Mine Dewatering Process: Improvement Strategies on Existing Systems

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Abstract: Water, an essential fluid for the mining progression, eventually finds its way to the bottom of the mine due to the effects of gravity. Expulsion of water is not simple and in fact is complicated due to a number of complex issues such as water build-up in the underground mine. By mapping water build up through out the mine identifies where problem areas are allowing for mechanical or geological means of diverting stagnant water to sumps. A coal mine in Australia has experienced inefficiencies and reliability problems with the current dewatering process. This study investigated and discussed the causes for the inefficiency. The optimum conditions relating to functionality, as well as environmental sustainability are discussed. Mapping of water flow is done in order to identify hazardous areas. Dewatering process model and its calculation, and methods of water quality improvement are elaborated. Strategies and the roles of maintenance leader for efficient dewatering system is developed, discussed and recommended for the mine authority.

Key-Words: Mine dewatering process, improvement strategies, dewatering model, hazardous areas

1 Introduction

Mining is a booming industry in the Australian market. Finding efficient ways to mine will ultimately reduce the cost of the mining process, whilst increasing the income and riches of Australians. Essential to any operating mine is the dewatering process whereby water is expelled from the mine. The efficiency and effectiveness of this process is directly proportional to the operating cost of the mine [1]. Vital to the engineers and supervisors overseeing the dewatering process is to know the parameters in which the dewatering system operates. A functional specification of the dewatering system involves water mapping of entire dewatering process and calculating water flows into and out of pumping stations. Consequently as the mine expands its production, the dewatering system finds itself in unknown territory.

The mine in this study had two working sites, arbitrarily named as Mine North and Mine South. Both mine north and south covers accumulatively 24 different levels with each level having a diameter of approximately 1km. Southern end of the mine is much deeper and was established long before northern mine. There are pump stations at different levels i.e levels 16, 14, 12 and 10 as shown in Fig. 1. At level 10 another high head, positive displacement type pump can be found connected in parallel with each other from which water is pumped directly to the tailings dam. North mine has a single pumping station at the bottom of the mine on level 15C. It consists of 3 positive displacement (PD) pumps connected in parallel from which the water is pumped to level 10 at Mine South. Level 10 pump Station is where water from the north and south of the mine combines and gets pumped straight to the tailings dam on the surface.

For the existing system, the parameters relating to efficiency, effectiveness, cost and critical functionality under optimum operating conditions are all unknowns. It is not even known what flow rates of water are being expelled or consumed by the reference mine over periods of time. Through out the mine certain sections or drives remain flooded causing not only operation difficulties but also serous health risk issues such as drowning, acid burning, tripping and many other common injuries. These areas need to be mapped and then determined how to best transport this water via means of gravity to a pumping station. Water seeping through rock to eventually find its way to the bottom of the mine is poor practice as the fluid becomes acidic or alkaline prior to being pumped, thereby causing not only mechanical pumping issues but also environmental issues.

This study revealed that there are imminent problems within the mine de-watering process. Expulsion of process water that filters down the mine is a difficult process due to the accumulation of impurities, complex dewatering flows and high head requirement of pumps due to underground mining requirements and limitations [2-4]. The common consensus is that the current dewatering systems are not performing at their peak. Stagnant water flow to the pumping stations needs to be improved. The benefits of this could be that flooding of certain drives underground can be eliminated. The added advantage is that the water would not be rich with acidic properties or with mud thereby extending the life of pumps and reducing operating costs. Equally as important is determining the dewatering capability of the pumping system as a whole.

