Modeling groundwater flow and salinity evolution near TSF Želazny Most. Part I – groundwater flow

Waldemar Świdziński

1Institute of Hydro-Engineering, Polish Academy of Sciences, IBW PAN, Gdańsk, Poland

ABSTRACT
Tailings which are by-product of the extraction of various metals (copper, gold, silver, molybdenum, etc.) are often stored in so called Tailings Storage Facilities (TSF), where they are deposited as a soil-water mixture by spigotting. In many cases the water discharged together with tailings to the TSF is rich in salts and other chemical compounds imposing negative pressure to the groundwater environment. Even in the case of total or partial lining of such facilities and well-developed drainage systems to control leaching, some portion of contaminated water often seeps either through the surrounding dams or the bed into adjacent groundwater bodies. Numerical models can be very helpful tools to assess the extent of the contamination and particularly to predict its potential development in the future. This paper and the companion one describe such a numerical model developed for Želazny Most Tailings Storage Facility (south-west Poland), one of the world's largest tailings sites. In the first part general information about the facility is provided and a 3D hydrogeological numerical model of the structure is described. Groundwater flow pattern near the facility obtained from numerical simulations is confronted with the measurements from a comprehensively developed monitoring system. Part II will be focused on the modelling of chloride transport in groundwater.

INTRODUCTION
TSF Želazny Most is a depository for post-flotation tailings, which are by-product of copper mined in three mines: Rudna, Lubin and Polkowice located in south-west Poland, operated by KGHM company. It belongs to one of the largest facilities of its kind in the world. Since this is only place to store tailings produced by the Polish copper mines it is a key element in this production. The tailings are transported to the TSF in the form of low concentration slurry which is discharged into the facility by spigotting along the whole perimeter of the object. Semi-liquid tailings are retained within the structure by earth dams surrounding the depository. During the spigotting the tailings undergo natural process of segregation which causes that the coarser material deposits near the dams whereas the finer one is gravitationally transported with flowing water towards the central part of the TSF, where the water is clarified forming a water pond (Figure 1). In order to accept new supplies of tailings (the annual production of which amounts 28 mln tonnes) the facility has to be continuously developed. The Želazny Most tailings facility is being raised using the upstream construction method. Only at early stage the so-called starter dams were constructed from borrow earthen material. Afterwards the dams have been raised by 5 m high embankments utilizing coarse tailings deposited near the dams. Total area occupied by the facility amounts 14 ha with the length of perimeter 14.3 km. Due to the natural terrain relief the present height of the surrounding dams varies: 41 m for the south dam, 47 m for the north one, 57 m for west dam and over 70 m for the east dam, at the crest elevation 185 m a.s.l. Total volume of tailings stored in the TSF exceeds 600 mln m$^3$ and according to the future plans of copper production in KGHM it should be ready to accept next 300 mln m$^3$. 

311
The dams as well as the bed are not sealed which means that the water discharged with tailings can almost freely infiltrate. In order to contain infiltration an extensive system of drainage has been developed. It consists of various elements, including several floors of circumferential drainage, the aim of which is to intercept the seeping waters at the highest possible elevation in order to control the position of phreatic surface within the dam body. At present there exist four floors of circumferential drainage, constructed every 10 m in height starting from the elevation 152 m a.s.l. and installed in the course of the facility development. Moreover, there is pipeline drainage of starter dam and finally the dich drains surrounding the facility at the dams’ toe (Figure 2).

Despite the comprehensive system of horizontal drainage some waters still seeps into the subsoil and next downstream, infiltrating into the groundwaters. The waters discharged with tailings to TSF come from dewatering of mining fields therefore they are highly contaminated, mostly by salts. In order to reduce the negative impact of the waters seeping...
downstream a system of drainage wells (approximately forty wells) located around the facility outside the dams’ toe has been installed. The second purpose of these wells is to reproduce the groundwater flow conditions prior to the construction of the TSF. The drainage wells continuously pump out the groundwater from the small local aquifers preventing the contaminated water from flow downstream, however small amounts of leachate still pass the hydraulic barrier. In order to recognize the existing flow paths of saline water, verify the efficiency of existing drainage system, but first of all to predict the development of salinity front with the raise of the dams and tailings, a numerical groundwater model of the TSF Żelazny Most and surrounding area has been developed.

