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Techno-economic assessment of underground mine dewatering systems

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Abstract

To meet the global demand for minerals, Canada will need to develop new underground mines, deepen existing underground mines or convert open pit operations to underground mines. Dewatering systems will need to be implemented to handle the water encountered when going underground, which is typically generated from natural fissure water, rainfall ingress, rapid ice melts and mine service water. Many designers of operations, when designing their dewatering system, do not holistically look at the overall life of mine costs associated with said system. The Hydraulic Institute and Europump therefore developed a lifecycle cost (LCC) calculator in order to quantify all the associated costs.

This paper will illustrate the use of the LCC calculator to conduct a techno-economic assessment of the three main dewatering systems as seen in industry, namely: cascading, single lift utilising in-line multistage pumps and opposed impeller multistage pumps. For each of the three systems, this paper will expand on the technology by way of their features, performance and maintenance requirements.

For the purpose of this analysis, a theoretical underground mine with a pump station located 500 m below surface, and dewatering at a rate of 460.8 m³/h, was used. The results of the techno-economic assessment showed that a single-lift system utilising the opposed impeller configuration multistage pump technology has the lowest lifecycle cost over a 15-year period, which in turn resulted in the lowest rate per cubic metre dewatered.

Keywords: *Mine dewatering systems, opposed impeller multistage pumps, lifecycle cost calculator, dirty water pumping, techno-economic assessment*

1 Introduction

1.1 Deep-level mine dewatering

Deep-level mining relies on large systems that absorb massive amounts of energy to ensure the mining environment remains safe for human workers. Mine dewatering is one of these critical systems, working alongside ventilation, compressed air and refrigeration. Combined, these systems absorb around 61% of the mine's energy, with pumping contributing as much as 15% of the mine's energy usage (Venter 2020). It is crucial to ensure that mine water is controlled for normal operations and that the pumping system is available for major flood events. Proper maintenance and the correct use of the mine dewatering system are therefore paramount to ensure the safety of underground workers and the economic benefit of the mine.

Most mine dewatering systems are developed out of necessity and implemented over time as the mine continues to go deeper underground. This practice can result in multiple temporary pumping stations being built across various levels to handle the mine's water; in some cases becoming the primary dewatering system for the mine. While this approach is required during the mine's development, this paper aims to show

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that this practice is not economically beneficial to the mine when compared to adopting main pumping stations designed to dewater the mine in a single lift or, in very deep mines, in multiple lifts.

1.2 Pump lifecycle cost

Pumps are typically purchased as single units, however, they can only provide a service when integrated into a system. The design of the system depends on the type of pump. While these elements are independent of each other they need to work together to ensure the greatest energy efficiency and reliability, and lowest maintenance cost, throughout their useful life.

It is often the case that the initial purchase price is of greatest concern when selecting pumps and designing their associated systems. However, the initial purchase price is of least importance for high-usage pumps, with energy costs and maintenance being the least considered and most costly factors.

'The lifecycle cost (LCC) of any piece of equipment is the total "lifetime" cost to purchase, install, operate, maintain, and dispose of that equipment.' (Hydraulic Institute 2001).

As stated in the (Hydraulic Institute 2001) LCC guide, the mathematical approach does not guarantee a particular result but allows the system designer to make a reasonable comparison between alternate solutions within the limits of the available data.

The LCC calculation analyses the costs incurred at the outset and considers the costs over the lifetime of a pumping system: typically 15–20 years. It is therefore essential to calculate a present value or discounted value for the LCC in order to accurately assess different solutions. It is also important to compare systems on a like-for-like basis.

The LCC equation and element are shown in Equation 1:

$$LCC = C_{ic} + C_{in} + C_e + C_o + C_m + C_s + C_{env} + C_d \tag{1}$$

where:

C_{ic} = initial cost, purchase price (pump system, pipe, auxiliary services, engineering and administration).

C_{in} = installation and commissioning cost (including training).

C_e = energy cost (predicted cost for system operation, including pump driver, controls and auxiliary equipment).

C_o = operation cost (labour cost of normal system supervision).

C_m = maintenance and repair cost (routine and predicted repairs).

C_s = downtime cost (loss of production).

C_{env} = environmental cost (contamination from pumped liquid and auxiliary equipment).

C_d = decommissioning/disposal cost (including restoration of the local environment and disposal of auxiliary services).

2 Methodology

2.1 System requirements

The LCC will be developed to compare three different dewatering systems typically used in deep-level mining. While the systems may vary slightly from mine to mine, they achieve a similar result with the use of different technologies. A theoretical case study with duty requirements of a 500 m static head and a required flow rate of 128 l/s or 460.8 m^3/h will be examined. Each system will have primary pumps and an installed standby pump to ensure 100% redundancy. The standby pumps will make use of the primary installed auxiliary equipment, including settlers, de-gritters, dams, suction and discharge pipework, but it will be assumed that they are fully installed and integrated into the power supply and control systems.

2.2 Dewatering systems

There are two very distinct approaches to mine dewatering, namely dirty water systems and clear water systems. Each approach is differentiated by where the solids are removed from the fluid, either underground or on the surface. The advantages of a clear water system include longer pump life and greater hydraulic efficiency, however, it comes with a large initial cost and complexity. On the other hand, dirty water systems have a lower upfront cost but traditionally suffer from greater maintenance costs and lower hydraulic efficiency. However, by the introduction of multistage pumps with opposed impeller arrangements and constructed of materials to handle dirty water applications, the maintenance costs and hydraulic efficiencies are comparable to clear water multistage pumps.