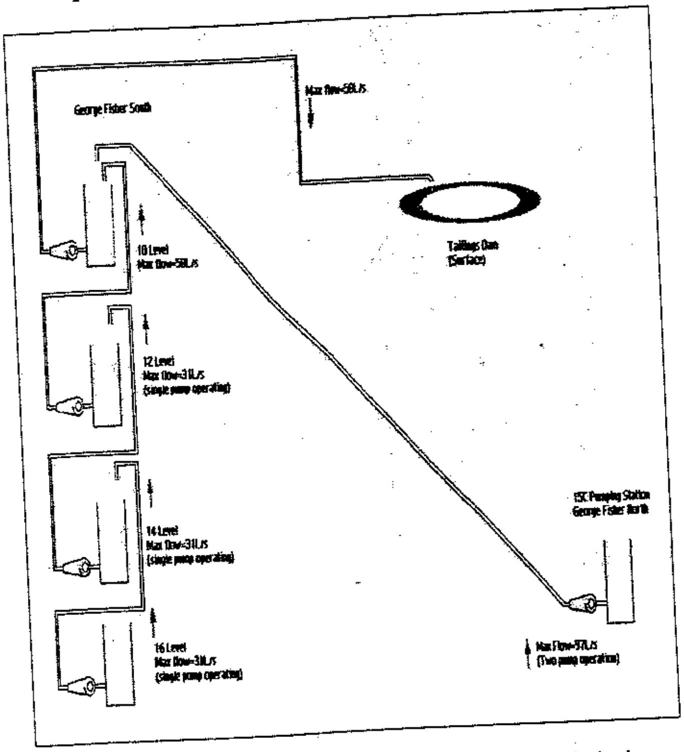

Fig.1: Different levels of pump stations and their maximum dewatering capability

The current pumping system is expensive to maintain and needs to be conducted more cost effectively. Certain high maintenance areas need to be targeted and effectively analysed to find an improved maintenance strategy. Finding a better pumping solution to the current system would involve mapping not only the pumping process water lines but also the gravity lines proposed to feed the pumping stations. By exploring these points a much more thoughtful system can be planned for in the future savings not only on maintenance costs but also infrastructure with an added benefit of environmental conservation due to reduced acidic levels.

Once it has been established where it is best to capture water in large quantities, a suitable system of water pumping can be designed. Currently the pumping system does not run efficiently and as such reliability centred maintenance issues need to be addressed in order to increase the efficiency of the current dewatering system. Eventually, a recommendation should be made in a manner where all personnel including the maintenance fitters through to the managers are able to retain a sense of ownership towards the dewatering system. This study presents water flow mapping and identify hazardous areas. Then how the water is expelled from the mine through means of efficient pumping systems is investigated. Strategies for improved dewatering system are developed and discussed.

2 Water Flow Mapping and Hazardous Areas

The ultimate goal of water mapping is to gain an appreciation as to which areas of the mine are flooded hence making regions inaccessible, dangerous and inoperable. Prior to this study no formal hazardous area identification had been conducted, hence creating hearsay arguments amongst maintenance and production departments, with no progression taking place in solving water problems. Water mapping of Mine North and South has been completed and plotted on "Mine Site" *(Software used by the Mine to model mining progress)* as shown in Fig. 2. Shaded area has been identified as flooded area. Inherently water has resided in mine South most likely due to poor mining practices dating back to the 1970's, whereby drives were not drilled to certain pitches coupled with associated frequent irregularities. In an ideal world these drives need to be redrilled however due to financial reasons this is not a viable option. However, Mine North does not have major water build up problems due to the gradient of new drives and associated modern mining methods.

The most logical solution to this predicament is to allow time for Geologists, Rock Mechanic Engineers, and Mining Engineers to find out if it is possible and financially viable to drill sump holes to drain flooded areas. Should the mining experts fail in their attempts to drain and expel water to localised points for dewatering reasons mechanical means such as "flygt" pumps can be employed to dewater certain areas of the mine prone to flooding [5, 6]. Flygt pumps are not the first choice in guiding and sending water to localised points for a number of reasons. The maintenance costs on these pumps would be high due to the erosive nature of the large amounts of sediment contained in the trapped water [4, 7]. It is to be noted that supplying electrical power to these pumps would be difficult due to the awkward physical position of the pumps. i.e. a single pump may be kilometres away from the closest electrical power source. Pneumatically driven pumps might be the answer, but these are expensive to run and air hoses still need to be linked from the pump to an energy source. As such it would be logical to first explore geological methods of water transfer. An automatic reduction in acid levels in the water having financial, environmental and safety cost benefits can be achieved by eliminating stagnant water.

The important advantage for mapping waterlogged areas in the mine is to create a system whereby stagnant water can be drawn to localised areas for water expulsion. The guidance of water to localised areas can be performed by preferably geological means or secondly mechanical means. A range of centrifugal as well as positive displacement (PD) type pumps can be employed to expel water from the mine once it has been accumulated to centralised points [8]. Currently the system is only capable of maintaining the present dewatering requirements. It is however not known what the full capacity of the dewatering system is as no functional specification is available in the mine. This information is crucial to future strategic planning, development and increased production. Maintenance as well as operational costs for the dewatering system is considered high. Engineering principals need to be applied to identify the viability of maintenance and operations targeted savings.