**STRUCTURE OF 3D HYDROGEOLOGICAL NUMERICAL MODEL**

The 3D model, which was originally developed at the beginning of the current decade and successively updated, reproduces flow conditions in the area of TSF Żelazny Most including the following elements (Świdziński et al., 2011):

- infiltration of saline waters through the bed of water pond, the beaches and next through the mass of tailings into the groundwater,
- downstream flow of groundwater and pollution migration,
- surface watercourses and the change of their quality,
- interaction between ground and surface waters,
- drainage system of the facility,
- drinking water intake wells.

The 3D model has been developed with GMS (GroundWater Modelling System) commercial software package, initially using version 6.5 and more recently using version 8.3. The groundwater flow equations are solved by MODFLOW software integrated with GMS. The model covers the area of the current impact of the facility determined by the field measurements and the predicted area of long-term future impact. The borders of the model are defined by watercourses or local watersheds. The model domain also includes Retków-Stara Rzeka water intake located within the area of Main Groundwater Reservoir (GZWP – 314) (Figure 3). Steady-state groundwater flow is considered. The bottom boundary of the 3D model was determined based on the assumption that the most important role in the impact of the facility on groundwater is played by the shallowest multi-aquifer formations i.e. quaternary and upper tertiary aquifers. The latter is well isolated from the lower inter coal (middle and early Miocene) and under coal (Oligocene) aquifers. The elevation of the model bottom was assumed at -70.0 m a.s.l., i.e. the lowest point of the tertiary aquifer formation. The model domain has 154.8 km$^2$ (12.9 x 12.0 km). It was subdivided into a grid of squares and rectangles with alternate sizes. Due to essential gradients in elevation and resulting hydraulic gradients, the area of very facility was covered by square mesh with the size 25 x 25 m, zone 1 km distant from the dams toe by squares 50 x 50 m, whereas the rest of the model area with squares 100 x 100 m (Figure 3). Such discretization allowed an appropriate modelling of the work of drainage wells as well as good reproduction of the inclination of downstream slopes of the facility. The orientation of the mesh has been chosen in such a way so that the mesh line follows main direction of flow and migration of saline waters (Świdziński et al. 2011). The grid for a single calculation layer is built of 289 rows and 282 columns. Geological and hydrogeological conditions of the modelled area are extremely complex since they were significantly impacted by three glaciations which passed over Żelazny Most in Pleistocene. The various ice sheets, which are believed to have been at least 1000 m thick, have induced widespread glacio-tectonic phenomena causing many thrusts of Pleistocene deposits into the initially horizontally bedded freshwater Pliocene
sediments (Jamiolkowski 2014). As a consequence it was very difficult to identify and separate single aquifers and aquitards in the subsoil (see Figure 2) as it is done in a standard approach in the schematisation process and generalisation of hydrogeological conditions. Moreover, despite a huge number of geological profiles (several thousands) obtained from various field investigations (standard boreholes, CPTUs, geophysical surveying) only small portion of them could have been used for identification of hydrogeological conditions since the majority of the profiles were located near the dams of the facility and a lot of other ones were too short to be included in the interpretation. Furthermore, very differentiated geological conditions which were changing very often and rapidly in plane and depth, prevented to use standard GMS tools to construct individual hydrogeological layers of similar hydraulic properties. Therefore, it was decided to construct 3D model of the subsoil in a non-standard way. First of all, for the generalization purposes four basic hydrogeological layers have been assumed:

- quaternary layers of permeable formations - $k = 10^{-4}$ m/s,
- quaternary layers of impermeable formations - $k = 10^{-9}$ m/s,
- tertiary layers of permeable formations - $k = 5 \times 10^{-4}$ m/s,
- tertiary layers of impermeable formations - $k = 10^{-9}$ m/s.

Next, the subsoil has been divided into 10 model layers of various thicknesses with the smallest thickness for uppermost layers and larger one for lower layers. The values of hydraulic conductivities, which have been assigned to generalized permeability categories, have been subsequently averaged for the given thickness of the model layers in terms of the

*Figure 3. Finite difference mesh of 3D model for TSF Želazny Most.*
geometric average. This procedure was applied for each hydrogeological borehole taken into account. Distributed averaged values of hydraulic conductivities were next interpolated between neighbouring boreholes for each model layer using the natural neighbour method. In such a way a fuzzy distribution of hydraulic conductivities was obtained covering the full and continuous range of permeabilities i.e.: from impermeable soils, via semi-pervious ones, and finally to fully permeable soils. The model of the foundation has been supplemented by the system of rivers and surface watercourses running within the model as well as along its borders, drainage wells around the facility, groundwater intake and farm wells in this area.

