformations. Most often, continuous deformations are observed in the form of subsidence basins, slopes and deformations caused by uneven subsidence of the rock mass (Salom, Kivinen, 2020; Strzałkowski, Ścigała, 2017; Strzałkowski, 2015). With shallow underground mining, under favorable circumstances, discontinuous deformations of the surface type (sinkholes or funnels) or linear type (terrain steps, sills, fissures) can be formed. For the formation of discontinuous surface deformations, suitable conditions must exist. Their formation is favored by shallow mining operations with roof collapse, the presence of old shallow mine workings, unclosed shafts or shafts (Strzałkowski, Szafulera, 2016; Strzałkowski, Tomiczek, 2015). The main factors that cause deformations of the linear type, may be the overlapping of mining edges in several seams and the associated unevenness of the deposit selection, as well as the occurrence of outcrops of tectonic faults on the Carboniferous roof with a small thickness of overburden layers (Salom, Kivinen, 2020; Strzałkowski, Szafulera, 2016; Strzałkowski, 2010).

The impact of mining operations on the environment covers not only the period of mining, but also a long time after the end of mining. Continuous deformations may manifest themselves until the extinction of the rock mass activity, that is, until about 5 years after the end of mining activities. The situation is different with the formation of discontinuous deformations, which can manifest themselves even decades after the excavations generating them have been performed (Strzałkowski, Ścigała, 2017; Strzałkowski, 2015).

Coal mining also significantly affects changes in water relations on the surface as well as inside the rock mass (Salom, Kivinen, 2020; Fajklewicz et al., 2004; Ignacy, 2017). After the end of mining by underground methods, the most common problem is the de-elevation of the ground surface, causing waterlogging and flooding of the most depressed zones, as well as changes in the direction and intensity of surface and underground water runoff. The most important element in the prevention of hazards resulting from changes in hydrogeological conditions caused by mine liquidation is the effectiveness of the dewatering system. Cessation of dewatering would result in flooding of lower-lying areas on the surface and contamination of near-surface aquifers of drinking water sources (Mhlongo, Amponsah-Dacosta, 2016; Mhlongo, 2023; Wysocka et al., 2019).

Post-mining activities also have a negative impact on water quality parameters in watercourses into which water from mine drainage is discharged. In this case, the decisive influence is the suspended solids found in these waters and the above-normal concentrations of chlorides and sulfates, whose values increase with the depth of the mining operation carried out.

At the mine site there is a system of eight pumping stations for rainwater in depressurized subsidence basins (Fig. 1.). Approximately 2.5% of the anticipated expenditures for the mine's liquidation are spent annually on the maintenance and operation of the pumping stations (Chmiela, Smoliło, 2023b; Magdziarczyk et al., 2023). For social reasons, some flooding may be particularly severe, since the northern part of the mining area is located within the three large cities of the Silesian agglomeration (Kaczmarek et al., 2022; Kaczmarek, 2022). Conducting drainage of non-drainage basins protects the local community from potential flooding during periods of increased rainfall. The Company's pumping stations discharge about 150 million m^3 (data for 2022) of rainwater and water carried into the non-drainage basins by local watercourses into the rivers annually. The purchase of electricity is one of the largest cost components. Energy consumption in 2023 at SRK S.A. was about 290 GWh, which corresponds to equivalent emissions of about 240 million Mg CO_2 into the atmosphere (Chmiela, 2022, 2023; Wojtacha-Rychter et al., 2021).

The main research objective of the analysis carried out was to identify the optimal solution for regulating water relations in the developed drainless basin and to develop a pilot project for a surface water pumping station, and to learn about the impact of changing conditions on the economic efficiency of the energy self-sufficiency model of an exemplary surface water pumping station (Chmiela et al., 2023b). Modernization of the existing pumping station infrastructure combined with new technologies that also serve the local community will be a partially self-financing solution with a positive social and image perception. One way to reduce the need to purchase electricity from the grid is to build photovoltaic farms (Chmiela et al., 2023a, 2023b). Equipping a pumping station with RES will be a pilot solution that can be replicated in subsequent locations. The combination of renewable energy sources (RES) and the drainage processes of the non-drainage basins is a new solution that has not been practiced before (Tokarski et al., 2021). In addition to meeting the energy needs of the pumping station, the project aims to revitalize degraded non-watershed areas and protect endangered drinking water intakes (Bukowski, 2007). A very important design element was to reduce future costs and increase the financial efficiency of the project (Smoliło et al., 2023). Economically, maintaining a surface water pumping station is expensive and cumbersome. A pumping station, even one operating under an automatic control system, requires control and supervision. Failure or malfunction can even in the short term lead to flooding (Khomenko, Jelonek, 2023; Prakash Pandey, Prasad Mishra, 2022). In the area of the pumping station, the near-surface layer is formed by clays or loams with very low filtration properties, which will lead to their filling with water if pumping is abandoned. Modernization of the existing rainwater pumping system can lead to measurable budget savings and the restoration of occupied land for the purpose of serving residents or the needs of owners (Bluszcz, Smoliło, 2021; Krzemień et al., 2022, 2023). The stabilization of rock mass movements caused by the cessation of mining activities makes it possible to present a definitive model for rainwater pumping stations.