2.3 Dirty water cascading system (System A)

Dirty water systems handle pre-treated water and discharge it to the surface, where further solids removal and treatment are applied. These systems typically make use of screens, grit traps or strainers to remove large particles prior to pumping. Due to solid contamination present in the water, the pumps utilised in dirty water systems are constructed of materials with high-wear properties in a single-stage overhung configuration. Single-stage pumps suffer from low discharge pressures so designers typically install these pumps in series to increase discharge pressures. However, as the casing pressures are typically limited, a number of pumping stations are required at various levels across the mine to achieve the desired lift. This approach has the disadvantage of being complex in nature, with multiple elements requiring maintenance across multiple locations within the mine. It also suffers from reduced hydraulic efficiency due to the higher specific speeds of the pumps. When installing these pumps in series the overall pumping train efficiency reduces dramatically and is calculated as shown in Equation 2:

$$Eff_{total} = \left(Eff_{pump1} \times Eff_{pump2} \right) \tag{2}$$

where:

Eff_{total} = total pump set hydraulic efficiency.

Eff_{pump1} = hydraulic efficiency of first pump of two pumps in series at duty point.

Eff_{pump2} = hydraulic efficiency of second pump of two pumps in series at duty point.

A cross-section of the aforementioned pump is shown in Figure 1.

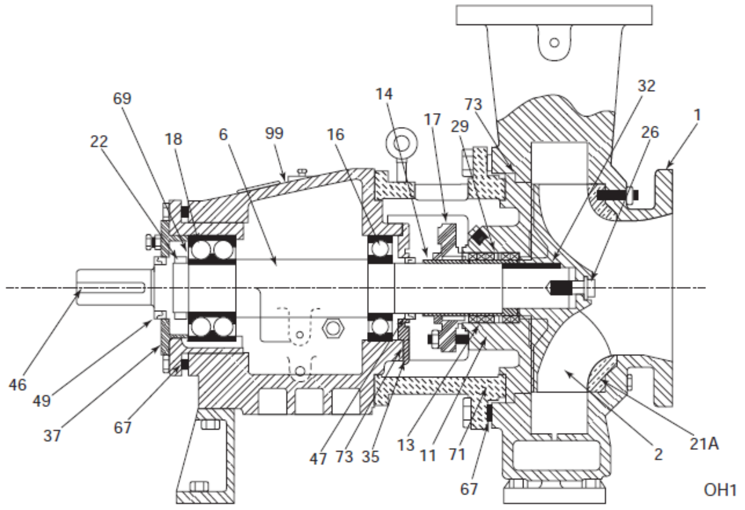

Figure 1 Section view of overhung (OH) single-stage pump (Hydraulic Institute 2019)

The system is designed to meet the requirements outlined in Section 2.1 and comprises four pump stations, each fitted with one duty and one standby train of two OH1 pumps in series. These are capable of developing 128 m total dynamic head (TDH) at a flow rate of 128 l/s, resulting in a total system lift of 512 m TDH with a pump set hydraulic efficiency of 56%. Each pump is equipped with 160 kW electrical motors driving a pulley system to rotate the pump at 1,490 rpm.

At each level a dam is constructed to remove grit, utilising a grit trap within the dam, and the overflow is strained in the suction line before being presented to the pumps. Water is delivered from each pump station to the next pump station's dam, with the last pump station delivering water to surface settling ponds.

The cost of the entire system has been considered in the LCC, including the cost of pre-treating the water, dam storage, pipework, valves, pumping systems, development and surface treatment systems.

The solution for the system requirements is shown in Figure 2.

