IMWA Proceedings 1997 | © International Mine Water Association 2012 | www.IMWA.info

THE USE OF HYDROGEOLOGICAL FORECASTING IN THE PROCESS OF SHUTDOWN OF THE IDRIJA MERCURY MINE

Metka Petrič[1], Jože Janež[2]

[1]M.Sc.Geol., ZRC, SAZU Karst Research Institute Postojna, Slovenia
[2]B.Sc.Geol., Geologija d.o.o. Idrija, Prešernova 2, Idrija, Slovenija

ABSTRACT

The Idrija Mercury Mine will be shut down by the year 2006. During 1992 and 1993 the lower part of the mine between the 15th and 11th levels was flooded. The paper presents the results of hydrogeological forecasting and monitoring of the mine water regime during that time. It was found that hydrogeological forecasting can be successful when good input data on water inflows and the hydrogeological environment (geological structure and mine maps) is available.

INTRODUCTION

Idrija has one of the oldest and most important mercury mines in the world. Since 1987, the mine has been in the process of gradual and definite shutdown, which is expected to be completed in 2006. The main reason for the gradual shutdown of the mine is its location beneath the town. The influences and consequences of mining activities have caused sinking, shifting and sliding of ground on the surface, as well as damage to buildings. The mine was comprised of 15 levels reaching a depth of 380 metres, with a ground plan area of approximately 1.5 x 0.5 km. All waters entering the mine were collected and directed into the pumping station on the 14th level, from where they were pumped up to the surface. In 1992 and 1993, the 1st phase of the mine's shutdown, which also included the flooding of the bottom part of the Idrija mine between the 15th and 11th levels, was successfully completed. In order to carry out the shutdown works, it was necessary to forecast the course of rising of the water level in the mine after moving the pumping station from the 14th to the 11th level. Hydrogeological forecasting was successful due to the good input data on the quantities of water entering the mine as well as data defining the hydrogeological environment - geological structure and mine maps showing unfilled areas and the size of backfills in the pit.

Reproduced from best available copy

IMWA Proceedings 1997 | © International Mine Water Association 2012 | www.IMWA.info