After analyzing the applied options for the use of RES in the modernization of pumping stations, models for the operation of pumping stations were determined on the basis of direct interviews with experts. The research was conducted on a representative group of 65 people. The experts were academics and engineering staff of the Company's energy-machinery departments. After the initial database of functional pumping station scenarios was created, they were again evaluated by the same experts in a second panel survey, asking them to assign each scenario a rating according to their preferences. On the basis of the obtained ratings for the best decision scenarios for pumping station upgrades, price discernment (surveys) was carried out, which made it possible to identify the optimal option for pumping station upgrades for current market conditions. The results also made it possible to assess trends in the change in economic efficiency of the planned project. (Gawęda, 2021; Gawęda, Sajnóg, 2020).

The study identified areas and research issues that need to be addressed in order to optimize possible future processes for the modernization of the drainage system of non-drainage basins. The study was carried out based on the results of cyclic surveying of the observation lines located in the mine site, carried out by the surveying services, as well as on the basis of additional surveying measurements commissioned by these services on an ongoing basis. For design purposes, geodetic measurements of situational and elevation parameters of the shape of the analyzed watercourse in the mining area were made. As part of the study, geodetic measurements of the vicinity of the analyzed watercourse (stream) were updated, as well as an audit of the operation of the surface water pumping station and the updating and adaptation of the design and cost-estimate documentation for the envisaged modernization. In order to analyze the feasibility of upgrading this pumping station, a geodetic survey of the creek bed was carried out. In the final stage, the size of the necessary expenditures that would allow the modernization of the pumping station and reduce the cost of drainage of the catchment of the analyzed drainless basin was updated.

In 2015, SRK S.A. took over the put into liquidation mining plant. The analyzed pumping station is located in one of the agricultural communities adjacent to large cities in the Silesian Agglomeration (Bondaruk et al., 2015; Chmielewska et al., 2020; Łabaj et al., 2020). The current surface morphology of the mine site should be considered unchanged due to the termination of mining operations in 2016. The increments of land surface subsidence caused by mining have disappeared, but the surface deformation caused by previous mining activities has triggered the formation of no-tide basins (Ignacy, 2017). The resulting drainless basins are drained through a system of surface water pumping stations. Figure 1 shows the location of the pumping station under study.

