Analytical control valve selection for mine water reticulation systems

F.G. Taljaard

20557744

Dissertation submitted in fulfilment of the requirements for the degree

MAGISTER IN MECHANICAL ENGINEERING

at the North-West University

Supervisor: Dr. J.F. van Rensburg

December 2012

CRCED Pretoria

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
POTCHEFSTROOM CAMPUS

ABSTRACT

Title: Analytical control valve selection of mine water reticulation systems

Author: Francois Taljaard

Promoter: Dr. J.F. van Rensburg

Keywords: water reticulation systems, control valves, water pressure control

Some of the largest and deepest mines in the world are situated in South Africa. Underground temperatures and humidity can be controlled by means of complex chilled water reticulation system. A cascade pumping system is used to pump the used water from the underground levels back to the surface.

The dewatering process is energy intensive. Large volumes of water are used during the general mine drilling periods (06:00 to 12:00). During blasting periods (15:00 to 18:00) a minimum amount of personnel are underground, yet large volumes of water are still sent underground due to a lack of control. Reducing the water sent underground, will reduce the amount of water pumped back to the surface; resulting in significant energy savings.

Water flow and pressure can be managed by installing control valves at appropriate positions throughout the water reticulation system. Selecting a control valve is typically governed by constraints such as cavitation, water hammer, flashing, safety ratings and control range. A basic set of calculations can be used to determine whether a valve conforms to a specific scenario. However, scenarios calculated by engineers are not indicative of all applied system scenarios.

When control valves are installed, to optimise the operation of a system, it affects the system's characteristics. Sampled system data will therefore no longer provide adequate readings to help with selecting the correct control valve. An analytical control valve selection method has been developed and implemented. The case study shows the results and practical implications of applying this method in the mining industry. Implementing the analytical valve selection method is shown to be viable, realising electrical energy cost savings for the mine by reducing power requirements from Eskom.

SAMEVATTING

Titel: Analitiese beheerklep seleksie vir mynwater-retikulasie stelsels

Outeur: Francois Taljaard

Studieleier: Dr J.F. van Rensburg

Sleutelwoorde: water netwerk stelsels, beheer kleppe, water beheer

Sommige van die grootste en diepste myne in die wêreld is in Suid-Afrika geleë. By hierdie dieptes word werksomstandighede onaanvaarbaar. Die hoë ondergrondse temperature moet deurentyd beheer word om geskikte werksomstandighede te verseker. Dit word bereik deur middel van 'n komplekse mynwater-retikulasie stelsel.

Die ontwatering proses is energie-intensief. Algemene myn produksie periodes, tussen 06:00 en 12:00, gebruik groot volumes water. Gedurende skietwerk periodes, van 15:00 tot 18:00, word onnodige groot hoeveelhede water ondergronds gestuur as gevolg van 'n gebrek aan beheer. As die watertoevoer na ondergrondse vlakke verminder word, sal die oortolige water verminder, wat lei tot beduidende elektriese energie besparings.

Water vloei en druktoetse kan beheer word deur die installering van beheer kleppe op geskikte posisies regdeur die waternetwerkstelsel. Die keuse van 'n beheer klep is afhanklik aan beperkings soos kavitasie, waterslag, veiligheid klassifikasies en beheer reeks. Basiese berekeninge kan gebruik word om te bepaal of 'n klep voldoen aan spesifieke vereistes. Die vereistes wat deur ingenieurs tydens berekeninge gebruik word, is egter nie 'n akkurate aanduiding van al die stelsel vereistes nie.

Wanneer beheer kleppe geïnstalleer word verander die stelsel eienskappe en die gebruik van gemiddelde stelsel data is nie meer voldoende nie. 'n Nuwe analitiese beheer klep seleksie metode was ontwikkel en geïmplementeer. Die gevallestudie ondersoek die resultate en die praktiese implikasies van die implementering van die metode in die mynbedryf. Die implementering van die analitiese klep seleksie metode blyk om lewensvatbaar te wees, wat lei tot elektriese energie koste besparings vir die myn, en verlaagde krag vereistes van Eskom.

ACKNOWLEDGEMENTS

Foremost I would like to thank the Lord my saviour Jesus Christ for giving me the opportunity and ability to further my studies. Without Him I would not have been able to do this.

I would like to thank my parents (James and Hermien Taljaard) and sister (Lozanne Taljaard) for their unconditional support and constant encouragement during the study. I love you all dearly and could not have asked for better. Thank you for always being an example to me.

To my promoter Dr. J. F. van Rensburg, thank you for your guidance, support and encouragement.

I would also like to thank Prof. E. H. Mathews and Prof. M. Kleingeld for granting me the opportunity to complete my degree at CRCED Pretoria.

To Mr. W. Booysen and Mr. D. Velleman, thank you for all the input and the long hours you have spent helping me shape this dissertation. Your effort is truly appreciated.

To my co-workers and close friends, a special thanks for the support, encouragement and contributions to the study.

I would also like to thank TEMM International (Pty) Ltd for funding the study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

BAC	Bulk Air Cooler
DSM	Demand Side Management
DME	Department of Minerals and Energy
ECS	Energy Conservation Scheme
EGM	Energy Growth Management
FCI	Fluid Control Institute
NERSA	National Energy Regulator of South Africa
NERT	National Electricity Response Team
NGD	Specific Valve Type
OPC	Object Linking and Embedding for Process Control
PCP	Power Conservation Programme
PLC	Programmable Logic Controller
PRV	Pressure Reducing Valve
REMS	Real-time Energy Management Systems
RM	Reserve Margin
RTC	Trading Right to Consume
SCADA	Supervisory Control and Data Acquisition
TOU	Time-of-use
VRT	Virgin Rock temperature

UNITS

C	Celsius
c	cent
dB	decibel
K	Kelvin
l/s	litres per second
kl	kilolitre
Ml	megalitre
kg/m^3	kilograms per cubic meter
km	kilometre
m	metre
mm	millimetre
m^2	metre squared
m^3	cubic metre
m/s	metre per second
m^3/s	cubic metres per second
Pa	Pascal
kPa	kilopascal
MPa	megapascal
R	Rand
V	Volt
kV	kilovolt
kWh	kilowatt hour
MW	megawatt
MWh	megawatt hour

SYMBOLS

A	Area of leak size
C_V	Flow coefficient
d	Nominal valve size
D	Pipe outside diameter
F_F	Critical pressure ratio factor
F_L	Recovery factor
F_P	Pipe geometry factor
G	Specific gravity
g	Gravity
H	Head
K	Head loss coefficient
N	Equation constant
ρ	Fluid density
P_1	Inlet pressure
P_2	Outlet pressure
P_C	Absolute thermodynamic critical pressure
P_V	Vapour pressure
ΔP	Pressure difference
q	Liquid flow
T	Temperature
V	Velocity
V_1	Inlet velocity
V_2	Outlet velocity

1. INTRODUCTION

Summary

This chapter provides a brief background regarding South Africa's electricity production and consumption. The objectives and need of the study is motivated and set.