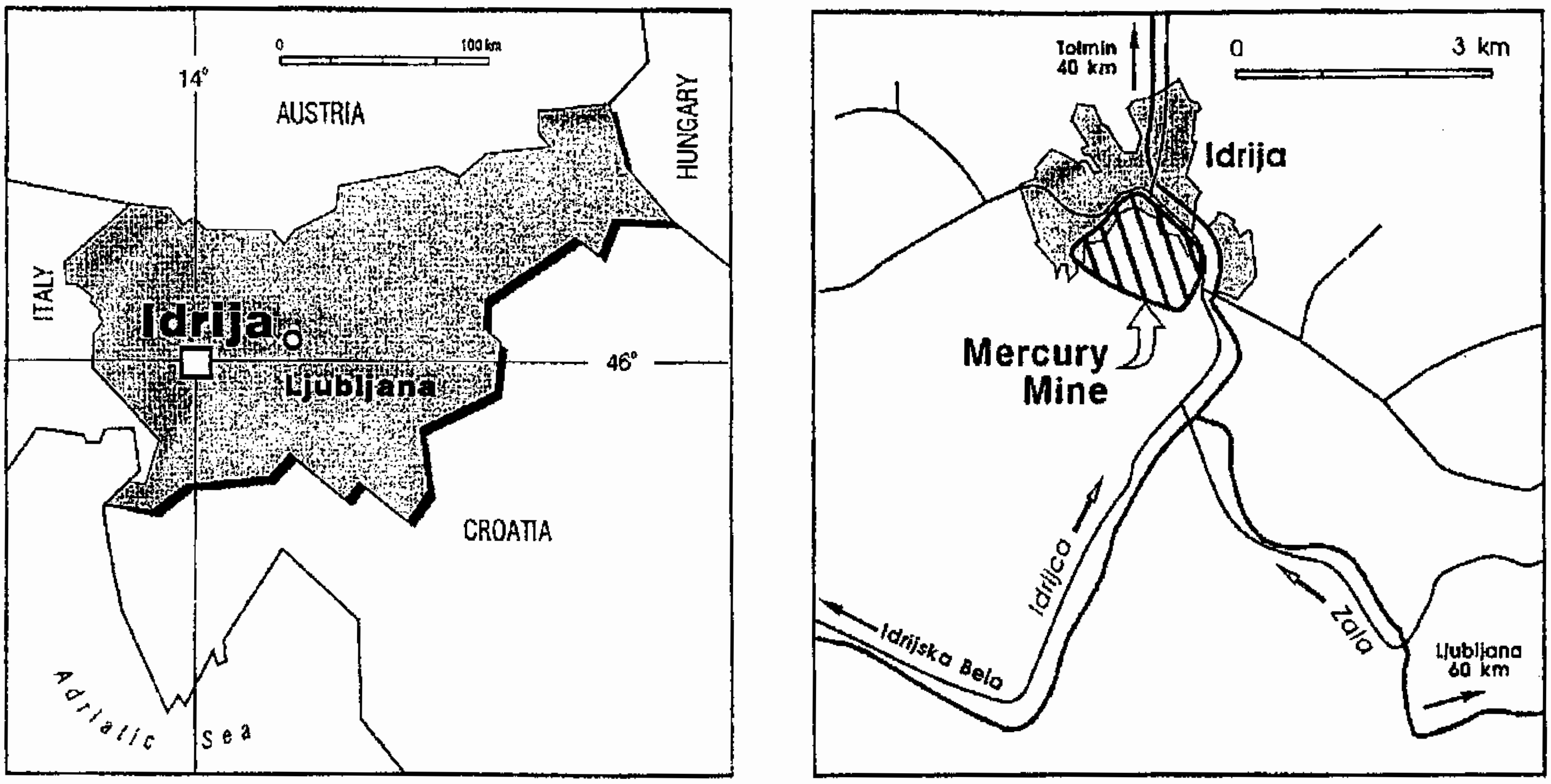


Figure 1: Idrija, geographic position

HYDROGEOLOGICAL STRUCTURE

The geological structure of the Idrija mine is relatively well known (I. Mlakar, 1969; L. Placer, 1982). Adequate geological data provides a good basis for the study of hydrogeological conditions. Nevertheless, an additional 16 observation wells were made for the needs of hydrogeological investigations during shutdown of the mine.

Aquifers

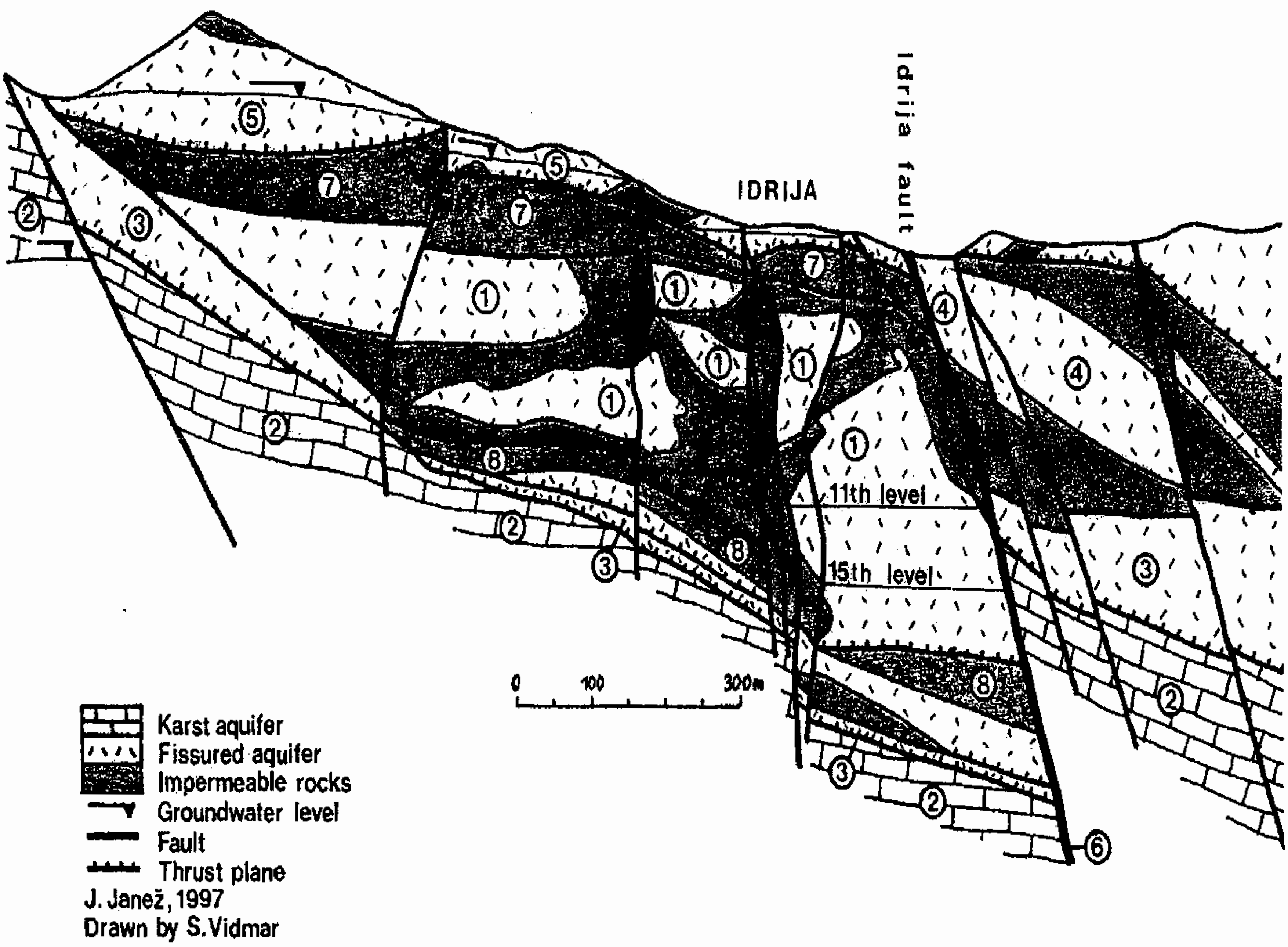
- Hydrogeological block of the Idrija mine (Figure 2, no. 1). Due to its favourable geological structure, the ore deposit was originally isolated on all sides by impermeable rocks and practically had no underground waters. The small water inflows encountered during mining soon ran dry. Permeable rocks include various Triassic dolomites, limestone-dolomite conglomerate and oolitic limestone. The major conduits within the block are open horizontal and vertical pit facilities and very porous backfills. Unfilled pit areas function as connected vessels with an unrestrained water level.
- Karst aquifer of the Koševnik interjacent slice in the southern and southwestern surroundings of the pit and in its base (Figure 2, no. 2). The aquifer is built up by bedded limestone of the Lower Cretaceous age. The piezometric level in the aquifer is on a height of approximately 330 metres above sea level, i.e. on the level of the bottom of the Idrijca River valley.
- Fissured aquifer of the Čekovnik interjacent slice (Fig. 2, no. 3) lying in the cover sheet of the karst aquifer of the Čekovnik interjacent slice. Its thickness reaches up to 200 metres and changes abruptly. It is even wedge-shaped in some parts. This is not a