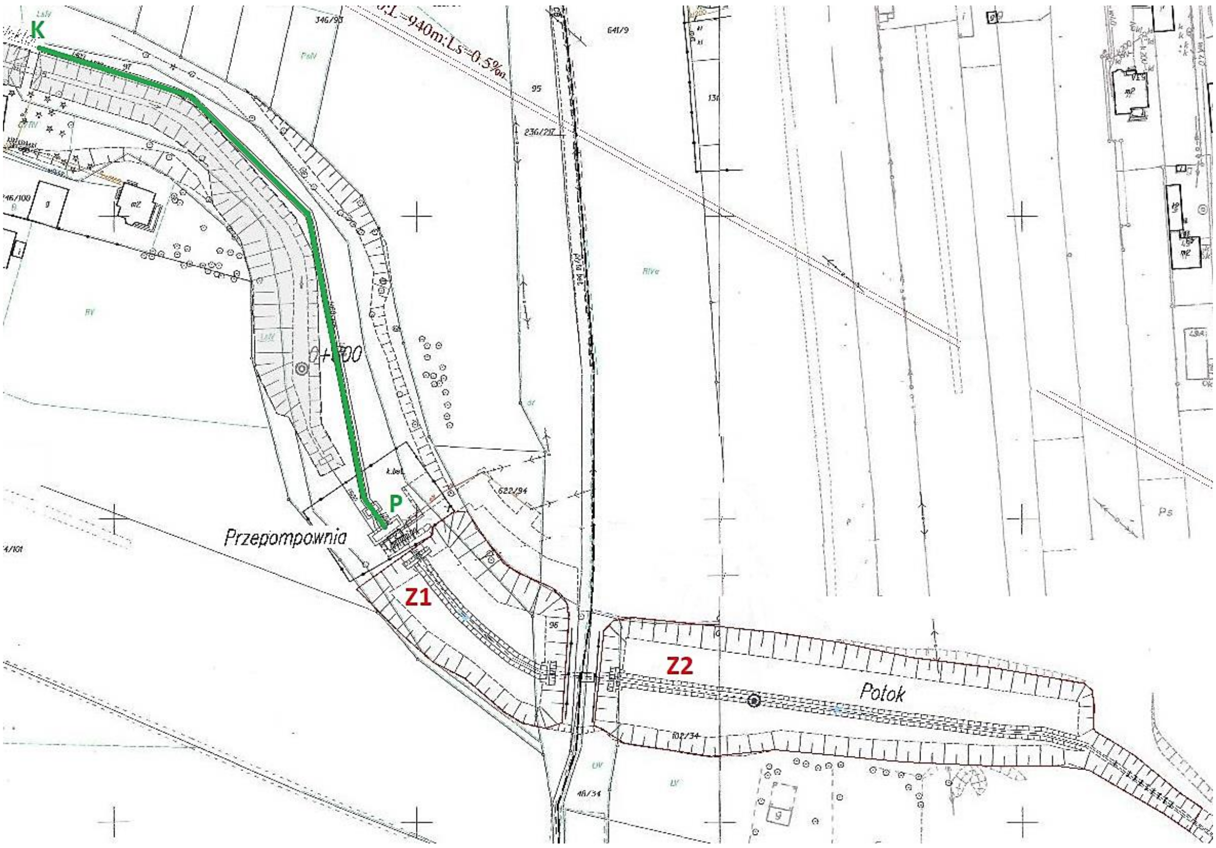

Figure 1. Location of the pumping station

Source: own study based on SRK S.A. internal materials.

The pumping station maintains a dewatering system based on a system of 4 pumps with a total pumping capacity of about 4000 m^3/h. Each of the pumps is driven by a 450 kW motor. The task of the pumping station is to drain the drainage basin of water carried by the stream and rainwater during increased rainfall. Pumping is carried out in a continuous system all days of the year, but due to the varied inflow, 1 to 4 pumps are activated. To the prepared catchment area Z1 in Figure 1, all water flowing into the stream and water from rainfall or snowmelt is directed. The waters from catchment Z1, in accordance with the water-legal permit, are pumped via pipelines about 470 m to a section of the riverbed (green line in Fig. 1), the same stream, located slightly above the river bed, from where they flow into it by gravity.

3. Results and discussion

The mining area of the mine closure is located in the Silesian province (Poland). The mine with its current area and mining site of 28.4 km^2 was launched in the late 19th century. As the shallow resources were depleted, it went deeper and deeper, and mining moved south. Mining at the mine was terminated in 2016 with the transfer of the mine to the Mine Restructuring Company S.A. (Prusek, Turek, 2018; Kaminski et al., 2022) The mine is being restructured in a model with some pits left to create a district pumping station for dewatering neighboring mines (Dźwigoł, 2007).

The greatest impacts in landforms were caused by subsidence (Strzałkowski, 2015; Shavarskyi et al., 2022). Approximately 90% of the mining area was within the range of influence of the ongoing mining operations. There were continuous and discontinuous land deformations, but mainly in the form of subsidence basins, within the range of I-IV influence categories (Fajklewicz et al., 2004). The filling of depressed developed areas with water can turn them into wastelands through the formation of floodplains, the formation of swamps and peat bogs (Riesgo Fernández et al., 2020; Rubio et al., 2019). In order to counteract the effects of the resulting land subsidence on the mine site, regulation of the river and its tributaries has been used so far by building embankments, deepening the bottom in their beds, building new and deepening existing drainage infrastructure, backfilling depressurized basins and restoring proper water runoff, and building surface and groundwater pumping stations (Knothe, 1984). As the legal successor of the mining operation, SRK S.A. is obliged to build water pumping stations for the protection of these areas (Strzałkowski, Tomiczek, 2015; Strzałkowski, 2010; Chudek, 2010). There are eight surface water pumping stations draining surface water and groundwater from the mine's unlined basins within the mine's range of influence.

The analyzed pumping station functionally includes 2 main watercourses. These are the creek that feeds water into its channel, which has been lowered by land subsidence, and the river, in which the creek originally had an outlet and into which water is currently pumped by the pumping station.