1.1 The South African electricity situation and demand side management

Energy and in particular, electrical energy (electricity), is a basic requirement for industries and facilities around the world [1]. The electricity demand throughout the world is also increasing because of the growing global populations and their economies. As a result the availability of non -renewable energy sources such as coal, oil and natural gas are becoming a concern. The environment has been negatively affected by using fossil fuels as an energy source to produce electricity. This is a raising concern particularly in South Africa [2].

South Africa's economy is energy intensive. South Africa's main energy resources are dominated by coal, because it is relatively cheap and abundant. During 2007, about 77% of the primary energy demands in South Africa were provided for by coal [3]. South Africa's energy resources include biomass, natural gas, nuclear power, hydro power, wind power, solar power and wave power [4]. Figure 1-1 shows a breakdown of South Africa's primary energy resources for 2009.

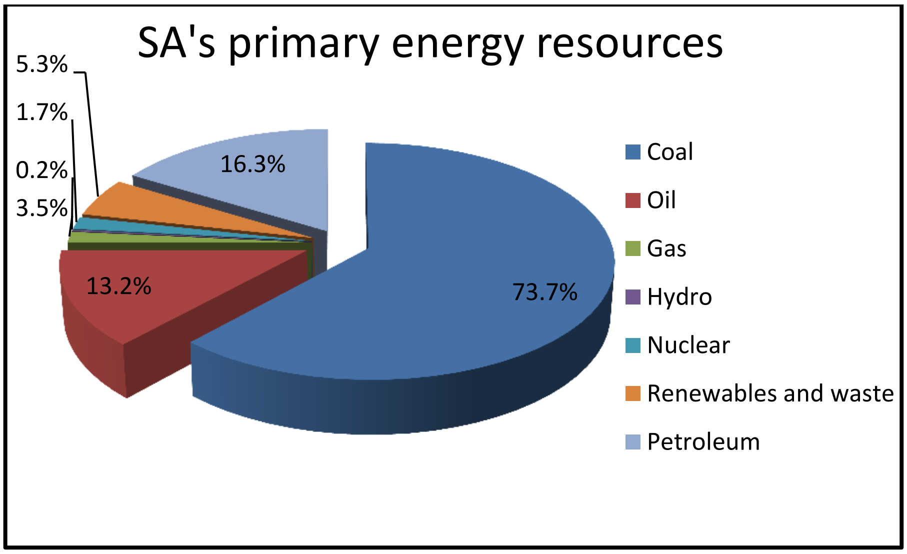


Figure 1-1: South Africa's primary energy resources for 2009 [4]

During 2009, 251 million tonnes of coal was produced in South Africa. Of this, 74% was used locally and 24% was exported to European and Asian countries [3].

Eskom, the state-owned enterprise, is one of the largest electricity generating utilities in the world with a nominal generating capacity of 44 193 MW and supplies approximately 95%

of South Africa's electricity [5]. During 2007, South Africa frequently experienced an excessively large demand for electricity. This compromised the supply reserve margins resulting in large scale load shedding during 2008.

A safe electricity reserve margin according to international standards is 15% of the maximum demand [6]. This is the minimum margin to ensure scheduled maintenance and to allow for unscheduled repairs. There has been an underinvestment in new generating infrastructure. An increase of electricity demand over the last 15 years caused South Africa's electricity reserve margin to decrease from 20% in 2004 to less than 10% in 2008 [6] [5]. Figure 1-2 shows South Africa's declining reserve margin [7].

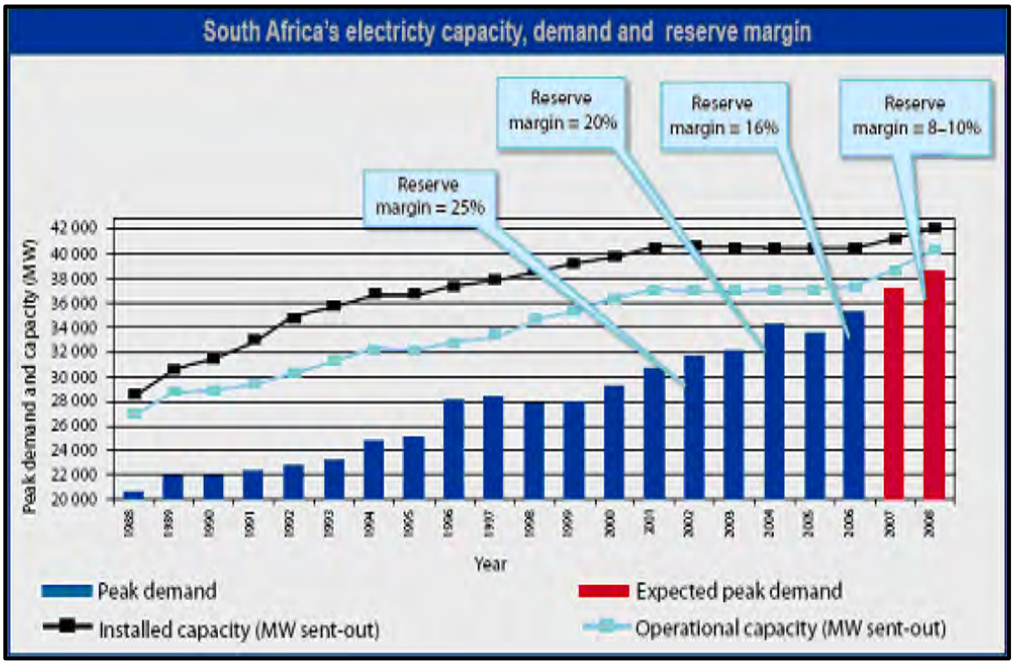


Figure 1-2: South Africa's electricity capacity, demand and reserve margin from 1988 till 2008 [7]

In order to overcome the electricity supply problems, at least short term, various energy saving programs were introduced. One such program, the Power Conservation Programme (PCP), was introduced by the National Electricity Response Team (NERT) to reduce the high electricity demand. The PCP can be divided into three main groups: the Energy Conservation Scheme (ECS), the Trading Right to Consume (RTC) and Energy Growth Management (EGM) [6].

In the year 2007, the National Energy Regulator of South Africa (NERSA) approved an annual electricity tariff increase of approximately 25% [6]. This would not only encourage consumers to use less electricity but also provide funds for new infrastructure. The electricity tariff increase emphasises the need to use electricity more efficiently [5].

Eskom defined time-of-use (TOU) pricing tariffs. These pricing plans encourage clients to use electricity more efficiently during certain times of the day, as illustrated in Figure 1-3 [8]. Eskom's Mega Flex tariff plans are applicable to mining, urban and industrial consumers that consume more than 1 MVA [8].

