International Journal of Surface Mining 3 (1989): 167-174

Groundwater control at Highland Valley Copper

Tony Sperling
Sperling GeoComp Incorporated, Consulting Geotechnical Engineers, Suite 101, 3663 West 16th Avenue, Vancouver, B.C., Canada, V6R 3C3

W.Ken Munro
Highland Valley Copper

R.Allan Freeze
University of British Columbia

ABSTRACT: Groundwater control is a very important component of mining operations at Highland Valley Copper. This paper presents an overview of ongoing engineering studies that are being carried out at Highland Valley Copper to identify the most effective overburden dewatering strategy, a strategy that must result in stable pit walls and a profitable mining operation.

The studies are in progress on four fronts. Foremost, this paper reports on the geologic investigations that have been completed in order to develop a geologic model, the basic building block of other focused geotechnical investigations. Second, interpretation of pump test data with the assistance of a state of the art software package is helping to unravel the hydrologic parameters that control groundwater flow in the overburden. Third, maintenance of the existing dewatering system at optimal performance levels is also a very high priority, achieved by groundwater technicians who monitor the dewatering system around the clock. They rely on a personal computer data base and graphics package to quickly scan the incoming data for indications of dewatering system malfunctions. Fourth, the dewatering system is still in early stages of development. Cost effective design of additional wells to meet depressurization requirements remains the greatest geotechnical challenge at Highland Valley Copper. A three dimensional numerical model capable of evaluating various dewatering alternatives is in early stages of development. Once operational, the model should help to achieve significant reductions in the dewatering budget, a budget that exceeds four million dollars over the next five years.

1 INTRODUCTION

Highland Valley Copper, located 350 km northeast of Vancouver, British Columbia, is a "world class" mining operation. It is currently the second largest copper mine in the world in terms of total tonnage mined per year. Ore is being mined in two pits on the property: at the mature Lornex pit, and at the new Valley pit. The groundwater control program described in this paper is located in the Valley pit.

Development of the Valley porphyry copper deposit commenced in 1982. When completed in approximately 20 years, the Valley pit will have a diameter of 2.5 km and a depth in excess of 750 m. The ore body is situated on the southwest side of the Highland Valley. Pleistocene glacial activity buried a portion of the ore body under a thick blanket of overburden that includes till deposits, fluvial sands and gravels, and glacio lacustrine silts and clays. The resulting overburden geology is complex. The fluvial sands and gravels form three relatively continuous aquifer horizons; each aquifer is confined by much less permeable till and lacustrine silt and clay aquitards. The aquifers are water bearing, with existing dewatering wells yielding 400 to 6000 l/min.

In the northeast sector of the Valley Pit the upper 225 m of the ultimate pit wall will be excavated in saturated overburden material. *Figure 1* illustrates the location of the overburden in relation to the ultimate pit wall. The position of the current pit profile is also shown.

1.1 Groundwater and Operations

The primary objective of the overburden dewatering program is to maintain stability in the very high overburden pit walls by reducing pore water pressures. Groundwater control is also required to limit seepage into the pit. Uncontrolled seepage leads to significant erosion of berms and very poor operating conditions for the truck and shovel fleet. Not all impacts of groundwater on operations are detrimental; because local surface water supplies are limited, most of the process water required by the mill is pumped 30 km from the North Thompson River at a cost that exceeds $1,100,000 per annum. As the dewatering wells come on line local groundwater resources are providing a significant proportion of the water requirement and substantial reductions in water supply costs are being realized.

1.2 Current Dewatering Program

At present the dewatering system consists of 21 wells. *Figure 2* shows the location of the wells in relation to the 1988 pit limits. Most of the existing wells are located within the ultimate pit limits, these wells will eventually be lost as the pit is expanded. Many new wells will be required to adequately dewater the extensive aquifer horizons at depth. The following sections describe the geotechnical data collection and analysis techniques that are being used to design the new installations.

2 OVERBURDEN GEOLOGY

A good understanding of the complex overburden geology is fundamentally important because the geologic interpretation provides the basic building block for all other dewatering and slope design studies at Highland Valley Copper.

2.1 Data Collection / Interpretation

The overburden geologic model is based primarily on information collected during well and piezometer drilling programs completed over the past four years. Logs from 21 wells and 20 piezometer holes comprise this data base. Additional information is derived from surface mapping of pit faces. The mapping information will become increasingly important as the pit progresses to depth.