Reproduced from best available copy

IMWA Proceedings 1997 | © International Mine Water Association 2012 | www.IMWA.info

uniform aquifer, but comprises several blocks that are hydraulically separated and were spatially shifted during the active phase of the fault. Because the Upper Triassic dolomite of the Čekovnik interjacent slice is squeezed in between other thrust structures, it is finely crushed and milonitized, and one may expect its permeability to be generally small. In a certain sense it represents a relative hydrogeological barrier for waters in a karst aquifer. The thickness of this aquifer is greater on the northeastern side of the Idrija fault than on the southwestern side. The underground water in the aquifer is mostly under pressure, while the piezometric level is higher than in the karst aquifer of the Koševnik interjacent slice, i.e. exceeding 330 m.

Figure 2: Hydrogeological profile of the Idrija Mercury Mine (Geological data according to



L. Placer, 1982).

- Fissured aquifers of the Kanomlja interjacent slice on the northeastern side of the Idrija fault (Fig. 2, no. 4). In 1993 a borehole G12/93 was made in this aquifer. This borehole was drilled 136 meters deep into the Lower Scythian dolomite lying below

Reproduced from best available copy

IMWA Proceedings 1997 | © International Mine Water Association 2012 | www.IMWA.info

the alluvial deposits of the Idrijca River. The piezometric level of the underground water is on the level of the Idrijca River (approx. 325 metres a.s.l.).

- Aquifers in carbonatic rocks of the 4th nappe (Tičnica thrust sheet of the Trnovo nappe) above the ore deposit (Figure 2, no. 5). There are also several shallow aquifers of a smaller size above the ore deposit. The aquifers are separated from one another by various impermeable rocks or tectonic relations, and do not communicate with the other, above-mentioned aquifers in the vicinity of the pit.

Aquifuges

- Idrija fault (Fig. 2, no. 6). The Idrija fault represents the northeastern border of the Idrija ore deposit. Carboniferous strata alongside the fault and an up to 10 metre-wide tectonic clay zone form an impermeable barrier preventing any natural water flows into the ore deposit. During the long period of mining activities this impermeable barrier was penetrated a number of times by means of drilling and tracing works towards the north and northeast on various levels. All those penetrations were closed with impermeable packers after the retreat.
- Impermeable nappe of Carboniferous strata (shale and siltstone) above the ore deposit (Fig. 2, no. 7). The Carboniferous strata belong to two thrust structures - the Idrija thrust sheet and the Tičnica thrust sheet, both of which are part of the Trnovo nappe. Their thickness ranges from twenty to more than one hundred metres. Water is allowed to enter the pit only through artificial pit facilities, primarily the Inzaghi and Delo shafts. By means of water permeability tests, the coefficient of hydraulic permeability of the Carboniferous shale and siltstone was found to be from $9.1 * 10^{-9}$ m/s to $3.7 * 10^{-10}$ m/s.
- Impermeable base of ore deposit (Fig. 2, no. 8). It is comprised of inversely lying rocks of the IIIrd nappe (Kanomlja interjacent slice), primarily Carboniferous and Middle Permian layers (shale, siltstone and sandstone), as well as clastic Carnian layers accompanying the Upper Triassic dolomite of the Čekovnik interjacent slice. According to available data, the thickness of the Kanomlja interjacent slice in the base of the pit reaches up to a hundred metres.
- Northwestern, western and southwestern periphery of the ore deposit (Fig. 2, no. 9). In this part the impermeable barrier between the pit and the karst aquifer of the Koševnik interjacent slice is the thinnest and has been penetrated a number of times by means of investigations and opening works. The hydrological barrier is comprised of tectonic clay of Carboniferous and Middle Permian shale and siltstone, milonite of the Lower Triassic dolomites, as well as Anisian dolomite and Ladinian tuff in the northwestern part. Tectonically crushed Norian-Rhetian dolomite also appears as a hydrological barrier. The penetrations of these water-bearing barriers caused the main water inrushes in the history of mining in Idrija. The majority of these water inrushes have been rehabilitated. The largest active water flow (3 to 7 l/s) into the pit is on the 7th level, and small quantities of water (0.3 l/s) continue to flow in on the spot of the rehabilitated water inrush on the 3rd level.

