

# THE ECONOMIC CHALLENGES OF DEWATERING AT THE VICTOR DIAMOND MINE IN NORTHERN ONTARIO, CANADA

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## ABSTRACT

The challenges of mining economically have never been greater than under current global financial conditions. The costs and efficiency of dewatering are particularly important at De Beers Canada's Victor diamond mine in northern Ontario where:

- 1) the bottom of the water-bearing carbonate country rocks is near the bottom of the planned pit, limiting the available drawdown in perimeter wells;
- 2) the majority of inflow to the wells comes from a very limited number of discrete zones in the carbonate rocks, resulting in low hydraulic efficiencies of the wells;
- 3) line power to the mine is limited, mandating efficient pumping over a wide range of yields and lifts; and
- 4) the relatively isolated northern setting and extreme cold winter temperatures (which can reach -40 to -60 deg C) present logistical issues (e.g., insulation of wellheads and pipelines, and having to truck in heavy materials over an ice road during a relatively short period of time).

The hydrogeology of the Victor mine area was characterised over three relatively short winter field seasons using packer tests, pumping tests, step-drawdown tests, and downhole logging (particularly production or "spinner" logs) to define the lateral and vertical variation in the hydraulic conductivity of the carbonate aquifer. Based on analysis of the resulting data, wells were designed and submersible pumps with variable frequency drives were installed.

Two 3-dimensional numerical groundwater flow models were constructed:

- 1) a "sub-regional" model to simulate the long-term effects of dewatering on aquifer conditions and on local rivers and creeks. This model was used for the feasibility study for the mine and in support of the mine permitting process; and
- 2) a near-pit "window" model to simulate groundwater conditions in the immediate vicinity of the mine. This model incorporates detailed local variations in the hydrostratigraphy and the construction and pumping performance of individual wells and is used as a management tool to optimise pumping from the dewatering system.

These models are used in tandem to direct design of the dewatering system, evaluate its effectiveness, and to predict long-term environmental effects.

In January 2009, seven dewatering wells were pumping at a combined rate of about 84,000 m<sup>3</sup>/day with the goal of maintaining water levels 15 m below the bottom of the pit. By January 2009, the ratio of m<sup>3</sup> of water pumped to m<sup>3</sup> of material excavated was about 9.8:1.

## 1. INTRODUCTION

The Victor diamond mine is located in northern Ontario in the James Bay Basin, a structural depression of Cambrian- to Ordovician-age sedimentary rocks within the main Canadian Shield craton (Figure 1). Unlike the other currently operating diamond mines in Canada -- Ekati, Diavik, and Snap Lake (all of which are in the Northwest Territories) -- which are surrounded by relatively low permeability crystalline rocks, the country rocks surrounding the Victor mine are primarily limestones and dolomites. The significant, but discrete nature of the permeability of these rocks has posed the greatest challenge to designing and implementing an efficient dewatering system for the mine.