Figure 1 GEOLOGIC CROSS SECTION OF VALLEY PIT LOOKING NORTHWEST

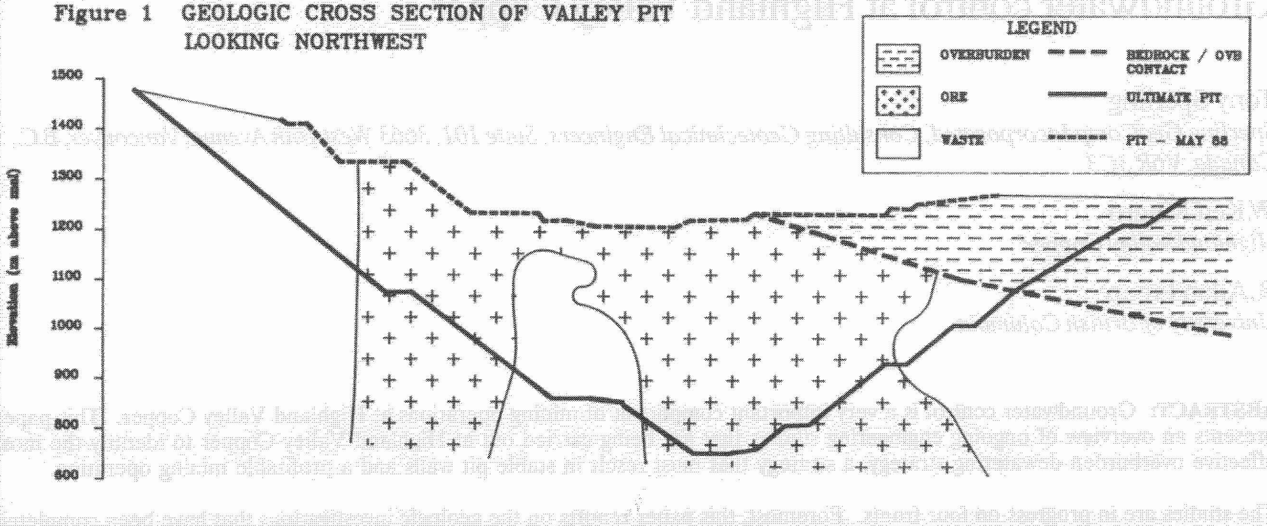
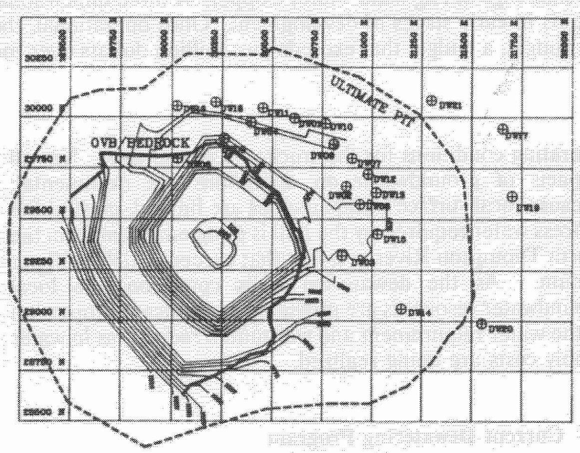


Figure 2 LOCATION OF EXISTING WELLS 1988 PIT CONFIGURATION



Most piezometer holes and small diameter wells are drilled with air-rotary rigs while large diameter wells are completed with a cable-tool rig. Geologic data collection begins with the drillers, who maintain a geologic log, noting each change in lithology and drilling conditions. Grab samples (approximately 15 kg) are also collected at 2 m intervals for future analysis. Later, a representative sample is split from each bag and stored in a small plastic sample cup.

The "cup" samples are logged in detail. Information that is collected includes: 1) geologic description of material, 2) "primary-secondary-tertiary" ranking, and 3) visual estimate of the percentage of each grainsize. Figure 3 is an excerpt from a typical geologic log.

In the "primary-secondary-tertiary" assessment the three most common grainsizes or material types (listed in Table I) are identified in each sample interval. The most common grainsize is recorded in the primary column, the intermediate grainsize is noted in the secondary column, and the third most common grainsize is noted in the tertiary column. For example, "Gravel, sandy, with minor clay seams" would be

Figure 3 Excerpt from Geologic Log DW-17

FROM	TO	CODE	DESCRIPTION	PRIM	SEC	TERT	WTR	MG	FG	CS	MS	FS	SL	CL
155.44	156.97	2g	Graded sand. Dark grey to black, volcanic fragments.	2	0	0	3	0	0	30	45	25	0	0
156.97	158.49	2g	Sand, medium to coarse, gravelly. Clean, dark grey.	2	0	0	4	0	10	30	45	15	0	0
			Gravel is fine, dark, mostly volcanic fragments.											
158.49	160.02	2g	Clay, silty. Dark grey to black, oxidized to dark green	4	3	0	0	0	0	0	0	0	30	70
160.02	161.54	2g	Clay, silty. Dark grey to black, plastic.	4	3	0	0	0	0	0	0	0	40	60

