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Technical Communication

A Computer-Aided System for Design of Drainage Facilities in Surface Mining

Vladislav J. Kecojevic[1], Marek J. Mrugala[2], Radomir D. Simic[3], and Ranka M. Stankovic[4]

[1] Asst Prof, Mining Eng, The Pennsylvania State Univ (PSU); [2] Assoc Prof, Mining Eng, PSU, University Park, PA, USA; [3] Prof, Mining Eng, Univ of Belgrade; [4] Research Asst, Dept of Computer Application, Univ of Belgrade, Yugoslavia; e-mail: vuk2@psu.edu

Abstract: Drainage systems in large surface mines are designed to accomplish three basic objectives: keeping working conditions dry, stable, and safe; lowering hydrostatic pressure and increasing the effective stress of soil to improve slope stability; and ensuring pit floor workability. This can be achieved with drainage facilities that include channels, water collection sumps, and pump stations. We report the development of a computer-aided system called Dewatering of Open Pit Mines (DEWOP), which can assist open pit mine designers to solve water-related problems. The system was developed in a Visual Basic object programming language, taking advantage of multi–user, open database connectivity, such as Microsoft Access, for storage and processing of information. In tests at coal and copper surface mines, it reduced drainage facilities costs by 8%.

Key words: Drainage; mathematical modeling; software; surface mining

Introduction

Mine production rates and operating costs are directly dependent on working conditions. Wet mine floors and working areas create difficult conditions for heavy equipment, decrease production, and lower overall system efficiency. In the extreme case, there is a risk of mine flooding and extended interruption of mine production. Protection of surface mines against ground and surface waters is accomplished by designing and implementing suitable drainage facilities. These facilities may include channels, pumping stations with water collection sumps, structures for river streams regulation and diversion, dewatering wells, vertical and horizontal boreholes, needle filters, and water impervious screens. A typical drainage facility system is shown in Figure 1.

Drainage system design is based on three groups of input parameters: hydrogeological, hydrological, and parameters related to mining and environmental conditions. Hydrogeological properties include overburden characteristics, grain size distribution, hydraulic conductivity, porosity, permeability, ground water level, transmissivity, specific storage, specific yield, and water quality. Hydrological parameters refer to runoff surfaces, infiltration, precipitation, evapotranspiration, moisture deficit, runoff coefficient, time and rate of concentration, time of retention, and river flows in the vicinity of the mine. Mining conditions consider spatial and temporal development of mine geometry; environmental issues relate to water treatment.

Groundwater flow calculations are typically accomplished using numerical models. Inflow forecasts are based on both analytical and numerical modeling. Based on an approximate representation of the physical principles of groundwater flow, these models are well suited for exploring a range of hypothetical scenarios. Most software packages are based on MODFLOW (McDonald and Harbaugh 1984; Harbaugh 1990; Harbaugh and McDonald 1996). Commercial software, such as Visual MODFLOW, Groundwater Vistas, and Groundwater Modeling System, has attained a high degree of sophistication. Anderson and Woessner (1992) provide an extensive discussion of groundwater numerical modeling. Hydrological modeling includes such tools as Surface Water Modeling System and Watershed Modeling System.

