EVALUATION OF MINE WATER INFLOWS AND ASSOCIATED IMPACTS AT THE OLYMPIAS MINE, HALKIDIKI, GREECE.

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ABSTRACT

Where the host rock for a mineral deposit is of low permeability, the inflows to a mine from surface waters may represent a significant portion of the total inflow. This scenario is particularly pertinent where shallow mining has taken place close to a surface water course and the mining activity has enhanced fracture permeability allowing increased infiltration of surface waters. In extreme cases this can cause the affected streams to flow only ephemerally. This situation impacts upon both the mine, through increased nuisance and pumping costs, and the local environment through loss of habitat.

The Olympias Mine in north-east Greece worked a mixed sulphide ore body for lead and zinc from 1970 to 1992 at depths of 100 to 300 metres below ground. The ore body is hosted in Lower Palaeozoic meta-sediments, principally low permeability gneisses and schists. During the late 1980's block caving was the mining method used and this caused surface subsidence adjacent to the course of an overlying stream, the Basdekilakkos Creek. This subsidence led to increased infiltration from the creek which now dries up during the summer months in the vicinity of the mine.

Since 1995 the mine has been re-examined as a potential gold project and Steffen, Robertson & Kirsten (UK) Ltd (SRK) were appointed as consultants for mine water management as part of an overall feasibility study. The objectives were to design and cost the infrastructure requirements for mine water management for the future life of mine. This required an assessment of the future inflows and the nuisance caused by background inflows and the perceived risk of sudden large volume (catastrophic) inflows.

SRK designed and implemented a monitoring network to identify the surface water component of background inflows and carried out a cost-benefit analysis to assess the feasibility of potential remediation strategies. Additionally, using available geological and mining records combined with geotechnical assessment and underground hydraulic testing, SRK established that the risk of catastrophic inflows is low.

INTRODUCTION

Greece is not a country renowned on a global scale for its metal mining. Nevertheless within Greece itself the group of three mines to which the Olympias Mine belongs (the Kassandra Mines Complex) was the largest mixed sulphide and pyrite mining operation during the late 1980's and early 1990's [1]. Even though metal mining in Greece is small on a world wide scale, it does have a long history. For example the earliest known mining activity in the Olympias area dates back around 2500 years to the time of Alexander The Great, who was a native of the local province of Macedonia. There are a number of exploration campaigns which are currently underway in the north-east of the country. Evaluating the gold-bearing potential of the Lower Palaeozoic Serbo-Macedonian Massif which extends northwards from Greece into Bulgaria and eastern Yugoslavia.

Background details to the project

Olympias and the other two mines of the Kassandra Mines Complex were acquired from the Greek government by TVX Hellas S.A. (TVX) in 1995. TVX plan to the exploit the Olympias Mine for gold which would then be processed by constructing a new mill and processing plant.

The mine water management study was carried out between April 1996 and October 1997 as part of an overall feasibility study. A feature of the study was to integrate as much as possible with ongoing emploration and underground development work and to develop an underground mine water management strategy to integrate with mining. This paper briefly describes the overall water management project and focuses on two key aspects of the study (conclusions from this work are presented here.)

Site details

The Olympias Mine is located in the Prefecture of Halkidiki in the province of Macedonia in north-east Greece. It derives its name from the local coastal town of the same name. The town (and mine) have no connection with Mount Olympus (fabled home of the Greek Gods) which is located some 130 km to the west

The mine consists of two parts; the west mine and the east mine. The west mine is accessed via a decline and the east mine via a 400 metre deep shaft. The west mine has been historically exploited for lead and zinc but no mining has taken place in the east mine.

OBJECTIVES

SRK undertook work at Olympias to provide input for the Pre-Feasibility and Feasibility studies. In this context there were three principal objectives.

1) Reassure management that mine water was not a fatal flaw in the project:

- from the risk of very large increases in inflows with increased mining depth; and
- from the perceived danger of catastrophic inflows causing development / mining delays and consequential increase in associated costs.

2) When objective 1) was satisfied, aim to minimise capital and operating costs by optimising the mine water management strategy through the following steps:

- optimise the pumping system by understanding the nature and magnitude of future inflows;
- control volume of water inflow to minimise pumping costs; and
- restrict location of water inflow to specific prepared sites in order to minimise in-mine contamination of the water and thus reduce treatment costs prior to discharge.