Figure 4 Excerpt from Graphic StripLog DW-17

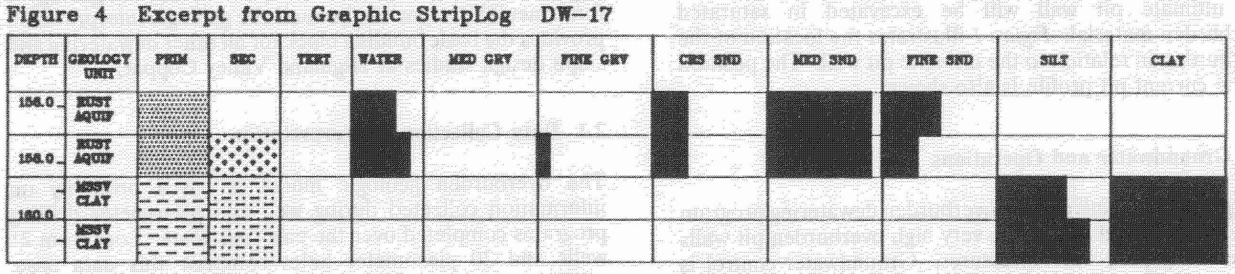


Table I Material Description Codes

Material	Code	Colour
Gravel	1	Orange
Sand	2	Yellow
Silt	3	Brown
Clay	4	Green
Till	5	Blue
Organics	6	Black
Bedrock - Weathered	7	Pink
Bedrock - Fresh	8	Red

coded as "1 2 4". The numeric and colour coding scheme has proven extremely valuable as a correlation tool when constructing geologic cross-sections.

Water bearing potential is indicated on a scale from 0 to 5. 0 indicates very impermeable materials such as clay or dense till, 5 indicates highly permeable material such as coarse, clean sand and gravel.

The descriptive and quantitative observations are entered into SG-CoreLog, a PC based data base and graphics program. The software is then used to process the data and generate coloured "Strip Logs" (see Figure 4) and cross sections. Both types of graphic output are used to update the geologic model as additional drilling information becomes available.

2.2 Geologic Model

Twelve overburden units have been recognized in the Highland Valley to date. The stratigraphic succession of lacustrine silts and clays, glacial tills, and interglacial outwash deposits is given in Table II. In the field the stratigraphic sequence is less ordered as individual layers thin out gradually or are abruptly truncated by paleo-outwash channels. *Figure 5* shows the characteristic interbedded / lenticular pattern observed on a cross valley geotechnical section in the north east design sector. The same pattern is

Table II Stratigraphic Succession

Unit Number	Unit Name	Relative Age
1	Upper Aquifer	Youngest
2	Till-0	
3	Oh-One Divider	
4	Till-1	
5	Silty Aquifer	
6	Till-2	
7	Main Aquifer	
8	Rusty Aquifer	
9	Till-3	
10	Massive Silt/Clay	
11	Till-Basal	
12	Basal Aquifer	
13	Bedrock	Oldest

observed on all other sections constructed to date; sections oriented down valley generally exhibit more continuity and less interbedding than sections oriented across the valley. A gentle, two to three degree down-valley dip is often noted.

Geologic features that will have the greatest impact on the dewatering program and pit-wall design include the Massive Silt and Clay, the Rust Aquifer, the Main Aquifer and the till aquitards.

2.3 Geologic Model Applications

Depressurization of the pit wall in the most economic manner possible is the main objective of the dewatering program. By locating wells in high yielding aquifer horizons such as the Rusty Aquifer and coarse zones in the Main Aquifer the dewatering system will be able to depressurize extensive areas of the pit wall and produce large volumes of process water with a reduced number of wells. Identification of these horizons is an important function of the geologic model.

The Massive Silt and Clay aquitard has been intersected at depth in a number of dewatering wells. Because

