PLIOCENE AQUIFER DEWATERING IN VELENJE COAL MINE AND ITS EFFECTS ON LAND SUBSIDENCE

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ABSTRACT

In Velenje coal mine the clay bed separates the coal from the water-bearing sand above it. The coal seam is up to 160 meters thick and we mine it in levels from 6 to 15 meters. Mining method for excavation of 1,5 to 2,5 kilometers wide and more than 8 kilometers long coal seam is so called *Velenje longwall method*. The basic concept is that the area of exploitation extends above the supported roof-coal of the face, thus aiding the natural forces which break and crush the coal seam, and/or helping the natural process by introducing an artificial method, i.e., blasting.

Because of the roof subsidence during the longwall mining, there is always a risk of breaking the isolating clay and of a water inrush.

As the criteria on the safety extraction method are set according to the thickness of the isolating clay layer and water pressure above it, the dewatering processes of water bearing sand are necessary.

In the forthcoming years the mining activities are moving towards the part, where the thickness of the isolating clay layer is less than 10 meters. In that part called a northwestern region of Preloge pit there are five line batteries of wells, consisting of 36 units for dewatering and prevention of rewatering. A successful dewatering of Pliocene aquifers above that part of mine has started in 1984.

The subsidence caused by underground mining is studied with constant mine surveying measurements on the surface. Maximum subsidence in area of intensive mining has already exceeded 80 meters. However, on the surface above the northwestern region of Preloge pit where excavating has not yet begun, subsidence has also been observed. The cause of land subsidence is substantial lowering of water head. Relationship between observed land subsidence caused by aquifers compaction and observed water head lowering is the basis for prognosis of the damage that might occur because of dewatering processes.

INTRODUCTION

The Velenje coal mine deposit is a part of the Velenje depression. This depression is of tectonic origin and there are many differently oriented and aged faults. The layers in the depression show a complete sedimentation cycle from arid phase over sump to lacustrine phase and vice versa again. In many cases fluviatile sands and gravel transported from northwest interrupt the sediments of still water.

The coal seam is 8.3 km long and 1.5 to 2.5 km wide. Only one layer that is very thick represents the economically important coal. In the central part, the exploitable seam is up to 168 m thick. In the central part the seam is most deeply deposited (approx. 450 m) and in the marginal parts it is closer to surface (approx. 100 m). In the lower part of the seam the coal gradually gets more ash contents however, the upper margin is very sharp. The coal seam is covered by marl with fossil snails followed by mudstone, sometimes laminated or massive. Within these mudstone, intercalations of water bearing sands and gravel of changeable thickness appear. The layer between coal seam and the first sands above is called isolation or the protective layer. This isolation prevents water and mud inrushes into the excavated spaces.

Coal extraction in the Velenje coal-mine has been carried out uninterruptedly since the end of the 19th century, during which time several stoping methods for excavation of wide coal seams have been tested. In the first half of the century the room and pillar and block caving were used. Since 1947 however, the longwall mining method with improvements has been practised and called The Velenje longwall method. Due to its specificity and high productivity, this method is now globally recognized and is also cited in the mining literature as a specific approach. The basic concept behind the approach towards excavating coal by using the longwall method is that the area of exploitation extends above the supported roof coal of the face, thus aiding the natural forces which break and crush the coal and/or assisting the natural process by introducing an artifficial method i.e. blasting. The face is divided into the lower excavation part and the upper excavation part. The lower part is 3 m - 4 m high and is protected by hydraulic shield support, thus enabling mechanized coal production with shearers and haulage with chain conveyors. the upper excavation part is 7 m - 17 m high and is exposed to dynamic stresses, which, in combination with blasting, cause the coal to disintegrate and crumble onto the conveyor. The direct roof crumbles into the cavity and consolidates in time, so excavation of the lower panel is enabled. Winning of the upper part can be continuous or timely delayed.

The described way of excavation causes fundamental changes on the surface because of deep subsidence (the deepest is over 80 m), filled with water and creating three subsidence lakes.