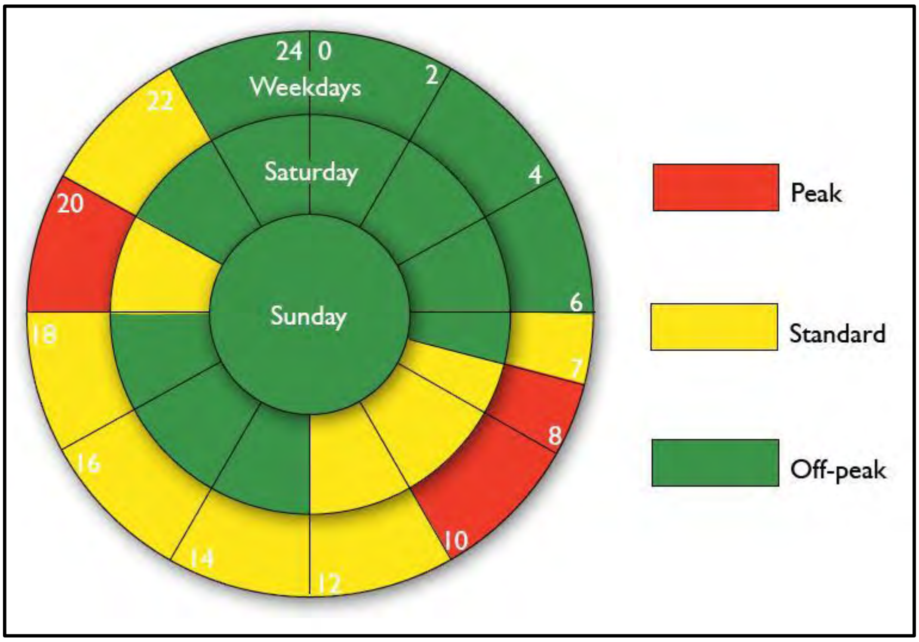


Figure 1-3: Eskom's TOU periods [8]

From Figure 1-3 it can be seen that Eskom's TOU periods are divided into weekdays, Saturdays and Sundays. Peak periods, marked in red, are allocated only to weekdays from 07:00 till 10:00 and from 18:00 till 20:00. Off-peak periods, marked in green, are allocated from 22:00 till 06:00 the next morning, on weekdays, Saturdays and Sundays. The cost of electricity is significantly cheaper in the off-peak period than the standard and peak periods.

The TOU tariff is also divided into two season periods: a high-demand and a low-demand season, as demonstrated in Table 1. Each demand season is divided into three time pricing periods, namely peak, standard and off-peak.

Table 1: Eskom Mega Flex tariffs for the period June 2012 to May 2013

Transition zone and voltage	High-demand season (June – August) [c/kWh]			Low-demand season (September – May) [c/kWh]		
	Peak	Standard	Off-peak	Peak	Standard	Off-peak
≤ 300 km ≥ 66 kV	182.83	47.52	25.39	51.04	31.27	21.87

As shown in Table 1, the high-demand season is during the winter months (June – August) and the low-demand season during the summer months (September – May). Table 1 illustrates a significant price difference between the high-demand and low-demand seasons. This is due to a higher demand for electricity during the winter months, as shown in Figure 1-4.

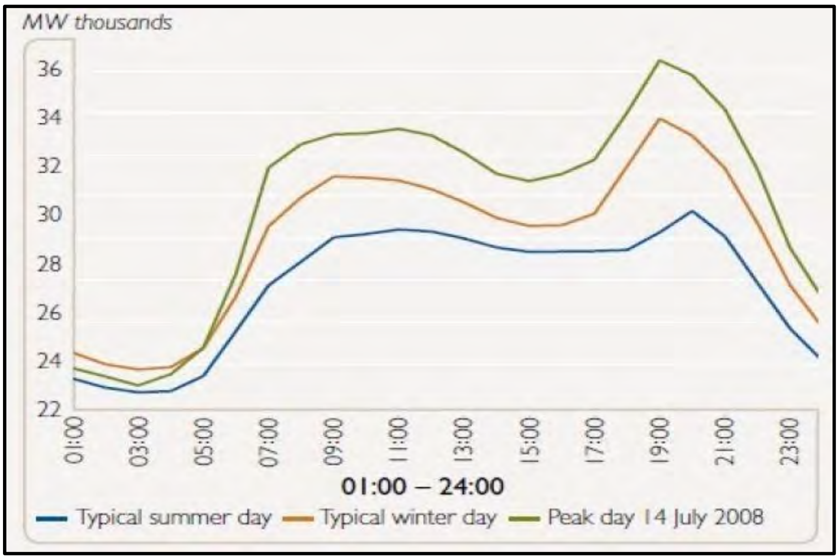


Figure 1-4: Daily average electricity demand profiles for the year 2008 [9]

The electricity-demand profile evidently shows the higher demand profile for a typical winter day in comparison to a summer day profile. The demand profiles consist of two peak periods from 07:00 till 10:00 and from 18:00 till 20:00. The maximum demand peak occurs during the evening period, from 18:00 till 20:00. This electricity demand profile shows that if electricity is used more efficiently, or if the peak use is shifted out of the national peak periods, energy savings can be achieved.

Eskom introduced a Demand Side Management (DSM) programme in 1992 to further decrease the electricity demand. To avoid load shedding Eskom uses various reserves to manage daily demand in which DSM contributes to these reserves [10]. Eskom DSM incorporates the following:

- Energy efficiency;
- Load shifting; and
- Peak clipping.

Energy efficiency, shown in Figure 1-5, involves a permanent reduction of the users' energy usage over a 24-hour period. Energy efficiency can be obtained by utilising existing equipment more efficiently or replacing old equipment with more efficient technology. Figure 1-5 shows the users' energy demand profile before and after the DSM intervention.

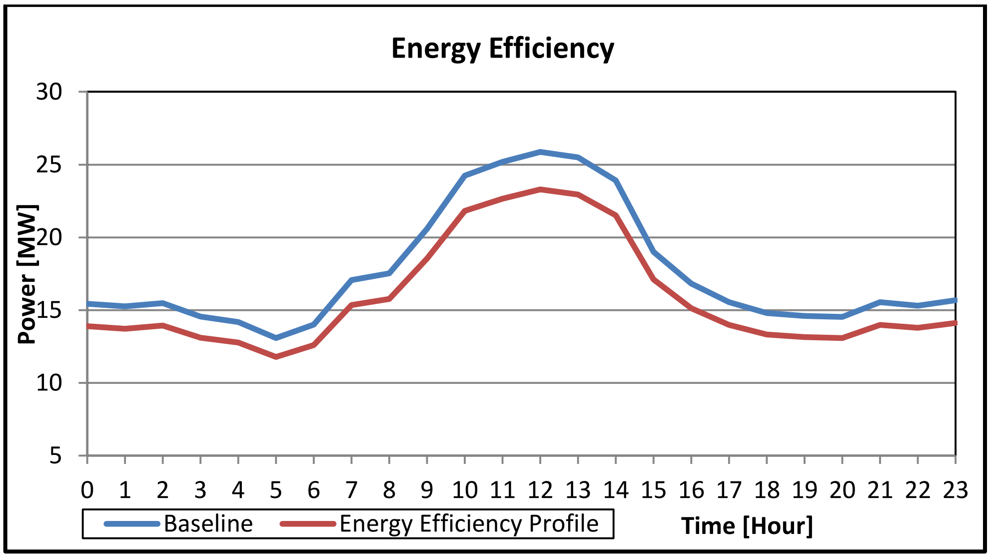


Figure 1-5: DSM energy efficiency profile over a 24-hour period

Load shifting profiles are shown in Figure 1-6. This procedure aims to shift the electricity load from the peak periods to the off-peak periods. Load shifting does not reduce energy consumption, it changes the consumption time during the day. Therefore, savings on electricity tariffs are gained by using less electricity during the peak periods, shown in red in Figure 1-6.