Figure 5 OVERBURDEN GEOLOGY – NORTHEAST SECTOR

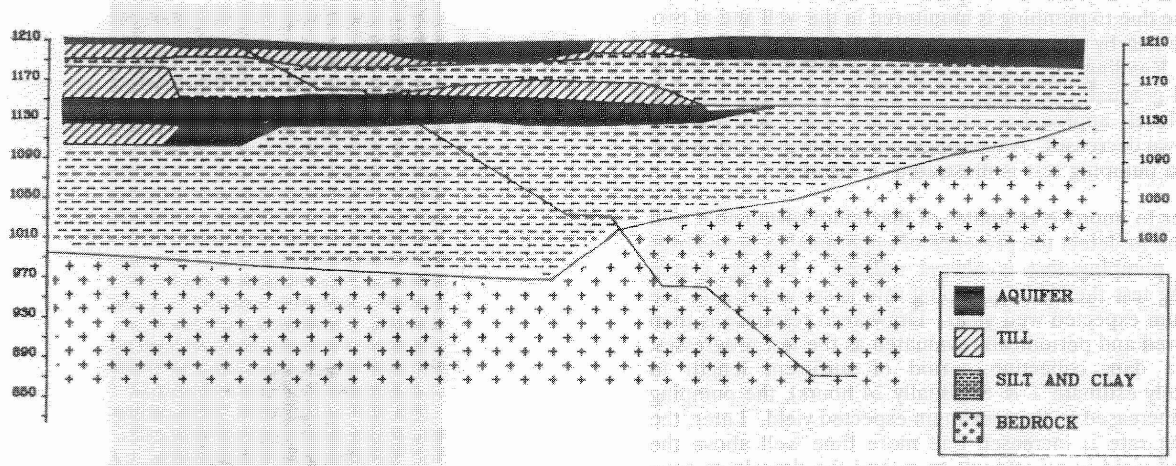
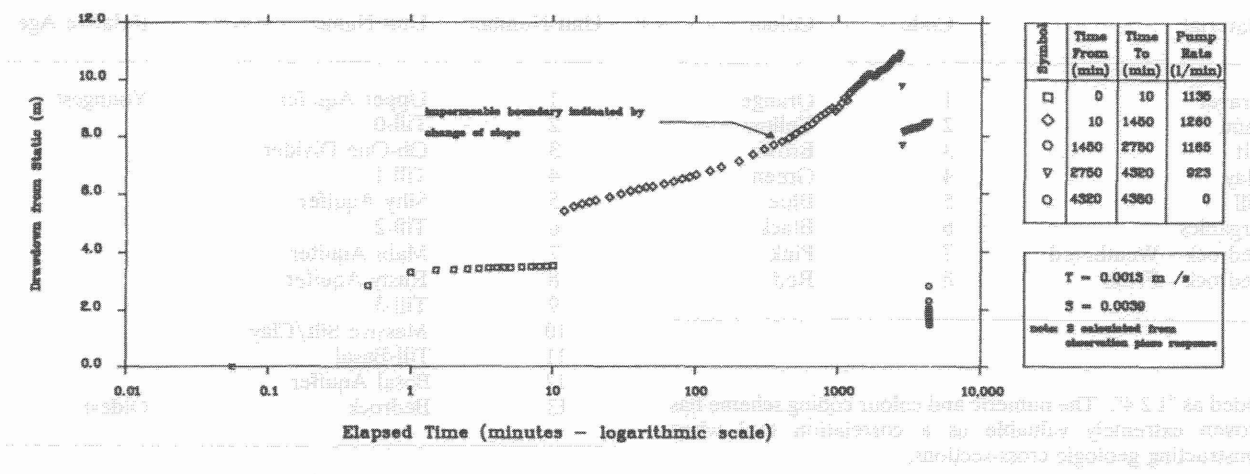


Figure 6 SEMI-LOG GRAPH OF DRAWDOWN RESPONSE – PUMP TEST @ DW-20



depressurization of this low permeability unit will be difficult to achieve pit walls may have to be shallower than in overlying aquifers and till horizons. The latest exploration program focused on determining the extent and strength properties of this problem unit. A geotechnical investigation is currently underway to determine whether it will be possible to depressurize the unit by pumping from the overlying and underlying aquifer horizons.

The geologic model is also being used to predict expected quantities and handling characteristics of each overburden material type. These estimates will play an important part in future selections of excavation and transport equipment.

3 PUMP TESTS

A pump test is completed in each new well on the property. The purpose of pump tests is three fold: 1) to establish the maximum sustainable yield of the well, 2) to estimate hydraulic parameters transmissivity T and storativity S, and 3) to identify the presence of impermeable aquifer boundaries that will reduce long term yield.

3.1 Pump Test Procedures

Each pump test is conducted over a period of two to three days. A submersible electric pump capable of exceeding the expected well yield is temporarily installed. Drawdown response due to pumping is monitored in the well and at two or three nearby piezometers with a conventional water level probe. Readings are taken around the clock, the sampling interval gradually increasing from 0.5 to 50 minutes as the water level approaches steady state and the rate of drawdown decreases. A typical graph of drawdown response during a pumping test is illustrated in *Figure 6*.

In order to improve estimates of maximum sustainable well yield and to detect the presence of impermeable boundaries a step pumping test is always utilized. During a step pumping test the initial pumping rate is set well below the maximum expected well yield. Drawdown response is then monitored and periodically evaluated as the test progresses. After a data collection period of sufficient length to accurately estimate T & S (usually 24 hours), the pumping rate is increased to the maximum expected yield. Later, the pumping rate is increased one more time well above the expected yield in an attempt to extend the drawdown cone as far as possible and detect the presence of distant impermeable boundaries that would affect well yield in the long term. When present, impermeable boundaries can be identified by an increase in the slope of the drawdown trace on a semi-logarithmic drawdown plot as shown in *Figure 6*. Finally, upon completion of the last pumping step the rate of water level recovery is also monitored and used to obtain one additional independent estimate of T & S.

3.2 Automated Pump Test Monitoring

During the summer of 1988 a single channel data logger and a pressure transducer were introduced to measure water levels during pump tests. It was hoped that the data logger would eliminate the need for a technician to monitor the well and piezometers around the clock while providing more frequent and accurate data. The data collection system, illustrated in *Figure 7*, consists of: 1) data logger, 2) pressure transducer, 3) break-out box interface, and 4) portable computer.