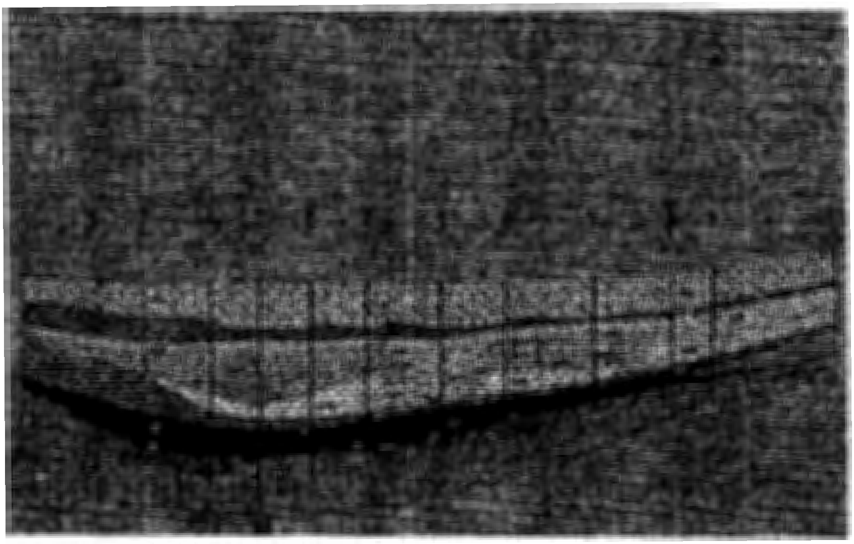

Fig. 1 Interpreted geological cross-section

Position of the longwall face in the seam mostly impacts the crumbling process:

- the face is directly under the isolation and the crumbling process extends completely over mudstone roof layer,
- the face is deeper in the seam so the crumbling process extends completely over coal only,
- the face is positioned in such way that the crumbling process extends partly over coal and partly over roof layer.

Between the coal that is excavated by the face and the water bearing layers there is a cracked layer of mudstone and/or coal. This layer crumbles, after winning of the upper excavation part, into the excavated space and enables the intact isolation to subside and to protect against water and mud inrushes with its shear strength.

Introduction of the "Safety criteria for excavation under water bearing layers in Velenje coal mine" enabled continuous change of excavation height considering the natural and design parameters of the face. The allowed excavation heights are calculated considering the isolation thickness, water table in water bearing layers, depth and relative position of the face in the seam.

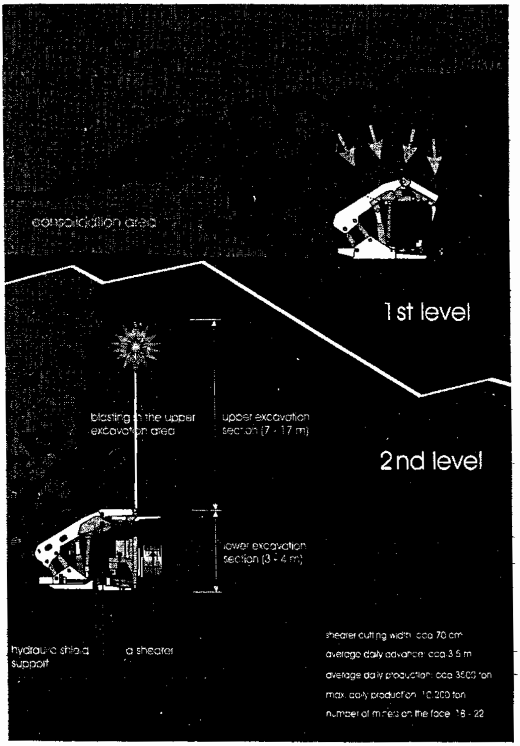

Fig. 2 Excavation method

Another way to come to solution is to calculate the maximal allowed pressure in first water bearing layer above the seam and to define the dewatering activities. The calculation is done considering the excavation height, isolation thickness, position of the face in the seam and the crumbling process.

HYDROGEOLOGICAL CONDITIONS

As seen on the cross-section, the coal seam separates Pliocene sediments into the roof part (capping) and the floor part.