Reproduced from best available copy

IMWA Proceedings 1997 | © International Mine Water Association 2012 | www.IMWA.info

WATER INFLOWS

Until 1990, only limited data on water flows into the Idrija mercury mine was available. The measurements were not systematic and the discharges were mostly estimated. The differences between the recorded values are considerable, which is why it is difficult to compare them. The parameters of water pumping on the 14th level have only been measured on a regular basis since 1990. The water flow into the lower part of the mine was determined on the basis of the known capacity of two pumps, the duration of their functioning, and changes in the water level in the pool of the pumping station. The pumping station on the 14th level operated from May 1990 to May 1992 in time intervals of two to three days. Thus, 14 to 17 inflow values are available for each month and the monthly mean inflows can be calculated. From June 1992 to November 1992 the pumping station on the 11th level was activated, and in the period between December 1992 and March 1994 only the pumping station on the 11th level operated occasionally in short time intervals. These three periods are therefore not directly comparable and the basic parameters for the calculation of average inflows need to be determined separately for each period. From May 1990 to May 1992, the values between 11 l/s and 28.8 l/s were measured. That gives monthly mean inflows ranging from 15 l/s to 20.3 l/s and a period average of 16.8 l/s. In the interval between June and November 1992, the pumping stations on the 14th and 11th levels operated parallelly, and the monthly mean values ranging from 4.7 l/s and 11.5 l/s on the 14th level were obtained. These values represent the difference between the total inflow and the inflow in the lowest part of the mine. In the period from December 1992 to March 1994, only a few measurements were performed each month. On the basis of the values obtained, the average monthly inflows during this period were estimated to be between 14 l/s and 17.2 l/s, with a period mean discharge of 15.5 l/s (Table 1 and Fig. 3).

Table 1: Monthly mean water inflows and precipitation

	Water inflows (l/s)							Precipitation	
	Q1			Q2	Q3			P (mm)	
	1990	1991	1992	1992	1992	1993	1994	1990	1991
Jan		17.1	15.2			14.8	14.6		174
Feb		16.4	15.5			14.6	15.6		157
Mar		16.2	15.2			15.6	17.2		160
Apr		16.5	17.1			17.2			174
May	16.9	20	15			15.7		76	
Jun	18.3	17.2		6.7		14.8		241	
Jul	16.6	15.3		4.7		14.1		145	
Aug	15.5	15		5.9		14		156	
Sep	15.4	15.1				16.9		157	
Oct	19.4	16.9		5.6		15.6		417	
Nov	20.3	18.9		11.5		16.3		455	
Dec	18.8	15.9			16.1	14.8		187	

The relation between the monthly mean water inflows and precipitation in the Idrija area is also presented in Figure 1. The precipitation station was active in the periods from May 1990 to April 1992 and from April 1993 to March 1994. The influence of precipitation on

Reproduced from best available copy

IMWA Proceedings 1997 | © International Mine Water Association 2012 | www.IMWA.info

the inflow is obvious, but particularly in 1993 and 1994 the relation is clouded by some additional effects.