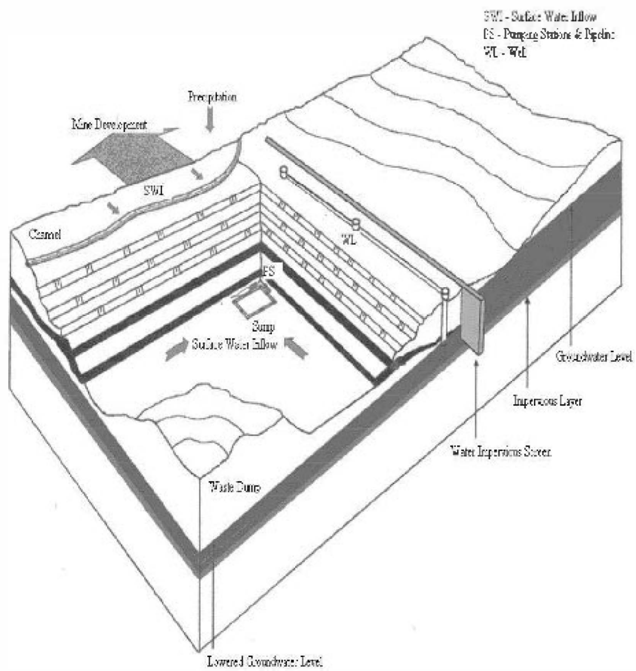


Figure 1. Drainage facilities in surface mining

More explanations regarding hydrological tools can be found in Wanielista et al. (1997). However, none of these software applications addresses the design and selection of drainage facilities.

In general, a surface water drainage system must account for both low and high water events. In cases where a sump system is used, the proper sizing of drainage channels, sump volume, capacity of pump stations and associated pipelines is essential. While each component can be designed separately, the interaction of all components has to be optimized to refine the performance of the entire system. This can be done efficiently with Dewatering of Open Pit Mines (DEWOP), a numerical modeling system which the authors have developed. The system uses a Visual Basic object programming language that operates in the Windows environment.

Description of the System

A general approach to the design of drainage facilities in surface mining involves six phases (Figure 2). System planning is the first essential activity in the design process. During this phase, key relationships among various system components and input data needs are identified.

The second phase encompasses a number of activities related to the acquisition of laboratory and field data. The relational database is a focal feature employed for storage and processing of the relevant data obtained from exploratory works, results from various laboratory tests, field measurements, hydrogeological and hydrological modeling, and the geographic information system (GIS) data. This database contains a combination of tables, queries, forms, and reports. Common statistical methods are employed to analyze the data quality and suitability for inclusion in various segments of the drainage system. The impact or influence of each parameter variable can be assessed by variant analysis. Possible relationships between different parameters can be tested using regression analysis. Different types of tests and curve estimation, reliability analysis, and multi-dimensional scaling can also be performed. The open database connectivity provides efficient intercommunication linkage with results obtained from the hydrogeological and hydrological modeling.

The third phase, system design, contains design modules, which are discussed below.

Channel design module

The channel module consists of four interrelated parts. In the first part, the user can select the

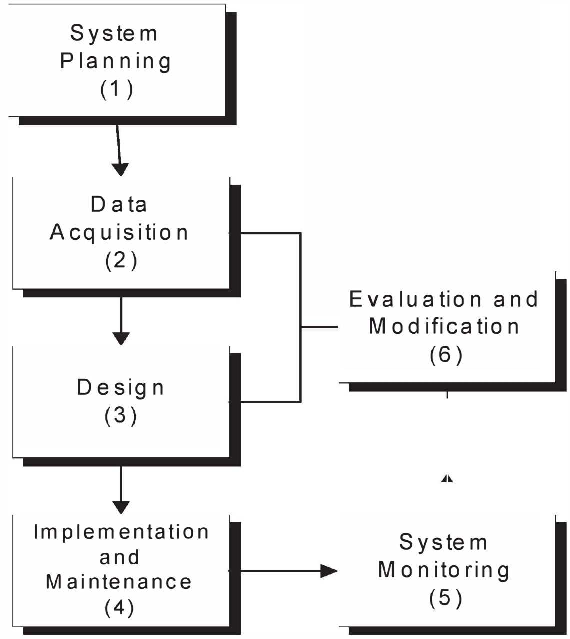


Figure 2. A simplified logic chart for drainage system design methodology

appropriate channel type: trapezoidal, rectangular, or triangular, and define channel wall angles (Figure 3).

The second part of the program calculates an optimum relationship between the channel bottom width and channel depth, the channel upper width and channel depth, and the cross-sectional area and channel square depth on one side, and channel wall angle on the other (Figure 4).

The third part of the program offers the option of selecting the material type to be used for channel construction. Then, the roughness factor for the selected material to be used for construction is defined. This part of the program also allows for defining individual channel sections, their lengths and gradients. The final part of the program (Figure 5) summarizes the results, including: channel sections, gradients (‰), lengths (m), depths (m), base widths (m), hydraulic radius (m), Basin's roughness coefficient, channel area (m^2), water velocity (m/s), required capacity (m^3/s), actual capacity (m^3/s), a diagram displaying the relationships of channel depth and capacity at different sections, and a cross sectional view of each channel section.

