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Assessment of Polder System Drainage Experimentation Performance Related to Tidal Floods in Mulyorejo, Pekalongan, Indonesia

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Abstract: During the last 20 years, Pekalongan was flooded by tides and rainfall, this had a big impact on the Mulyorejo area as a pilot project. There were a lot of rice fields that turned into salty fishponds. The land is located below the sea and river water level. The objectives of the research are to assess a temporary polder infrastructure, to analyse the in-out flow and its water balance. The research knows different stages of the investigation and data collection that contains water system analysis. Mulyorejo has a catchment area of 1,841,148 m2 (184 ha) that contains houses, batik industry, offices, schools, agriculture and aquaculture. The polder system has different inlets i.e. Meduri river, rainfall, southern canal and there are water outlets like pumps and evapotranspiration. To design for t=25 year rainfall return periods of 187,797 m3/hour and to analyse a water balance. The area has a large surplus of 186,950 m3/hour water. The method 'Bakken model' is used to visualize the different waterways, inlet and outlet and retention areas. The pond will secure a retention capacity of 37,372 m³. Also, a new pump house will drain water into the Sengkarang river instead of Meduri river.

Keywords: assessment, temporary polder, tidal floods

1. Introduction

The Northern part of Java deals with some serious water-related issues. Cities like Demak, Semarang, and Pekalongan are facing problems like tidal floods, erosion, and sedimentation [1]. The research paper mentioned that the dominant problem in the area found below the sea water level is called tidal floods. More so, during heavy rainfall, the rivers cannot drain their water into the sea and the rivers will often have a higher water level than in the area.

During the last 20 years, Pekalongan was flooded by rainfall and tides that had a big impact on the city and regency. The example condition can be seen in figure 1. The city is known for its production of Batik. Also, there were a lot of sawahs (rice fields). Because of the floods, growing rice in the rice fields was made impossible. That is why the rice fields along the coastline turned into fishponds.

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Besides these fishing ponds, the area is characterized by partly flooded lands. Because the land is located below the water level of the surrounding rivers and sea in most areas, the water is not able to drain via the existing system which used to drain the water by gravity [2].

To protect Pekalongan Regency from future flooding, polder systems along the coast are being realised. The Mulyorejo area as a pilot project is part of these future polder systems. The area already has dikes along the rivers, a dam to prevent seawater from flowing into the area and there are some canals to discharge the water to the pump station. For the Mulyorejo system this is not possible anymore and a polder system will be made in the future, the building of the dam in the north was the first step.

Fig. 1 - Flood condition on an inhabited area

There are three research questions and objectives. The objectives of the research are to assess temporary polder infrastructure and to analyse the in-out flow and the water balance. There will be two extra research questions about how to maintain the polder system in a good state after the polder is realised.

2. Description of Research Area

Kota Pekalongan are sinking with a speed of 1.8 to 3.9 cm/year. This is a quote from the paper That Tim De Waele And Thijs De Bruijn wrote a year ago. It is possible that the city sank 3.9 cm since they wrote their paper. It is mentioned in the paper that the people of Pekalongan see no other option for tap water then the extraction of groundwater [3].

The extraction of ground water and gas is called anthropogenic subsidence. The anthropogenic subsidence sinks at a much faster rate than natural subsidence. It results from intense land modifications in environments with compressible deposits, is written in the paper of Chaussard. This kind of subsidence due water, gas or oil extraction can occur at high rates of op to tens of centimetres per year [4].

In conclusion, Pekalongan is rapidly sinking below sea level. This will lead to an increase of inundation both in frequency and spatial extent. It will also put coastal cities below the relative sea level within years. These problems combined, sea level rise and land subsidence will cause a lot of floods in the polder area and Pekalongan.

Currently, the Mulyorejo water system consists of roughly seven aspects which need attention. Being the following: Inundated land, Drainage canals, Two main rivers bordering the Mulyorejo area, Two dikes alongside these two rivers, A newly built dam in the north, The Java Sea in the North, and A pumping station.