Three different water bearing strata can be found in the floor:

- Triassic aquifer in the northern part, somewhere directly under the seam
- in the central part of the depression lithotamnic limestone aquifer appears
- Pliocene sand layers under the coal seam and as intercalations in the coal seam.

Pliocene roof aquifers are layers of sand, silt, gravel, between mudstone layers and this sequence represents real multilayer system consisting of over one hundred layers somewhere. These layers proceed laterally from one to another, they are lense or belt shaped and interweave and therefore it is impossible to separate them regionally.

The roof complex is separated into sections mainly according to a water table analyses after pumping and hydro-geochemical analyses, while the isotope methods are not selective enough till now.

In the vertical direction two systems can be distinguished:

- The upper system is quaternary one, its lower border is anticipated as Pliocene - quaternary border. The water is characterized by relatively low mineralization. Dewatering activities do not affect the water table essentially.
- The Pliocene system is the lower one and is separated from the coal seam by the isolation. These aquifers affect the excavation activities mainly in the northwestern part of the mine, where the isolation is relatively thin. Water mineralization in Pliocene aquifers is considerable, due to criteria it is a mineral water of Na-Mg-Ca-hydro carbonate type, almost without economic value because of high NH_4 content.

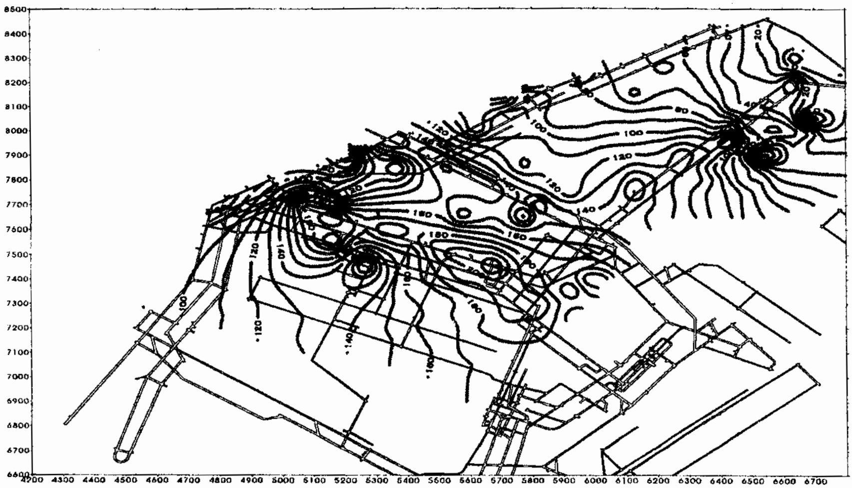

Fig. 3: Drawdowns until 1997

Hydrogeological analysis of Pliocene aquifers system extension limits gave the values for permeability coefficient between 10^{-5} and 10^{-7} m/s. The common thickness is changing. These aquifers are divided into three separate systems according to the distance from a coal seam. Aquifers marked Pl_1 are the first above the seam, those marked Pl_2 are 20 - 80 m's above the seam and upper Pliocene aquifers are marked Pl_3. Besides water table criteria in single aquifers, the reaction to pumping, logging and chemical analyses were adopted for the division. The Pl_1 aquifers and the water pressure in these are the most important for mining respectively safety excavation criteria. Reaction of these aquifers for dewatering is most evident, but somewhere they appear only as limited lenses without a direct link with surroundings.

From a hydrodynamic point of view, the Pl_2 and Pl_3 aquifers are much more homogeny as Pl_1, nevertheless they consist of many partly or completely separated sand-gravel layers.

Because of explicit anisotropy (and dewatering economy), only the lower part of aquifers is being dewatered. The dewatering processes occupy only the Pl_1 and Pl_2 aquifers directly, the Pl_3 exceptionally and indirectly because of vertical leakage.

Thickness of the whole complex that is dewatered by line batteries of wells is about 150 m. Considering the impermeable layers of mudstone, sandy clay, silt and clay, the thickness of a real aquifer is reduced overall. The whole Pliocene complex above the coal is up to 350 m's thick.