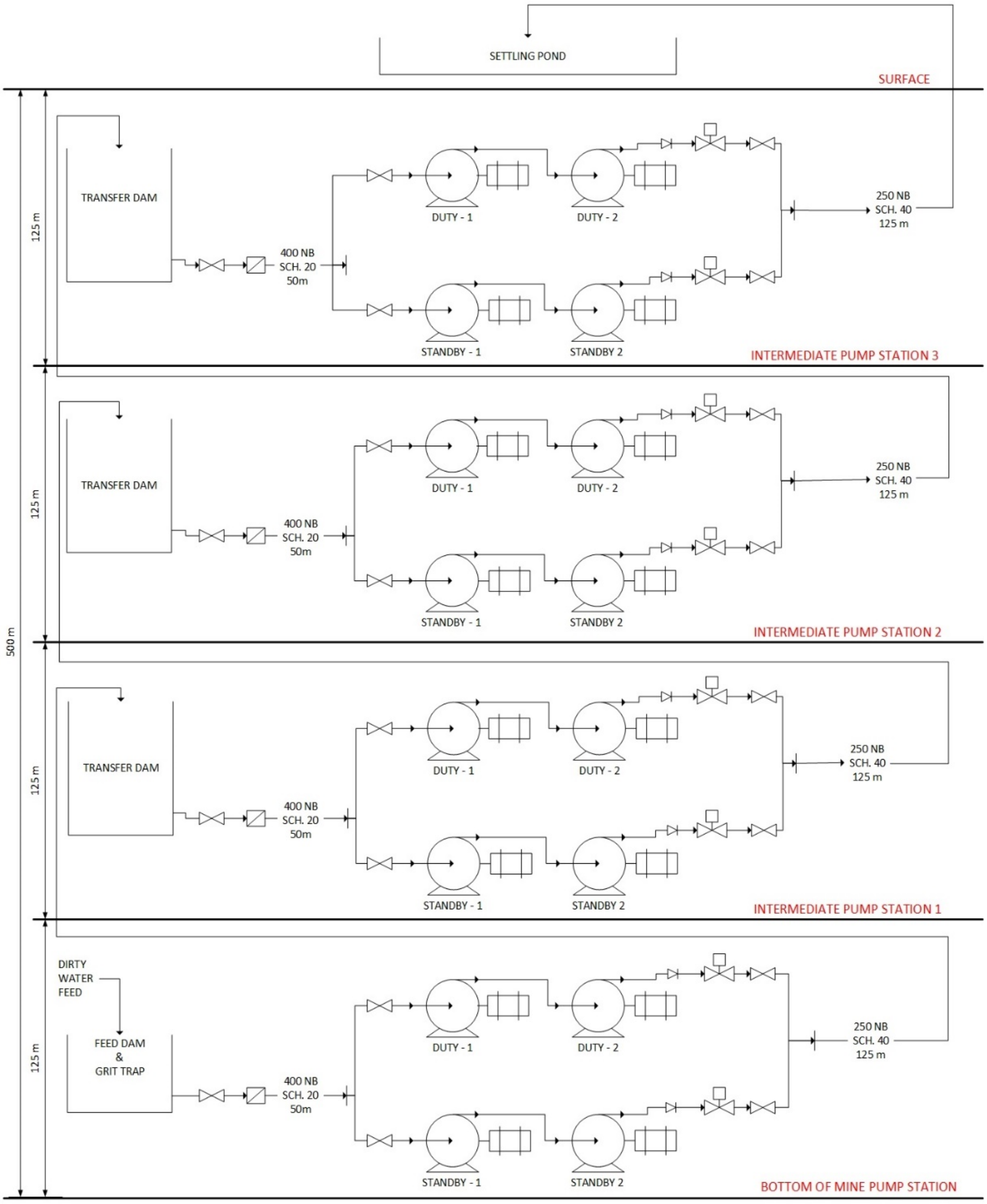

Figure 2 System A dewatering solution using overhung (OH) pumps in series across four pump stations

2.4 Clear water system (System B)

Clear water systems are typically designed to remove any solids from mine water prior to pumping it to the surface. This process requires an underground de-gritter, settler, flocculation plant, and a mud handling system. Clear water is then handled with a clear water pumping system which consists of ring section BB4 multistage pumps in an inline impeller arrangement with a balancing arrangement.

These pumps are typically constructed with bronze hydraulic components, tungsten-coated neck rings and impeller journals, and steel casings. The rotating element's axial thrust is balanced by a balance disc arrangement which counters the impeller axial thrust. However, the balance disc arrangement requires axial float of the rotating element, which can result in misalignment of the hydraulic centres of the impellers and diffusers. If not maintained, this can result in the pump ‘thrusting’, where the rotating element axially displaces beyond the space allowance and fouls up against the neck rings and casings.

These pumps are typically installed in parallel to achieve higher flow rates. A cross-section of the aforementioned pump is shown in Figure 3.

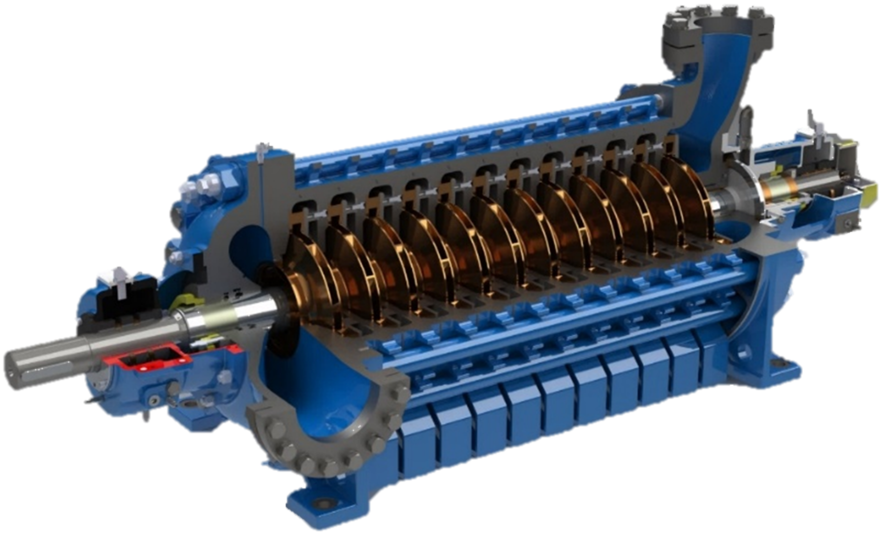

Figure 3 Section view of an impeller between-bearing type pump (BB4) multistage ring section pump with inline impeller configuration (courtesy of Scamont Engineering)

These pumps are designed with low specific speeds for high-pressure applications.

In designing a solution to the system requirements stated in Section 2.1 the following solution, as shown in Figure 4, was assessed.

