Diagnosis of Operating Mine Dewatering Wells Efficiency through Groundwater Modelling

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Abstract

Pumping wells are used to dewater operating mines at various sites around the world. The usual objective of the pumping from dewatering wells is to intercept most of the groundwater flow such that only a small amount of residual inflow would reach the mine.

Decrease of pumping wells production usually occurs over time [1] either due to the extent of the groundwater level drawdown around the mine and depletion of the aquifer storage, or to decline of the well efficiency because of deterioration of the well installation. Therefore, decrease in the pumping rate in a dewatering well does not necessary means that the latter requires rehabilitation or replacement. Borehole rehabilitation or replacement is often costly and should be carried out only if justified upon diagnostic of the reasons behind the decline in the pumping rate.

In ideal world, dewatering wells are designed taking into account the hydraulic and physical properties of the target geological formations, and their efficiency estimated upon installation and commissioning. During the mine operation the efficiency of dewatering wells is (or should be) estimated/reassessed regularly to enable better planning of borehole maintenance and replacement where necessary. However, such procedures are not usually implemented and in some cases even measurements of pumping rate and water level in the wells are not collected.

Assessment of dewatering wells efficiency during the mine life is usually carried out using pumping tests and down-hole surveys. In some circumstances such costly field tests, which may also interfere with the dewatering operation, are not necessary for all dewatering wells. This paper presents an alternative desktop-based approach for an initial diagnostic of the dewatering wells efficiency and a case study is given for an operating pit. The method consists of using groundwater models to simulate the pumping potential of dewatering wells over time. The estimated achievable pumping rate from a dewatering well is then compared to the actual/observed rate to verify if the well is operating at the expected level. The results of the model can be used by the mine managers to decide if there is need or not for down-hole surveys and borehole rehabilitation or replacement. The results enable more efficient planning of the field work based on the predicted pumping potential of each well, and the priority areas identified by the model as potential source of the residual inflows of groundwater into the mine.

Key words: Mine dewatering, numerical groundwater modeling, pumping well efficiency

Introduction

For many operating mines around the world, active dewatering wells are required for one or more of the following reasons:

- To reduce residual inflows into the mine to manageable level;
- To reduce cost of water treatment and discharge constraints;
- To improve mine stability and steepen the slope angles to save cost;
- To improve the productivity of the mine (e.g. improve blasting and loading efficiency);
- To improve safety of the mining operation.

One of the common methods of mine dewatering is the use of vertical pumping wells. Therefore in order to achieve the desirable objectives of dewatering, the pumping wells efficiency must be kept at acceptable level. However, it is evident that the pumping rate of dewatering wells declines over time for various reasons, some of which are not related to the borehole condition or efficiency.

Water well pumping efficiency is defined as the ratio of aquifer loss (drawdown) in the well to the total loss (total measured drawdown) in the well during pumping ([2], [3], [4]). It reflects the capability and resistance of the well installation to transmit water from the surrounding aquifer to the pump. The total drawdown is the sum of linear aquifer losses and the linear and non-linear well losses. The pumping well efficiency is estimated from step pumping tests data with the help of equations such as the Hantush-Biershenk [5] and Rorabaugh [6] equations.

In principle, pumping tests are (or must be) carried out regularly in dewatering wells to estimate the efficiency of the dewatering wells over time. This is a reliable method to quantify the well efficiency and thus assess the degree of its deterioration over time. However, pumping tests are costly, especially in projects where many wells exist, and may interfere with the dewatering operation itself. Furthermore, in some circumstances, the tests may not provide accurate results due to interference between the dewatering wells and the potential effect of other boundary conditions.

Considering the cost and complication related to pumping tests, as highlighted above, groundwater modeling can be used as an initial tool to assess the efficiency of the dewatering wells, before any field work is undertaken. The model results may help reduce the number of dewatering wells to be tested, rehabilitated or replaced. This is due to the fact that in some cases the decline in dewatering well productivity is due simply to aquifer drawdown, or other natural factors such as heterogeneity in the geological formation(s) or anisotropy in the aquifer thickness.

In this paper a case study is presented in which groundwater modeling was carried out to simulate an operating mine dewatering system. The results corroborate some of the assumptions above and highlight the importance of groundwater flow modeling in guiding the planning of dewatering wells rehabilitation and replacement and reducing cost.