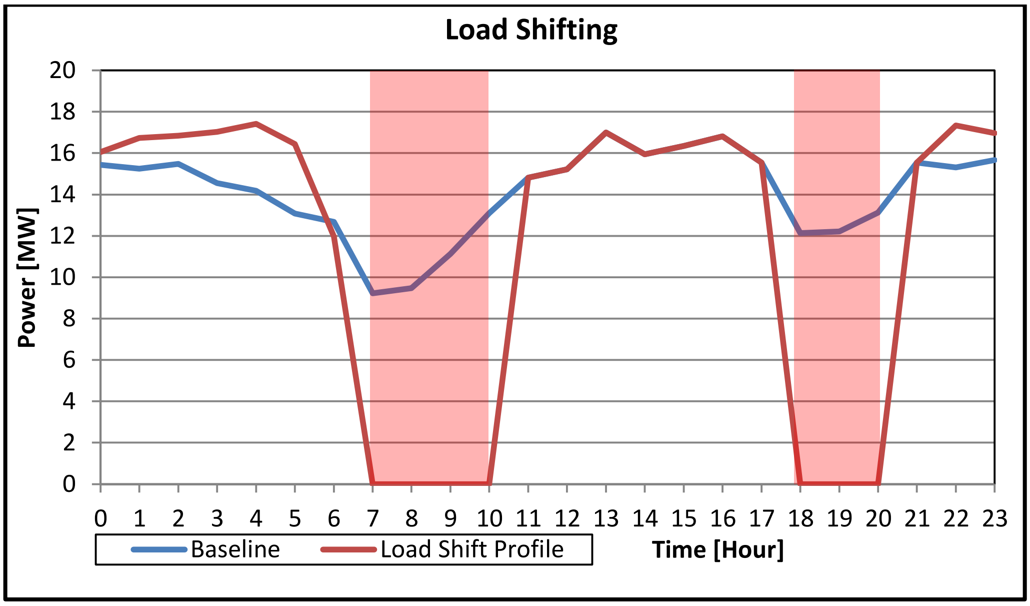


Figure 1-6: DSM load shifting profiles over a 24-hour period

Peak clipping, shown in Figure 1-7, is a typical form of load management. Peak clipping is the reduction of peak, or maximum demand usage and can be obtained by switching off a system or process. Peak clipping is usually only done during peak tariff periods, although the maximum demand may occur during any time of the day.

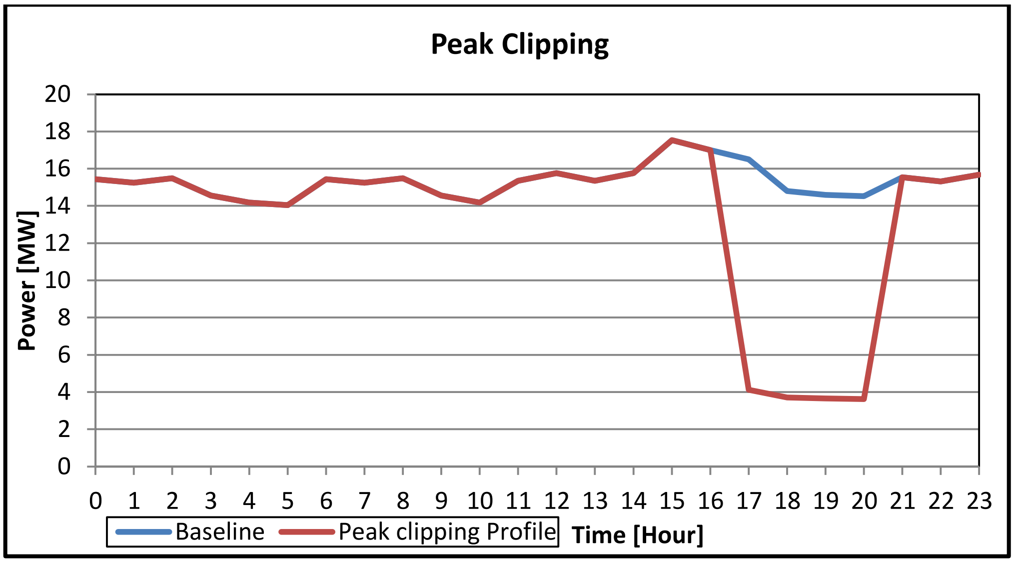


Figure 1-7: DSM peak clipping over a 24-hour period

South Africa, among countries worldwide, has set comprehensive targets regarding improvement towards energy efficiency [11].

The Department of Minerals and Energy (DME) compiled an energy efficiency strategy for South Africa which proposed the following:

- Reduce the energy demand with 12% by the year 2015; and
- Obtain an energy savings of 4 255 MWh over twenty years.

DSM plays an important role in the reduction of South Africa's electricity demand, therefore it can be said that DSM virtually increases South Africa's reserve electricity capacity. DSM initiatives in South Africa have made a significant contribution to improving the availability and sustainability of electricity supply as shown in Figure 1-8.

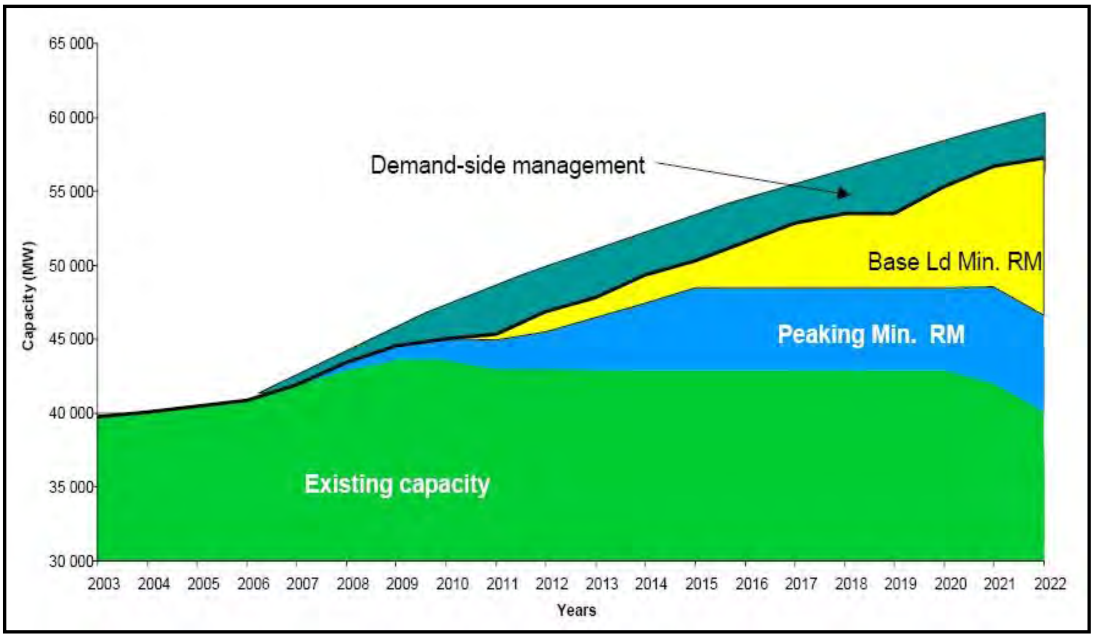


Figure 1-8: South Africa's electricity capacity development from 2003 till 2022 [12]