The 184 acre Mulyorejo area is located between two rivers which are bordered by dikes. In the north, the area is protected from the Java Sea by a 500 meter-long dam which was built last year. The Java Sea has already inundated big parts of land north of the dam. Because of land subsidence and sea level rise, the salt water from the ocean is able to travel further inland than ever before. The same thing used to happen to Mulyorejo before the dam had been built. The build of the dam already shows a drastic decrease of water level in Mulyorejo. While the water level north of the dam (Oceanside) is at a much higher level. Although the dam did lower the water level of inundated land in Mulyorejo, the water system in the area is currently not up to the task of draining the area completely and making it function like a polder system. On the next few pages the current water system in the area will be explained and reviewed. The same goes for the problems that come with it.

The functioning of the current water system will be reviewed from outside, to inside the area. Starting with the two rivers which flow along the east- and west side of Mulyorejo. In the eastern part of the area the Meduri river flows from south, through the area of sub-district Tirto, to north where it borders Mulyorejo. From the most Northern part of Mulyorejo it only has to travel 2.2 kilometres before reaching the Java Sea. Meduri river is about 20 metres wide and only has flowrate of about 60 m^3/s. All these numbers and other information about the technical aspects of the water system can be found in Water System Analysis Polder Mulyorejo Pekalongan.

Fig. 2 - Meduri river which forms the eastern border of Mulyorejo

Meduri river is extremely polluted. This is because it flows through a part of sub- district Tirto where a lot of batik- and rubber industry is located. All these factories tend to discharge their wastewater straight into the river. For the rubber industry these are the wastes of the production of the rubber fabrication, the stronger debris is burned. While the batik industry discharges everything into the river. Containing paint and very dangerous chemicals which are used to produce the traditional batiks. Fig. 3 shows that the water indicates which colour of the batik is produced that day.

Fig. 3 - The batik industry waste water outlet into the surface water

Besides that, Meduri river is very polluted, the extremely slow flow-rate causes the sedimentation of this river to have almost come to a halt. The sediment which would usually be transported to sea barely gets the chance to reach it. The sea level rise causes the river to flow in the opposite direction, being land inwards at high tide. This causes not only the sedimentation to come to a halt. But also, the water level in Meduri river to rise to an extremely high level. Especially in the rain-season (September till March) this causes piled up sediment in the area, that in some parts caused the river to become extremely shallow. Fig. 4 Besides, a lot of debris which is dumped into the river by inhabitants' traps even more sediment creating huge banks of sludge mixed with plastic and other debris. The picture below shows just how bad the piled-up sedimentation can get in some places and take up more than half of the river.

Fig. 4 - The sedimentation in the Sungai Meduri blocks a lot of the water flow

Because of the sea level rise and the capacity of the Meduri river which is getting smaller, gathering data about the water fluctuation is important. Since this river has been noticed to be very prone to flooding. Besides, the water fluctuation has a serious impact on the dike alongside this river. More about this can be read in chapter 3.1.3 and in the Water System Analysis). From low to high tide the water in Meduri river is able to rise about 66.5 centimetres (with average rainfall). The table which shows the fluctuation has been added in appendix 1. More about this can be read in the Water System Analysis. In the heart of the rain season it was assumed that the fluctuation can be as much as one meter or even more at the Mulyorejo area.

In the west side of Mulyorejo, Sengkarang river borders the area. Sengkarang river is much bigger than the Meduri river. It is about 70 metres wide. The flowrate of this river is about 745 m^3/s. Sengkarang river is much cleaner than Meduri river as well. Before the river borders the Mulyorejo area, there is flooded land which varies between 50 and 200 metres wide from the east bank of the river to the west side of the Mulyorejo area. This shows that the water level in the river is definitely rising, since some structures like soccer goals can be found abandoned in this area.

Fig. 5 - Sengkarang river is a completely different river than Meduri river

Sengkarang and Meduri river are both bordered by dikes which are meant to protect the area against flooding from these rivers. The dike which is found alongside the Sengkarang river is a very decent dike which fulfils its function like it should. The first few hundred meters of this dike consist of a stoned-made embankment of almost five metres high. This seems very sturdy. During fieldtrips there has never been any experience of leaks or other kinds of water related problems caused by this dike.

Fig. 6 - The dike alongside Sengkarang river changes from a stone-made embankment to a soil-made one

3. Research Methodology

These methods were used to answer the different research questions. The research has different stages of investigation. The preliminary investigation was done in HHSK Rotterdam. HHSK is a Dutch water board which was assigned to this research. This system contains data, reports, presentations, movies, and pictures about recent studies in Indonesia and other countries. Furthermore, two interviews were held with professionals. The first interview had the subject ‘Water system’. Useful information was gathered about where to begin with the problem, marking the borders of the area, measuring height differences, and mapping the delta area, rivers and canals. These information sources and interviews were used to specify the upcoming work [5]-[7].