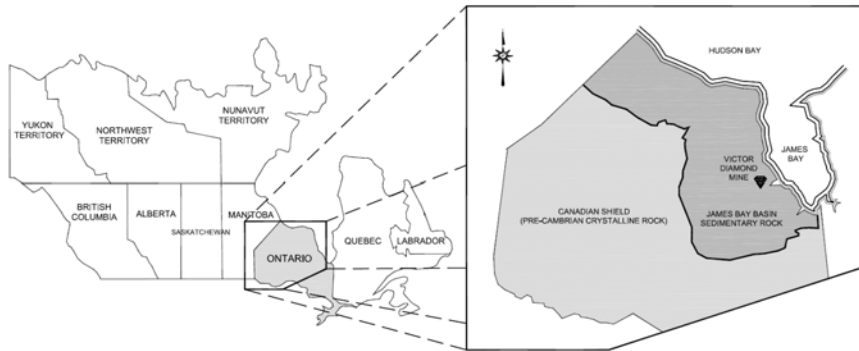


Figure 1. Location of Victor diamond mine

## 2. HYDROSTRATIGRAPHY OF COUNTRY ROCKS AT VICTOR MINE

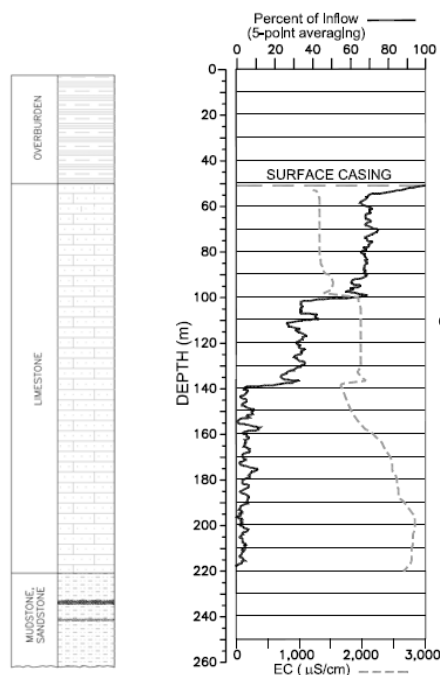
The hydrostratigraphy of the country rocks surrounding the Victor mine area was characterised over three relatively short winter field seasons (usually limited to the coldest months of January through March when drilling equipment could be moved around on the frozen muskeg) using packer tests in coreholes, pumping tests, and step-drawdown tests in a prototype dewatering well. The most valuable tool in defining the discreteness and vertical variation in the permeability of the carbonates aquifers was production (or “spinner”) logging. This was done on site by mine personnel or consultants using small portable equipment (Figures 2a and 2b) that was purchased because it was not economically feasible to bring in a logging subcontractor who would have spent the vast majority of his time on stand-by.



a) Winch and datalogger



b) Impeller on logging tool



c) Typical production log

Figure 2. Production (“spinner”) logging

A typical production log of the various wells, shown in Figure 2c with the production normalised to 100%, indicates that essentially all of the production from any well came from a very limited number -- in this case three -- of discrete zones. It should be noted that such discreteness had not been detectable by any of the previous core logging and packer testing, so the production logs became a most valuable and definitive tool.

## 3. HYDRAULIC TESTING OF DEWATERING WELLS

The discrete nature of the permeability leads to a major problem in being able to pump both effectively and efficiently from the wells. First and foremost is the flow in the discrete fracture zones (most likely micro-karstic bedding planes) becoming non-Darcian or turbulent near the borehole. Figure 3 illustrates the components of so-called two-regime flow that can occur around a well producing from fractures (Atkinson et al., 1994).

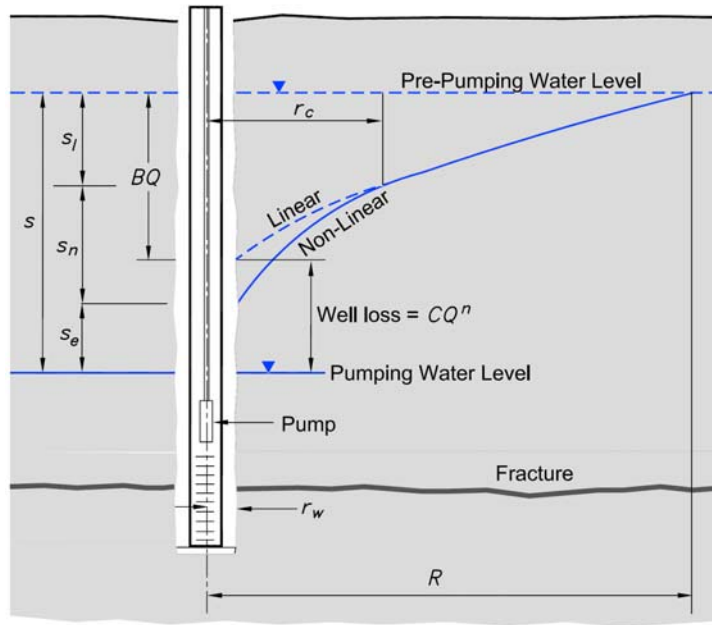


Figure 3. Components of drawdown in a well producing from fractures

The total drawdown in such a well is described by:

$$s_t = s_l + s_n + s_e \quad (1)$$

where:

- $s_t$  = the total drawdown in the well,
- $s_l$  = the hydraulic head lost due to viscous drag as the water moves through the fracture at relatively low velocity in the laminar flow region,
- $s_n$  = the head lost due to non-laminar (or non-Darcian) flow in the fracture in the relatively high velocity region in the immediate vicinity of the well,
- $s_e$  = the “entrance losses” or the head lost through the screen and gravel pack,
- $R_c$  = the critical radius, the distance at which the flow transitions from laminar to non-laminar,
- $R$  = the so-called radius of influence (the distance at which there is relatively insignificant drawdown), and
- $r_w$  = the radius of the borehole.