Discussion

Mine hydrogeological setting and dewatering system

The site is located in a former-soviet country, and consists of an operating pit around 1 km wide and 2 km long (**Fehler! Verweisquelle konnte nicht gefunden werden.**). The mine has been operating for seven years and the operating depth is 120m, with the target final depth being 500m. The ore body is covered by a sedimentary overburden material of thickness varying between 50m and 70m, made up of a succession of sand and clayey formations arranged as follows, from top to bottom (Figure 2):

(1) A layer of alluvium sands and silt;

(2) Clayey Siltstone;

(3) Clay; and

(4) Sands.

In addition to the main stratification above, various intercalations and horizontal heterogeneities exist within the layers. The ore body is hosted in the crystalline rock formation, beneath the overburden series.

As indicated above, the overburden material contains two sand aquifers separated by impervious clayey material. The thickness and bottom elevation of the aquifers vary across the site. The presence of two aquifers with high storage capacity and hydraulic conductivity required the use of dewatering wells to reduce groundwater inflows into the pit. The total observed inflow of groundwater (pit and dewatering wells) is about 60,000m^3/day. Because of the presence of clayey material between the two aquifers there was need to install two sets of dewatering wells, each targeting a specific aquifer (**Fehler! Verweisquelle konnte nicht gefunden werden.**). Accordingly, a total of 85 wells were installed in the top aquifer to an average depth of around 25m, whilst 77 wells were installed in the deep aquifer to an average depth of about 75m.

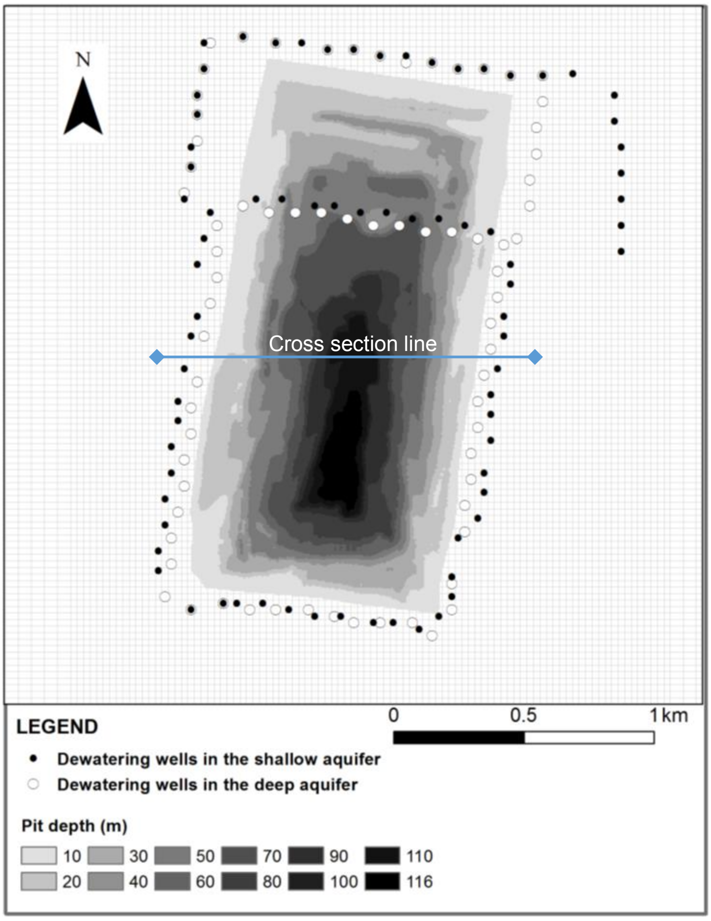

Figure 1 *Configuration of the pit and the dewatering wells in the shallow and deep aquifers.*