The stream has a length of about 3.9 km and a catchment area of 2.7 km^2. At the lowest point of the basin caused by post-mining subsidence of the land surface, a water pumping station has been built (Fig. 1). Water from the pumping station is pumped into the bed of the watercourse in question by four pipelines ø 600 (green line in Fig. 1) and then after a distance of about one kilometer it flows into the River. The waters of the stream in their entirety are pumped into its bed in the lower course from where gravity outflow of pumped waters to the river is already possible. The River flows from Katowice to its confluence with the Oder River. The total length of the River is 75.3 km, and the analyzed section crossing the Mine Area is 3.9 km long. In this section, the riverbed is regulated and embanked on both sides to a height of 1.5 m to 8.0 m (Fig. 2). In the Mining Area, the slope of the river bed along almost the entire section is close to 0.0‰.

Figure 2. River embankments built as part of the removal of 'mining damage'.

Source: SRK S.A. internal materials.

All the pumping stations located in the mining area of the Branch are located in the regions of drainless basins created by mining operations and are located in the catchment area of the River. The pumping stations discharge water directly into the River or into its tributaries. The location of the analyzed pumping station is shown on the map in Figure 1. The pumping station receives inflowing water from the "upper" lowered channel to the higher section of the channel of this stream in its lower course. The threat of flooding obliges the owner, which is the Mine Restructuring Company S.A., to continuously divert water from the upper, lowered channel of the stream to its lower section. The area of the drainage basin is about 250 hectares. Two reservoirs (Z1 and Z2 in Figure 1) have been constructed on the Stream above the pumping station for the retention of excess water, during periods of snowmelt or particularly intense rainfall. The total retention of the reservoirs is estimated at about 15,000 m^3. A pumping station is built below the lower reservoir (Figure 3 and P in Figure 1). The task of the pumping station is to maintain the desired level of the inflowing water table in the Z1 reservoir. The pumping station is equipped with four pumps with a total pumping capacity of 4000 m^3/h. With the help of these submersible sewage pumps, water is pumped through four pipelines down the creek to collector K in Figure 1. From the aforementioned collector, water flows freely into the unlined portion of its base channel. In the downstream section of the creek, the water was dammed both by a culvert under the DK road and by natural outfalls in the downstream, estuarine section, where the ordinates of the creek bottom reach the ordinates of the river bottom.

Figure 3. Intake of stream waters in the lower floodplain by the pumping station (view toward the NW)

Source: internal materials of SRK S.A

During times of heavy precipitation, attention has been drawn to the relatively rapidly rising water level in the estuary section of the Creek. In addition, these waters cannot be properly discharged into the river because the water table in the river is also rising. As a result of the high water level in the riverbed, the so-called backflow of surging waters into the stream bed may occur and the lowest-lying areas may also be flooded (Gajdzik et al., 2022).

Figure 4. Reconstruction of a bridge over a creek along the DK state road.

Source: SRK S.A. internal materials.

For this reason, the mine has already reconstructed the bridge under the DK national road (Figure 4) and dredged and regulated the "lower" section of the stream bed (Figure 5). Failure of the pumping station; electrical or mechanical, may cause flooding reaching the water table ordinate of about 220.0 m above sea level, causing flooding on the left bank of 810 meters. Flooding on the right bank will be much smaller and will only occur over a distance of 550 m.

Figure 5. Widening and deepening of the stream bed with a change in the shoreline.

Source: SRK S.A. internal materials.

Another problem is the mouth of the creek to the river, and at the same time the discharge point of the pumped waters. It has been observed that during periods of intense precipitation, the water level in the river rises significantly, causing water to pile up in the estuary section of the stream bed, leading to flooding of areas in the estuary area. However, such a state of affairs is not directly related to the pumping station. Under such circumstances, the solution is to drain the dammed waters into a previously prepared floodplain polder (Salom, Kivinen, 2020).

There is still a possibility of drilling absorption wells in the reservoirs to filter surface water deep into the Quaternary formations to the 1st aquifer. According to a geological borehole located about 200 m south of the reservoir, there is a package of 25 m of sands below a layer of clay 1 m thick. It will be possible to drill about 4 absorption wells, responsible for draining some of the rainwater from surface runoff.

In order to improve runoff, the section of the old "lower" stream bed should also be made clear on an ongoing basis, with the goal of gravitational flow of rainwater into the river. Currently, water stagnates in many parts of this section, providing a place for rotting and decaying vegetation.

Photovoltaic farms can be established on industrial land for production purposes, but attention should be paid to the existing technical infrastructure (cabling, pipelines, gas pipelines, etc.) and to the contamination of the site by previous production processes (Chmiela, Smoliło, 2023a; Doorga et al., 2022). An additional advantage for locating the farm next to a pumping station is good access for technical vehicles.