Sump design module

The module for design of water collection sumps enables the design variant based on inflow of surface or ground water, or both. Each option is designed as a subprogram, which use the individual inflows separately. Figure 6 shows the total water inflow, water sump volume, and pumped-out water volume

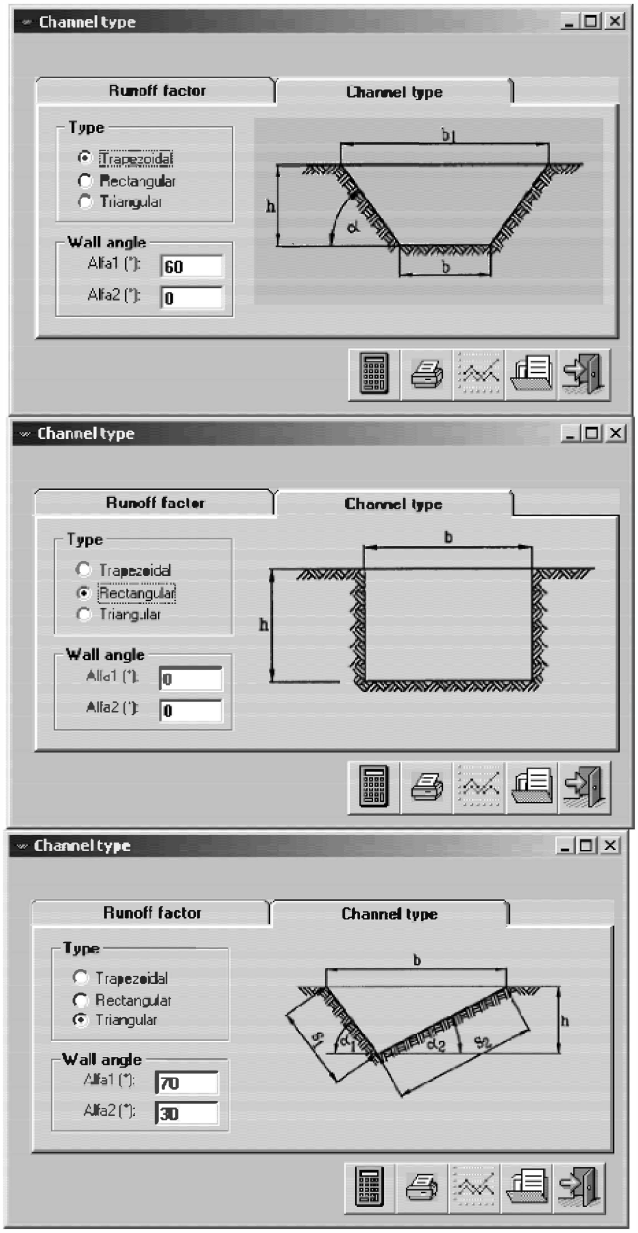


Figure 3. An example of channel type selection

as a function of collection sump discharge time. This approach allows one to calculate the minimum volume for the water collection sump for the selected delay between the onset of precipitation and the start of pumping. Designers of water drainage systems in surface mines found this approach highly desirable, as it allows them to size the water collection sump appropriately, thus avoiding flooding. The flexibility of this module also permits the designer to size the system based on selected discharge time, or in accordance with the available pump capacity.

Pump station and pipelines selection module

The module for calculation and selection of pumping station and pipeline consists of several programming entities, all of which contain a series of subprograms.