The relationship is usually determined by a step-drawdown test (Figure 4a) and the results are expressed in terms of

$$s_t = BQ + CQ^2 \quad (2)$$

where:

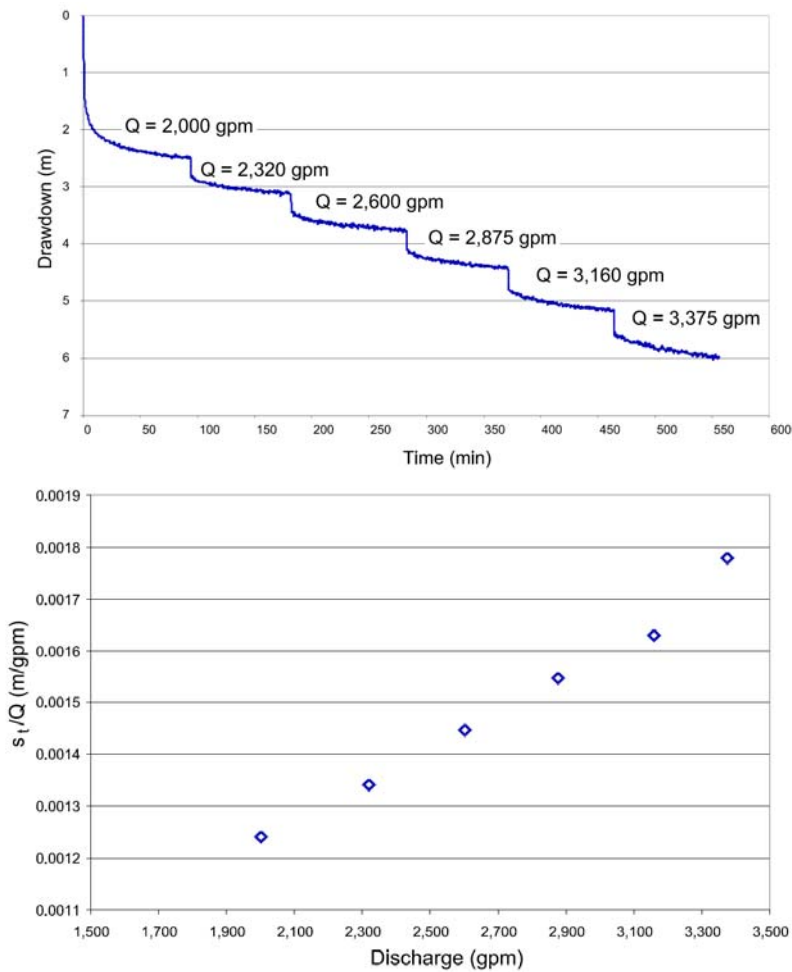
- $Q$  = pumping rate,
- $B$  = the so-called laminar flow coefficient, and
- $C$  = the so-called non-laminar flow coefficient,

in any dimensionally consistent set of units. A very useful analytical solution for converting data as shown in Figure 4a into the form of Equation 2 is *FASTEP* (Labadie and Helweg, 1974).

Based on Equation 2, it is easier to graphically visualise the relationship in terms of specific drawdown, defined by:

$$\frac{s_t}{Q} = B + CQ \quad (3)$$

When the results are plotted then in terms of  $s_t/Q$  vs.  $Q$ , the nature of the flow becomes immediately obvious from the shape of the curve as shown in Figure 4b.



a) Plot of drawdown vs. time (arithmetic) of step-drawdown test

b) Plot of specific drawdown vs. discharge

Figure 4. Results of step-drawdown testing

As should be apparent from Equation 3, there would have been a horizontal segment (with an  $s_i/Q$  value equal to B) if the flow were primarily laminar. However, as shown in Figure 4b, the flow in a typical Victor dewatering well is completely non-Darcian in which  $s_i/Q \approx CQ$  where  $C$  is the slope of the essentially linear curve in Figure 4b.