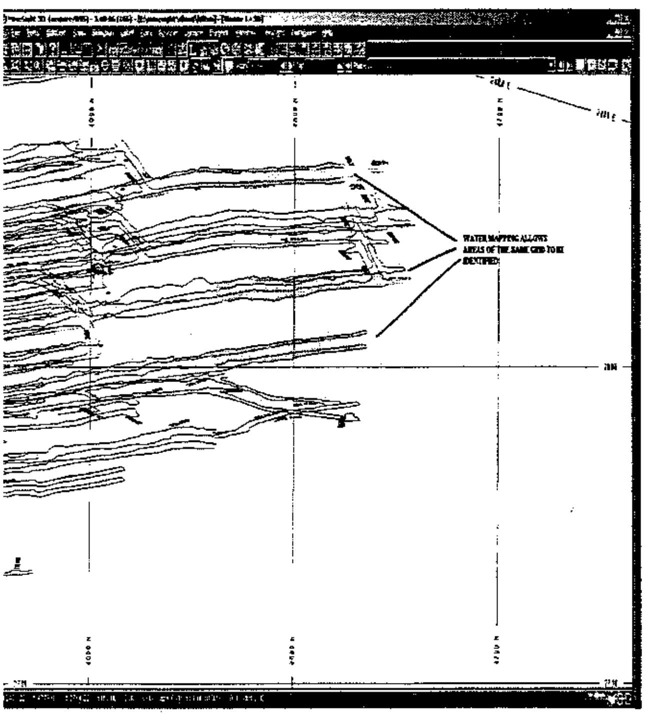

Fig. 2: Mine water accumulation map

3 Theoretical Considerations

3.1 Dewatering Model

A suitable dewatering/pumping system is required to determine the maximum possible process water flow rates out of the Mine. This information is essential for planning for the future dewatering demands, as well as establishing a maintenance strategy. Bernoulli's equations were used to determine duty curves of the pumping system [9, 10]. The equations used were:

$$E_p = (Z_2 - Z_1) + \left(\frac{P_2}{\gamma} - \frac{P_1}{\gamma}\right) + \left(\frac{V_2^2}{2g} - \frac{V_1^2}{2g}\right) + Losse \qquad (1)$$

Where, E_p is the required pump head which can be converted to fluid energy required by the pump impeller, Z is the elevation level at the designated point (in meter), P is the pressure acting at the designated point (in Pa), V is the fluid velocity in the pipe (in m/s), and Losses is the summation of pipe and fitting losses of the system (in meter).

The flow rate (Q) was assumed conserve, given by,

$$Q = AV \qquad (2)$$

where, A is the cross-sectional area of pipe in m^2 and V is the fluid velocity in m/s.

Pump power, in kW, can be determined by,

$$Pump\ Power = \rho g Q E_p \qquad (3)$$

Cavitation (NPSHA, the net positive suction head available) and specific speed (N_s) check was done by,

$$NPSHA = \frac{P_o}{\rho g} - \frac{P_v}{\rho g} - Z_s - h_L \qquad (4)$$

Where P_o = atmospheric pressure (Pa), P_v = vapor pressure fluid (in Pa), Z_s = height of suction side (in m) and h_L= head loss in suction side (in meter).

$$N_s = \frac{N\left(Q^{\frac{1}{2}}\right)}{\left(gE_p\right)^{\frac{3}{4}}} \qquad (5)$$

Where N = speed of pump in rad/s

Losses were calculated as follows:

$$h_L\ pipe\ friction = f\frac{L}{d}\frac{V^2}{2g} \qquad (6)$$

$$h_L\ valves = k_L\frac{V^2}{2g} \qquad (7)$$

$$h_L\ enlargement = k_L\frac{(V_1 - V_2)^2}{2g} \qquad (8)$$

Where f = pipe friction factor, L = length of pipe (in meter), V = velocity of fluid (in m/s), d = internal diameter of pipe (in meter) and k_L = valve friction factor.