3) Identify environmental impacts or liabilities resulting from mine dewatering or mine water discharge.

OVERALL APPROACH

From the outset of the project SRK recognised that the relatively unusual situation at Olympias, with an existing mine undergoing a full Feasibility Study, necessitated a different approach to that which would be used for a completely green field site. The approach was to use available historical mining information and rather than undertake specific hydrogeological drilling, ground water monitoring and hydraulic testing would be integrated with the ongoing programme of exploration drilling, underground infill drilling and mine development.

This approach had the advantage of minimising costs and direct applicability to the future dewatering strategy, but had disadvantages in that the hydrogeological investigation aspects of any drilling were of secondary importance which often affected the quality and timing of the information.

Methodology

Prior to SRK's involvement in the project a preliminary desk study was undertaken by Klohn-Crippen Ltd. of Toronto who reviewed the historic geological, hydrogeological, hydrological and meteorological data. At the same time that this was being undertaken a programme of environmental monitoring including mine water flow and quality monitoring was set up by TVX.

Field Work Programme

The field work programme was based on obtaining data from test work integrated with the geology and mining development work.

Piezometers were installed in the surface drilled exploration holes, but with limited success.

Three out of four piezometers in deep exploration holes were lost. Additional piezometers should be installed in any future, surface drilled holes. In the available piezometer a water level of -102 mamsl was recorded.

Underground, flows were estimated from various parts of the mine. There were inevitably large errors in measuring these flows based on channel dimensions.

Pressures were measured in a wide number of infil exploration boreholes, to try to compile a piezeometric surface position.

Hydraulic tests were carried out by draining or pumping from an underground hole while monitoring pressures in an array of nearby observation holes. All the holes were drilled for exploration information.

Key observations were that the cone of depression is anisotropic. Drainage is from fractures which appear to 'dewater' and have limited storage or recharge even though the footwall is partially karstic marble.

Water chemistry was also assessed to characterise the inflow water as much as possible.

SRK reviewed the desk study and the ongoing monitoring record from the TVX programme and used this data to produce an initial conceptual model of the hydrogeology of the mine area. This assisted in the recognition of key areas where more information was required and in the identification of potential environmental impacts due to the mine dewatering. The conceptual model is shown in Figure 1.

To address the issues SRK planned and designed additional data requirements and monitoring points which would complement the existing monitoring network and which could be easily incorporated into the on-going monitoring programme. The additional data were used to continually refine the conceptual model which was then used as the basis for planning the mine water management strategy for the Feasibility Study.

Results

The first objective of the investigation was satisfied by carrying out hydraulic testing to show that water pressures in the mine were generally low and that newly intersected, high volume inflows rapidly depleted themselves if allowed to flow rather than being held back. The occurrence of specific water bearing horizons was identified using a hydrogeological / structural model and this provided a predictive capacity for future development to allow specific cover drilling to be carried out in higher risk zones.

One element of the second objective was the investigation of the infiltration from the Basdekilakkos Creek and whether it would be cost effective to carry out remedial measures.