#### 4. DEWATERING CONSIDERATIONS

The practical -- and most deleterious -- significance of the non-laminar flow is shown in Figure 5. At Victor, the bottom of the carbonate aquifer is coincidentally about the depth of the proposed pit. Even if there were no well losses, there would be some "freeboard" at the bottom of the wells; and the composite drawdown with little or no well losses would be as shown in Figure 5. However, if non-laminar flow is significant, a major portion of the drawdown occurs only within a very short distance of the wellbore (often less than one m!). This component of drawdown does not propagate as drawdown in the formation. This results in the water levels in the highwalls of the pit being much higher with the consequence of greater inflow to the pit. This inflow -- referred to as residual passive inflow (RPI) -- would occur much earlier in the mining process if there are high well losses. In addition to contributing essentially nothing to dewatering, the well losses also add considerably to the pumping lift in each well and, hence, the cost of pumping (as will be discussed further below).

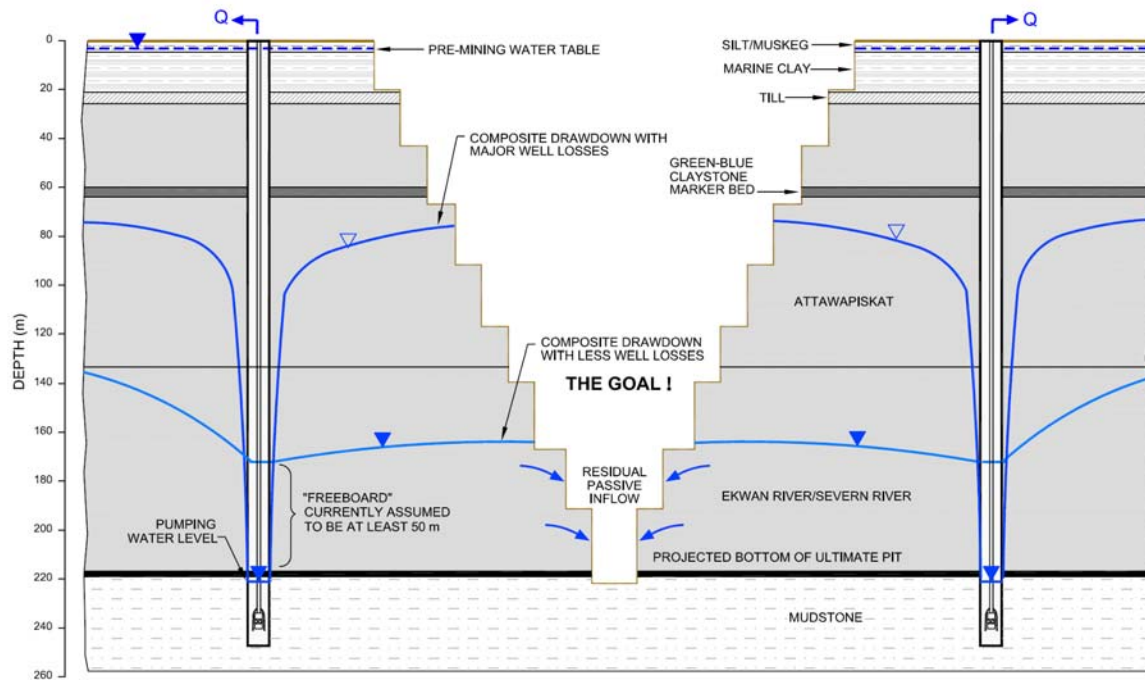


Figure 5. Effects of well losses on dewatering

As part of the environmental permitting process and to design and evaluate the effectiveness of the dewatering system for the Victor mine, two numerical groundwater flow models were constructed using the 3-dimensional finite-element code *MINEDW* (Azrag et al., 1998):

- 1) a “sub-regional” model to simulate the long-term effects of dewatering on aquifer conditions and on local rivers and creeks. This model was used for the pre-feasibility and feasibility studies for the mine and in support of the mine permitting process; and
- 2) a near-pit “window” model to simulate groundwater conditions in the immediate vicinity of the mine. This model incorporated detailed local variations in the hydrostratigraphy around the pit and the construction and pumping performance of individual wells (defined by the step-drawdown tests) and is used as a management tool to optimise pumping from the dewatering system.