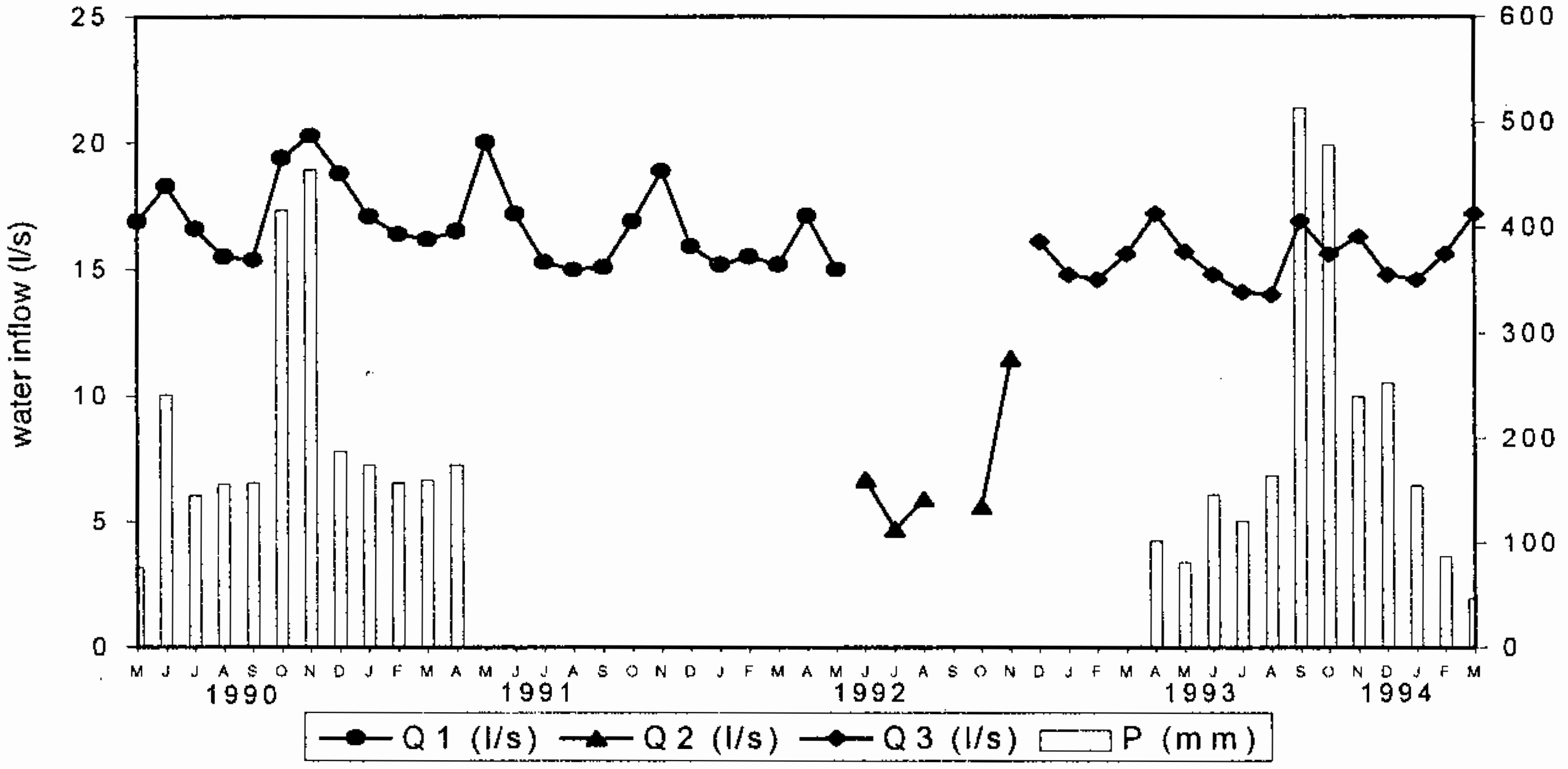


Figure 3: Monthly mean water inflows and precipitation

ESTIMATED AND MEASURED INCREASE OF WATER LEVEL IN THE PROCESS OF FLOODING OF THE LOWER PART OF THE MINE

Estimation of volume of the aquifer

The modelling of flooding of the lower part of the mine between the 15th and 11th levels is based on some simple principles. The known and estimated characteristics of the studied aquifer and the supposed inflows of water were used to calculate the increase of water level. For this purpose two parameters were used: effective volume V_e and water inflow Q. The effective volume is a parameter used to describe the volume of empty voids in the aquifer that can be filled up with water during the flooding process. The water inflow represents the quantity of water that flows into the mine and can fill these voids.

The effective volume can only be estimated approximately, because the exact borders and the porosity of the aquifer are not known. The sprawl of galleries and shafts in the mine additionally complicates the estimation. According to hydrogeological characteristics, the aquifer may be divided into three units of different porosity: basic dolomite rock, packs (old backfilled galleries), and unfilled galleries and shafts. The vertical heterogeneity of the aquifer was also taken into account. Each level between the 15th and 11th levels was divided into two sections. In the lower section, extending up to a height of 2.6 metres, unfilled galleries are dominant and thus the average porosity of this area is much greater than the porosity of the upper section above 2.6 m.

A separate estimation of effective volume was performed for each hydrogeological category of the aquifer. First, the volume of galleries and shafts was determined. The lengths of galleries on individual levels and the shafts between levels were determined

Reproduced from best available copy

IMWA Proceedings 1997 | © International Mine Water Association 2012 | www.IMWA.info

with the help of 1:1000 scale mine maps. The total volume is equal to the product of the total length and the average cross-section area of galleries (6.76 m^2) or shafts (6 m^2) (Table 2). Since the porosity of galleries and shafts is 1, the effective volume is the same as the total volume.

Table 2: Estimation of the effective volume of galleries and shafts

Part of the aquifer	Effective volume (m^3)
15th - 14th level, below 2.6 m above 2.6 m	9689 146
14th - 13th level, below 2.6 m above 2.6 m	41191 122
13th -12th level, below 2.6 m above 2.6 m	45706 128
12th - 11th level, below 2.6 m above 2.6 m	57895 128

After the ore was excavated, the stopes were filled up with muck and these packs also contribute a significant share to the effective volume of the aquifer. 1:2000 scale mine maps were used to estimate the effective volume. The size of areas marked as packs on the level plans was determined and, on the basis of values obtained, the volume of packs between two consecutive levels was calculated. Since they are distributed very unevenly in the area between two levels, this method gives only rough estimates. The estimates were therefore corrected according to the precisely measured volumes of packs in four ore bodies. The overestimation of the volume calculated using the approximate method was proved by a comparison of results. The correction factor was estimated at 34% and the final estimation of the volume of packs was made.

The porosity of packs also had to be known in order to calculate the effective volume. Since the porosity had never been previously determined by measurements, some assumptions based on experience had to be made. Three different values of porosity n_p were used in the models: 0.1, 0.25 and 0.4 (Table 3).