To make sure that these field trips were efficient, preparations took place in Semarang. In addition, several ways of collecting and processing data were used (Excel, Adobe Illustrator, GPS, Arc GIS). Data gathered from the field trip is processed. The data is converted into reports; excel sheets, Arc GIS maps, and illustrations. The result of the data will be a review that contains a water system analysis, a problem description of the Mulyorejo area and recommendations to improve the polder system [8].

The area in between the two dikes, being Mulyorejo, used to consist of rice fields. But because of groundwater extraction, the groundwater level dropped drastically causing the entire land to subside. Also, the heat in combination with a low water level in some areas causes the soft soil to settle, causing a sinking effect on the area. Coastal erosion causes seawater to flow further upstream, in to the system. This caused water from the rivers to be able to flow in to the area, inundating the already low-lying area most of the time. This is when inhabitants turned the rice fields into fishing ponds which are now located all over the northern part of the Mulyorejo area.

On average, the Regency area of Pekalongan subsides. This caused the area to be located about one metre above sea level. In conclusion, Pekalongan is rapidly sinking below sea level. This will lead to an increase of inundation both in frequency and spatial extent. It will also put coastal cities below the relative sea level within years [3], [9].

Mulyorejo does contain some drainage canals that are part of the water system These canals are used to drain water from inundated land to the pumping station, but because these canals are connected with fishponds, the canals don't fulfill their function. Water can flow freely from fishponds, through the canals onto dry-land because these water-bodies are not separated. In this way, the canals do not fulfill their function of draining excess water from the area.

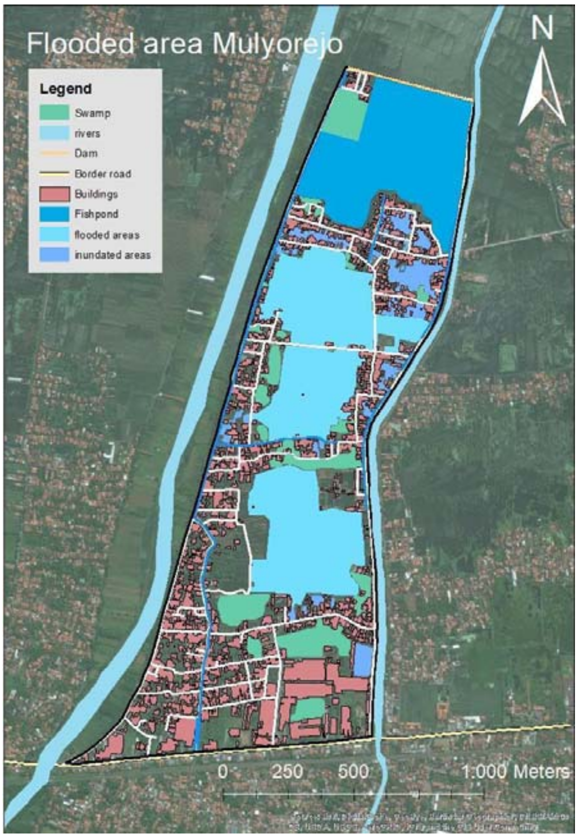

Fig. 7 - The Catchment and flooded area of Mulyorejo drainage system

4. Results and Discussion

The research presents a first catchment area, retention basin, water inflow and outflow condition, and analysis of the water balance using the Bekken model.

4.1 Physical Characteristic of Catchment Area

Mulyorejo is a village in Tirto Sub-Regency, Pekalongan Regency. In the southern part of Mulyorejo, Jl. A. Yani, a main northern Java road, marks the beginning of the catchment area. On the west and east side, the polder is bordered by two rivers. The river on the east side of the system is called the Meduri River, and the river on the west side is called Sengkarang River, which is a big river. The Meduri River is about 20 metres wide and is very polluted because of the rubber and batik industries which are found upstream. It is also full of debris and the flow rate is 60 m^3/s. It was noticed that when the sea level was at high-tide, water from the sea flows into the river such that its water level was higher than land level. This also causes a very bad situation for sediment from the river to the coastal areas. This sediment is deposited on the banks of the rivers itself instead of the coastal zone.