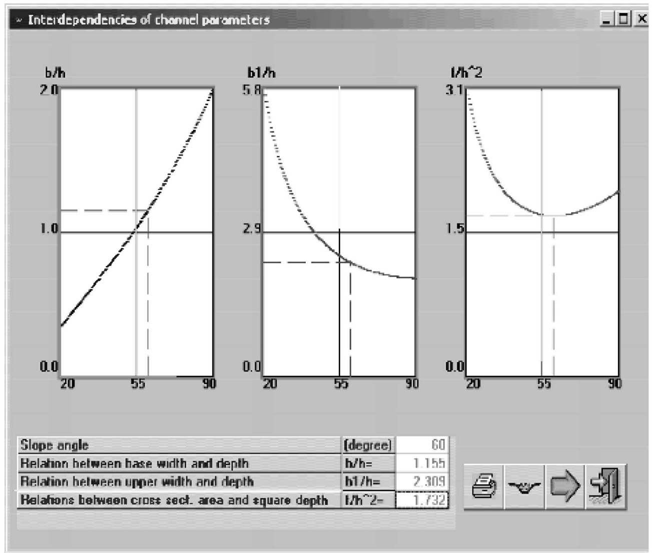


Figure 4. An example of relationships between basic channel parameters

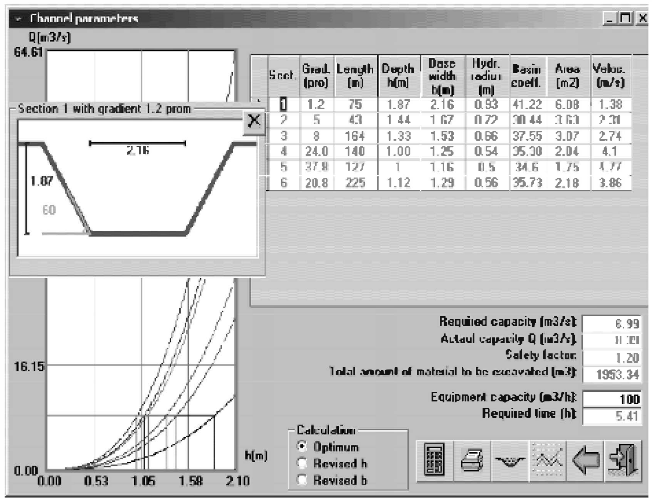


Figure 5. An example of designed channel parameters

The pump database allows for an introduction of a new pump or an inspection of the existing pumps along with their operating parameters. The initial value of water pump station output, obtained from the earlier-discussed sump design module, is used here as input. Upon selecting the required pumping output for the specified collection sump discharge time, it is possible to calculate the required pipeline diameter adopted in this model in accordance with standard dimensions. This result is followed by geodetic suction and thrust heights, as well as the pipeline suction and thrust lengths on the designed pipeline route. The value and control of the true water velocity in the pipeline, the Reynolds number value, the Darcy's friction factor and line losses in suction and thrust pipelines are then displayed, as shown in Figure 7. In the second part of this program, the local resistances are calculated. There are a series of subprograms, where each solves a local resistance

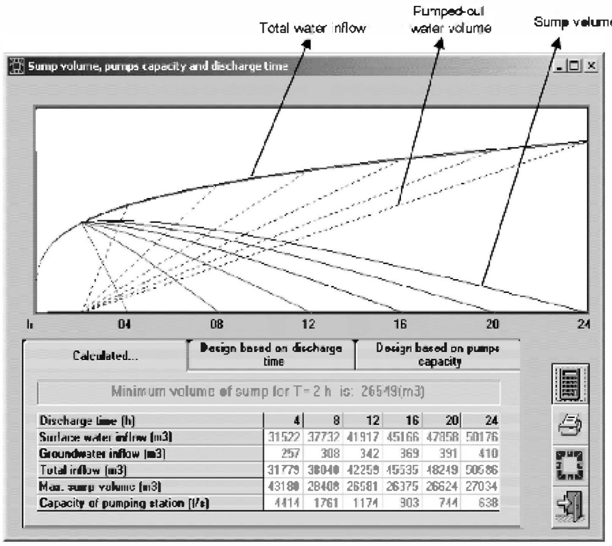


Figure 6. An example of water collection sump sizing

factor. The following elements occurring along the pipeline route can be defined: pipeline narrowing or widening, suction valve, diaphragm, sharp elbow, curve, gate, butterfly valve, cut-off valve, and throttle. During the interactive procedure, all local resistance factors are recorded. Values for the total local losses, the required capacity, head and power of pumping station are also displayed within this module, as shown in Figure 8. Finally, an overview containing the pump QH (capacity-head) curve is aimed at attaining the highest level of system availability possible.