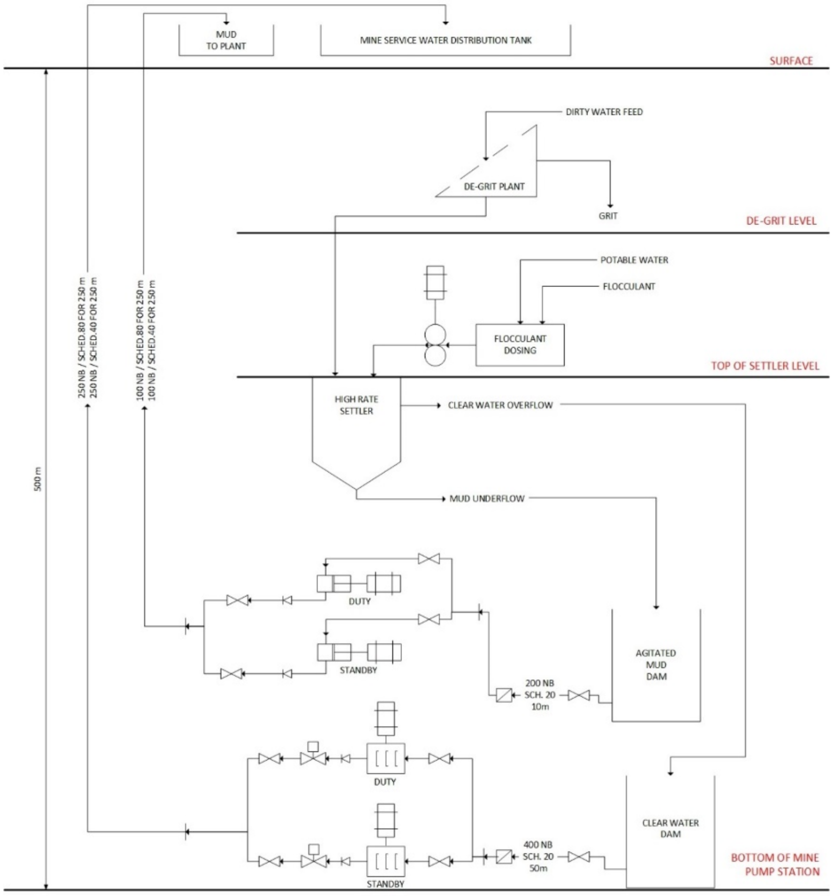

Figure 4 System B clear water dewatering solution using an underground treatment plant and a mud handling system

The system comprises one pumping station, which includes underground pre-treatment of mine water utilising a de-gritter to remove solids, a high-rate settler, and a flocculation plant to remove suspended solids before directing the outflow to a clear water dam and a mud dam. The clear water dam holding fluid at a specific gravity (SG) of 1 feeds one duty and one standby BB4 multistage pump with an inline impeller configuration, providing a TDH of 512 m at a flow rate of 128 l/s and a hydraulic efficiency of 80%. Each pump is fitted with a 1000 kW motor operating at 2980 rpm. The clear water pumps feed into a clear water column which discharges at the surface level into the mine service water distribution tank.

The agitated mud dams, which are controlled to keep SG at 1.1, feed one duty and one standby positive displacement slurry pump, developing a TDH of 535 m at a flow rate of 6.35 l/s. Each mud pump is fitted with a 110 kW electric motor operating at 1490 rpm. The mud pump feeds into a mud column which terminates on the surface at a processing plant.

The cost of the entire system has been considered in the LCC, including pre-treating the water, the mud handling system, dams, pipework, development and valves.

2.5 Dirty water single-lift system (System C)

Recent developments in ring section multistage pumps, manufactured with materials to increase wear resistance and configured with opposed impellers, have improved the life, maintenance intervals and performance of multistage mine dewatering pumps. These pumps are self-balancing through the use of opposed impellers and do not rely on any balance disc or drum arrangements. This technological advancement eliminates the need for balance disc/drum maintenance, offering an ideal platform on which to alter the materials to handle high-pressure dirty water pumping.

Furthermore, the rotating element is locked in the axial direction, perfectly aligning the impeller and diffuser cordial centres. These pumps are designed with low specific speeds for high-pressure applications and can be installed in parallel for high-flow requirements. A cross-section of the aforementioned pump is shown in Figure 5.

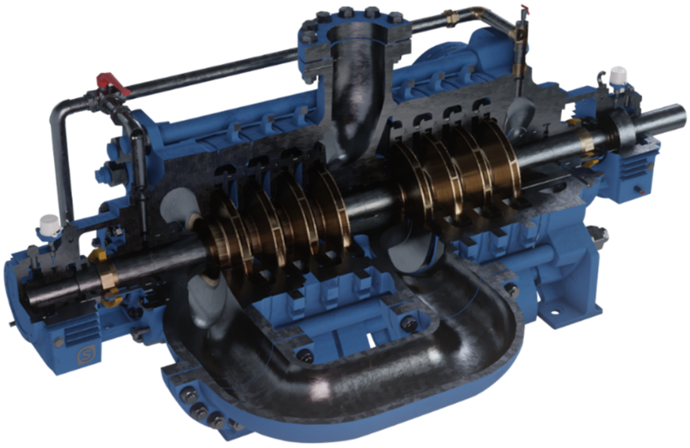

Figure 5 Section view of impeller between-bearing type pump (BB4) multistage opposed impeller arrangement (courtesy of Scamont Engineering)

The solution for the system requirements is shown in Figure 6.