1.2 Electricity consumption in the mining industry

The recent Eskom tariff increases have had a significant effect on the profitability of the mining sector. South Africa's mining industry consumes 17% of the electricity generated. Figure 1-9 shows townships and municipalities consume large amount of electricity during morning and evening peak periods. To reduce the electricity demand for thousands of households will be more time-consuming compared to the same effect when reducing the electricity demands of a typical mine [13].

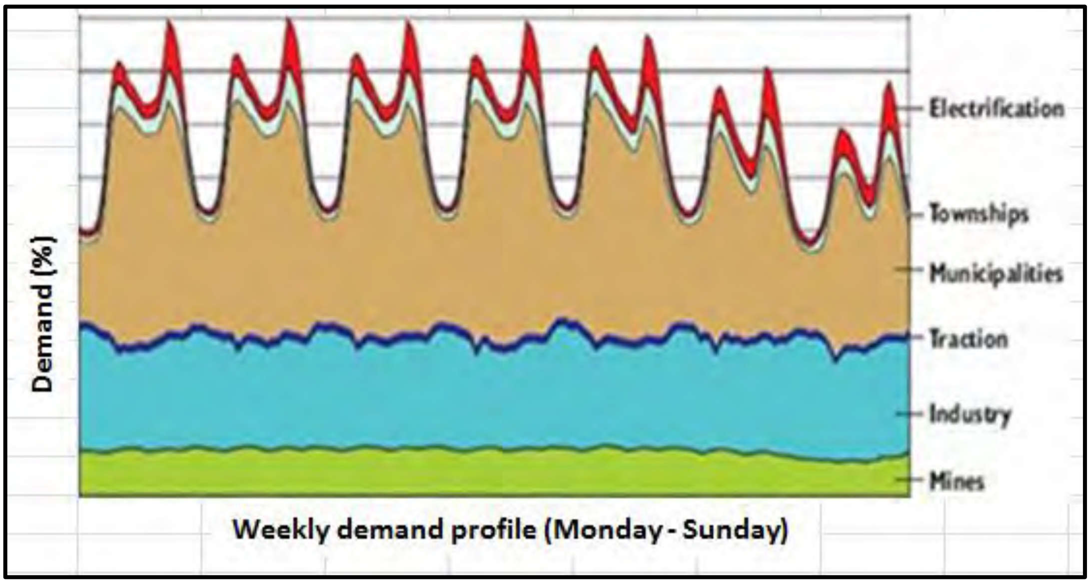


Figure 1-9: South Africa's total electricity demand profile, in percentages, for a period of Monday to Sunday [13]

South Africa is one of the world's largest gold producers. In 2004 South Africa produced 14% (approximately 342 tonnes) of the world's gold output. The gold mines in South Africa can be seen as an important drive for the country's economy. Extracting the gold is an energy intensive process and consumes 47% of the total electricity demand of all mining industries [14] in South Africa.

Some of the largest and deepest mines in the world are situated in South Africa, reaching depths more than 3 700 m below the surface [15]. At these depths, with virgin rock temperatures reaching up to 60° C, working conditions become unacceptable [16]. Underground temperatures must be controlled to ensure acceptable working conditions. Most of the time air ventilation is used to cool mines. However, due to the great depth of these mines, chilled water has also become a popular method for controlling the underground temperature [17]. This is achieved by means of a complex water reticulation system that can be divided into three sections:

- Refrigeration plants;
- Underground water supply; and
- Underground dewatering systems.

Figure 1-10 shows the average electricity consumed for typical deep-level mines, according to the different processes in the mine.

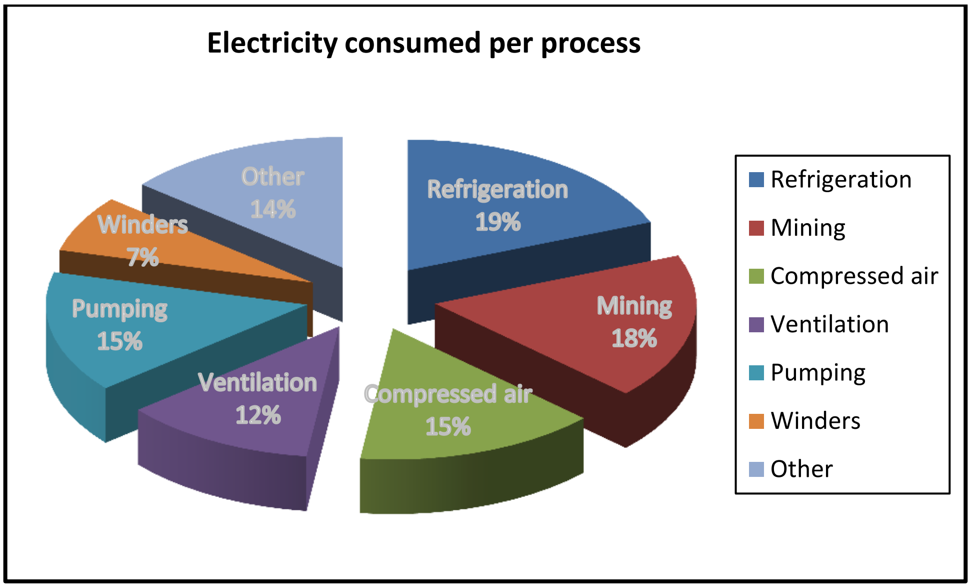


Figure 1-10: Average electricity consumption per mining process in a deep-level mine [5]

Figure 1-10 shows that 34% of the electricity used in the mine is associated with the primary functions of a water reticulation system (refrigeration 19% and pumping 15%). An additional 30% electricity usage is also associated with the water reticulation system through mining and ventilation. The reason for the additional usage is that the cooling (cooling cars etc. of the ventilation process) and production (drilling and sweeping part of the mining process) depends on the water reticulation system.

The chilled mining water supplied to underground production levels is mainly used to cool drilling machines, ventilation air and rock faces [18]. The used water is pumped from the underground levels back to surface by use of a cascading pumping system. This system typically consists of several dams and pump stations. The dewatering process is energy intensive, because the average volume of water pumped from underground back to the surface can vary between 15 Ml to 25 Ml per day.