Mulyorejo has an area of 1,841,148 m^2 (184 ha). A 405,052 m^2 (40 ha) part of this area is cultivated with houses, schools or shops, see the figure 2. The remaining area of Mulyorejo consists of agriculture and aquaculture.
Houses, rice fields, and schools are lost because of flooding. A pumping station must pump the water out of the system into the river Meduri to get inundated land clear of the water. Rain will fall on the wetland, dryland, and houses.

Mulyorejo does contain some drainage canals that are part of the water system. These canals are used to drain water from inundating the land to the pumping station, but because these canals are connected with fishponds, the canals don't fulfill their function. Water can flow freely from fishponds, through the canals onto dry land because these water bodies are not separated. In this way, the canals do not fulfill their function of draining excess water from the area. Retention is a good solution to handle that large amount of water that will come into the polder system. 703,381 m^2 (70 ha) is already an inundated area or used as a fish pond. These areas, especially the fishponds, could be used as a retention area. These areas could be multifunctional land. They will only be used as retention when the area is high [10].

4.2 Hydraulic Characteristic of Inflow

This short paragraph will present the different types of in and outlets of the polder system. It will also calculate the amount of water in every inlet and outlet in units of m^3/hour. All these inlets can be calculated to m^3/hour, so a water balance can be made between the inlet, outlet, and retention [10]. The Mulyorejo polder system has different types of inlets i.e. dike of Meduri river, rainfall, southern canal.

4.2.1 Leaking of Meduri River Dike

During field research, it has come to light that the river Meduri is leaking into the polder system. By counting the number of leaks and measuring how much water flows through into the system, it was possible to measure two of these leaks. By calculating the average flow of these leaks, it is possible to assume the total flow of water from the Meduri river into the polder system. According to some samples of observation, It can be estimated that at least 221.3 m^3/hour of water flows into the polder system.

The dike along the Meduri is a 1.5 metre high wall. Because of land subsidence in the area, this dike is cracked in multiple places. It also seems that the dike is not funded deep enough into the soil. This does not only cause water to flow through the cracks, but also to flow underneath the dike. On top of that, the dike is interrupted by multiple bridges which create gaps in the dike. These bridges are at soil-level instead of at the top of the dike. This causes the dike to not be able to function as a whole. More about this can be found in the Water System Analysis.

The water only flows through these interruptions when the water level gets extremely high. According to the measurement found in appendix 1 it should be at 120+ centimetres to overflow these bridges. Which is only 6 centimetres more than the highest measured water level during the field trips. On another note, the water does flow underneath and through the crack in this dike starting at a water level of only 83 centimetres. This causes water to flow from the Meduri, through the dike, into the open water in the Mulyorejo area.

Fig. 8 - Water flows underneath and through cracks of the dike forming giant puddles

4.2.2 Rainfall

The polder system is designed for T=25 rainfall. T=25 means that this type of rainfall occurs once every 25 years, that optimal drainage design Indonesia criteria. Nevertheless, to get a good view on the working of the polder system, there will be calculations for t=2, t=5, t=10 and t=25 [6]. The calculation results are mentioned in Table 1. According to data in Table 1, unit hydrograph can be estimated as in Table 2.

4.2.3 Southern Canal

In the southern area of Mulyorejo, a drainage canal was found. This canal should be seen as an inlet for Mulyorejo since it discharges water from an area located further south in Tirto, into Mulyorejo. How much water this canal is able to bring into the area is unknown. But it is clear that, if Mulyorejo wants to function like a proper polder, this canal should be regulated properly with a lock. For a polder system, it is possible to have inlets from outside, as long as they are separated by locks or gates. However, since this canal will bring water into Mulyorejo that is so polluted, it should be considered whether this canal can keep its function in the future.

The canal is a drainage canal which drains water which is gathered in sub district Tirto. Mulyorejo is part of Tirto as well but it is bordered by a big road called Jalan A. Yani. The canal flows underneath this road, into the Mulyorejo area, creating a gap in the dike (when the Jalan A. Yani. Is seen as a dike). A canal like this would normally not form a serious problem since locks and gates would normally regulate when water is able to enter the area. In this case, there actually is a small gate in this channel which can be closed to stop water from the Tirto drainage canal to flow into Mulyorejo. During fieldtrips it has never been witnessed that this gate was closed. This means that there is a constant water influx from outside of the area.