In turn, hydrogeological model for the facility also consists of 10 calculation layers, the lowest three of which have differentiated thickness so as to have horizontal top of the third lowest layer at the elevation of 160 m a.s.l. The subsequent 7 higher layers of the depository have equal thickness of 5 m reaching final elevation of 195 m a.s.l. Each of the calculation layers consists of external embankment and the tailings filling the depository with decreasing permeability going towards the pond. In order to reflect the change of the fines content in deposited tailings, for each calculation layer 9 zones with the same permeability have been distinguished following the decrease of permeability coefficient as a function of the distance from the embankment. Finally, based on accessible digital maps and half-tone screen of the terrain of concern the system of surface watercourses as well as all drainage elements installed in the depository together with water intakes were implemented in the model. For the majority of river sections flowing along the borders of the model the first-type (Dirichlet) boundary condition was assumed (specified head). At the north-west corner, the only artificial border of the model, the so-called specified–flux boundary was assumed which in fact is a second-type boundary condition. For all watercourses located inside the model area the third-type boundary condition (Cauchy) was specified. The work of any wells (drainage, relief and intake wells) was modeled by the second-type (Neumann) boundary condition (constant discharge). Recharge was assumed based on the long-term mean annual precipitation at the level of 597 mm reduced respectively to the effective infiltration depending on the type of the surface soils. With regard to the facility, the infiltration of saline waters throughout the mass of tailings under the pond was simulated by first-type boundary condition assuming elevation of water head whereas the infiltration of waters discharged on the facility beaches during spigotting process was simulated by third order boundary condition using MODFLOW RIVER package.

Figure 4. Observed and calculated elevations of piezometric head in a) drainage wells b) in observation points downstream the facility.
MODELLING OF GROUNDWATER FLOW REGIME
The model was calibrated so as to achieve the best fit of the simulated and real (based on the in situ measurements) hydrodynamic field downstream the facility. The calibration process involved adjusting local hydraulic permeability and recharge values. The comparison of calculated and measured values of the piezometric heads for drainage wells and numerous observation points downstream (piezometers, intake and farm wells - in total 533 observation points) is shown in Figure 4. It can be seen that the model reproduces accurately groundwater flow conditions within the facility and its neighborhood near and far downstream. This can be confirmed by comparing the groundwater table contours obtained from standard hydrogeological mapping with the contours obtained from the model - the match is very good (results not shown here).

DISCUSSION AND CONCLUSIONS
The groundwater flow model developed for Tailings Storage Facility Żelazny Most, Poland appeared to be a very efficient tool in reproduction of real groundwater flow regime. Taking into account the dimensions of the modeled area, complexity of the hydrogeological structure of the subsoil as well as highly differentiated flow conditions within the facility the agreement of the results of numerical simulations with the observations obtained from comprehensive monitoring system is very good. It should be stated that such a good agreement has been achieved by very careful verification, calibration and modification (if appeared necessary) of local groundwater flow conditions during calibration process which has been very much time consuming however yielding very good final results. It mostly regarded the direct vicinity of the facility, specifically near the drainage wells for which given discharge capacity has been assumed and depression simulated and compared with measured values. In some cases such modification has been carried out for intake and farm wells as well as piezometers located far downstream from the facility and for which high differences between measured and observed piezometric heads have been found. Well calibrated 3D hydrogeological model was a basis for simulation of migration of saline water into groundwater presented in Part II.

REFERENCES

Świdziński W., Maciejewski St., Walter A. and Franz M. 2011. Prediction of the Żelazny Most facility impact on ground and surface waters during its operation to the elevation of 195 m a.s.l. and after its closure. Report for KGHM POLSKA MIEDŹ S.A.

Świdziński W., Maciejewski St., Walter A. 2014. Integrated assessment of the impact of the Żelazny Most facility on ground and surface waters till 2012 together with updated protection plan. Report for KGHM POLSKA MIEDŹ S.A.