Table 3: Estimation of the effective volume of packs

Part of the aquifer	Volume (m^3)	Effective volume n_p=0.1 (m^3)	Effective volume n_p =0.25 (m^3)	Effective volume n_p =0.4 (m^3)
15th-14th level, below 2.6 m	1710	171	428	684
above 2.6 m	16051	1605	4013	6420
14th-13th level, below 2.6 m	8666	867	2167	3466
above 2.6 m	135610	13561	33903	54244
13th-12th level, below 2.6 m	25900	2590	6475	10360
above 2.6 m	258879	25888	64720	103552
12th-11th level, below 2.6 m	37006	3701	9252	14802
above 2.6 m	301561	30156	75390	120624

Reproduced from best available copy

IMWA Proceedings 1997 | © International Mine Water Association 2012 | www.IMWA.info

Table 4: Estimation of the effective volume of basic dolomite rock

Part of the aquifer		Volume of dolomite (m^3)	Effective volume n_d =0.005 (m^3)	Effective volume n_d =0.01 (m^3)
15th-14th level,	below 2.6 m	586471	2932	5865
	above 2.6 m	6281248	31406	62812
14th-13th level,	below 2.6 m	694351	3472	6944
	above 2.6 m	5901077	29505	59011
13th-12th level,	below 2.6 m	722980	3615	7230
	above 2.6 m	5936614	29683	59366
12th-11th level,	below 2.6 m	615991	3080	6160
	above 2.6 m	5405552	27028	54056

The third hydrogeological element in the aquifer between the 15th and 11th levels is the basic rock. It is built up by Upper Permian black and grey bedded dolomite, Lower Scythian grey sandy micaceous and granular dolomite, and Upper Scythian grey granular dolomite. The volume was estimated on the basis of 1:1000 scale mine geological maps. The size of dolomite area was determined for each level separately. The mean value of the dolomite areas on two consecutive levels and the vertical distance between them were used to calculate the volume of dolomite between two levels. The volume of packs, galleries and shafts (Tables 2 and 3) was subtracted from this value. The porosity n_d of dolomite was also estimated. The effective volumes were calculated using the values 0.01 and 0.005 (Tab. 4).

The sum of the effective volumes of all three hydrogeological units represents the effective volume of the aquifer between the 15th and 11th levels. Since different values of porosity of dolomite (2) and packs (3) were estimated, 6 different models of the aquifer are to be taken into account (Table 5). The large differences in the results obtained with the above 6 models lead to the conclusion that the anticipated porosity values have a significant impact on the final results.

Table 5: Estimation of the effective volume of the aquifer between the 15th and 11th levels

Part of the aquifer		Effective volume (m^3)					
		n_d=0.5% n_f=10%	n_d=0.5% n_f=25%	n_d=0.5% n_f=40%	n_d=1% n_f=10%	n_d=1% n_f=25%	n_d=1% n_f=40%
15th - 14th level,	below 2.6 m	12792	13049	13305	15725	15982	16238
	above 2.6 m	33157	35565	37972	64563	66971	69378
14th - 13th level,	below 2.6 m	45530	46830	48129	49002	50302	51601
	above 2.6 m	43188	63530	83871	72694	93036	113377
13th -12th level,	below 2.6 m	51911	55796	59681	55526	59411	63296
	above 2.6 m	55699	94531	133363	85382	124214	163046
12th - 11th level,	below 2.6 m	64676	70227	75777	67756	73307	78857
	above 2.6 m	57312	102546	147780	84340	129574	174808
Sum (15th - 11th level)		364265	482074	599878	494988	612797	730601

Reproduced from best available copy

IMWA Proceedings 1997 | © International Mine Water Association 2012 | www.IMWA.info

Prognostic curves of the water level increase in the process of flooding

The beginning of flooding of the lower part of the Idrija Mercury Mine was planned in October 1992. Before then, some prognoses of the water level increase from the 15th to the 11th level during the flooding process had to be made. The model was based on two parameters: water inflow and effective volume of the aquifer. The monthly mean inflows were calculated for the period from May 1990 to May 1992, and the obtained average values were used in modelling (Tab. 6). The estimation of the effective volumes of individual parts of the aquifer is described in the previous section (Table 5).

Table 6: Monthly mean inflows (for the period May 1990 - August 1992)

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Q (m^3/s)	18.2	19.6	17.4	16.2	15.9	15.7	16.8	18.4	17.7	15.9	15.2	15.2

The curves of water level increase were calculated on the basis of these two parameters. Since 6 different models of the aquifer were taken into account (Table 5), 6 different prognostic curves of water level increase were obtained (Fig. 4).