As shown in Figure 6, the sub-regional model predicted the amount of water that would need to be pumped to maintain a dry pit as long as possible. These predictions were used to design the water discharge system (e.g., pipeline sizes) and for obtaining discharge permits. The occurrence of significant RPI beginning about 2017 will have to be addressed. During the winter months at Victor the temperatures can reach -40 to -60 degrees C. This creates logistical problems when trying to remove problematic sump water during the winter from the active mining areas.

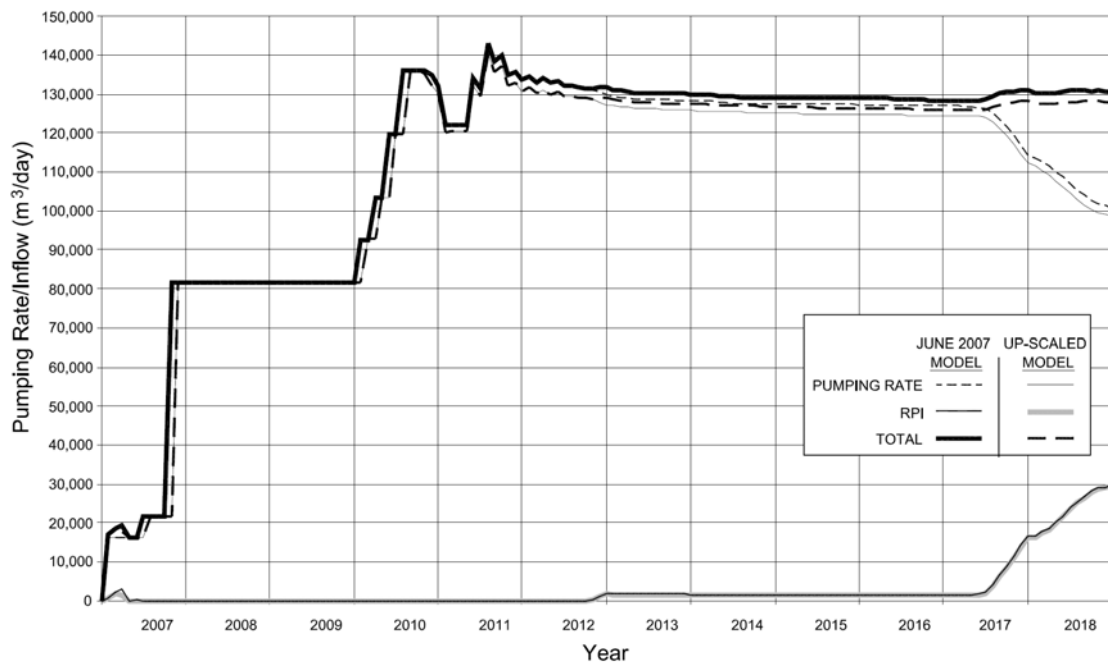


Figure 6. Predicted dewatering rates and residual passive inflow with time

The window model is being used to direct the short-term implementation of the dewatering. Line power to the mine is limited, and a critical consideration is minimising the power requirements for dewatering. As shown in Figure 7, the goal is to maintain the water level beneath the pit to 15 m below the lowest mining elevation at any point in time. To accomplish this, pumps would only be brought on line and pumped at the minimum rates to maintain this target. This would save money in unnecessary power consumption of well field pumping operations.