Contact Information: Waldemar Świdziński, Institute of Hydro-Engineering PAS, Department of Geomechanics, Kościerska 7, 80-328 Gdańsk, Poland, Phone: +48585222945, Fax: +48585524211, Email: waldek@ibwpan.gda.pl.
Modeling groundwater flow and salinity evolution near TSF Żelazny Most. Part II – chloride transport

Waldemar Świdziński
Institute of Hydro-Engineering, Polish Academy of Sciences, IBW PAN, Gdańsk, Poland

INTRODUCTION
In Part I of this set of two papers a 3D hydrogeological numerical model (Figure 1) simulating the groundwater flow regime near the huge Tailings Storage Facility Żelazny Most, Poland was described and discussed. TSF Żelazny Most stores post-flotation tailings which are a by-product of copper mining and its extraction. The tailings are transported and discharged into the facility as a slurry containing highly saline waters which can infiltrate into groundwater strongly impacting the water environment near the TSF. Essential part of these waters is intercepted by comprehensively developed drainage system, however some small portion still passes by the drainage and enters groundwater and finally the neighboring surface watercourses. The aim of the model was to have efficient tool to simulate the groundwater flow pattern near the TSF and the transport of saline waters seeping from the facility. The results presented in Part I showed that after careful calibration and validation the model acceptably well reproduces real groundwater flow conditions within the modelled area. Next, based on the 3D model the migration of saline waters was simulated and confronted with the in situ measurements of the range and concentration of chlorides downstream the facility. The final step was the prediction of the change of groundwater flow regime due to increasing water level in TSF at higher elevations of the dams and stored tailings, and the associated changes of contaminated zones with the course of the facility development. In Part II the simulation of chloride transport near TSF by 3D model is described and the predicted development of salinity zones is presented.

MIGRATION OF SALINE WATERS WITHIN THE MASS OF TAILINGS
The seepage process from the pond through the mass of tailings and dam is generally determined by two factors: the water head and the permeability properties of tailings and subsoil layers. The conditions for infiltration of saline waters in the mass of tailings are dependent on its gradation which is the result of segregation and sedimentation during the spigotting process. Coarse fractions of relatively high permeability are deposited near the embankments whereas the finest fractions are deposited near the pond and, due to sedimentation process, onto its bed. Thus the infiltration of saline water throughout the tailings cannot be avoided, particularly in the close distance from the embankments. Essential portion of water infiltrates into the tailings mass via beaches of the facility during discharging of a slurry. The closer distance to the embankments the more intensive infiltration occurs. The spigotting is carried out periodically section by section which means that for a given section it effectively lasts 11% of the year, only. In the periods between spigotting the process of draining and drying takes place. However, huge reservoir of water stored in tailing mass (voids) causes that the drainage process is strongly delayed and lasts much longer than breaks between consequent discharges. It induces overlapping the effects of following discharges and equalization of the rate of water infiltrating into the subsoil. Therefore, continuous infiltration of saline waters has been assumed in the model.
Segregation of tailings during discharging of a slurry as well as controlled discharge of finest material directly into the center of the facility cause large variety of hydraulic permeability of tailings both in vertical and horizontal directions and complex flow conditions within the tailings mass. *In situ* investigations of the permeability as a function of a distance from the East and West dam embankments, carried out in the past, have clearly revealed that near the pond values of coefficient of permeability are close to those corresponding to impermeable soils ($10^{-9}$ m/s) whereas near the embankments these values represent fully permeable material ($10^{-4}$ m/s). Moreover, the mass of tailings is a strongly anisotropic medium due to numerous laminations of semipervious layers which may partly result from the process of beach stabilization by asphalt emulsion against dusting, however correct determination of the anisotropy degree of tailings stored in the depository is very difficult. Based on infiltrometric tests the value of anisotropy can be assumed as $K_H/K_V \approx 2$-$3$. However, the interpretation of piezometric heads observed in tailings shows that this ratio can be much higher - $K_H/K_V \geq 10$ $\div$ 15.

The 3D model has been first calibrated for the conditions occurring at TSF at the end of 2005 and re-calibrated for 2012 implementing new information regarding the hydrogeological conditions of the subsoil. Next the model has been used to predict the impact of TSF Żelazny Most on surface and groundwaters for higher elevations related to planned lifetime of the facility. Due to some limitations, in this paper the prediction of the impact in years 2005-2012 will be presented, only.