3.2 Model Calculation

The following steps were used to calculate system head curves:

1. Appropriate flow rates (in l/s) were chosen to calculate fluid velocity using Eq 2 for each pipe id change. Point 1 (inlet) and point 2 (outlet) were marked.
2. Elevation levels and pressure conditions of points 1 and 2 were recorded.
3. Pipe, valve and fitting losses for the fluid system were determined using Eqs 6, 7 and 8. k_L factors were obtained from manufacturers specifications [11].
4. E_p (pump head) required to overcome frictional losses was calculated using Eq 1.
5. Pump power was calculated using Eq 3. This power can be converted to electrical energy of motor with respect to pump and electrical motor efficiency and power factor.
6. Cavitation check of the pump was done by using Eq 4. If NPSHA>NPSHR {NPSHR from pump charts}, cavitation shall not occur.
7. Specific speed check was done using Eq 5 to evaluate what type of pump is required for this design.
8. Steps 1 to 7 were repeated for a range of flow rates to produce E_p results. E_p vs flow rate were plotted on a certain pump chart. Intersection between E_p and impeller curve gives duty point. Duty point also gives NPSHR and pump efficiency and power from intersection of relevant graphs.

4 Results and Discussion

Currently, two types of pumps, called Denver Orion and National Oilwell, are being used in the mine dewatering process [1]. Pump flow curves have been obtained for all pumps located in the mine. All pumps excluding the PD pumps on levels 10 and 15C are Denver Orion HM Slurry pumps. "Svedala" the company distributing Denver Orion pumps only have pump flow curves available for single Denver pumps. The Denver Orion's in use at mine have all been connected in parallel, consequently the pump flow curves would be different for a single pump as opposed to two of the same pumps connected in parallel. A theoretical means must be sought to finding a pump flow curve for two pumps in parallel. It should be noted that the parallel connection is only employed in emergency situations.

Operational data on PD pumps have been collected. The type of pipes transporting fluids as well as the paths being followed and number of bends and fittings in piping etc are known. Using the model equations presented in section 3, the dewatering capabilities of each pump station have been calculated. Once the maximum flow rates have been established for each individual pump a dewatering flow rate can be accurately calculated for the entire mine. Additionally maintenance issues need to be addressed regarding the pumping situation. The Denver Orion pumps are operating at high speeds and cause large amounts of wear. According to maintenance work orders mechanical seals are a costly item ($6000 per single replacement). If a second pump was to be connected in series both pumps together would be operating at a slower operating speed whilst achieving the same duty point. As such, more efficient pumping can take place as power is not dissipated in wear but rather proportionally in greater work.

The PD pumps on levels 10 South and 15C North appears to suffer from sleeve, valve as well as seat damage. The valves and sleeves show excessive wear. This wear is a direct cause of particles in the process water measuring greater than 6mm [4]. These particles are caught in between the valves, seats and sleeves when the valves open and close. Consequently the stones and particles are crushed thereby creating wear in the valves, seats as well as the sleeves. The only present means of cleaning water prior to it entering the positive displacement pumps is by screening the water through what is known as a trommel screen. The trommel screen removes large particle sizes yet unfortunately lets through smaller sized particles still measuring greater than 6mm in diameter. It is these particles that cause damage to the valves of the PD pumps

The maximum dewatering rates for the Denver Orion pumps as well as the National Oilwell pumps were calculated. The following parameters are known for level 10 pump station: Number of turns in pipe above surface = 10, Number of turns below surface = 2, Pipe diameter = 0.2metrs (internal), Pump type= 300TP-8m type size 5"*8" and Max operating pressure = 7033 kPa. The calculated duty curve of level 10 pump is shown in Fig. 3. Similar calculations have been done for other pumps too. It is to be noted that level 10 Pump station transports water not only from Mine South but also from Mine North. Level 10 pump Station has a maximum dewatering capacity of 58L/s. The maximum possible flow rate from 15C to Level 10 is 97L/s, this figure combined with 31L/s dewatering rate from level 12 indicates that level 10 pump station could have an influx of 128L/s of water. This bottleneck effect could be cause for concern and should be considered in the long term planning strategy. It is very important to note that the level 10 pump station having three 300TP-8M *(National Oilwell)* pumps connected in parallel would not produce any more flow if a fourth pump had to be added in parallel also, as the pumps are already operating at their maximum allowable pressure whilst producing 58L/s of process water flow.