During the pump test a pressure transducer is submerged in the well and connected to the data logger. The data logger is programmed to interrogate the transducer at a pre-specified sampling frequency. Again, the sampling interval is increased with time as water levels approach steady state.

Figure 7. Pressure Transducer / Data Logger

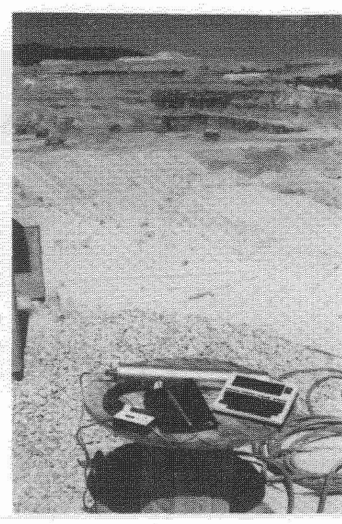
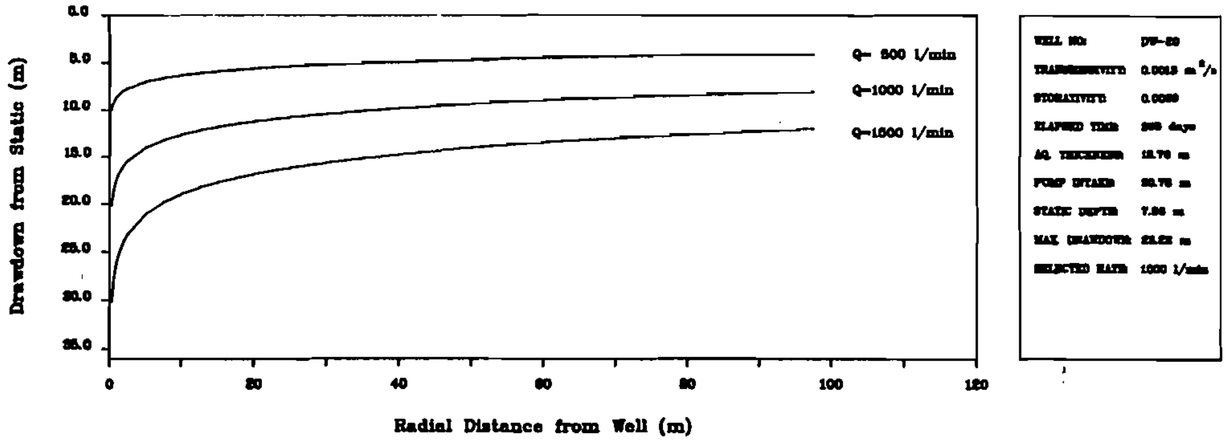


Figure 8 EXPECTED DRAWDOWN AT DW-20 UNDER VARIOUS PUMPING RATES



Twice a day, the information is downloaded from the data logger to a portable personal computer and analyzed by the supervising hydrologist. Flow rate adjustments are made as required.

The automated monitoring approach has proven very successful at Highland Valley Copper, meeting all initial expectations. Because monitoring personnel previously provided by the drilling contractor are no longer required, the mine has achieved significant reductions in testing costs.

3.3 Analysis of Data

The Jacob semi-logarithmic approach is used to analyze pump test data and calculate T and S. However, the Jacob equations require that a single constant pumping rate be used during the entire test. Using the principle of superposition, the equations have been extended to allow analysis of each step of the pump test, including recovery. With the extended equations it is possible to obtain several independent estimates of T and S from one test.

A day or more was required to carry out a detailed pump test analysis using the conventional semi-log graph approach. Personal computer program SG-PUMP was developed at HVC to speed up the interpretation process and allow for rapid analysis of data while the test is in progress . Time/depth observations are entered into the computer from the keyboard or downloaded directly from the data logger. A drawdown plot very similar to *Figure 6* is then generated on the computer screen. Using the cursor control keys the user can quickly select the pump step and best straight line interval to analyze. T and S values are reported instantly by the computer each time a new interval is selected.

After selecting the most representative T and S values and pump intake elevation SG-PUMP is used in predictive mode to calculate the expected drawdown response for a number of possible pumping rates. The drawdown response is calculated using the Theis solution. Only a few iterations are required to establish the maximum sustainable yield of the well, a pumping rate that will maintain the water level a few meters above the pump intake in the long term. *Figure 8* shows expected drawdown curves for three possible pumping rates at DW-20. Based on the predicted drawdown response a pump capable of 1000 l/min against a total dynamic head of 20 m was selected for this well.