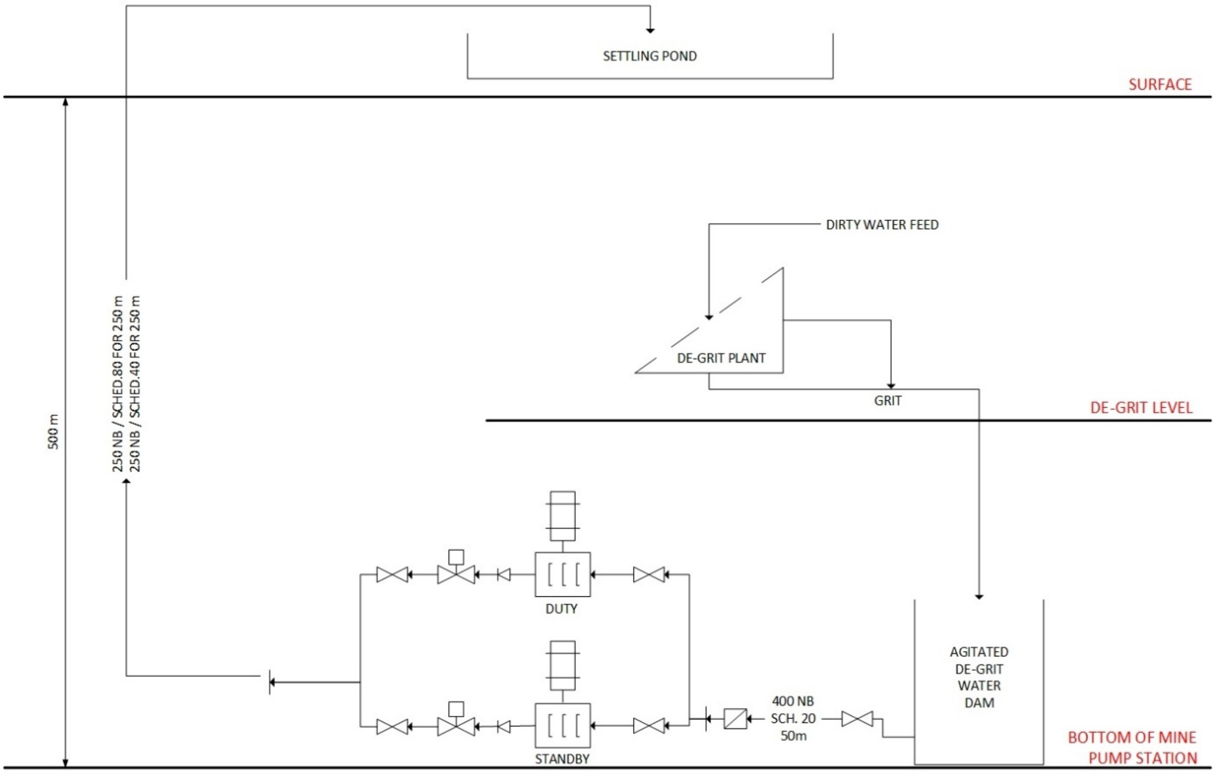

Figure 6 System C dirty water dewatering system using multistage pumps with opposed impeller and enhanced construction materials

Designed to meet the requirements outlined in Section 2.1, the system comprises one duty and one standby BB4 multistage pump with an opposed impeller arrangement. Constructed with high-wear-resistant materials, it develops a TDH of 512 m at a flow rate of 128 l/s, with a hydraulic efficiency of 80%. Each pump is fitted with a 1000 kW electric motor running at 2980 rpm.

The water undergoes pre-treatment through a de-gritting plant with a cut size of 100 µm and above. The de-gritted water is held in a dirty water dam which is controlled to keep the SG of the fluid below 1.005. This feeds a suction manifold with a strainer box directing flow to the multistage pumps. The pumps deliver dirty water to the surface through a vertical dirty water column and the water is directed to settling ponds.

The cost of the entire system has been considered in the LCC, including pre-treating the water, dam storage, pipework, valves, pumping systems and surface treatment systems.

3 Lifecycle cost study

3.1 Lifecycle cost formula

The LCC study was conducted using the South African deep-level mining industry as a benchmark. This includes South African-produced pumping products, labour costs, energy tariffs and supply channels. No backup power system costs were included in the study.

Due to the similar environment in which the systems will operate, the following elements have been assumed to be equal in cost and therefore immaterial in the comparison:

- environmental costs (C_{env})
- decommissioning costs (C_d).

Due to the critical requirement of a mine dewatering system, the analysis will assume standby systems to handle full duty requirements. Therefore, downtime costs (C_d) will also be removed for this analysis. The LCC equation will therefore be amended to:

$$LCC = C_{ic} + C_{in} + C_e + C_o + C_m \tag{3}$$

3.2 Lifecycle cost key assumptions

Each system is allocated the following resources, with key assumptions outlined during the LCC analysis presented in Table 1.