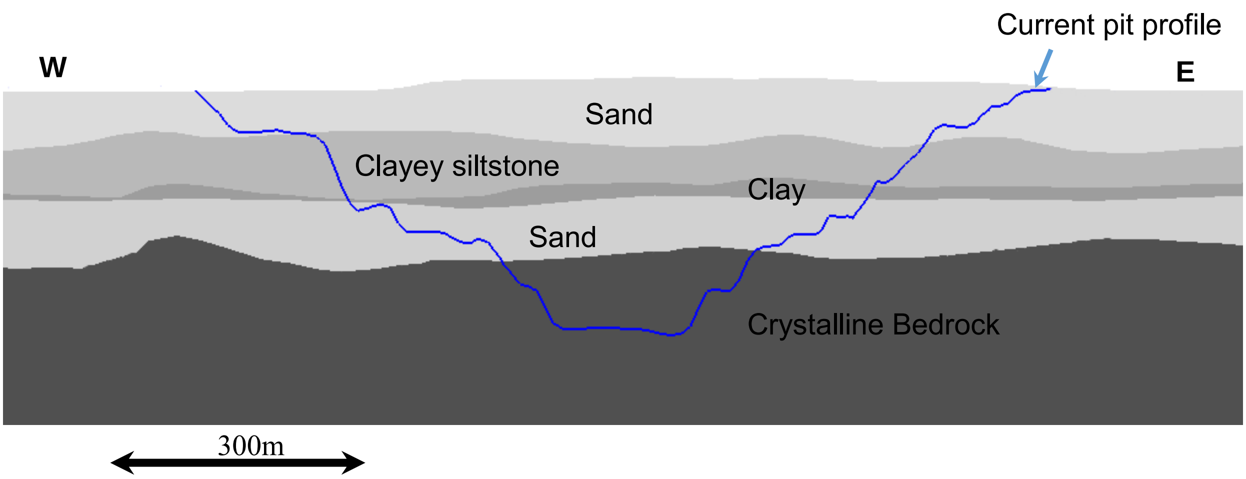

Figure 2: *East-West geological section across the pit (vertical exaggeration: 3x)*

The pumping wells were not properly tested initially (upon completion of the installation) to determine the initial well efficiency and monitoring of the pumping rate has not been carried out in the wells since the dewatering operation began. The dewatering wells system is divided into 7 fields, each consisting of a cluster of variable number of wells. Accordingly, the pumping discharge from each field is combined in a single pipeline that conveys water into the discharge locations along surface water streams. Monitoring of the pumping flow rates was not carried out at each pumping well, but rather at the discharge points of wellfield pipelines only, using flow meters.

Over time some of the dewatering wells started failing and the system was unable to reduce the inflows of groundwater into the pit to the desired level. Therefore, borehole rehabilitation and replacement have been carried out on a number of wells. However, due to the scale of the operation, the heterogeneity of the aquifers and the lack of accurate monitoring of the pumping rates from the dewatering wells over time, it was difficult for the mine to know which wells were not performing well and plan the rehabilitation programme properly. Therefore, it was envisaged to use groundwater modeling tools to simulate the pumping system and assess the performance of each well and prioritize accordingly the well replacement and rehabilitation work depending on the magnitude of the failure of each well and the contribution of this to the observed inflows of groundwater into the pit.

The diagnosis technique presented in this paper can be applied to other mines with complex borehole dewatering systems. It can help the mine to save cost and time by targeting the testing and rehabilitation work of dewatering wells with a particular focus on the ones that are more relevant to reducing groundwater inflows into the mine.

Groundwater Model Setup

Groundwater modeling was carried out to assess the efficiency of the dewatering wells and effectively plan the rehabilitation or replacement of the deficient wells. Modflow [7, 8] was used to simulate the groundwater flow in the project area. A regional groundwater flow model was initially calibrated for the site, and this consists of a finite-difference model with a grid consisting of 274 rows and 193 columns, and 15 layers. For the evaluation of groundwater inflows into the mine, the model grid was refined to 499 rows and 331 columns, and 15 layers. The model grid cells within the open-pit and surrounding area were initially discretized to 50m x 50 m cell size in the calibration model and then refined to 12.5 m in the predictive model. The horizontal dimensions of the outer cells of the groundwater model grid range from 200 to 50 m.

The hydrogeological input parameters (horizontal (K_h) and vertical conductivity (K_v), specific storage (Ss) and specific yield (Sy)) were assigned to model cells or zones depending on the geology of the area. The parameters were estimated based on field data from borehole tests, and model calibration. Due to the lateral variation of hydraulic conductivity of the two aquifers, spatially distributed maps were generated from the pumping test results and used in the model (Figure 1).