3.4 Hydraulic Parameter Model

Pump tests provide the most reliable estimates of hydraulic properties in the sub-surface. Because the wells are widely spaced pump test results are supplemented with additional hydraulic conductivity estimates from a number of sources when compiling a hydraulic conductivity cross section or plan. The sources include:

- falling head tests conducted in piezometers
- air lift inflow estimates during drilling
- estimates of K based on grainsize distribution
- qualitative estimates of K based on drill cutting inspections during logging

The long range goal is to develop a three dimensional block model of overburden hydraulic parameters and other material properties that will be compatible with the existing geologic model of the ore deposit. The block model will be accessed for a number of applications that include: 1) numerical modelling of groundwater flow, 2) slope stability evaluation, 3) mine planning, 4) excavation equipment selection and 5) reclamation planning.

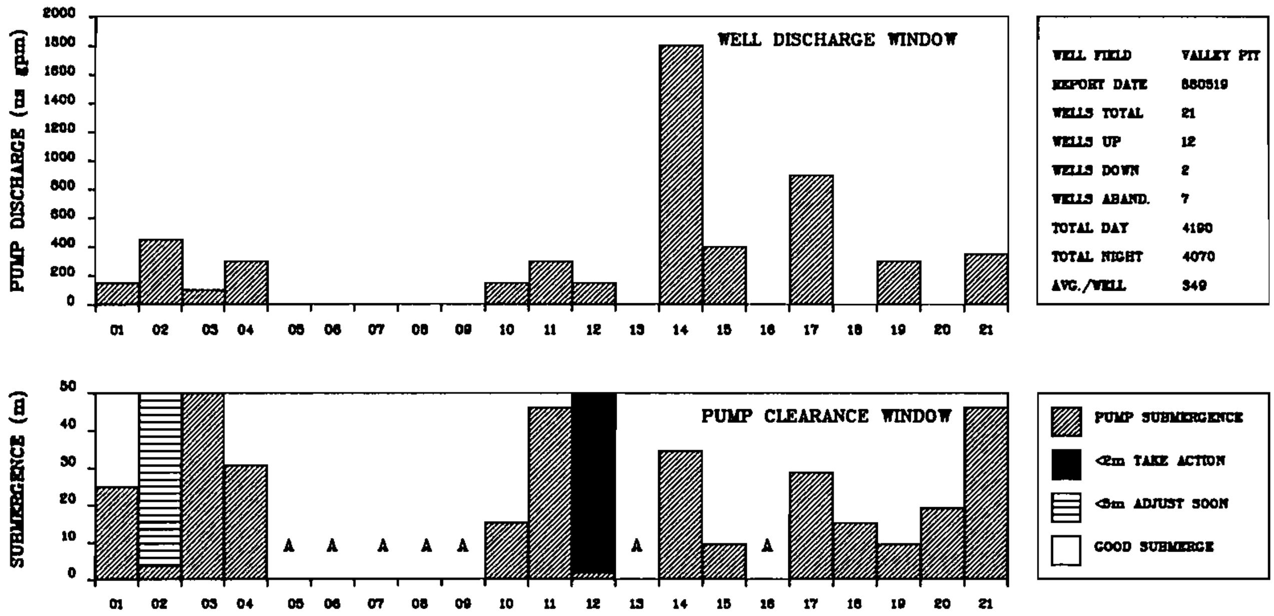
4 MONITORING

Monitoring of dewatering wells and piezometers is an important part of the groundwater program. All operating wells are monitored twice daily to ensure that they are pumping at optimum levels and that there is no danger of any well going dry. Piezometer readings are taken once a week to evaluate dewatering progress and ascertain that the water table is being lowered well in advance of mining activity. A personal computer is used extensively to store and analyze the large amount of information that is collected. The feasibility of a remote telemetry system capable of performing the well monitoring function is under investigation.

4.1 Monitoring Procedures

Maximum dewatering yields are realized when a steep hydraulic gradient is established toward each pumping well. To achieve the steepest possible gradient water levels in pumping wells are maintained 5 m or less above the pump

Figure 9 WELL FIELD STATUS REPORT



intake. Precautions taken to ensure that no pump goes dry include a low flow and low pressure sensor and twice daily monitoring of the water level in each well. Parameters that are monitored include:

- Water Level in Well
- Flow Rate
- Cumulative Flow
- Pressure at Well Head
- Current Drawn by Motor
- Cumulative Hours of Operation

4.2 Computer Data Base

Upon completion of his rounds, the groundwater technician enters collected data into SG-MONITOR, a groundwater data base program that is used to store observations and generate a daily status report, illustrated in *Figure 9*. The report summarizes the total amount of water produced and the amount of submergence in each pump. Colours (shown as different hatching styles in *Figure 9*) are used on the video display to alert the groundwater technician when a well is nearly dry. A blank field indicates that the pump is well submerged, widely spaced hatching means that the pump is approaching a dry condition and should be adjusted, and solid hatching warns of a dangerously low water condition requiring immediate corrective action.