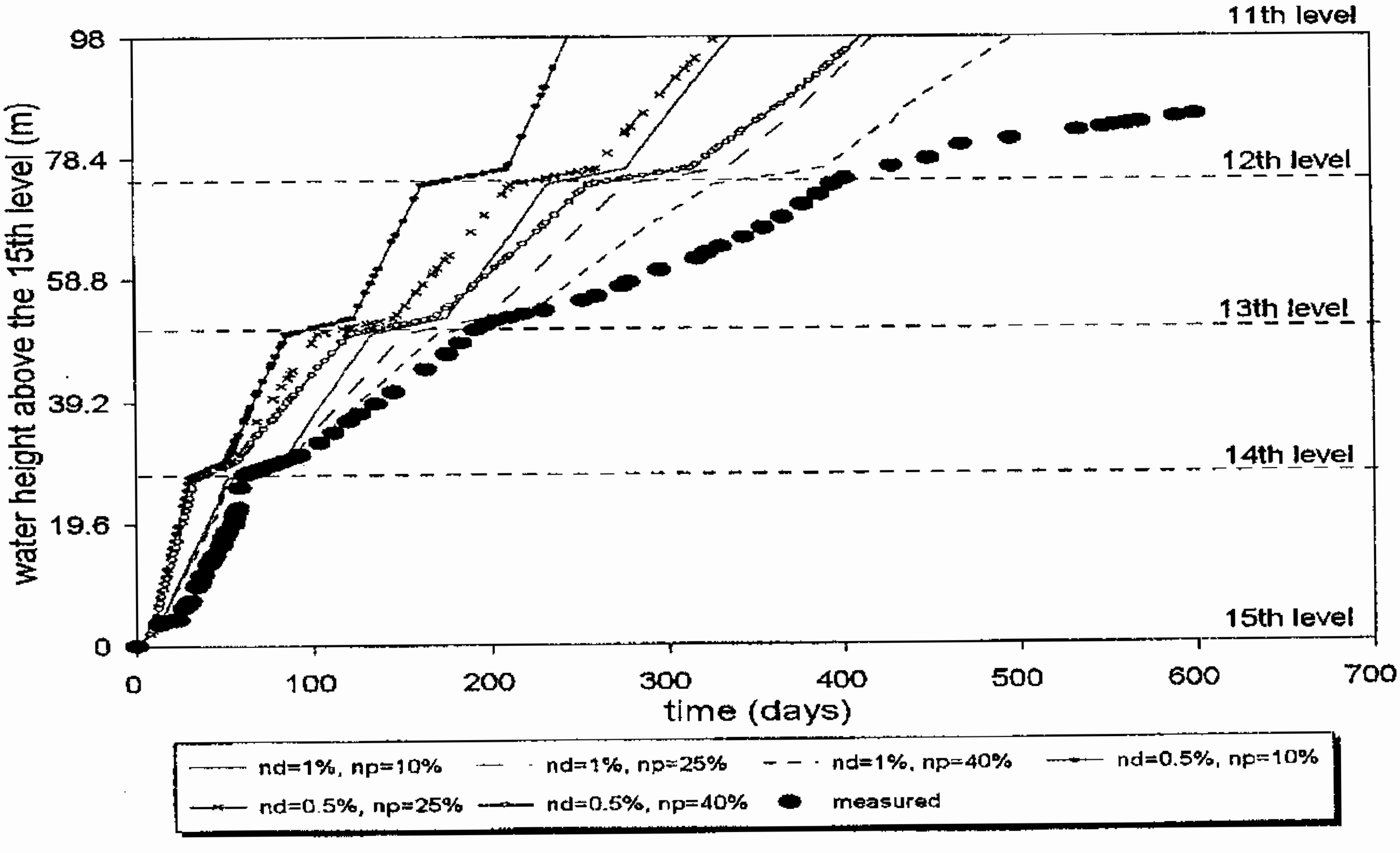


Figure 4: Prognostic and measured curves of water level increase between the 15th and 11th levels

Reproduced from best available copy

IMWA Proceedings 1997 | © International Mine Water Association 2012 | www.IMWA.info