Mine production periods are typically from 06:00 till 12:00 during which large volumes of water are required. From 12:00 till 15:00 all underground working personnel will be transported back to surface for the periods when blasting takes place (15:00 to 18:00). No production occurs and yet unnecessary large volumes of water are still sent underground and pumped back to the surface.

1.3 Refrigeration, underground water supply and mine dewatering

1.3.1 Introduction

Intricate water reticulation systems are required where mining operations are carried out. A basic layout of a typical deep-level mine water reticulation cycle is shown in Figure 1-11.

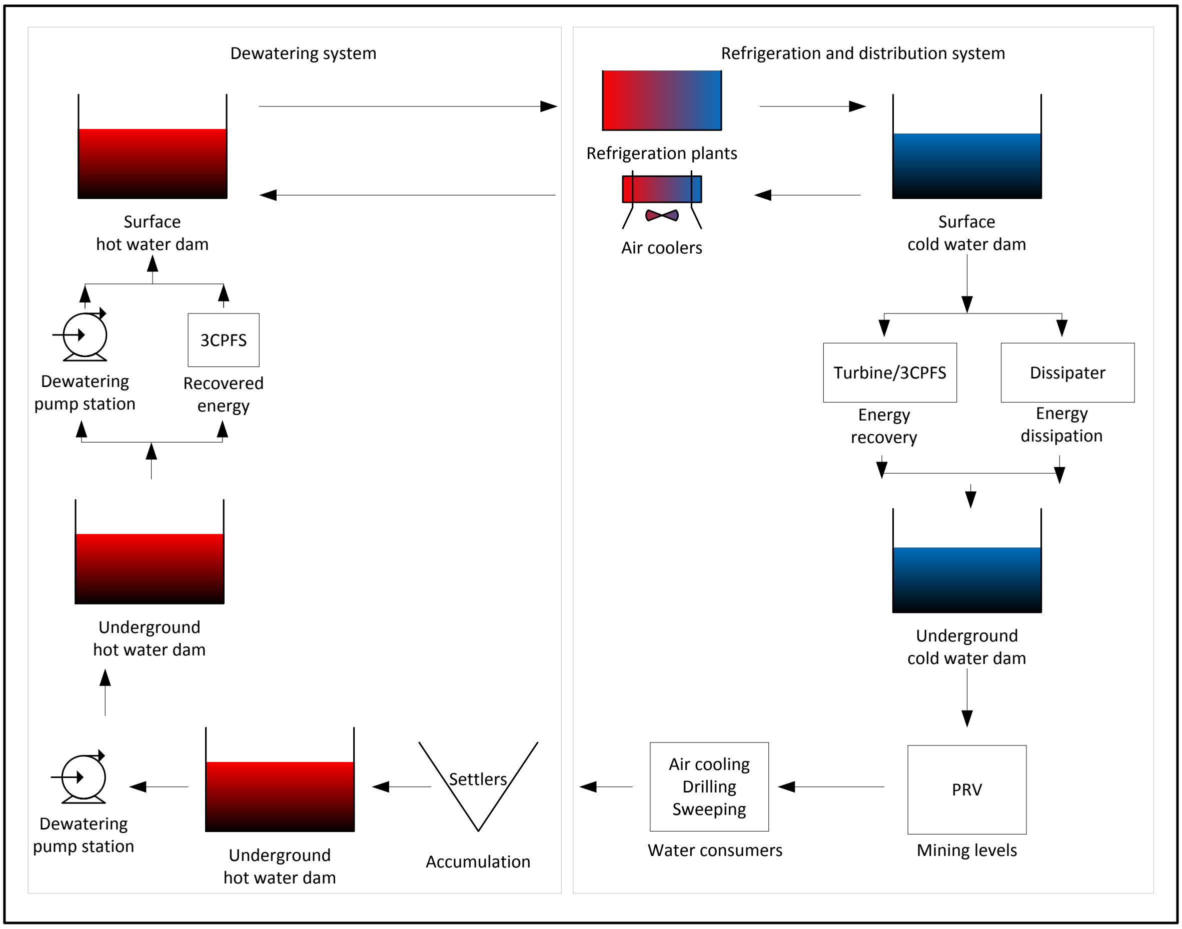


Figure 1-11: Basic layout of a deep-level mine water reticulation cycle [5]

1.3.2 Refrigeration plants

Used water is pumped from the underground levels to the refrigeration plant. The temperature of the used water varies between 25° C and 30° C. The water is fed through pre-cooling towers to lower the temperature. Pre-cooling towers use ambient air to lower the temperature of the water to between 15° C and 20° C. The cooling towers use ambient air to cool down the hot water. From the towers the water is pumped to the refrigeration system which cools the hot used water to temperatures between 3° C and 5° C. This water is then stored in surface cold water dams [19]. Figure 1-12 shows a layout of a typical refrigeration plant.

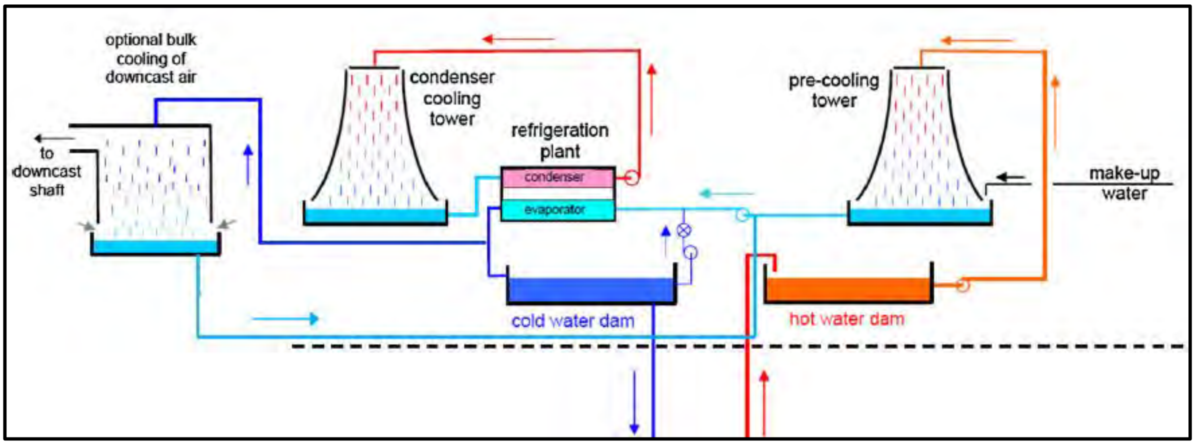


Figure 1-12: A layout of a refrigeration plant [19]

The cold water is then gravity fed from the surface cold water dams to the underground storage dams and from there it is pumped to various working levels. A percentage of the cold water from the refrigeration plants is circulated through the heat exchangers, also referred to as bulk air coolers (BAC's). The cold water absorbs the heat from the air that passes over the BAC, cooling the ventilation air sent down the shaft. The used water is fed back to the refrigeration plant for cooling.