The final phase in the outlined approach includes system evaluation and possible modification. All parameters of the system obtained through monitoring must be compared with designed parameters; when differences are identified, specific changes can be made in the system planning process.

Case Study

This system for design of drainage facilities was tested and applied at the Drmno coal mine (DCM) and the Veliki Krivielj copper mine (VKCM) in Yugoslavia. Both are surface mines. Using our software, we sized the drainage facilities, selected the equipment for excavation, and determined the funds that would be required for purchase of pumps and pipelines. Savings came from reductions in the volume of material that had to be excavated for channels and collection sumps, reduced equipment time, reductions in pump capacity and consequently their size, and reductions in pipeline diameters. The revised drainage facilities produced a net savings of 8% for DCM and 8.12% for VKCM. The solutions were accepted and applied at both mines.

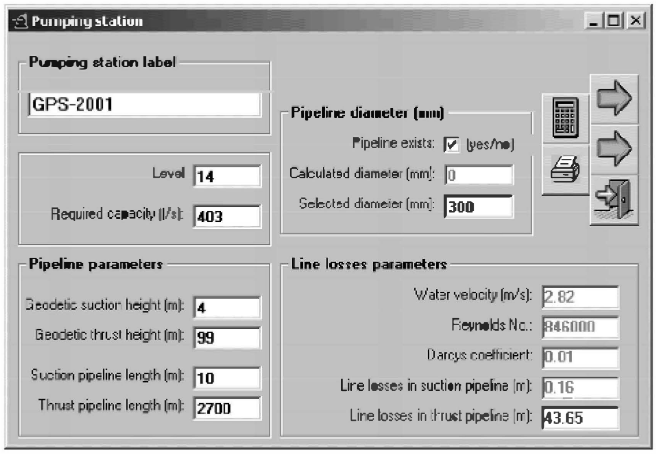


Figure 7. An example of line losses calculation

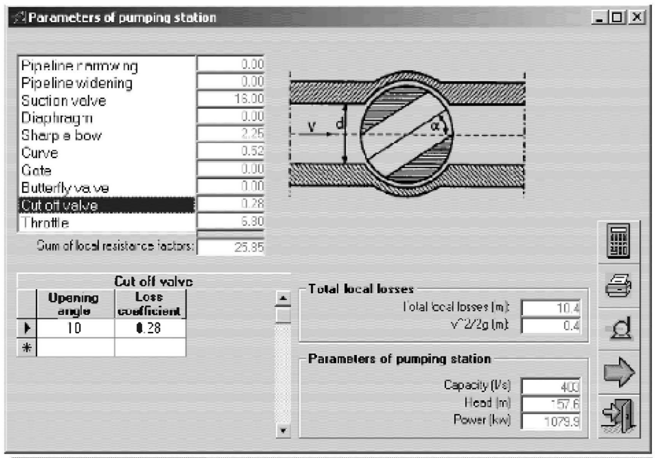


Figure 8. An example of local losses, capacity, head, and power calculation

Data for DCM is presented in Figures 9, 10, and 11. This mine operates in complex hydrogeological and hydrological conditions, where approximately 9 millions m^3 of water is pumped annually from the collection sumps.

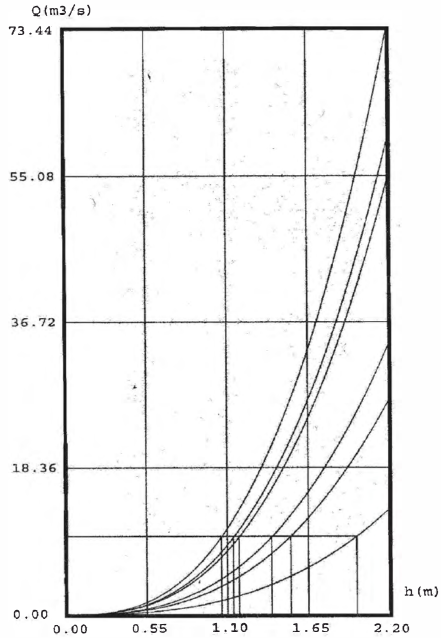
Conclusion

Proper design of drainage facilities decreases the cost of mined minerals and improves safety and working conditions. The process must provide for an optimal combination of all of drainage components, including their design parameters. This paper presents an original approach to the design of surface mine drainage facilities using software developed in object programming language. The software includes a number of modules needed to design the following system components: channels, water collection sumps, and pump station with pipelines. Implementation of the system was illustrated through a case study, using field data related to an existing surface coal mine where the system application resulted in an 8% savings in drainage system investment.