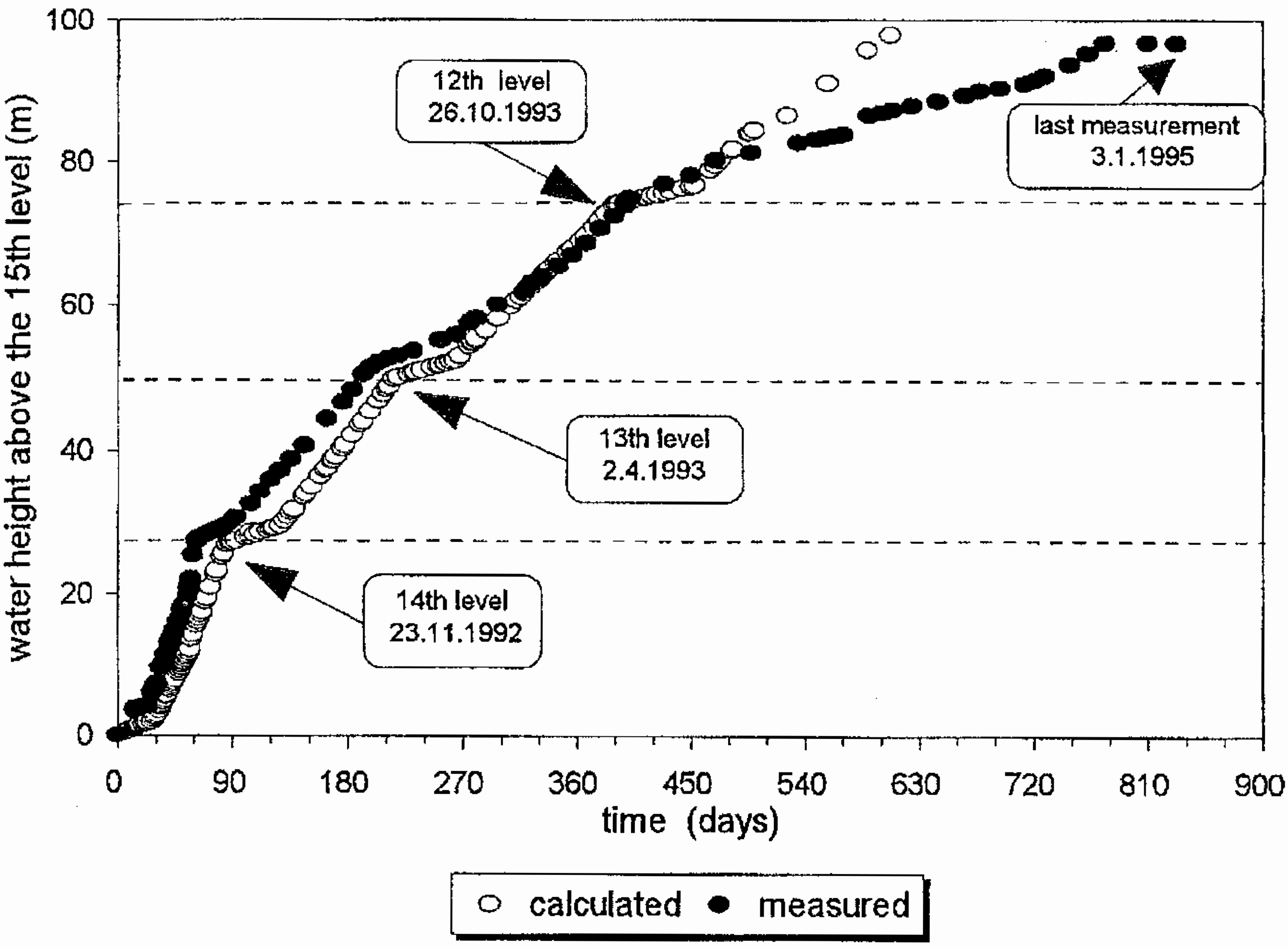


Figure 5: Corrected prognostic curve and measured curve of the water level increase

The flooding of the lower part of the mine was begun on 2nd October, 1992. The pumps were stopped and water began to fill up the voids in the aquifer. The rise in water level was regularly measured using a piezometer. The measured values are presented together with the prognostic curves in Figure 4.

Each curve has two different slopes in the sections between two main levels (15th to 11th). The gentle part characterises the area where open galleries and shafts prevail. Due to the larger effective volume, the water level increases at a slower pace in this section. The steeper part of the curve corresponds to the section above 2.6 m with lower porosity and more rapid water level increase. The measurements have confirmed such shape of water level increase curves.

According to the presented models, the lower part of the mine between the 15th and 11th levels should have been flooded within a period of 247 to 500 days. However, the measurements show a somewhat slower rise of water level. This lag can be explained by the inaccurate estimation of effective volume or water inflow. A comparison of the results of all 6 aquifer models shows that the selection of porosity values has a significant impact on the estimation of effective volume, and consequently, a major error is possible. But since the inflows in the period between October 1992 and March 1994 were measured, our first step was to correct the values of this parameter.

Reproduced from best available copy

IMWA Proceedings 1997 | © International Mine Water Association 2012 | www.IMWA.info

Corrected prognostic curve of water level increase

Based on the measured values of inflow in the process of flooding (Tab. 1), the prognostic curves were corrected accordingly. Among 6 models taking into account different effective volumes, the model (n_d=1%, n_f=40%) whose results best correspond to the measured values was used for comparison between the prognostic and measured curves (Fig. 5). The agreement between both curves is generally very good, however, the measured curve in the area near the 11th level is somewhat gentler than the predicted one. The reason for this is more frequent pumping on the 11th level at a time when the water table was approaching this level.

Since the aim of our study was to predict the increase of water level in the process of flooding, the results can be evaluated on the basis of a comparison with the measured values. The prognostic curves have proved to be a good orientation in the planning of works in the mine during flooding. The modelling can be assessed as successful also on the basis of the good match between the corrected prognostic curve and the measured curve. Finally, it was established, on the basis of anticipated models, that the hydrogeological characteristics of the aquifer are best described when the porosity of dolomite is 1% and of packs 40%.

CONCLUSIONS

The Idrija Mercury Mine lies below the town, which faces the threat of sinking ground. For this reason the shutdown of the unprofitable mine is a very complex procedure and needs to be conducted gradually. For the needs of shutdown works, it was also necessary to determine the hydrogeological conditions as accurately as possible. Before commencing the flooding of the lower part (15th to 11th levels) of the 330 metre-deep mine, a hydrogeological model comprising space and time components, i.e. a prognosis of the water level increase in the mine and its consequences, had to be developed. The model, which served as a basis for the planning and execution of shutdown works in the period from 1992 to 1994, proved successful and was verified with observations. Both the prognosis and the actual changes are presented in the paper. The model was successfully applied because adequate input data was available or well determined: geological structure, mine maps and hydrogeological parameters. The acquired experience will help us to forecast events and plan the shutdown of the upper part of the pit. An inappropriate approach to the shutdown of the upper part of the pit would have much more fatal consequences for the town lying above the mine.

REFERENCES

1. Mlakar I., 1969: Geološka zgradba idrijsko žirovskega ozemlja. Geologic Structure of the Idrija-Žiri Region.- Geologija, 12, 5-72. Ljubljana.
2. Placer L., 1982: Tektonski razvoj idrijskega rudišča. Structural History of the Idrija Mercury Deposit.- Geologija, 25/1, 7-94. Ljubljana.

Reproduced from best available copy