To accommodate future mine expansion and development, surface refrigeration plants are usually over-designed. When mining operations grow beyond the capacity of the surface refrigeration plants, underground refrigeration plants can be added. These underground refrigeration plants have some advantages and disadvantages, listed in Table 2 [20].

Table 2: Advantages and disadvantages of underground refrigeration plants

Advantages
• Chilled water gains less heat due to a decrease in distribution distance • A reduction in the amount of water to be pumped to surface and dewatering cost

Disadvantages
• Underground installation requires extensive excavation • Underground location results in high costs and difficult maintenance • Operational cost is high due to high ambient temperature

Other alternatives to underground refrigeration plants, such as ice plants, can also be used to cool down service water. Ice, compared to the chilled water, produces better cooling which uses less volumes of water [20]. But, although ice is a better cooling medium some disadvantages such as the transportation of ice slurry and operation costs, create more challenges [21].

1.3.3 Water supply (distribution)

Water was initially used for dust suppression but has now become an essential cooling medium in deep-level water mine [22]. Studies conducted by Stephenson [17] in South Africa shows that virgin rock temperature (VRT) increases with 12° C per vertical depth (km) and can reach temperatures as high as 60° C. Due to high temperatures, underground working conditions become unsafe. The underground wet-bulb temperatures should be kept under 28° C [23], [24]. Water is used instead of other fluids due to its cooling benefits. Studies have shown that sending cooled water underground, the wet-bulb temperatures in the working stopes are reduced [25], [26].

After cold water flows from the refrigeration plants to surface cold dams, it is gravity-fed to underground cascading storage dams. From here it is gravity fed to various underground working levels. The water gravity fed to the lower levels exerts extreme pressures (due to total head) making it difficult to distribute.
Water pressure is calculated by:

$$Water\ pressure = \rho g H \qquad [Pa] \qquad \text{Equation 1}$$

Where:

ρ = *Fluid density [kg/m³]*

g = *Gravitational acceleration [m/s²]*

H = *Depth below the surface [m]*

For a deep-level mine, 3000 m below the surface, the pressure at the lowest level would be approximately 30 MPa. The water pressure can be reduced by installing dissipaters for example:

- Pressure reducing valves (PRV's);
- Cascading storage dams; and
- Turbines.

PRV's reduce the supplied water pressure to a safe useable pressure. Older PRV's have a fixed pressure drop over the valve, however modern PRV's are self-regulating and ensure a constant downstream pressure regardless of the inconsistent upstream pressure [13]. See Figure 1-13.

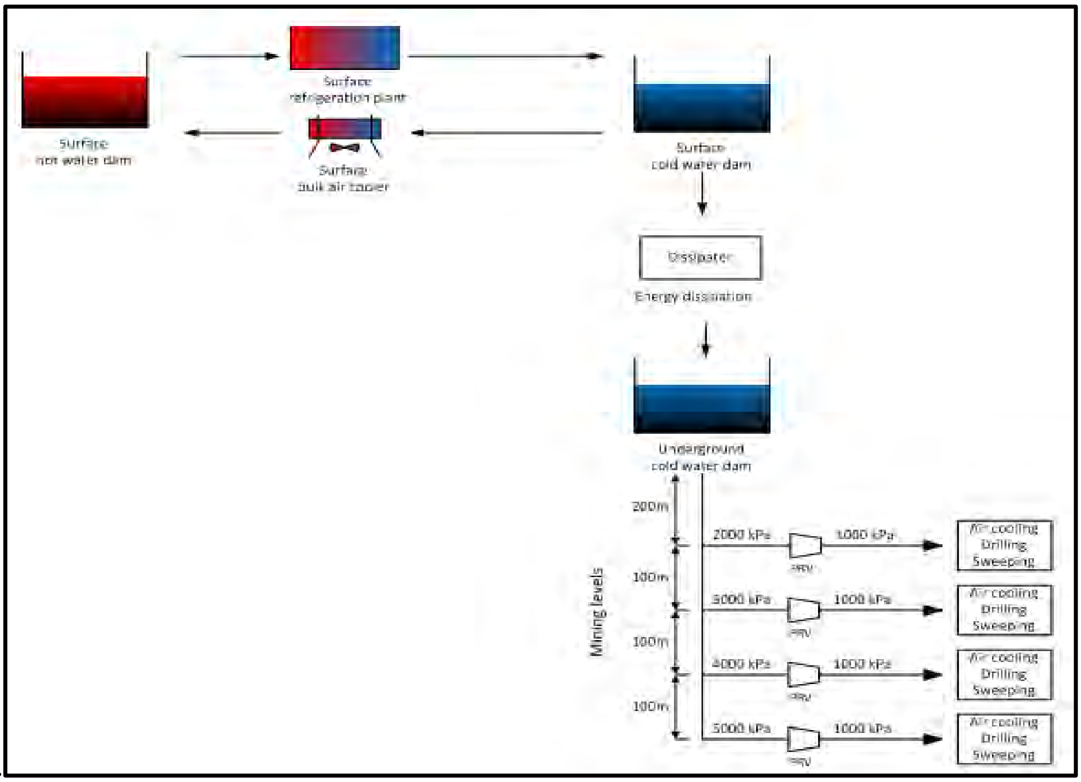


Figure 1-13: A typical layout of a mine's underground water distribution system

PRV's are usually installed on every working level close to the main water supply column. In some cases, where the water pressure is too high, multiple valves are used in series, forming a pressure reducing station. These pressure reducing stations decrease the potential for cavitation due to a smaller differential pressure occurring over each valve. Figure 1-14 shows a typical pressure reducing station.

The cascading storage dams serve as a storage dam during low water demand periods. The storage dams also act as pressure-breaking dams reducing the high water pressure to a suitable working pressure [17]. Some mines dissipate the high water pressures by making use of a turbine. The water pressure is transferred to energy to drive the turbine.

Figure 1-14: A typical pressure-reducing station [27]

After the water's pressure has been reduced it can be used for various tasks, such as cooling air or mining industry equipment. Typical mining industry equipment using chilled water at underground working areas includes:

- Cooling cars;
- Drills;
- Water cannons; and
- Water sprayers.

Figure 1-15 shows a picture of a cooling car. Warm air is sent through the cooling car and flows over the radiator. Chilled water flows through the radiator of the cooling car absorbing the heat of the warm air, resulting in cold air exiting the cooling car.

Figure 1-15: Underground cooling cars [28]

Chilled water is used to supress dust and cool down the drill bit when drilling with conventional drills. Hydropower drills use water as a medium to operate the drilling action as shown in Figure 1-16.

Figure 1-16: Hydropower drilling [27]

Rocks broken by the blasting operations can be moved with the help of high pressure water cannons and water jets during stope cleaning and sweeping. The water cannons and water jets replaced earlier scrape winches, brushes and shovels. An image of a high pressure water cannon can be seen in Figure 1-17.

Figure 1-17: A typical high pressure water cannon [27]

After blasting, a cleaning and sweeping team goes underground. Water spray, as shown in Figure 1-18, is used to suppress dust as well as to rapidly cool down the stope area allowing production personnel to re-enter the area.