For the needs of Pliocene aquifers dewatering, 36 wells were elaborated between 1979 and 1988 for pumping into the pit. In 1997 the well for direct pumping onto the surface was finished. In 1983 the first wells were connected to the underground dewatering pipeline.

The dewatering activities caused water table drawdown for more than 250 m.

SUBSIDENCE

Excavation method applied in Velenje coal mine causes enormous subsidence. On the surface, one general and some partial observation networks are paced. More than 300 measuring points enable to establish the vertical and horizontal shifts of the surface above mine workings. Trilateration and triangulation are used for establishing the horizontal shifts and levelling for vertical shifts. Lately the modern GPS technology is used too.

For subsidence prediction the mathematical model developed by dr.Milan Medved in 1994 is used. The basis of this complex model are statistical analyses of measured horizontal and vertical shifts combined with geomechanical consolidation model. Analyses and predictions upon this model are reliable and concur with later verification based on measured data either where maximal or marginal subsidence occurs.

In the northwestern part of the Preloge mine field, where excavation activities have not begun yet, some vertical surface movements were observed. Considering the described model and all experiences, these movements are not the consequence of underground excavation.

Two observation networks were established, one above central line battery and the other called Druzmirje - Gaberke.

In 1982 the observation network above central line battery was established and in the same year the first measurement followed. The network consists of nine profiles with five points per profile and of one profile with three points. Direction of the profiles is generally southeast - northwest and they are right angled to direction of line battery of wells.

Measurements of vertical shifts (settlements) are done on these points only and the measuring error is estimated to be less than ± 1 cm. The starting point of levelling is on the southern margin of the depression where no dewatering effects appear. Observation area with profiles coveres approximately 17 hectares. Starting from the first survey in 1982 the measured subsidence until 1997 reaches from 283 mm up to 553 mm.

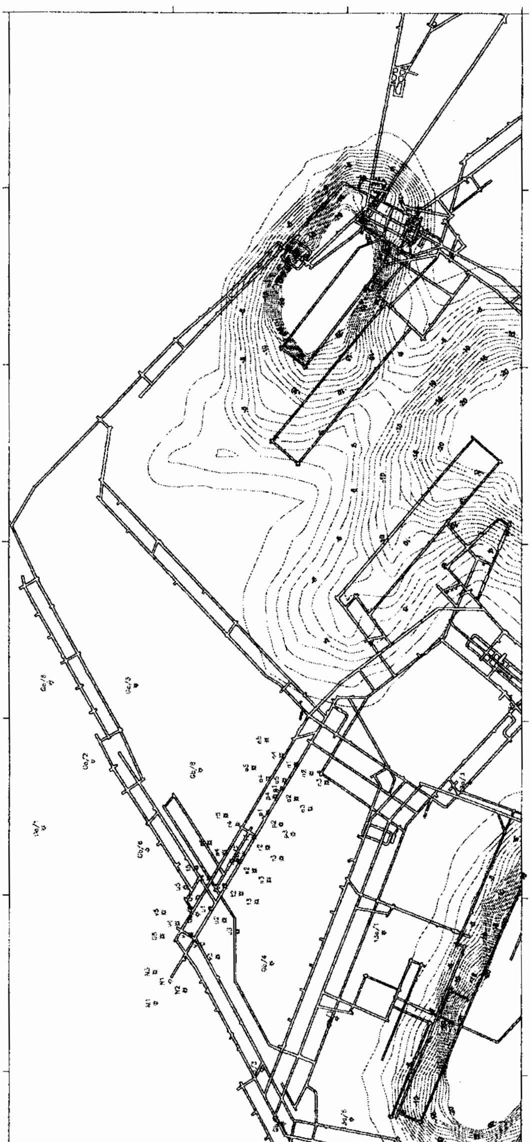

Fig. 4 shows the measuring points, subsidence caused by excavation (measured and verified with mathematical model) and underground structure's layout.

Measuring results of the subsidence concerning the observation network above central line battery are gathered in table 1.