The computer software also allows groundwater personnel to study current and historic performance of the dewatering system. Performance graphs generated on the video display help to identify wells that are improperly adjusted, poorly sized, or gradually wearing out. For example, a comparison of two identical pumps operating under similar total dynamic head showed that one pump was producing at approximately 1/3 the rate of the other. Provided with performance statistics, the pump supplier quickly identified the cause of

Figure 10 GRAPH OF PUMPING RATE VS. TIME AT DW–21

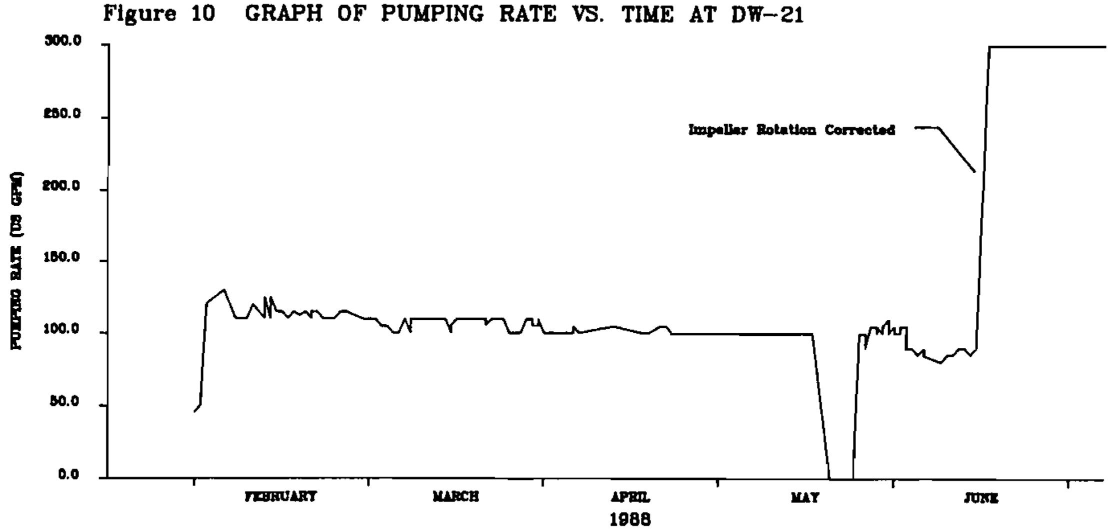
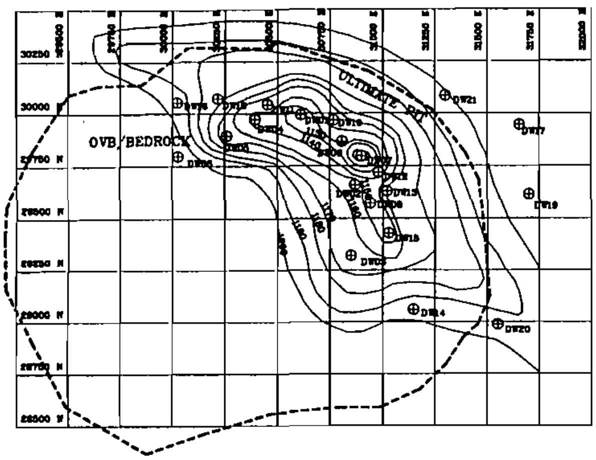


Figure 11 PIEZOMETRIC SURFACE
MAIN AQUIFER – 1988



the problem as reverse polarity on the power cables that caused reverse rotation of the impeller. *Figure 10* shows how corrective action resulted in an increase in flow from 100 to 300 gpm.

Water levels in stand-pipe piezometers and pressure readings from pneumatic piezometers are also entered into the groundwater data base. Graphs of water elevation vs. time and contour plots of the potentiometric surface in each of the four overburden aquifers (illustrated in *Figure 11*) help monitor dewatering progress and identify areas where the rate of drawdown is inadequate and additional dewatering wells are required.

Access to historic monitoring records will prove very useful in the design of future dewatering wells, especially as input and calibration data for a numerical aquifer model. Representative pumping rates for each well will be obtained from pumping rate vs. time graphs. Calibration of the numerical model will be achieved by comparison of predicted potentiometric surfaces generated by the computer program to actual observed surfaces, such as *Figure 11*.

4.3 Telemetry Concept

At present, all monitoring is performed manually. Four groundwater technicians are employed to monitor wells around the clock to ensure that the dewatering system is operating at peak efficiency. A feasibility assessment of an automatic telemetry system that would monitor and adjust each well as required has recently been initiated. The telemetry system would consist of a number of data logger units, one located in each pump house. The data logger would periodically query sensors monitoring each of the six performance parameters. The information would be relayed via HF radio to a central computer in the mine engineering office. The computer would automatically check that all parameters are in a pre-specified range. If discrepancies were detected the computer would trigger a warning system or take corrective action such as shutting down the well.