Net Positive Suction Head (NPSH) is the difference between suction pressure and vapour pressure at the pumps intake whilst the pump is in operation. In a positive displacement type pump a minimum NPSH is required to open and close the inlet valves and also to overcome the friction losses and acceleration head within the pump liquid end. Of course in a rotary or centrifugal type pump NPSH is required to push the cavities created by the impellers [4]. If appropriate NPSH is not provided by the system the fluid (fluid being pumped) will cavitate or boil as it flows in the pump. As the vapour flows to areas of higher pressure it will condensate back to water. The collapse of vapour bubbles occurs with significant impact, enough to impinge on the surfaces of metal and hence to break out small pieces of material. The described phenomenon is called cavitation damage. The shock created by bubble collapse may even be severe enough to break a crank shaft.

Since water normally contains dissolved air, the vapour pressure of the solution is higher than for de-aerated water, but is often overlooked when NPSH calculations are performed. The Hydraulic institute recommends an NPSH margin of around 20Kpa for power pumps in systems where the pump age has been exposed to gas other than the liquids own vapour [4]. In the event that changes to the feed system of either positive displacement type pumps or centrifugal type pumps be considered, careful thought should be placed into how an appropriate NPSH will be supplied to the pumps, possibly "primer" pumps need be considered.

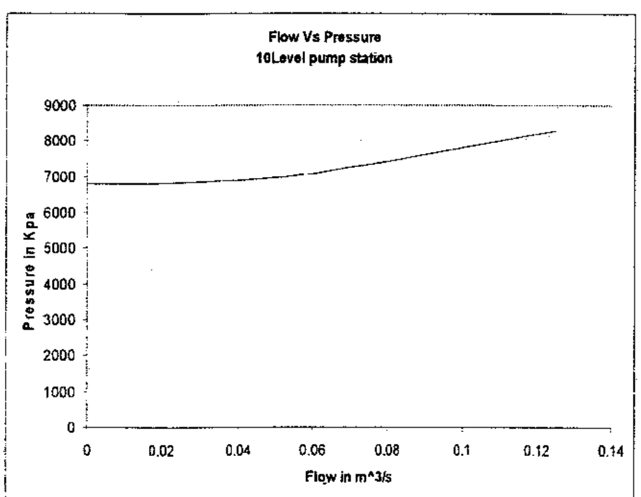

Fig. 3: Duty curves for Level 10 Pump

4.1 Pumping Directly from 15C to Tailings Dam

Of interest to the mining department are the comparisons of costs in pumping directly from Mine North to the tailings dam instead of pumping via Mine South 10 Level pump. Calculations proved that it is not viable to attempt pumping from Mine North to the tailings dam as the existing pumps are grossly undersized for this operation. The pumps are only capable of producing pressures that would support a column of water halfway to the surface from 15C. The only way it would be possible to pump from 15C to the tailings dam would be if the pump station was significantly upgraded. Another practical factor and financial factor hindering the direct pumping proposal is the cost associated with drilling a hole nearly a kilometre deep to 15C in order to make pumping possible. It is financially a smart decision not to endeavour in pumping from 15C Mine North to the surface.

4.2 Optimal Connection of Denver Orion Pumps

Calculation demonstrates that the Denver Orion pumps operate at a duty point where the pumping efficiency is approximately 53%. This means that 47% of the power going into the pump is not put to work but rather causes wear and contributes to inefficiencies such as Eddie currents etc. It can be seen from the pump curves that the maximum efficiency of the Denver Orion pumps is in the vicinity of 67% [1]. This value is still low considering that most centrifugal water pumps operate in the locality of 80% efficiency. Upon consultation with Svedala *(suppliers of the Denver Orion pumps)* it was made clear that the pumps are in fact slurry pumps and due to the nature of the water being transported need bulkier impellers etc thereby reducing the efficiencies. 67% maximum efficiency seems low and it is in the Maintenance's department favour to explore avenues like connecting the pumps in series, to increase head and reduce unnecessary wear as explained earlier.

Normally a pump can be slowed down to operate at its most efficient duty point. This however is not possible with the current Denver Orion pump setup as the head needed to pump exceeds the maximum efficiency value. Experimental work can be carried out whereby pressure gauges are connected in the water line with two Denver Orion pumps connected in series. Flow values can be measured as well as power consumption values thereby creating a pumping system that could be as much as 14% more efficient. Should more efficient pumps be available this figure could be increased to as much as 26%. Bearing in mind that as much as 26% less power would be needed to pump the same amount of water, savings can be made not only directly on power bills but there would be 26% less wear on expensive mechanical seals. Usually the "ball park" costs for operating and maintenance of Denver Orion pump is: 45% operating cost, 45% maintenance cost and 15% initial investment cost. A reduction of 26% of the total maintenance cost as well as operating costs is a substantial savings.