In 1989 the observation network Druzmirje - Geberke was measured for the first time, but here the horizontal shifts are measured too. The observation points are found above the whole area of pit Preloge and only 18 are above the area affected by dewatering. Some of these were influenced by underground excavation activities. Vertical shifts measurement and accuracy of both networks is the same.

Table 1: Subsidence of observation points above central line battery

	y	x	z	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
n1	5874	7646	375	10	55	71	108	130	158	183	216	246	260	306	335	360	392	405
n2	5848	7603	375	10	52	67	108	124	152	177	209	239	252	303	331	358	395	407
n3	5822	7559	375	10	50	61	102	118	144	169	201	228	245	296	327	355	395	408
n4	5899	7689	376	9	55	70	109	132	162	200	230	256	265	306	335	360	391	404
n5	5942	7732	376	7	56	72	113	135	161	193	225	253	269	313	337	361	410	422
o1	5804	7687	374	10	52	68	108	123	146	173	202	223	242	287	314	339	368	380
o2	5776	7646	373	5	50	67	125	133	153	171	202	231	244	290	318	344	380	394
o3	5747	7606	372	3	55	62	103	111	135	167	196	221	239	289	318	346	373	392
o4	5832	7727	373	6	50	62	103	111	134	168	195	219	230	269	294	318	346	359
o5	5863	7769	373	7	49	63	101	120	137	182	209	231	246	286	309	333	360	372
p1	5736	7728	376	9	47	65	106	123	145									
p2	5703	7690	376	16	49	65												
p3	5675	7656	374	-5	36	52	102	114	135	166	192	214	238	294				
p4	5782	7707	376	10	45	64	109	135										
p5	5828	7681	377	8	44	62	103	130										
r1	5666	7768	377			18	64	80	100	141	153	179	202	244	270	293	324	340
r2	5637	7729	376	8	53	71	127	134	157	191	218	238	263	305	328	355	388	403
r3	5607	7689	376	8	51	70	122	136	156	188	216	238						
r4	5702	7816	378	9	47	66	108	124	143	184	194	223	237	277	301	323	351	366
r5	5726	7849	378	116		190												
s1	5598	7809	377															
s2	5573	7767	376	10	55	73	135	145	161	196	220	245	271	319	349	393	424	440
s3	5547	7724	376	131	173	194	252	262	284	318	349	375	399	447	471	500	537	553
s4	5623	7852	378	10	46	68	167	183	203	242	259	286	303	342	363	382	412	429
s5	5649	7895	378	8	184	201	250	263	281	317	329	355	371	405	425	443	471	487
t1	5529	7850	378	14	45	78	129	143	164	202	221	243	268	309	331	352	383	418
t2	5508	7805	377	14	61	84	230	240	257	295	315	345	372	415	438	463		
t3	5486	7760	376	16	62	83	131	236	262	307	329	357	386	432	456	485		
t4	5551	7895	378	16	52	73	119	133	155	189	211	236	276	347	366	385	416	444
t5	5579	7934	379	8	46	90	113	121	146									
u1	5465	7891	381	13	57	78	132	138	170	196	215	239	264	299	319	339	367	402
u2	5433	7853	381	17	63	86	142	152	202	235	284	310	339					
u3	5401	7815	382	18	64	88	152	159	192	223	248	276	310	351	374	400	440	486
u4	5497	7929	382	97	138	156	207	213	241	269	284	307	327	360	378	396		
u5	5526	7964	384	10	48	66	112	122	152	209	222	244	261	293	310	326		
v1	5391	7948	397	18	52	80	130	140	160	183	196	221	249	277	296	314	340	363
v2	5365	7915	393	16	58	78	136	146	173	197	210	236	269	302	320	341	372	398
v3	5329	7871	394	15	60	82	143	156	185	212	227	258	297	333	354	378	405	430
v4	5423	7987	398	14	45	71	115	127	142	165	174	198	229	247	266	282	303	319
v5	5454	8026	400	9	35	62	103	113	133	153	155	181	215	233	250	268	288	303
O1	5323	7966	ni bila															
O2	5289	7930	399	15	54	76	132	143	171	195	203	232	267	298	317	337	365	388
O3	5254	7894	396	11	54	76	121	134	161	181	193	222	262	294	315	337	372	395
O4	5355	7998	402	13	40	68	108	120	141	166	168	194	221	243	262	277	298	321
O5	5386	8030	407	11	38	64	102	112	127	154	155	175	203	225	240	256	274	294
N1	5258	8008	420	16	46	68	112	125	155	175	175	178	219	249	264	281	301	319
N2	5233	7965	410	11	48	68	119	130	158	180	179	202	245	272	289	307	329	349
N3	5284	8051	419	15	41	63	100	113	138	157	157	164	202	222	238	252	264	282
M1	5196	8049	420	11	58	58	99	112	134	156	154	160	203	223	237	252	266	283