The specialized software focuses on solving a particular design problem, and serves as a vehicle for revealing interdependence between drainage theory and practice. As an integrated system, it can be used to improve the user's ability to understand, model, and control the complex issues related to drainage problems in surface mining. The system could also interest those working in other areas, such as civil engineering, agriculture, environmental engineering, and water management projects. Copies of the software and more details on its application are available from the first author via e-mail.

CHANNEL

Runoff factor: 0.25
Precipitation (mm): 43
Time of precipitation (min.): 50
Inflow area (km^2): 2
Inflow of surface water (m^3/s): 7.16
Additional inflow (m^3/s): 1.02
Total inflow (m^3/s): 8.18
Slope angle (degrees): 60
Relations:
Base width/depth: 1.15
Upper width/depth: 2.31
Cross section area/square depth: 1.73
Roughness factor upon Basin: 1.07
Actual channel capacity (m^3/s): 9.82
Safety factor: 1.2
Total amount of earth to be excavated (m^3):2185
Equipment capacity (m^3/h): 100
Required time (h): 5.41



Sect.	Grad. (‰)	Length (m)	Depth (m)	Base width (m)	Hydr. radius (m)	Basin's coef.	Area (m2)	Velocity (m/s)
1	1.2	75	1.98	2.29	0.99	41.84	6.82	1.44
2	5	43	1.53	1.77	0.76	39.06	4.07	2.41
3	8	164	1.4	1.62	0.7	38.13	3.43	2.86
4	24.8	148	1.14	1.32	0.57	35.98	2.28	4.29
5	37.8	127	1.06	1.23	0.53	35.19	1.97	4.99
6	20.8	225	1.18	1.37	0.59	36.32	2.44	4.03

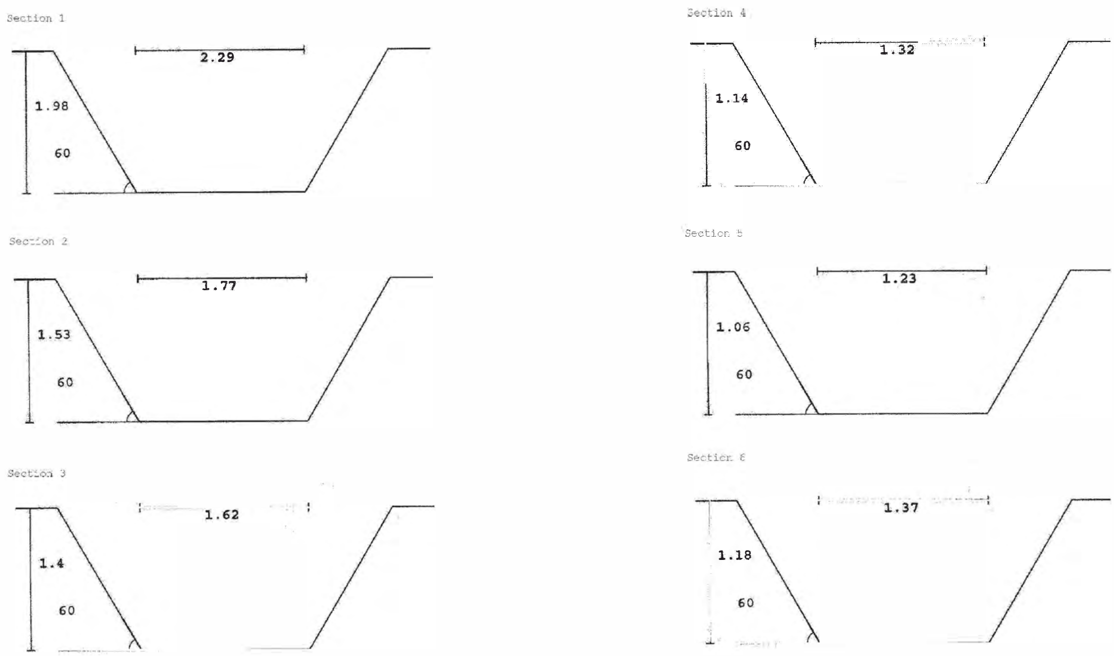
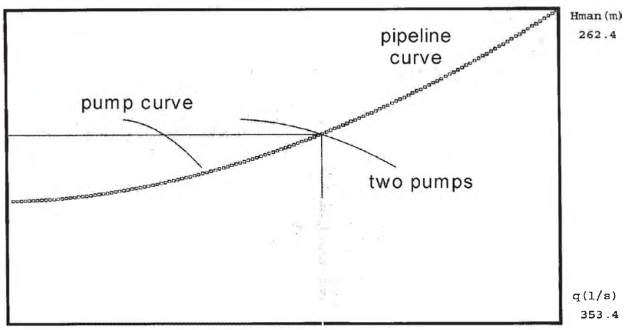