4.3 Water Quality Improvement

The main issue clouding the operation of the positive displacement pumps on level 10 Mine South and 15C Mine North is poor quality of water. Trommel screens have been employed on Level 10 Mine South with some success. Due to the large hole sizes in the trommel screen copious amounts of grit is able to flow through the trommel screen and into the positive displacement pumps. Large particles cause wear in the valves, seals, seats and cylinders [4]. It is expected that particles over 6mm in diameter would need to be removed from the process water in order to reduce operating and maintenance costs. The cheapest method of extracting large particles from the water would be to install a settling dam on level 10 Mine South. The settling pond or dam will extract large particles in the water due to the effects of laminar flow together with gravitational effects.

The settling ponds need only to remove large particle sizes that would otherwise be crunched between the pumps valve and polyurethane seals causing damage. As the positive displacement pumps are designed to pump "dirty water", clear water is not a necessity, and may even be a hindrance as the settling ponds would accumulate up to 0.85 meters of sediment in a one month time period at the bottom of each pond. When a settling pond has been saturated with sediment it needs to be "mucked out" and the sediment taken to either back fill small stopes or be taken to the surface as waste material. The cleaning out frequency is heavily dependant on the amount of "grit" taken out of the water.

A settling pond can be installed on level 10 with relative ease as an existing "drive" can be closed up curving around the P49 Shaft (Fig. 4). Water may be allowed to flow in one end in a "dirty" condition and flow out the other end after settling in a "clean" condition. Inevitably a settling pond needs to be constructed on level 10, when this happen water will no longer flow into the positive displacement type pumps with an adequate NPSHA. For this reason primer pumps will have to be employed thereby eliminating cavitation and other related effects.

4.4 Maintenance Strategies

Reactive maintenance forms the current cornerstone of the maintenance strategy surrounding the Denver Orion pumps and to an extent the National Oilwell pumps. When the pumps seize to work, maintenance is carried out. Reliability centred maintenance issues need to be employed whereby thermocouples are placed in bearings, oils etc. as well as pressure gauges installed in the discharge pipeline. As the temperature rises in the bearings or the water discharge pressure reduces *(indicating warn impellers)* a planner would be able to schedule maintenance on the pumps in a far more efficient manner than the current system allows for.

Reliability centred maintenance issues can once again be applied to the PD pumps, whereby pressure sensors be installed on the discharge line as well as thermo couples be installed on critical bearings. By allowing planned maintenance to occur rather than reactive maintenance, efficiency will be increased and downtimes reduced. The pressure sensors will not only indicate what efficiency the pumps are operating at but will also indicate if impellers have been warn out when for example the efficiency gradually reduces. Many sensors such as flow meters or pressure meters (where installed) are not in working order as evident in mine control documents. By having a trend of information available, planners will be able to schedule replacement of items such as bearings, impellers and mechanical seals. By employing such methods one can ensure that there are no late night call outs to repair pumps.

By and large the best method of maintenance improvement is to create ownership amongst the people working with the pumps on a daily bases. Their specific knowledge is valuable and the maintenance department needs to mobilise its resources by motivating the maintenance fitters. The supervisors are at the forefront of this task and they inturn need to have mobilised funds and resources available to them.

4.5 Long Term Mining Development Strategies

A strategy needs to be developed by the mining department on exactly where and how long term mining development will take place. By knowing precisely where the mine will be expanding towards will ensure that an appropriate pumping system be installed in Mine North and to a lesser degree Mine South. Essentially one needs to know if 15C pumping station will be able to cope with an influx of even greater amounts of water. Currently 15C pumping station is more than capable of coping with the volume of water passing through its system.

Level 10 Pump however could prove to be a bottle neck where water from Mine South and Mine North are combining. Currently the system is only able to cope with the amount of water, however should water flow increases to higher than expected values, maintenance need to be aware of the predicament in order to plan for the future.