Table 1 Variables used within the lifecycle cost calculation (continued next page)

Variable	System A	System B	System C
System description	Cascading dirty water system with 2 × OH1 pumps in series - split into four pump stations	Clear water system with BB4 multistage pumps with inline impeller configuration and mud handling system	Dirty water system with BB4 multistage pump with opposed impeller configuration
Number of pumps	16	2 clear water pumps 2 mud pumps	2
Valves	36 manual control valves 8 actuated control valves	18 manual control valves 4 automated control valves	9 manual control valves 2 automated control valves
Instruments	2 per pump	12 per clear water pump 2 per mud pump	12 per pump
Number of dams	4 × 172m^3 dirty water dams	1 × 700 m^3 clearwater, 1 × 100 m^3 mud	1 × 700 m^3 dirty water dam

Variable	System A	System B	System C
Number of columns	4 each with 125 m static head, Sch.40	1 clear water HP, 1 mud HP each with 500 m static head, Sch.40 & 80	1 x HP with a 500 m static head, Sch.40 & 80
De-gritters	0	1 underground	1 underground
Settler and flocculation plants	0	1 underground	0
2-year operational spares cost	50% of new pump x no. operating pumps	30% of new pump x no. operating pumps	12% of new pump x no. operating pumps
Critical spares cost	30% of 2-year operating spares	30% of 2-year operating spares	30% of 2-year operating spares
EPC costs	12% (of initial + installation cost)	12% (of initial + installation cost)	12% (of initial + installation cost)
Required development volume	3,840 m^3 (980 m^3 per pump station)	3,840 m^3	2,280 m^3
Development cost per m^3 (Moxham 2007)[1]	ZAR 2962/m^3	ZAR 2962/m^3	ZAR 2962/m^3
Life of pumping station	15 years	15 years	15 years
Energy tariff (Statistics 2023)	ZAR 1.25/kW.hr	ZAR 1.25/kW.hr	ZAR 1.25/kW.hr
Energy escalation[2]	10% PA	10% PA	10% PA
Daily usage	20 hours	20 hours	20 hours
Inventory of spares	2 years' operating spares + critical spares	2 years' operating spares + critical spares	2 years' operating spares + critical spares
Hyd eff. of pump[3]	(75% individual) 56.25% combined	80%	80%
Eff of motor	(96% individual) 92.16% combined	96%	96%
SG of pumped fluid	1.01	1.0 for clear water, 1.1 for mud	1.01
In situ conditional monitoring	12 per year	12 per year	12 per year
In situ maintenance events	25 per year	25 per year	25 per year
Labour cost per person	ZAR 350/hr	ZAR 350/hr	ZAR 350/hr
Escalation on labour and maintenance costs	8%	8%	8%
Running hours between major repair	3,000 hours	10,000 hours	8,000 hours
Major repair cost as percentage of new	30%	30%	30%

[1] The present value of the development costs (as per Moxham 2007) was calculated using a 10% escalation.

[2] Average of energy increases over previous 10 periods.

[3] Pump efficiency of pumps in series are calculated per equation 2 in Section 2.3.

This information is based on knowledge of the South African mining industry at the time of writing this paper.

4 Results

The results of the LCC study are presented as a percentage of the costs of the most expensive system, that being System A. This approach was adopted to ensure the paper's relevance remains unaffected by changes over time.

Comparing the costs of System A as a baseline against Systems B and C reveals insightful results, as depicted in Table 2 and Figure 7.

Table 2 Comparison of System B and C costs compared to System A

Lifecycle cost (LCC) elements	System A	System B	System C
Initial cost	100.00%	73.82%	40.93%
Installation cost	100.00%	96.60%	57.46%
Lifetime energy cost	100.00%	67.50%	67.50%
Lifetime operational cost	100.00%	12.50%	12.50%
Lifetime maintenance and repair cost	100.00%	60.12%	18.76%
Total LCC	100.00%	67.37%	55.99%

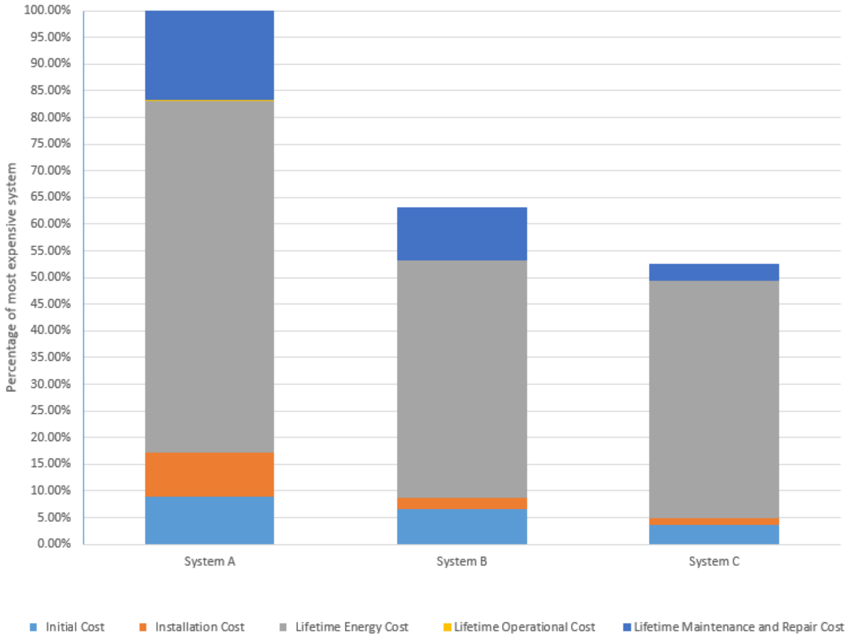

Figure 7 Lifecycle cost comparison of systems using System A as the baseline

4.1 Summary of individual systems

To compare the results of the LCC study for Systems A, B and C, the detailed attributes and performance characteristics of each system, along with their associated costs, must be considered.