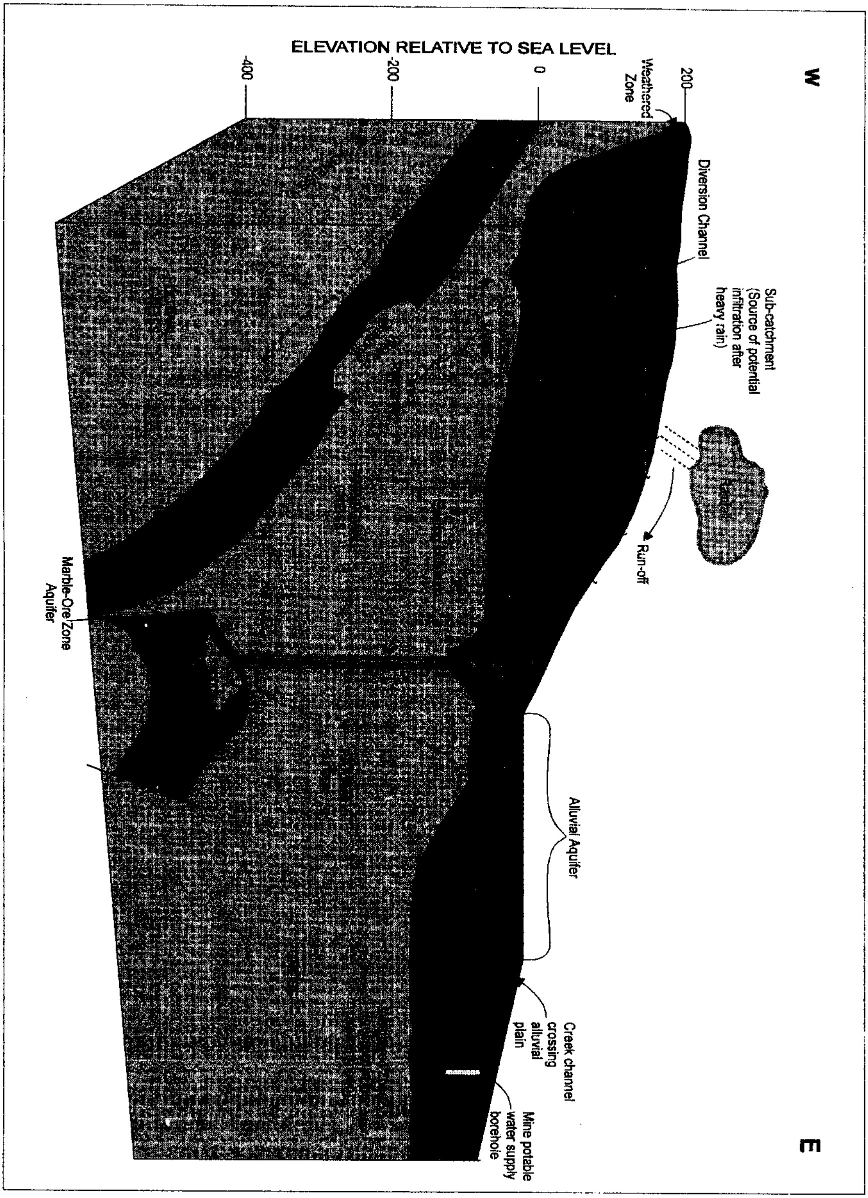

Figure 1: Conceptual hydrogeological mode west-east section along the Basdekilakkos Creek

To satisfy the third objective potential environmental impacts were identified from the conceptual model and these were found to be:-

- loss of the water resource of the nearby alluvial aquifer due to vertical infiltration into the bedrock and hence into the mine;
- the water quality of the alluvial aquifer due to discharges from the mine into streams which infiltrated into the aquifer;
- interruption of the flow regime and habitat of the Basdekilakkos Creek due to direct infiltration into the mine workings.

The impacts to the alluvial aquifer were potentially serious as it provides a significant component of the public water supply to the local town via a number of abstraction boreholes. However during the course of the hydrogeological investigation it was concluded that the risk to both the resource and quality of the alluvial aquifer was low.

Hence the remainder of this study concentrates on the impacts upon the Basdekilakkos Creek and the cost / benefit analysis related to possible remedial strategies.

INVESTIGATION OF INFILTRATION FROM THE BASDEKILAKKOS CREEK

Site details

The flow in the Basdekilakkos Creek is derived from a spring which rises some 2 km upstream from the mine. The creek flows down a the narrow valley past the mine infrastructure and then out across a flat alluvial plain to the sea. The valley in which it flows is heavily wooded and the valley sides rise steeply for some fifty metres from the creek to the narrow ridge crests above. The base of the creek channel is formed from coarse fluvial material ranging from sand and gravel to large boulders. There appears to be very little clay grade material present in the bed deposits. It is recognised that a proportion of the flow in the creek takes place as interflow through these permeable bed deposits. A plan of the site is illustrated in Figure 2.

Historical background

Even before any of the current investigations had taken place there was a recognition on the mine that there was a potential for future infiltration of water from the creek. During the late 1980's block caving was the mining method being used and this caused significant subsidence in one of the valley sides. The proximity of the creek channel to the expanding area of subsidence was seen as a sufficient risk at that time to motivate the construction of a sealed, artificial channel (known as the diversion channel) to carry the creek flow in the vicinity of the subsidence zone. However the scale of subsidence was such that the block caving method was discontinued and this also halted work on the diversion channel which was left only partially completed and unused.