In this area intensive dewatering processes are going on since 1984 and subsidence of the surface is mainly caused by water table lowering - drawdown. Until today this statement is only supposition never proved through empirical method. Based on two previous aquifer models (lit. 1 and 2), the idea of subsidence modelling was born.

Table 2: Subsidence of observation points above Druzmirje - Gaberke area

	y	x	z	1990	1991	1992	1993	1994	1995	1996	1997
13a/1	5400	7394	368,93	56	103	155	263	327	406	536	839
13a/2	5625	7261	372,77	40	76	124	219	280	342	409	
13a/3	5823	7147	371,72	26	50	67	123	150	174	211	267
13a/4	6048	7009	371,14	26	48	55	88	109	136	199	442
13a/5	4873	7486	382,20	53	101	150	203	234	316	473	1642
Ga/1	5687	8369	408,10	-1	0	26	32	40	47	54	57
Ga/2	5878	8228	383,51	9	23	10	20	32	41	52	55
Ga/3	6095	8106	379,99	24	38	52	56	75	92	107	121
Ga/4	5902	8511	400,97	1	4	20	22	26	30	37	40
Ga/5	6101	8347	384,27	6	17	21	31	35	42	42	51
Gb/1	5156	7529	371,84	51	87	141	224	272	351	486	661
Gb/2	4860	7682	399,63	20	57	121	151	173	206	246	332
Gb/3	5011	7745	394,86	26	63	109	144	169	201	238	307
Gb/4	5311	7716	377,50	26	60	104	155	183	219	274	345
Gb/5	5449	7929	392,19	6	40	67	100	114	133	159	194
Gb/6	5629	8072	383,38	12	29	43	65	77	91	107	127
Gb/7	5620	7796	376,87	12	37	61	104	126	148	181	197
Gb/8	5855	7921	378,00	18	29	43	74	93	112	133	148

MODELLING

The purpose of the mathematical model is first to predict the subsidence of the surface above northwestern part of pit Preloge and an attempt to make a prognosis for the area above the pit Sostanj. Approximately 100 million tons of coal are in the pit Sostanj and excavation should start in the second third of the next century. Long before excavation activities dewatering process of Pliocene aquifers above the coal seam must start in this area. This mathematical model should predict the range of surface subsidence in three settlements in this area, Sostanj, Florjan and Topolsica.

Considering the complexity of the whole system and lack of qualitative data, we decided to elaborate a test model for modelling the subsidence as an effect of dewatering and compaction of Pl_1 and Pl_2 aquifers. These aquifers were modelled with a pre-elaborated hydrodynamical model that we used as groundwork.

We are aware of the fact that because of lack of qualitative data (extensometers) pinpointing at certain clay and silt layers that contribute at most to the subsidence progress on the surface are impossible. There is a whole series of thin interbeds of clay, silt and silty sand in the Pl_1 and Pl_2 aquifer complex (that is dewatered by line batteries of wells) and there are thicker impermeable layers and aquitards in upper Pliocene aquifer complex. The upper Pliocene aquifer complex is mainly indirectly dewatered.

Analysis of Pl_1 and Pl_2 aquifer water table showed relatively quick reaction for dewatering processes (first quick drawdown, then calm down). The mathematical model calculation resulted the same. Reaction of the water table in Pl_3 aquifers is quite different while drawdown is very constant in time.