4.1.1 System A: Dirty water cascading system

Initial and installation costs: high initial and installation costs due to the complexity of multiple pump stations, each with multiple pumps in series, and the need for grit removal at each level. Accounts for 11.8% of the LCC.

Energy costs: moderate energy costs as the system relies on multiple stages of single-stage pumps in series, which are less efficient and require significant power. Accounts for the majority of the LCC at 70%.

Operational costs: high operational costs due to the need for extensive maintenance across multiple pump stations and multiple running pumps. Reliability of the system is also greatly reduced as the mine dewatering system relies on eight pumps, four dams and columns being operation simultaneously.

Maintenance and repair costs: high maintenance costs due to the wear and tear on pumps handling dirty water and the complexity of the system. Accounts for 17.8% of the LCC.

Total LCC: baseline for comparison (100%).

Figure 8 shows the graphical representation of the costs for the dirty water cascading system.

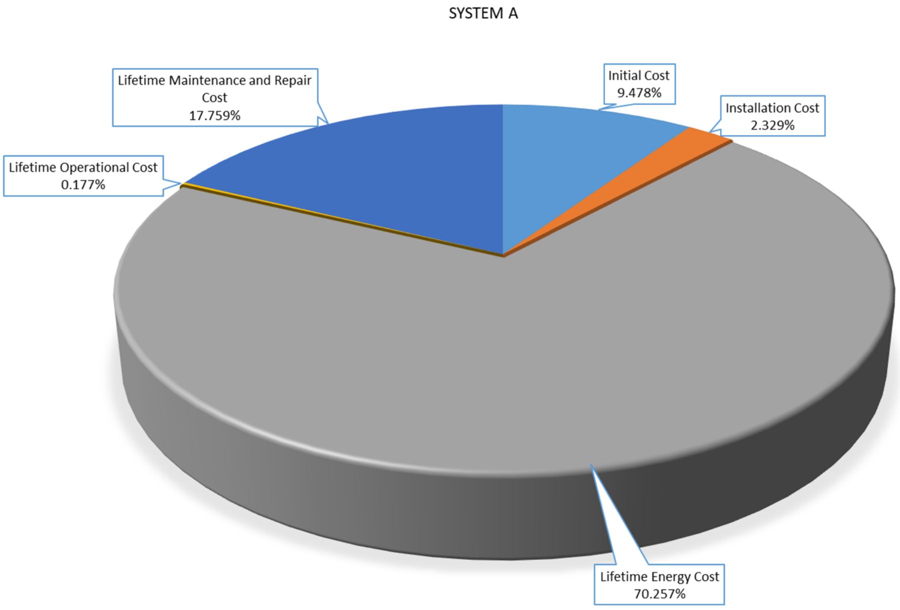

Figure 8 System A breakdown of lifecycle cost element contribution to the total cost

4.1.2 System B: Clear water system

Initial and installation costs: lower than System A but still significant due to the need for underground pre-treatment facilities such as de-gritters, settlers, flocculation plants and a complete mud handling system. Initial and installation costs account for 13.7% of the LCC.

Energy costs: lower energy costs due to higher efficiency of clear water pumps (BB4 multistage pumps). The energy costs account for 70.4% of the LCC, however, only 67.5% of actual cost compared to system A.

Operational Costs: Significantly lower operational costs due to less operating pumps compared to System A.

Maintenance and repair costs: lower maintenance costs than System A due to better materials and fewer pump stations, however, the mud handling system requires a large quantity of spares to remain operational.

Total LCC: 67.37% of System A.

Figure 9 shows the graphical representation of the costs for the clear water system

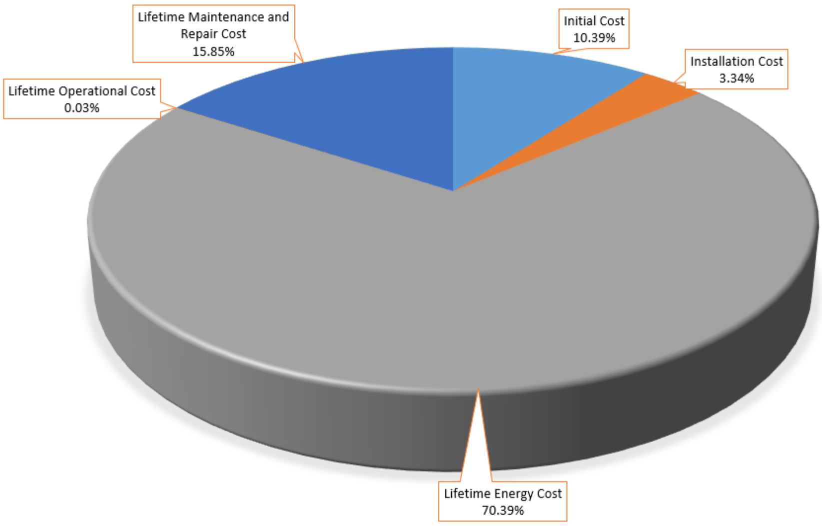

Figure 9 System B breakdown of lifecycle cost element contribution to the total cost

4.1.3 System C: Dirty water single-lift system

Initial and installation costs: lowest among the three systems due to improved pump technology and no need for mud handling and extensive pre-treatment. There is also less development required due to the smaller footprint of the system.