5 COMPUTER MODELLING

Subsurface investigations have shown that geologic conditions are complex and response of the aquifer system to pumping will be difficult to predict with conventional analytical methods. Estimates of well influence based on the Theis equation and T & S values obtained from pump tests suggest that effective radius of influence is approximately 125 m. The current six year dewatering plan, utilizing a well spacing of 200 m, calls for an additional 30 wells to be developed in two concentric rings around the ultimate pit perimeter. The cost of the drilling program will exceed four million dollars.

Detailed predictions of pore pressure response to various well configurations and pumping schedules can be achieved only with a computer model of groundwater flow. By using the model to experiment with different well spacings and depths in each unique geologic domain it will be possible to identify a dewatering strategy that will minimize the total meterage to be drilled while achieving pre-specified drawdown responses in all areas of the overburden pit wall.

Before selecting a computer model, efforts were focused on collecting sufficiently detailed data on geologic conditions, hydrologic parameters, and the historic response of the aquifer system to pumping for verification / calibration purposes. After developing a good understanding of the real geologic system to be modelled it was possible to compile a list of features and capabilities that the numerical model would require. These included:

- horizontally layered geologic system
- hydraulic conductivity contrasts within layers
- large hydraulic contrasts between layers
- transient response
- transient seepage face boundary condition at pit wall
- variable mesh spacing (high node density in area of interest)
- up to 60 dewatering wells

The USGS - MODFLOW software package was selected for the simulations because it is capable of modelling each of the important field conditions noted above. Because the software has been used extensively by members of the UBC Groundwater Group and is widely applied elsewhere in industry we have confidence in model reliability and accuracy. Therefore, less time had to be devoted to computer program development, debugging and verification, and proportionately more time was spent on collection of accurate input parameters.

At the time of writing this paper the model was still in early stages of construction and simulation results could not be included.

6 CONCLUSION

Overburden pit walls as high as 225 m will be excavated in the Valley pit at Highland Valley Copper. An effective overburden depressurization program is a critical component of the pit wall design. It is required to improve slope stability, minimize seepage and erosion at the pit face, and maintain trafficability on working benches.

This paper has reviewed key geotechnical investigations for the design of this dewatering system. To date, investigations have focused on compiling existing data from four years of drilling and monitoring at the site and synthesizing this information into an accurate geological and hydrologic model.

Important features of the geologic model include a 125 m thick, massive silt and clay aquitard at depth that will be difficult to depressurize, local lenses of highly permeable alluvial fan deposits of the Rust Aquifer with well yields over 6000 l/min, and semi continuous till aquitards that impede vertical flow and create perched water table conditions in the upper aquifer horizons. SG-CoreLog, a geologic data base and plotting program, has proven very useful in analyzing the complex geologic conditions at the mine site.

Stepped pump tests are completed in each production well on the property. Test results are analyzed with computer program SG-Pump to obtain estimates of aquifer transmissivity, storativity, and expected long term well yield. A pressure transducer and data logger system has recently been introduced to automatically monitor water levels in the well and eliminate the need for continuous test supervision.

Dewatering wells are monitored twice daily by groundwater technicians to verify that each well is operating under optimum conditions and no well is in danger of running dry. A personal computer is used to store and analyze the large amount of information that is collected. Piezometer readings are taken and evaluated once a week to check on dewatering progress. The potential economic and technological advantages of an automated telemetry system have been recognized. A system that monitors pump performance and controls flow will likely be installed in the near future.

Control of groundwater will become progressively more important as the Valley pit expands to depth and overburden pit walls are steepened to the ultimate pit configuration. Having established the subsurface conditions, efforts are now being directed to development of a numerical groundwater flow model of the site. The model will facilitate prediction of groundwater responses to different dewatering designs and selection of the most effective dewatering strategy.

REFERENCES

Cooper, H.H., and C.E. Jacob. 1946. A generalized graphical method for evaluating formation constants and summarizing wellfield history. Trans. Amer. Geophys. Union, 27, pp. 526-534.

Freeze, R.A. and J.A. Cherry. 1979. Groundwater. Prentice-Hall of Canada Ltd. Toronto, Ontario, pp 304-378.

McDonald, M.G. and A.W. Harbaugh. 1984. A modular three-dimensional finite-difference ground-water flow model. U.S. Department of the Interior, U.S. Geological Survey National Center, Reston, Virginia.

Sperling T. and R.A. Freeze. 1987. A risk-cost-benefit framework for the design of dewatering systems in open pit mines. 28th U.S. Symposium on Rock Mechanics, Tucson, Az., pp. 999-1007.

Sumer, S.M., J.J. Elton and J.A. Tapics. 1987 Dewatering optimization using a groundwater flow model at the Whitewood Open-Pit Coal Mine, Alberta. Proceedings, 40th Canadian Geotechnical Conference, Regina, Sask., pp. 79-87.

Theis, C.V. 1935. The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage. Trans. Amer. Geophys. Union, 2, pp. 519-524.