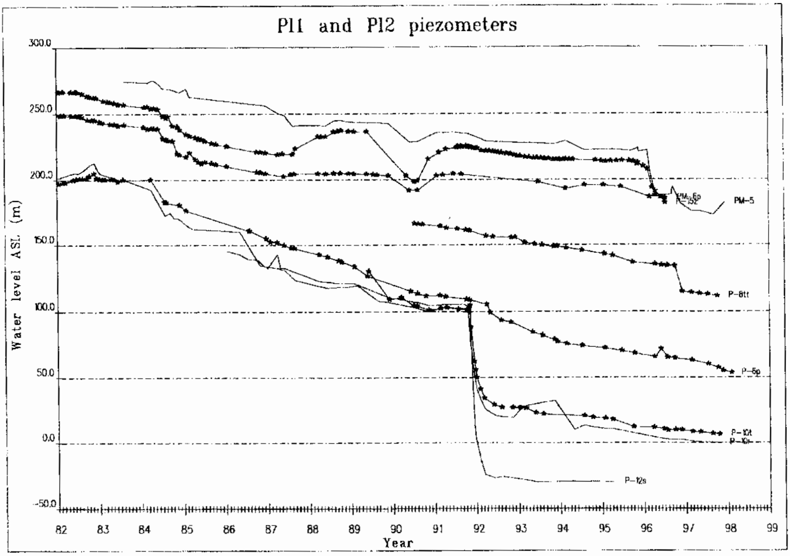

Fig. 5 Examples of water table oscillation on piezometers that belong to the Pl_1 and Pl_2 aquifer complex.

Fig. 5 shows examples of water table oscillation on piezometers that belong to the Pl_1 and Pl_2 aquifer complex. The lower three piezometers are typical representatives of Pl_1 system, which is characterised by very quick reaction for dewatering changes. Piezometer P-6p represents the same group but its distance from line battery is greater and the reaction slower. The second group (the upper ones) belongs to the Pl_2 aquifer complex. This system reacts relatively fast but slower than the first one. Directly in the vicinity of the subsidence observation network, no qualitative data from piezometers (especially Pl_2) can be found until 1990. From that time some multilayer piezometers were elaborated in the area. Analysis of water table oscillation is limited to the period from 1990 till now.

Fig. 6 shows examples of water table oscillation on piezometers that belong to the Pl_3 and quaternary aquifer complex. The lower four piezometers belong to Pl_3 aquifer complex. These are characterised by constant drawdown from the beginning of pumping. Separate dewatering phases characterised by inclusion of wells are not evident. The thickness of this complex is up to 250 m. Upper four piezometers belong to quaternary complex and till now the pumping in the lower system caused no influence in quaternary complex.

Diagrams on fig. 5 and fig. 6 show the reaction of some piezometers to activation and test pumping on separate dewatering objects. These events were timely and spatially very variable and are not considered in the model.

We used the software MODFLOW (Modular finite-difference groundwater flow model) made by USGS for surface subsidence modelling. The software includes an additional package (Interbed storage package) for compaction or elastic expansion calculation of aquifers. Consequently the surface subsidence as an effect of pressure change in the aquifer is the result.