Energy costs: similar to System B, benefiting from the higher efficiency of modern multistage pumps with opposed impeller configurations. Accounts for 85% of the LCC.

Operational costs: low operational costs due to advanced pump design and efficient handling of dirty water.

Maintenance and repair costs: lowest maintenance costs due to the durability of materials and the self-balancing nature of the pumps. Accounts for 6% of the LCC.

Total LCC: 55.99% of System A.

Figure 10 shows the graphical representation of the costs for the dirty water single-lift system

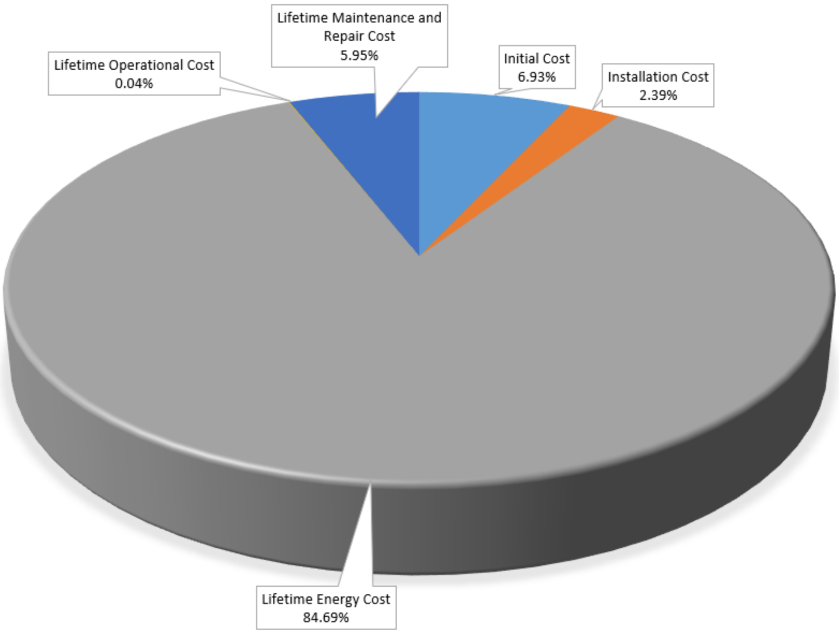

Figure 10 System C breakdown of lifecycle cost element contribution to the total cost

4.2 Comparison of the lifecycle cost elements within each system

4.2.1 Initial and installation cost

System A has the highest initial and installation costs due to its complex set-up with multiple pump stations.

System B reduces these costs significantly by utilising a more efficient clear water system.

System C further reduces these costs by implementing advanced technology and efficient dirty water handling.

4.2.2 Lifetime energy cost

Both System B and System C have lower energy costs compared to System A, thanks to higher pump efficiencies.

4.2.3 Lifetime operational cost

When comparing the lifetime operational costs of the systems the following comparisons are observed:

- Systems B and C both have dramatically lower operational costs due to their more efficient and reliable pump designs.
- Lifetime maintenance and repair cost
- System A incurs the highest maintenance costs due to the harsh operating conditions and complex maintenance requirements.
- System B's costs are lower due to improved pump materials and design.
- System C achieves the lowest costs with advanced materials and self-balancing pumps, reducing wear and the need for maintenance.

4.2.4 Total lifecycle cost

The LCC analysis of three dewatering systems used in deep-level mining reveals significant cost differences. Using System A (dirty water system) as the baseline with a total LCC of 100%, System B (clear water system) has a total LCC of 67.37%, and System C (advanced dirty water system) has a total LCC of 55.99%.

System A incurs the highest costs due to its complex set-up with multiple pump stations and extensive maintenance requirements. In contrast, System B achieves cost savings through more efficient clear water pumps and reduced maintenance needs. System C is the most cost-effective, leveraging advanced pump technology, improved materials, and a streamlined system design to minimise initial, operational and maintenance costs. Both Systems B and C offer substantial cost reductions compared to System A, with System C being the most economical choice due to its lower overall LCC.

4.3 Rate per cubic metre pumped

Table 3 shows the results of the LCC as expressed as a rate per cubic metre of fluid dewatered from a mine.

Table 3 Rate per m^3

Rate	System A	System B	System C
ZAR/m^3 (excl. energy)	ZAR 3.04	ZAR 2.04	ZAR 0.88
ZAR/m^3 (incl. energy)	ZAR 10.21	ZAR 6.88	ZAR 5.72

5 Conclusion

The LCC analysis of dewatering systems for deep-level mining demonstrates the significant impact of system design and technology on overall costs.

These findings highlight the economic advantages of investing in advanced dewatering technologies. While initial and installation costs are important, the long-term savings in energy and maintenance costs are critical in determining the most cost-effective solution. System C, which employs advanced technology with opposed impeller multistage pumps and wear-resistant materials, emerges as the optimal choice, offering the best balance of performance, reliability and cost-efficiency. As the mining industry continues to push deeper underground, adopting such innovative dewatering systems will be essential for maintaining economic viability and operational safety.

Acknowledgement

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