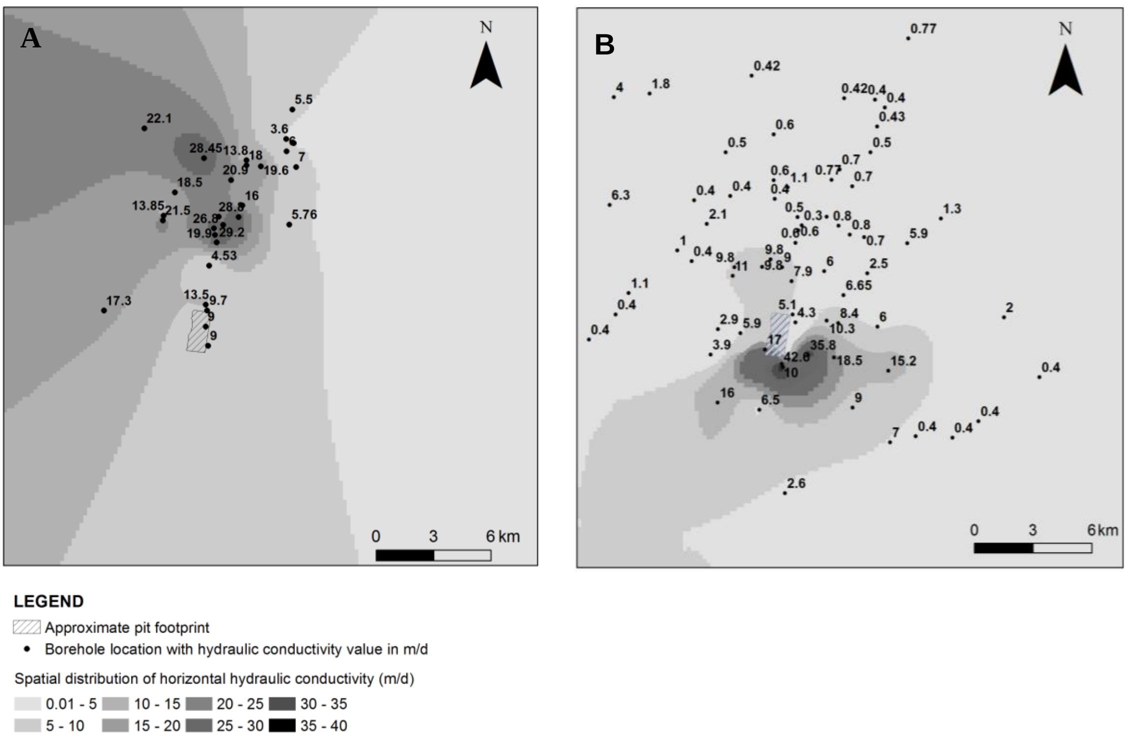

Figure 1: *Spatial distribution of hydraulic conductivity of shallow aquifer (A) and deep aquifer (B)*

The hydraulic conductivity of the top aquifer varies between 1 and 26 m/d across the model area, whilst the deep aquifer shows greater variation with values ranging between 1 and 40 m/d. The hydraulic conductivities of the shallow and deep sand aquifers vary between 3.6 and 29.2 m/d; and 0.3 to 42.6 m/d, respectively. The layer thickness (calculated from elevations of the top and bottom interfaces) of each geological formation was obtained from several boreholes across the site, and spatially distributed thickness grids prepared by interpolation of the points data and used in the model. The geological model was verified at various new borehole locations and compared to observations from the pit excavation to confirm the accuracy of the layers configuration.

The spatial variation of the above hydraulic parameters and aquifer thicknesses have significant impact on the dewatering wells yields and therefore the groundwater model is an effective tool to combine these parameters and simulate inflows into the dewatering wells and the pit.

Simulation of the dewatering system

Because the initial groundwater level at the pit location was only less than 5m below the ground surface, active dewatering, using vertical wells, has been carried out since the start of the mine excavation. Locations of the dewatering wells targeting both aquifers are shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**. For the calibration of the model, simulation of the borehole dewatering system was carried out using Modflow "Well" package. The wells were started and shut-off in the model according to the actual operation schedule provided by the mine, as shown for the shallow wells in **Fehler! Verweisquelle konnte nicht gefunden werden.**. The pumping rates assigned to the dewatering wells were either provided by the mine for the periods where such data are available, or assigned according to the capacity of the corresponding pump where no data are available.