The results of modelling of groundwater flow regime within the facility and downstream have revealed that the waters infiltrate mainly through the area of beaches during the discharging of a slurry in the proportion of 99% of all waters infiltrating from the facility whereas percolation from the pond amounts 1%, only (Świdziński, 2018). Such result can be justified taking into account drastic reduction of tailings permeability with the distance from the surrounding dams towards the pond.
MODELLING THE MIGRATION OF SALINE WATERS NEAR THE FACILITY

In order to model the migration of saline waters in groundwater MT3D (Modular Transport 3 Dimensional) software was used and to solve the advection-diffusion equation third order TVD scheme (ultimate) or MMOC (Modified Method Of Characteristics) were applied, both being an integral part of GMS package. The conservative chlorides were selected as a the modelled substance, since they do not undergo sorption process, nor react with other chemical compounds. Moreover, the chlorides, besides sulphates, are the main indicator of polluted groundwater near the facility, and thus enable a reliable assessment of changes occurring in aquatic environment caused by the facility operation. The waters discharged to the facility with tailings come from dewatering of the copper mines. They are reach in salts, the concentration of which increases with the course of exploration of new mining fields. In Figure 2 the changes of average annual values of chlorides concentration in water discharged with tailings into TSF Żelazny Most starting from 1996 till 2012 are shown.

![Figure 2. Mean annual concentration of chlorides in waters stored in the TSF Żelazny Most.](image)

For the model calibrated at the end of 2005 the value of chlorides concentration in mine waters discharged into the facility was 11000 mg Cl/dm$^3$ and it increased at the end of 2012 up to 14280 mg Cl/dm$^3$. It was assumed that excess state over hydrochemical background would be modeled, only. Within the model domain woodlands and agricultural as well as meadow areas dominate, for which the average natural concentration of chlorides is 40 mg Cl/dm$^3$. Therefore, for the sake of simplicity as the ultimate value for groundwater pollution by chlorides 210 mgCl/dm$^3$ was assumed so as the total chlorides concentration would not exceed the ultimate value assigned to the III class clean water (250 mg Cl/dm$^3$), the last class corresponding to good quality water according to the recent Polish regulations. Consequently, the initial condition in the form of given concentration of salts was applied only for the areas polluted by saline waters from the facility identified by the in situ measurements. Such measurements are being carried out annually in the frame of operational monitoring. The distribution of concentration of salts in the groundwater downstream the facility, introduced to the model as initial condition, corresponded to that observed in 2005,
the year the model was originally calibrated and validated. For the rest of areas the concentration of chlorides was assumed to be 0. In turn, in order to model the intrusion of saline waters during the spigotting the slurry over the beaches and from the pond first-type boundary condition was assumed. The condition relies on providing the value of chlorides concentration for specified grid blocks. As it is shown in Figure 2 the concentration of chlorides increases with time, thus such change had also to be incorporated into the prognostic calculations for 2012. The dispersion process was modelled using two hydrodynamic dispersion constants i.e. longitudinal ($\alpha_L$) and transverse ($\alpha_T$). For the analysed case 20 m and 6 m for longitudinal and transverse dispersion constants were assumed, respectively. Moreover, the effective porosity of the foundation soils varied depending on their permeability, while for the tailings a constant value was assumed. Taking into account that the rate of facility development is relatively slow (increase of water level in the pond 1.5 m/year) as well as that the in situ observations show small fluctuations of groundwater level near the TSF, steady-state flow conditions have been incorporated. Little change of groundwater regime near the TSF is mostly caused by the work of drainage system overtaking the essential portions of water infiltrating into the subsoil in the near downstream whereas far downstream groundwater level is mostly impacted by precipitation. Despite the stationarity of flow process assumed, in long-term predictions quasi non-steady-state approach was applied by execution of calculations for higher elevations of the dams in several time steps. The calculation stages of groundwater flow regime were coupled with the simulation of chloride transport in groundwater. The latter was modelled as fully non-steady-state process based on the stationary hydrodynamic field being the solution for a given time step (assumed to be one year starting from 2005). The elevations of the water in the pond for consequent years were introduced into the model based on the real measurements at the end of the year. The initial condition for calibration year (2005) was the distribution of the concentration of chlorides in the groundwater downstream the facility based on in situ measurements. In turn, the initial condition for the concentration of chlorides in subsequent years was the distribution of this concentration downstream the facility being the result of numerical calculations for previous year as well as average concentration of chlorides in the pond based on the in situ observations.