Figure 9. Results of channel design for the Drmno Coal Mine, Yugoslavia



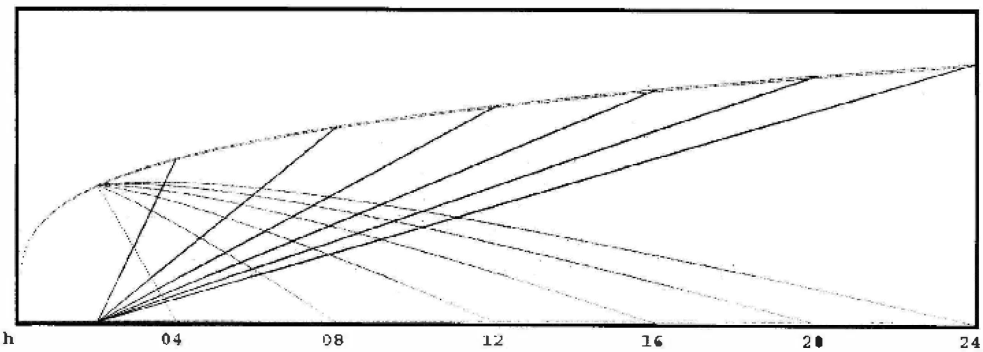
PUMP STATION AND PIPELINE

Required capacity q (L/s): 403
Calculated pipeline diameter (mm): 413
Selected diameter (mm): 300
Geodetic suction height (m): 4
Geodetic thrust height (m): 99

Suction pipeline length (m): 10
Thrust pipeline length (m): 2700
Water velocity (m/s): 2.82
Reynolds number: 846000
Darcy's coefficient: 0.01
Line losses in suction pipeline (m): 0.16
Line losses in thrust pipeline (m): 43.65
Total local resistance factors: 25.85
Total local line losses (m): 10.40
Velocity head V^2/2g (m): 0.40
Pumps capacity (l/s): 403
Head (m): 157.60
Pumping station required power (kW): 1079.90
Number of pumps: 2
Connection: parallel
System capacity (L/s) 201.5
Head (m): 158.3
Required number of pumps in the system: 4

Figure 10. Results of pump station and pipeline design for the Drmno Coal Mine, Yugoslavia

WATER COLLECTION SUMP



Minimum volume of sump for delay T = 0.25 h: 12535 (m^3)

Discharge time (h)	4	8	12	16	20	24
Surface water inflow(m^3)	31522	37732	41917	45166	47858	50176
Groundwater inflow (m^3)	257	308	342	369	391	410
Total inflow (m^3)	31779	38040	42259	45535	48249	50586
Maximum sump volume (m^3)	43180	28408	26581	26375	26624	27034
Capacity of pump station (L/s)	4414	1761	1174	903	744	638

Figure 11. Results of water collection sump design for the Drmno Coal Mine, Yugoslavia

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