In recent years there was anecdotal evidence that infiltration from the creek was occurring. It was common knowledge within the mine that inflows were higher after periods of heavy rain. There was also a single incident around 10 years ago when the mine was nearly flooded due to infiltration through a fissure in the creek bed. This fissure was located and infilled but not sealed and thus the infiltration through it was highly reduced but not eliminated. There have been no repeats of this incident so it appears that the peak infiltration from the creek is limited by the transmission capacity of the bed deposits and of the underlying fissures.

Monitoring of some subsidence cracks has been regularly carried out but it appears that the extent of subsidence cracking may have reached the river resulting in increased losses.

The current study

At the start of the investigation it was recognised that infiltration from the creek could potentially be a significant mine water inflow component. This flow would pass through old mine workings and potentially become contaminated due to sulphide oxidation before arriving in the present dewatering sumps. From studies on the creek flow it was apparent that the visible flow component decreased in the vicinity of the mine but it was unclear whether the losses were principally into the bed material, with the water then reappearing downstream, or whether the flow was infiltrating into the bedrock and descending to the underlying mine workings. Attempts at quantifying the flow losses by current metering the stream flows were hindered by the undefined flow component in the creek bed deposits.

To ascertain whether the infiltration from the creek was significant and thus worthy of additional study the hydraulic link between the creek and the mine workings needed to be