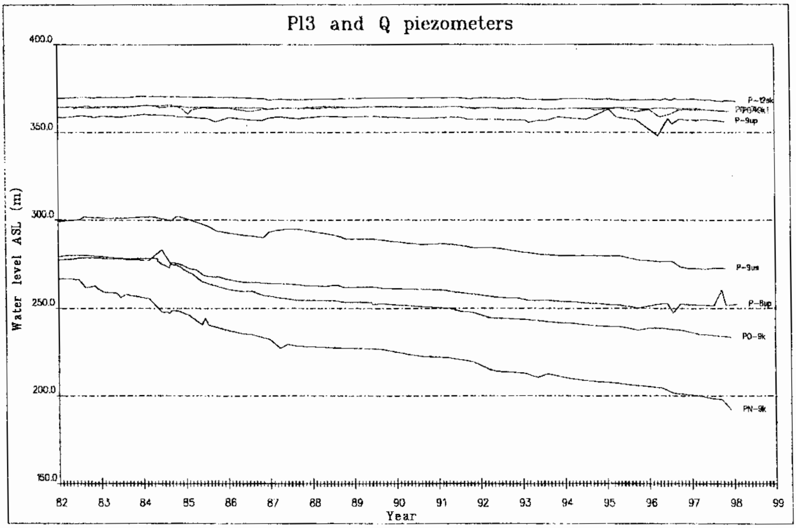

Fig. 6: Examples of water table oscillation on piezometers that belong to the Pl_3 and Q (quaternary) aquifer complex

The whole calculation is based on long known principles: the elastic (and plastic) compaction is proportional to pressure change in the layer and the constant of proportionality is the product of the skeletal component of elastic specific storage (and inelastic specific storage for inelastic compaction) and the thickness of the sediments. The whole calculation principle used by the software, is described in detail in software documentation (lit 6) and is therefore omitted here.

As mentioned before for the test model (that used unified layer for Pl_1 and Pl_2 aquifers because of calculation simplicity), we chose modelling with support of the pre-elaborated hydrodynamic model. The basic parameters of the hydrodynamic model were used as input parameters for the subsidence model. Results of the calculation for some chosen measuring points (measuring points layout - Fig. 4) are shown on the following diagram:

From the diagram on Fig. 7, the model obviously cannot describe the subsidence as an effect of dewatering. The reason is that the calculated values for subsidence are initially too big and later the measured subsidence is greater than calculated (model shows a tendency of subsidence calm down). During a model calibration (history match), we could shift the calculated diagram on the vertical axis by changing the parameters, but the general shape of the subsidence course remained the same. The conclusion from this is such that the relatively simple model scheme does not enable a satisfying description of the real state in the system.

Although the model calculation resulted the right size rank, it is not precise enough for a qualitative, long term subsidence prognosis. The reasons for this are numerous, but the main reason is the complicated aquifer system structure. Using simple model schemes, the satisfactory mathematical description is impossible. Considering then the time, needed for some saturated, permeable and compressible material to reach the definite stage of compaction, possibly all the parameters, influencing the speed and size of subsidence in time and space are listed.

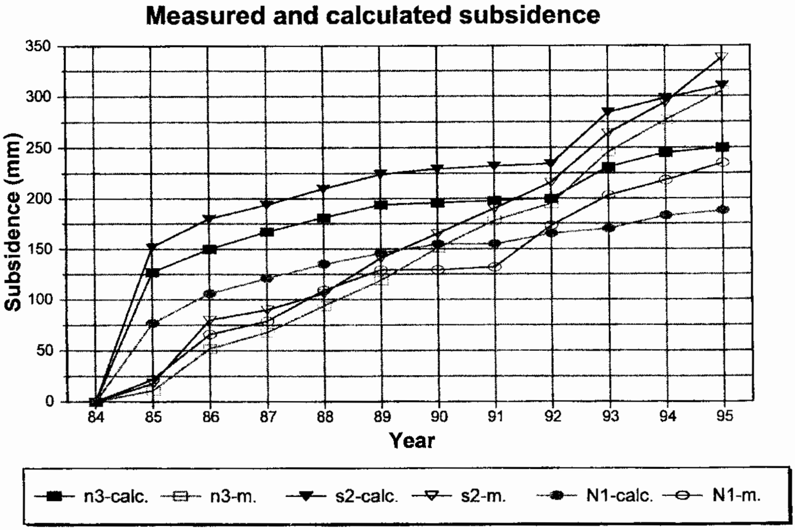

Fig. 7: Calculated and measured subsidence for three chosen measuring points

On the surface, the subsidence is caused by: compaction of the interbeds in directly dewatered part of an aquifer, compaction of single layers in indirectly dewatered part of the aquifer and compaction of thick clay and silt layers that separate particular aquifers.

In future we are going to try to make better spatial and time dependant subsidence prediction, using multilayer mathematical model which can describe the complicated geological structure more satisfactory.

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