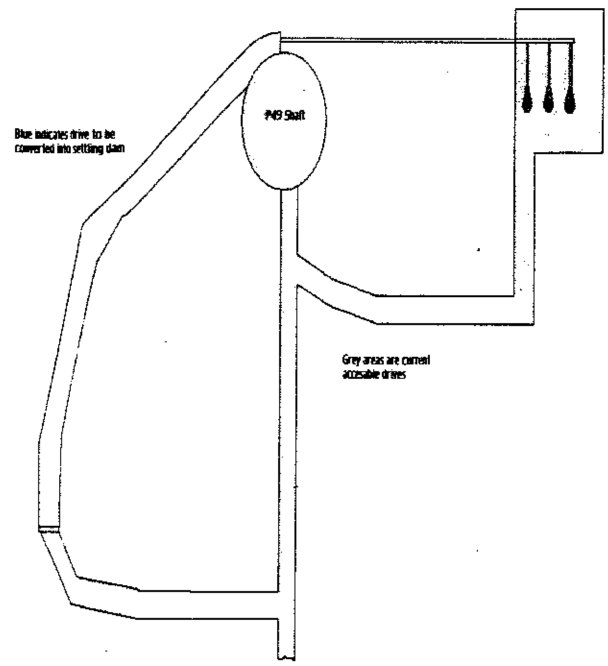

Fig. 4: Proposed settling pond on Level 10 prior to water being fed to pump station

4.6 The Maintenance Leader's Role in Strategic Change

Often strategies which are devised by consultants or strategic planning departments fail to be implemented correctly. Lost money is spent on analyses and strategy formulation that yield very little results other than fancy power point presentations and managerial reports [12]. Organizational behaviour is often at the forefront of such circumstances influenced by the culture of that organization. When the organization attempts to implement a new strategy due to a change in circumstances, it finds itself in a difficult situation in trying to remain competitive. Russell and Beer [12] suggest that "an organization as a whole must be able to coordinate the efforts of individuals and groups in a way that allows it to respond to the market as a whole."

Strategic change challenges what an organization is and what it stands for and raises questions about attitude, culture, values, beliefs, goals etc. Managing change is a difficult process with many variables. In essence, change in an organisation can be implemented according to by the following six steps to effective change [12].

1) Mobilizing commitment to change through joint diagnosis of business problems
2) Development of shared visions on how to organize and manage for competitiveness
3) Consensus on new vision, competence to act, and cohesion to keep the project moving
4) The spread of devitalization to all departments without the enforcement of top management
5) Policies, systems and structures need to institutionalize devitalisation
6) Constantly monitoring, changing and adjustment of strategies.

It is the maintenance leader's role to monitor and influence change in attitudes, values and beliefs in an organization in a manner that is not disruptive to the long term productivity of that organisation. Implementing change is complicated due to the involvement not of technical hurdles but rather the interaction of teams and individuals within the organization in an attempt to reach mutual goals that meet the terms of a dynamic market. The maintenance leader is ultimately responsible for implementing change through project management and the use of different processes.

Significant changes would possibly be necessary to the current crews maintaining the pumping system if a positive outlook is to be achieved. By changing certain members in the maintenance teams to different positions and promoting certain members of the team would inevitably create a positive attitude. A positive attitude is essential in achieving optimal outcomes.

5 Conclusions

In order to mobilise the current dewatering system into an effective and efficient process, the following outcomes have been achieved:

- Water mapping of problem areas is now available to be viewed on "Mine Site" for both the production and maintenance departments. Both parties are now fully informed as to where the water build ups are, and can effectively communicate concerning possible solutions.
- A fully functional specification for the Mine dewatering system is available highlighting the maximum dewatering capabilities of each pump station.

- Calculations have confirmed that pumping water from Mine North to the surface is not possible due to the low pressure capabilities of the pump station. Thus water needs to be carried out via Mine South.
- The Denver Orion pumps are operating at very low efficiencies consuming large amounts of unnecessary power. Series connection of the pumps needs to be explored as well as alternative pumps be considered to increase current efficiencies.
- Settling ponds need to be constructed hence supplying PD pumps with water that is not contaminated with large suspended particles, causing damage to valves, seats and seals etc.
- A maintenance strategy needs to be developed whereby a shift from a reactive maintenance is made to a more efficient preventative maintenance strategy.
- Vital to the long term dewatering strategy for the Mine, is to acquire a long term mining development strategy from the production department, outlining its expected increase in water consumption as well as physical trend of future mining progress.

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