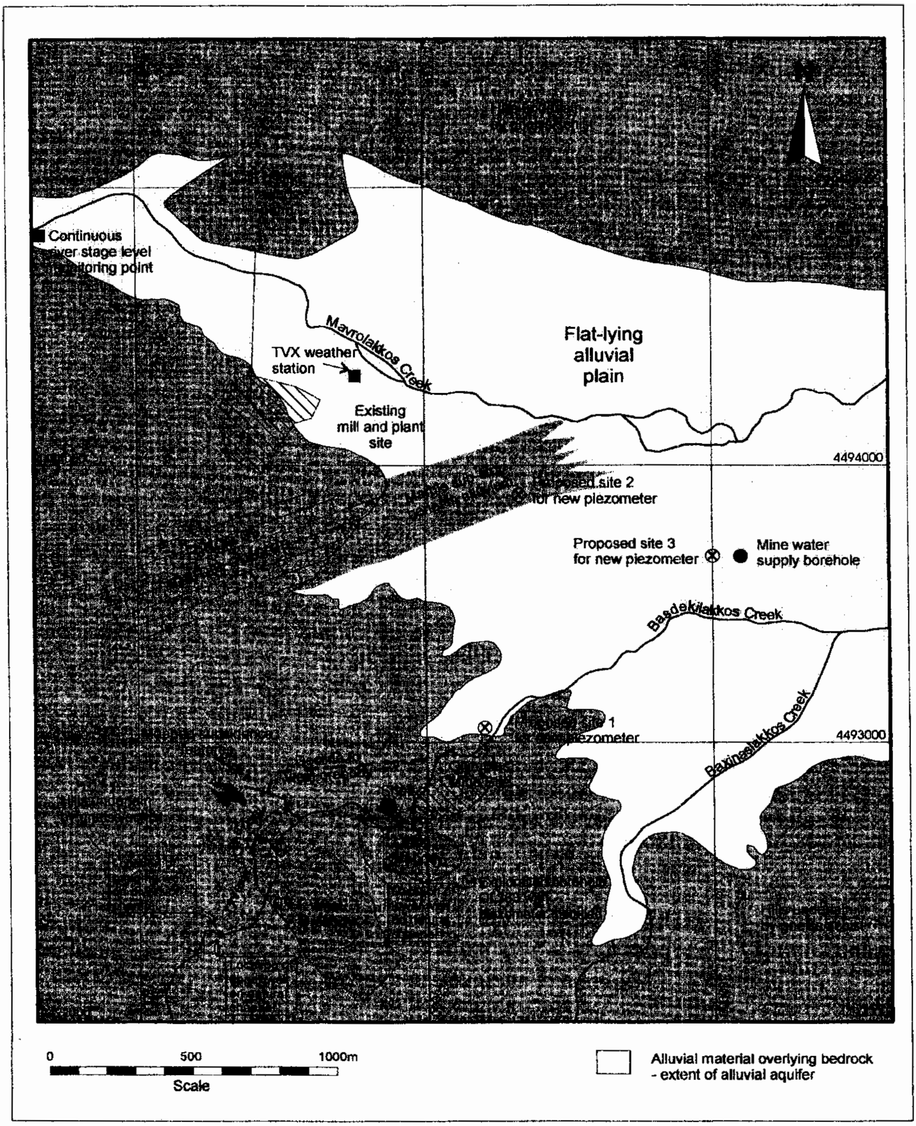

Figure 2: Plan of regional geology and site water features

confirmed. To do this it was decided to carry out a ground water tracer test using a similar technique to that employed by hydrogeologists and speleologists in Karst aquifer systems to establish the connectivity of cave systems.

Tracer testing

The tracer test involved the following steps:

- Suitable monitoring points were identified in the mine and equipped with passive detectors of cotton lint.
- The locations of major flow losses in the creek were identified and marked.
- At these marked locations hollow pipes were hammered into the bed material and a small, measured quantity of the tracer was introduced. The tracer used was Photine CU which is an optical brightener used in washing detergents and which fluoresces under ultra-violet light.
- The passive detectors were regularly monitored using an ultra-violet lamp.

The results from the test showed very rapid flow from the creek to many locations in the mine. Surprisingly the first positive response, after less than 1 hour, occurred in the deepest part of the mine at around 360 metres below ground level. However, over the following 24 hours positive responses were recorded from all over the mine.

The monitoring technique used gave no indication of recovery of the dye and thus was only useful for indicating first arrival at a point. However the test gave conclusive proof that there was a very good hydraulic connection between the creek and all parts of the mine.

Surface water flow monitoring

Having proved that there was a connection between the creek and the mine it was then necessary to quantify it so that the cost / benefit of potential remediation schemes could be evaluated.

It was planned to use two existing weir structures on the creek as upper and lower gauging points so that the infiltration losses could be identified. The upper weir located above the subsidence zone was refurbished and equipped with V-notch gauging weirs to record flows. The lower weir, located downstream of the subsidence zone, was intended to be equipped in the same way but it was recognised that flow was occurring beneath the weir. Thus it was first necessary to prevent flow beneath the weir before it could be used as a monitoring point. However, when the foundations of the weir were excavated it was found that the structure was underlain by more than 5 metres of uncemented coarse alluvial material. As the cost of renovating the structure would be a considerable portion of any likely cost savings from reducing infiltration into the mine it was decided to abandon the lower weir as a potential monitoring point.

The 600mm pipe was optimised in terms of the costs and benefits. It was not practical to channel flows in the peak flow events.

Possible remedial options

Two potential options were evaluated:

1. Utilising the existing diversion channel by sealing its bed with a membrane or carrying the flow in a semi-circular channel;
2. Installing a pipeline of around 600 mm diameter in the natural channel to carry the creek flow for all but approximately 15 % of the time, when the additional flow would utilise the diversion channel.

Cost / benefit analysis

The cost of the diversion channel option was calculated as around $125 000 whilst the cost of the pipeline option was calculated at around $230 000.

Inflows from the creek of between 50 and 100 m^3/h were estimated and used to estimate the costs of pumping. The only parameter evaluated was the power cost for pumping that quantity of water from a certain level in the mine to surface. It was found that the pumping costs varied from $16 000 to $75 000 per year, with an average of around $45 000.

It was concluded that the costs of remediation were not warranted compared to the costs of pumping for the estimated life of mine of seven years.

DISCUSSION / CONCLUSIONS

The impact on the flow regime of the Basdekilakkos Creek at Olympias was the result of a short term economic decision in the past to utilise a mining method (block caving) which was unsuitable for the prevailing conditions. The surface subsidence affected the creek channel and caused increased infiltration into the underlying mine workings. This was to the detriment of both the local environment and the mining operation. The former suffered a loss of habitat whilst the latter incurred increased operating costs. To remove or eliminate the infiltration problem would require a relatively costly remediation scheme.

The protection of the local environment need not be to the detriment of the mining operation. If sufficient planning and investigation is carried out prior to potentially damaging activities then future problems can be minimised and future impacts reduced or eliminated. This removes the need for costly remedial strategies or spiralling environmental liabilities on closure.

ACKNOWLEDGEMENTS

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