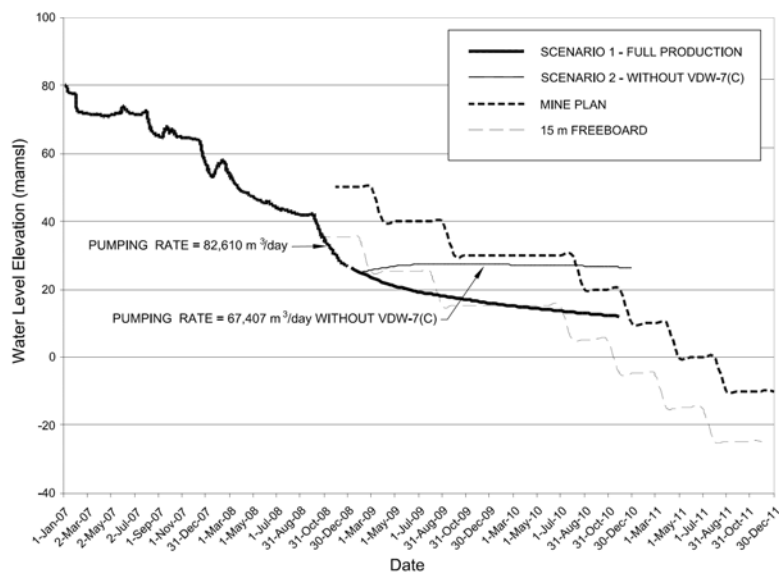


Figure 7. Goals and optimisation of dewatering

One of the greatest challenges to dewatering at the Victor mine is the delivery of well completion materials to the mine. Long lead times are required for the delivery of heavy pumps and motors, and oversized items. These must be shipped to the site during a brief window of time (about 60 days) every winter when an ice road to the mine is operational. The first round of pumps had to be ordered before the testing programme was complete.

All of the pumps were equipped with variable frequency drives (VFDs) to maximise the range of their performance envelope. This enables the pumps to operate under variable pumping conditions to avoid damage to the pump bearings (i.e., operating in either an up-thrust or downthrust condition) and to minimise power consumption. Simply valving back the discharge from the wells would be a waste of energy.

Using the regional and window models, another major goal is to accurately predict the timing for construction of any new wells based on the required pumping flow rates. Value is added by using these models to construct the dewatering system in various stages, thus deferring capital infrastructure costs and the raising of this money or shortening the term of any loans. As well, the time in between phases of construction allows for the collection of additional data that continually improves model predictions for future planning/construction.

Figure 8 shows a performance curve -- sometimes referred to as a tornado curve -- for one of the pumps. The black dot indicates the flow rate vs. total dynamic head (including lift, hydraulic losses in the pump column, and wellhead back pressure) under the optimal operating conditions of the well for the targeted dewatering described above. In the case, the pump is operating within the recommended performance envelope (shown by the dashed lines on either side of the maximum efficiency conditions indicated by the solid) at a frequency of 35 Hz as controlled by the VFD.

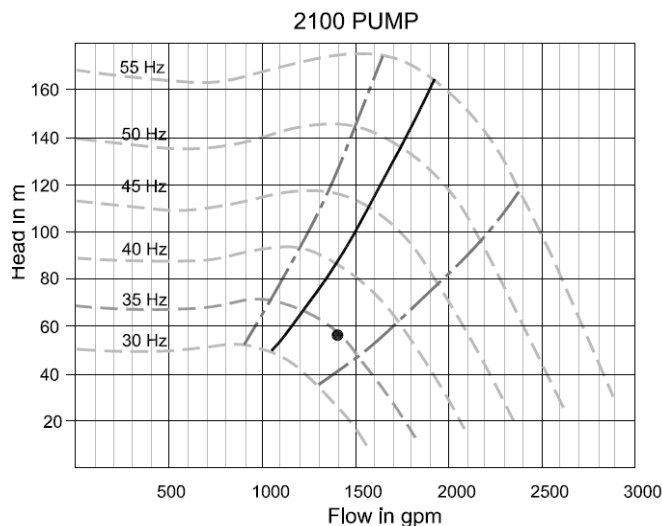


Figure 8. The performance of a pump with a variable frequency drive

As of January 2009, seven dewatering wells were pumping at a combined rate of about 84,000 m<sup>3</sup>/day at the Victor mine, meeting the goal of maintaining water levels 15 m below the bottom of the pit. At that time, the ratio of m<sup>3</sup> of water pumped to m<sup>3</sup> of material excavated was about 9.8:1.