### Table 1. Predicted budget of groundwater near TSF Żelazny Most.

<table>
<thead>
<tr>
<th></th>
<th>Inflow m³/s</th>
<th>Inflow m³/d</th>
<th>Outflow m³/s</th>
<th>Outflow m³/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infiltration from the pond</td>
<td>0.00248</td>
<td>214</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Infiltration through the beaches</td>
<td>0.37910</td>
<td>32754</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Precipitation through the dams</td>
<td>0.01650</td>
<td>1426</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Discharge of drainage wells</td>
<td>-</td>
<td>-</td>
<td>0.14474</td>
<td>12506</td>
</tr>
<tr>
<td>Discharge of horizontal drainage system</td>
<td>-</td>
<td>-</td>
<td>0.23393</td>
<td>20212</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>0.39808</td>
<td>34394</td>
<td>0.37867</td>
<td>32718</td>
</tr>
<tr>
<td>Difference between inflows and outflows</td>
<td><strong>0.01940</strong></td>
<td><strong>1676</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**THE RESULTS OF NUMERICAL SIMULATIONS**

The groundwater budget for the area of the facility and its closest vicinity (including the location of drainage wells) calculated by the numerical model for the end of 2012 is presented in Table 1. According to the results given in Table 1, at the end of 2012 the amount of saline waters not captured by the drainage system flowing out of the facility...
downstream was 1676 m$^3$/day and it was lower comparing to 2005 (2078 m$^3$/day, (Świdziński et al. 2011). It can be also seen that the amount of waters seeping downstream is equivalent to approximately 5% of total amount of waters infiltrating through the mass of tailings into the subsoil whereas 95% of it is captured by drainage system. Modelled range of groundwater with concentration of chlorides higher than limit level (> 250 mg Cl/dm$^3$ – solid line) together with the pollution zones based on in situ measurements (filled areas) for 2012 is shown in Figure 3.

![Figure 3. Measured and calculated ranges of polluted groundwater downstream TSF Żelazny Most at the end of 2012.](image)

Simulated total polluted area is approximately 92 ha larger than resulting from in situ measurements (~316 ha), however both the maximum ranges as well as the shape of polluted zones designated by the 250 Clmg/dm$^3$ contour, are similar. There are some regions where modelling results show the presence of chlorides higher than the limit value which is not confirmed by the results of operational monitoring e.g. larger range of saline waters in zone I-N downstream north dam as well as opposite situations e.g. zone I-E in the central part of east dam. There are also some separated regions where field measurements do not show higher concentration of chlorides whereas they are simulated by the numerical model (e.g. the polluted “island” in zone I-E). Best quantitative agreement with regard to the polluted area has been achieved for eastern part for which the difference between measured and simulated results was around 9% what proves good calibration of the model for this particular region. Somewhat worse agreement was obtained for the rest of the dams. In general, the numerical results overestimate the in situ observations whereas quite good
reproduction of the shapes of polluted zones is observed. The largest difference with regard to the polluted area is for northern part (100%) and 50% for western area downstream the facility, however it should be noted that the total contribution of these areas is lower than the eastern part.

DISCUSSION AND CONCLUSIONS
In the set of two papers a 3D numerical model which simulates groundwater flow and its chemical changes caused by the largest Tailings Storage Facility Želazny Most, Poland has been presented. The model serves mainly for prediction of the potential future changes of groundwater flow regime and the extent of contamination by salinity downstream the facility in the course of its further development. The results of predictive simulations for the period 2005-2012, confronted with in situ observations, have proved that the model quite well reproduces the shape, range and area of polluted zones. Long-term in situ measurements of the salinity of groundwater, carried out every year in hundreds of the observation points near the TSF, show that the polluted areas do not change too much. It was confirmed by predictive simulations for the whole planned lifetime of the facility (results not presented here). The results of numerical calculations have shown that the situation should not essentially change in future and a decrease of the amount of saline waters flowing out of the facility can be expected. It means that the hydraulic barrier created by drainage wells installed around the facility efficiently prevents the outflow of saline waters downstream the facility.

REFERENCES

Świdziński W., Maciejewski St., Walter A. and Franz M. 2011. Prediction of the Želazny Most facility impact on ground and surface waters during its operation to the elevation of 195 m a.s.l. and after its closure. Report for KGHM POLSKA MIEDŻ S.A.

Świdziński W., Maciejewski St., Walter A. 2014. Integrated assessment of the impact of the „Želazny Most” facility on ground and surface waters till 2012 together with updated protection plan. Report for KGHM POLSKA MIEDŻ S.A.

Contact Information: Waldemar Świdziński, Institute of Hydro-Engineering PAS, Department of Geomechanics, Kościerska 7, 80-328 Gdańsk, Poland, Phone: +48585222945, Fax: +48585524211, Email: waldek@ibwpan.gda.pl.