The operation of the pumping station required leaving the pumps in the cast controlled from a container building located nearby (Figure 6).

Figure 6. Equipment of the pumping station (view in SW direction).

Source: internal materials of SRK S.A.

The surface facilities are accompanied by an area of 0.2 hectares (Fig. 7). In 2022, the pumping station pumped out about 9 million m^3 of water. The project to upgrade the pumping station involves the construction of a farm with a generating capacity of about 0.16 MWp resulting from the area of available land adjacent to the pumping station. The built photovoltaic farm will be able to produce up to about 260 kWh of "green", "clean" electricity per year. The calculations assume 1600 hours of sunshine per year, which is the average for the area. In selecting the size of the photovoltaic farm, the maximum use of available areas including the area of available roofs was assumed. The pumping station at minimum load (only 1 active pump) requires about 450 kW. It is estimated that the pumping station, to carry out its operations, requires about 3.9 MWh of electricity per year.

Figure 7. SRK S.A. properties adjacent to the pumping station.

Source: own study based on https://mapy.geoportal.gov.pl/imap/

Assuming a minimum load of only one pump, the farm could meet up to about 36% of the pumping station demand on sunny days and up to 7% of the energy required for the pumping station on an annual basis. This leads to a reduction in equivalent atmospheric emissions of about 214 Mg CO_2 (Howaniec et al., 2023; Woszczynski et al., 2023; Villar et al., 2020). The use of the potential of RES sources is limited by technical and atmospheric conditions, but even on sunny days the generated energy will be completely consumed by the built-in pumps. The missing part of the electricity throughout the year, the pumping station will draw from the national grid. Table 1 shows the basic operating parameters of the modernized surface water pumping station.

Table 1.
Operating parameters of the upgraded surface water pumping station

	Units	2022	IV 2023	I 2024
Energy price	Multiples of the purchase price of 1 sewage pump installed in the pumping station	0.004	0.011	0.006
Energy savings		1.3	2.7	1.8
Outlays for the farm		8,1		
Simple payback time	[years]	6.5	3.0	4.6

Source: own study.

For the unit purchase price of electricity in the fourth quarter of 2023, the energy produced by the farm would give savings equivalent to the purchase of about 2.7 sewage pumps installed at the pumping station (Table 1.). Taking into account the cost of constructing the farm plus the additional cost of maintaining the installation, the simple payback time for the additional expenditures would be about 3 years. Such a short payback time for additional expenditures is due to the fact that the vast majority of maintenance costs are already incurred, and the additional ones are minimal.

In the first quarter of 2024, there will be a change in electricity unit charges. The decrease in the unit price of electricity negotiated with the local supplier has reduced the cost of purchasing electricity, resulting in an extension of the simple payback time for additional expenditures to 4.6 years. Further reductions in the unit energy purchase price and another extension of the simple payback time for additional expenditures are likely (Table 2). Due to inflation and other market conditions, it is estimated that the unit power purchase price will not fall below the 2022 price. With such a low unit price under the current market situation, the simple payback period for additional expenditures will not exceed 6.5 years. Even such a payback period for additional expenditures suggests carrying out the described project (Gawęda, 2022; Gawęda, Złoty, 2023; Schoenmaker, Schramade, 2019).

4. Conclusions

The long-term exploitation of the deposit has led to the creation of drainless basins, and this has necessitated the construction of a number of pumping stations that allow the use of acreages at risk of flooding or permanent inundation.

- The pumping station, which is the subject of the study, was constructed in a basin caused by mining operations, covering part of the stream bed. It is responsible not only for the transfer of rainwater, but also for the uninterrupted pumping of water flowing in this watercourse. The pumping station is the only mine facility that pumps the running waters of the watercourse, not to another watercourse, but 470 meters below, to an unlined old section of the same stream. Stopping pumping or failure of the pumping station can cause flooding. This forces the uninterrupted transfer of the creek's waters to its lower section.
- Combining surface water pumping stations with RES is an innovative solution to the reality of liquidated mines. In addition to covering the energy needs of the pumping station, the project aims to revitalize degraded non-floodplain areas and protect endangered drinking water intakes. A very important design element was to reduce future costs and increase the financial efficiency of the project.
- The proposed project is economically justified and recommended for implementation due to increased flood safety. Implementation of the proposed project requires capital expenditures equivalent to the purchase of about 8.1 sewage pumps installed at the pumping station, and the expenditures incurred should pay for themselves after about 3 to 7 years.

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