### FUTURE DEWATERING AT THE VICTOR DIAMOND MINE

As indicated in Figure 6, it is predicted that potentially problematic RPI will begin during the last two years of mining. This assumes that the hydraulic efficiency of the wells will be as high as possible given the limiting hydrogeologic conditions described above, certainly not a given. Another major uncertainty at this time is what will happen as the main water-bearing zones are “orphaned” (i.e., the water levels in the wells drop below them).

The window model will continue to be updated with discharge and water-level data from the dewatering system and a series of monitoring wells. Again, the main goal will be to pump the minimum amount of water at the minimum cost to maintain acceptable water levels beneath the pit and to keep the pit as dry as possible for as long as possible.

In the future, the pit perimeter dewatering wells will most likely need to be supplemented with in-pit wells (Figure 9). These wells would be completed into the lower part of the carbonate section where production logging indicates no major water-bearing intervals. Consequently, hydrofracturing is being considered for these in-pit wells.

Even though they are not major water-producing units, there are sandstones within the mudstones beneath the main carbonate aquifer. It is not anticipated that the dewatering of the overlying carbonate rocks will depressurise these units to any significant degree. Thus, if future slope stability analyses suggest it would be worthwhile, angled depressurisation wells could be completed into these units from the lower benches of the pit.

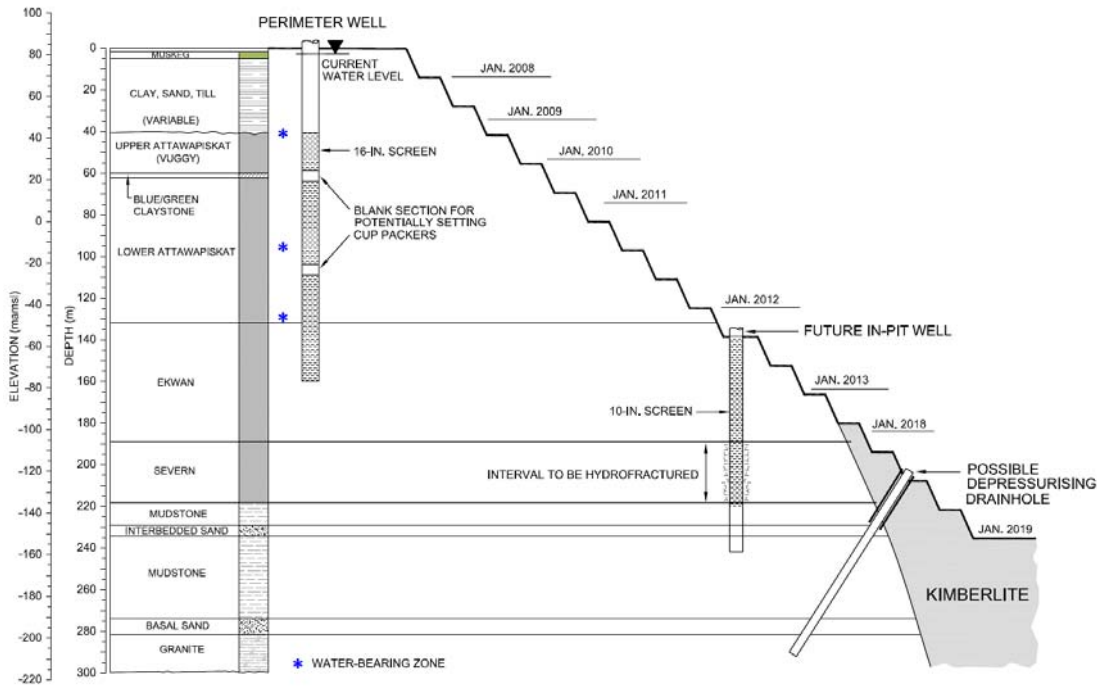


Figure 9. Future hybridised dewatering

This proposed future dewatering system at the Victor diamond mine will comprise a hybridised system composed of perimeter wells, in-pit wells, drainholes, hydrofracturing, in-pit pumping, and grout curtains, designed to be as effective and efficient as possible under very challenging hydrogeologic, climatic, and logistical conditions.

## 5. ACKNOWLEDGMENTS

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