Table 1 - Calculations for rainfall in Mulyorejo area

Rainfall	Area (A)	Rainfall
T = 2 (71 mm/hour)	1,841,148	130,721
T = 5 (88 mm/hour)	1,841,148	162,021
T = 10 (94	1,841,148	173,067
T = 25 (102 mm/hour)	1,841,148 m2	187,797

Table 2 - Rainfall for every T-type rainstorm per time unit (Unit Hydrograph)

Minut	Hou	T =	T =	T =	T =
10		2	2	3	4
15		3	3	4	5
30		5	6	6	7
60	1	7	8	9	102
	2	8	10	129	158
	3	9	11	138	170
	6	10	13	159	191
	1	11	16	192	222
	24	116	180	207	241

Fig. 10 - A small lock is located in the canal but is always opened

4.3 Hydraulic Characteristic of Outflow

A polder is a closed system where water can’t get out. But there are still ways the water can leave the polder system like pumps and evapotranspiration.

4.3.1 Pumps

Pumps can be used to get water out of the system. We evaluated the pump installed that not be done by design. The system of Mulyorejo temporarily has two of these pumps that are placed in the northeast side of the polder system. In this way, the water can be discharged into the Meduri. The Meduri will be dammed in the future. In the review part of this research, it is kept in mind that a pumping station will be realised on the Sengkarang side of the future polder system.

Besides, the pumping station relies on the functionality of the drainage system. Since the drainage canals do not fulfill their function, the pumps could be switched on, but would then drain every water body in Mulyorejo. Not only the water that flows from land, into the canals. That is what should happen; the water that falls on land should be transported into the drainage canals.

The pumping station will discharge the water into the Meduri. To do so, the station needs an amount of power. The capacity of 1 pump is 6000 L/min. Because there are two of these pumps, the total capacity is 12000 L/min to discharge all the water from the polder system. The maximum and total capacity of the pump station is 720 m^3/hour for an area of 187 ha. The standard capacity of a pump station in Indonesia is 1 m^3/s/100 ha, while the pump in Mulyorejo has a capacity of 0,1 m^3/s/100 ha. This is 10 times less than the standard capacity. [13]

Fig. 11 - The current pump house

4.3.2 Evapotranspiration

As mentioned before, the area of Mulyorejo is 1,841,148 m^2. In the current situation, 405,052 m^2 of the area is cultivated with houses or shops. These buildings drain directly on to the unpaved area. In a report of Witteveen & Boss about the banger polder, they also mentioned that evaporation of unpaved areas is similar to open-water evaporation. Therefore, the same numbers will be used that were used to make the calculations for the banger polder. On average, they get 4.5 mm/day, so 4.525/24 = 0,189 mm/hour, 0.000189 x 1,841,148 = 347.97 m^3/hour [14].

4.4 Retention Basin

Retention basin is usually called for water storage in polder drainage system. The different types of 'bakkenmodel' have showed that a retention area is needed. Because of the large surplus of water in the drainage system area. More so, the schematization has showed us that the Sengkarang river must get involved in the water system. The big river is perfect to drain a large amount of water out of the polder system.

Retention is a good solution to handle that large amount of water that will come in the polder system. 703.381 m^2 is already inundated area or used as fishpond (Fig. 7). These areas, especially the fishponds, could be used as retention area. These areas could be multifunctional land. They will only be used as retention when the need is high [15].

Fig. 12 - Some parts of inundation area look like a small lake

4.5 Water Balance

They also mentioned that evaporation of unpaved areas is similar to open-water evaporation [16]. Because the houses and shops drain directly to the unpaved area, the whole area of Mulyorejo will be assumed as an unpaved area. And therefore, the same numbers will be used that were used to make the calculations. After all the inlets and outlets are calculated, it is possible to make a water balance. By doing so, it is possible to establish if there is enough water in the area or too much. By knowing the surplus or shortage of water, it is possible to calculate the capacity of the pump or the area of retention. The principe of water balance is mentioned in the following schema on Fig. 13.

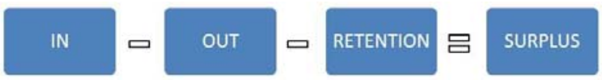

Fig. 13 - Water balance schematic in Polder system

By doing so, it is possible to establish if there is enough water in the area or too much. By knowing the surplus or shortage of water, it is possible to calculate the capacity of the pump or the area of retention. In the current situation, there is no retention and the capacity of the pump is 720 m^3/hour, which is way too small (refer Table 3).