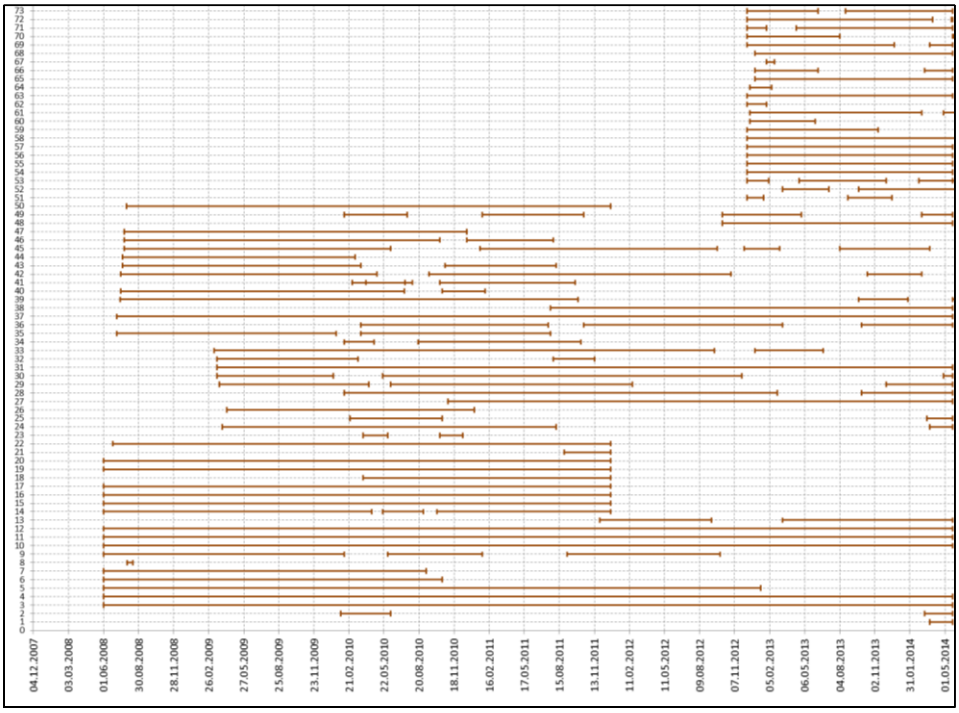

***Figure 4:** Pumping schedule of the shallow dewatering wells.*

Once the model was calibrated, the dewatering wells were replaced by drain cells in the model to assess the efficiency of the wells. To ensure no restriction of flow into the well-drains, high conductance was applied to the drain cells. Several dewatering wells around the pit have been inactive and others reported to be operating at low debits. Simulation of the dewatering wells as drains for the period 2008-2014 provides an estimate of flow rate that is likely to be achieved in each well location assuming all wells are 100% efficient. The comparison between the predicted inflows into the ideal well-drains and the current/observed pumping rates in the dewatering wells provides an insight into the wells that are not functioning properly, those where the inflows are too low to run a pump, and those that are operating properly (at full capacity).

Groundwater model results and discussion

The main results of the model for estimating the well efficiency are the predicted achievable rates (inflows into the well drains) that are compared to field dewatering well records. The following criteria are applied to assess if the existing dewatering wells are efficient or not:

- The minimum threshold of 10m^3/h has been applied, which means a well is put in operation only if the flow rate is 10m^3/h or more. If the actual pumping rate from a dewatering well in 2014 is equal or more than what is predicted by the model, or it is lower but by less than 5m^3/h, the well is considered efficient and acceptable.
- If the achievable pumping rate predicted by the model in an operating well is more than 10m^3/h AND at least 5m^3/h higher than the operating rate of 2014, this indicates that the well needs either rehabilitation or replacement.
- If the achievable pumping rate predicted by the model in a well that is indicated as inactive from the database, is more than 10m^3/h, this indicates that such dewatering well needs replacement if it is inactive because of being dry.
- If the predicted flow rate is less than 10m^3/h the well is considered as not needing replacement because the low flow rate doesnt justify active pumping.

The comparison between the predicted inflows into the ideal well-drains and the current/observed pumping rates in the dewatering wells in both aquifers allowed the identification of wells that can be considered acceptable, the wells that are actually dry and may not need replacement because the predicted inflows are too low, and the wells that possibly need rehabilitation or replacement. Based on such diagnosis, specific action (or no action) was recommended for each dewatering well. Recommendations were made to the mine to guide the rehabilitation programme, with the aim to prioritize the wells that were identified as failing and can contribute to reducing significantly the inflows into the mine if rehabilitated or replaced. Table 3 shows a summary statistics of the diagnosis of the dewatering wells in both the deep and shallow aquifers.

As shown in Table 3, based on the efficiency criteria defined above, the following conclusions are made concerning the deep dewatering wells:

- 35.4% of the existing 65 deep dewatering wells are acceptable (this means 23 wells are operating at the expected rate). The total number of wells is 65 because some of the wells were decommissioned during the pit extension;
- 12.3% of the deep wells (8 wells) are actually dry or low yielding wells, and this is in accordance with the model prediction that these wells are expected to be dry or low yielding. Therefore these 8 wells do not need replacement or rehabilitation;
- 52.3% of the deep wells are operating at a flow rate lower than 10m^3/h or higher than 10m^3/h but 5m^3 less than expected. This means these 34 wells need either rehabilitation or replacement.

The following conclusions are made concerning the shallow dewatering wells (Table 3):

- 18% of the 61 existing shallow wells are acceptable (this means 11 wells are operating at the expected rate);
- 36% of the shallow wells (22 wells) are actually dry or low yielding wells, and this is in accordance with the model prediction that these wells are expected to be dry or low yielding. Therefore these 22 wells do not need replacement or rehabilitation;
- 46% of the shallow wells are operating at a flow rate lower than 10m^3/h or higher than 10m^3/h but 5m^3 less than expected. This means these 28 wells need either rehabilitation or replacement.

Table 3 *Summary statistics of well efficiencies based on the groundwater model results.*

Well categories according to model results	Shallow wells		Deep wells	
	Number of wells	Percentage	Number of wells	Percentage
Acceptable wells	11	18%	23	35.5%
Dry or low yielding Wells that do not need replacement	22	36%	8	12%
Wells that may need rehabilitation or replacement	28	46%	34	52.5%

It is worth noting that in some circumstances, the well flow rate predicted by the model is lower than that reported in the 2014 monitoring data. This is likely to be due to the fact that in the model the entire network of dewatering wells are assumed active (withdrawing water), contrary to reality where gaps of inactive wells exist, and therefore the wells at the edges of each gap may be withdrawing more water from the aquifer than the model shows. Part of the discrepancy would also be due to inaccurate measurements of flow rate in the well, because of lack of flowmeters, and the numerical model error but the contribution of these to the overall rate difference would be limited.

The amount of $5m^3/h$ difference between observed flow and predicted flow that was applied in the criteria above was selected to allow for the errors of both the model and the flow measurements, which are expected to be generally lower than $5m^3/h$.

Conclusions

The efficiency of dewatering wells is a very important factor in mine dewatering to keep groundwater inflow into the mine at manageable level. Usually pumping well efficiency is estimated from pumping tests. In the present paper, groundwater modeling was used instead of pumping tests to assess the efficiency of operating dewatering wells around an operating pit. Because the hydraulic parameters and the thickness and bottom elevation of the productive aquifers vary across the site, pumping rate can decline despite the efficiency of the pumping well itself. Therefore instead of pump testing all the dewatering wells, some which may be dry or low yielding due to the natural conditions cited above, groundwater modeling is a suitable tool to assess the efficiency of the wells before any field test is carried out.

The groundwater flow model was first calibrated using existing field data, and the dewatering wells were simulated using observed flow rates and according to the actual pumping schedule. To assess the efficiency of the dewatering wells, the latter were subsequently simulated as drains to estimate the achievable flow rate into the well.

The calibrated model simulation, in which drains were used instead of wells, enabled the comparison between the observed flow rate in the dewatering wells and the achievable rate predicted by the model. Such comparison allowed identification of wells that need rehabilitation or replacement, and those that are acceptable or dry because of depletion of groundwater storage and do not need replacement.

According to the pumping threshold/criteria used in this paper, the model results suggest that 52% of the existing 65 deep wells (34 wells) need either rehabilitation or replacement. For the shallow wells, 46% of the 61 wells (meaning 28 wells) need either rehabilitation or replacement.

Based on the results of the assessment of the existing dewatering wells efficiency using the groundwater model, a monitoring programme and down-hole survey were recommended for the dewatering wells that have been identified by the model as potentially deficient wells.

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