Table 3 - Water Balance simulation.

Period	Rainfall(m^3/	Leaks	Evaporation	Pump (m^3/h)	Surplus (m^3/h)
T	130,721	2	3	720	129,874
T	162,021	2	3	720	161,174
T=	173,067	2	3	720	172,220
T=25	187,797	221	348	720	186,950

Because there is no retention in the area and the capacity of the pump is small, the area has a large surplus of water. The surplus has to be storage in in long canal, retention area, pond. For example, after rainfall that occurs every 25 years, Mulyorejo will have a surplus of 186,950.55 m^3/hour water. This calculation showed that a retention area is needed to find balance in the water system of Mulyorejo. More possible future solutions are projected on the Mulyorejo system.

In the southern area of Mulyorejo a drainage canal was found. This is the same canal as described previous paragraph. This canal should be seen as an inlet for Mulyorejo since it discharges water from an area located further south in Tirto, into Mulyorejo. How much water this canal is able to bring in to the area is unknown. But it is clear that, if Mulyorejo wants to function like a proper polder, this canal should be regulated properly with a lock.

4.5 Bekken Model of Water System

To make the water system of Mulyorejo clearer, the method 'Bakken model' will be used. In this method, you will visualize the different types of waterways, in –and outlets and retention areas (see Fig. 14). This method will be useful to ascertain current bottlenecks or upcoming bottlenecks [1].

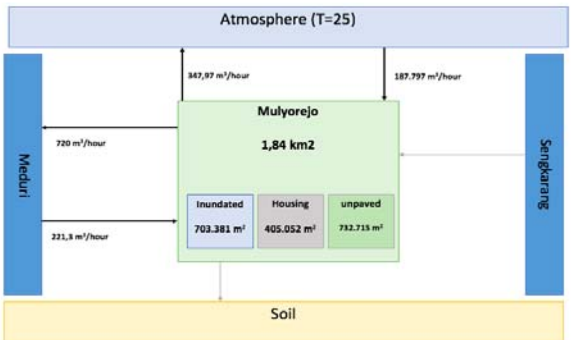

Fig. 14 - Bekken model of water simulation

Eventually, it was concluded that the northern fish pond should stay, and a dammed canal should be built around it which is connected to the drainage system of the entire area. This way the fish pond is secured by a dam and the drainage system is able to drain water into a retention capacity 5% of catchment area and 1 m difference level. It has 97,000 m^3 water storage. Also, a new pump house will drain water into the Sengkarang River instead of the Meduri river since this river has a much higher flow rate. The combination of the amount of retention and the new pump house would be able to free the area of water during a T=25 year rainstorm within 24 hours need about 1.2 m^3/s pump capacity.

Eventually all these different aspects of research gave insight in how the Mulyorejo area needs to find a balance between inlets flow, retention and outlets flow, while the quality and opportunities for the area are taken into account. A balance between inlets and outlets, only can be made when the southern canal is closed off and the leaks in the Meduri dike are solved. In combination with the built of a proper retention basin in combination with a pump with the above-mentioned numbers which cover a serious capacity is needed to ensure the quality and opportunities for the area. The area be able to go back to farming again; creating more jobs, a better water quality, better hygiene and most of all, no more flooding.

5 Conclusions

A lot of land in the area is still underwater. It has been globally calculated with Arc-GIS that about 40% of the area is inundated, before protected by dike in polder system. The sea dike can protect water from sea side, but water from rainfall have to be stored and pumped.

The pumping station, which is located on the east side, on the west bank of Meduri river has a capacity of 720 m^3/hour. When calculating the inlets with the projected T=25 type of rainstorm, an amount of 187,797 m^3/hour would enter the 184-hectare area trough rain. Adding an extra 221 m^3 for the leaks, there is a 186,950 m^3 surplus of water that will be in storage and more pump capacity. The retention capacity 5% of catchment area and 1 m difference level. It has 97,000 m^3 water storage. The temporary pumping is not yet good performance. The combination of the amount of retention and the new pump house would be able to free the area of water, and for 24 hours need more about 1.2 m3/s pump capacity.

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