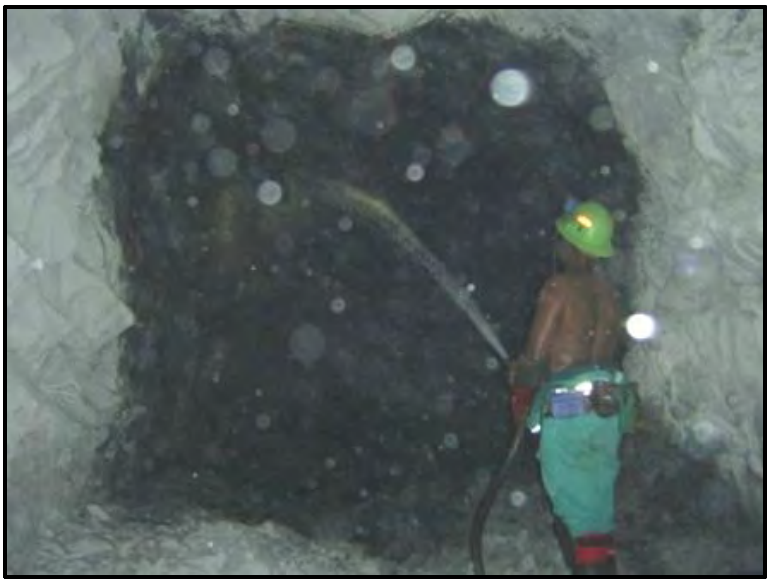


Figure 1-18: Using chilled water to cool the rock face

After the chilled water has been used for cooling, drilling and sweeping, all the water from the various levels are channelled into underground settlers as seen in Figure 1-19.

Figure 1-19: Mine underground settlers

Natural underground water also enters the settlers. The settlers are used to separate mud (sludge) from the used water. The density of the mud particles is increased with flocculent situated in the channels, causing the mud to sink to the bottom of the settler. To ensure an effective reaction, the alkaline levels need to be maintained [29]. To maintain these pH levels, lime is added to the water before it enters the settler [30]. The clean (clear) water is then fed to clear water dams.

1.3.4 Mine dewatering systems

The clear water is pumped to surface by a series of dewatering pumping stations. The dewatering system is a complex system and has to be operated efficiently. The purpose of the dewatering system is to prevent underground flooding and to regulate correct water levels in the storage dams (system water balance) ensuring proper operations of the water reticulation system [30] [31].

Figure 1-20 shows a typical underground dewatering pumping system with three pumping stations situated on different levels. The mine, illustrated in Figure 1-20, reaches a depth of more than 1200 m below the surface. The mine makes use of two cascading pumping stations. Hot water is pumped from a lower level hot water dam to an upper level hot water dam until it reaches the surface hot water dams.

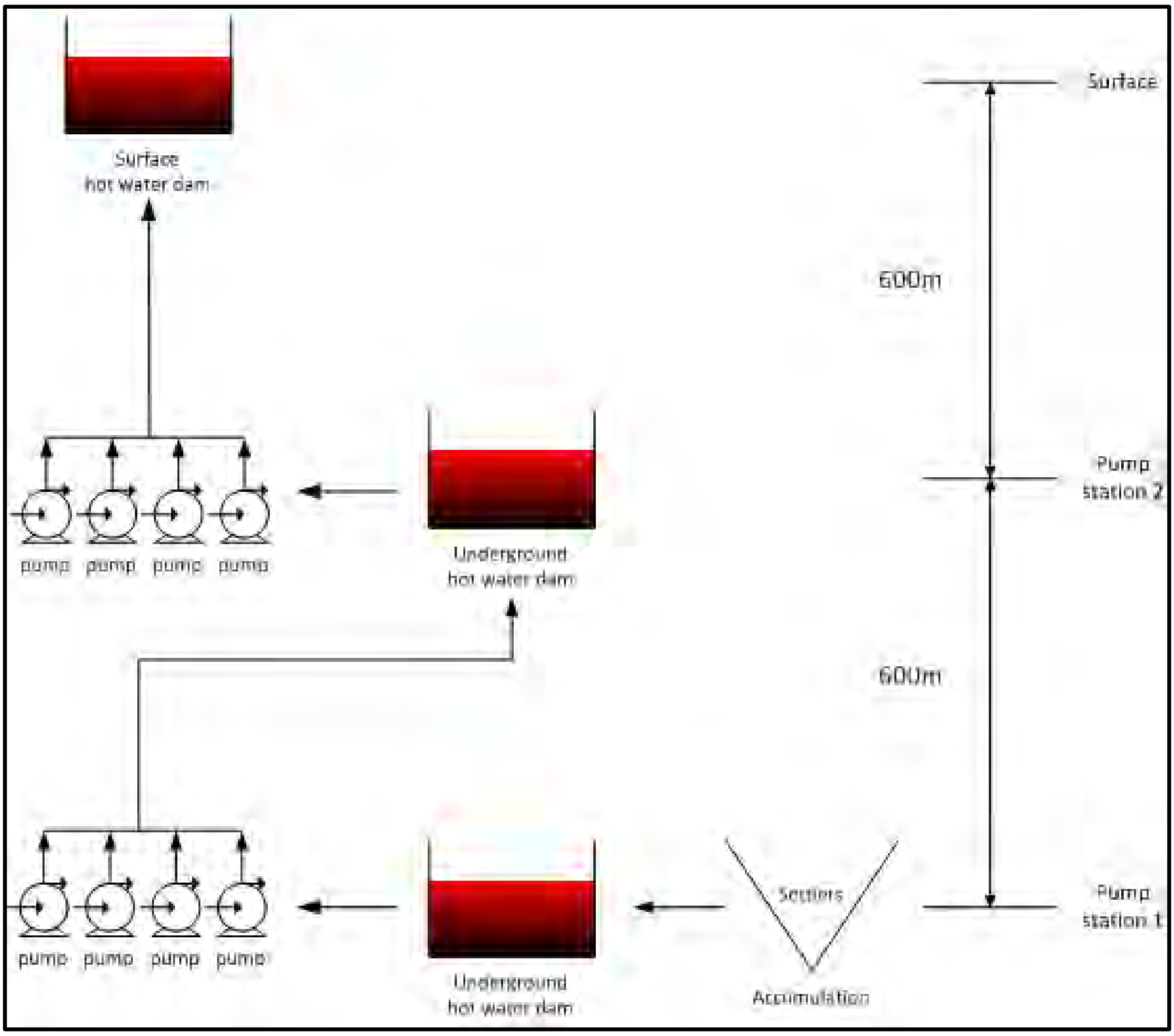


Figure 1-20: A typical underground dewatering pumping system [5]

Each pumping station consists of several large multistage centrifugal pumps [32]. Multistage centrifugal pumps are used in the mining industry due to the heights water needs to be pumped to get to the surface. Figure 1-21 shows a typical multistage centrifugal pump.

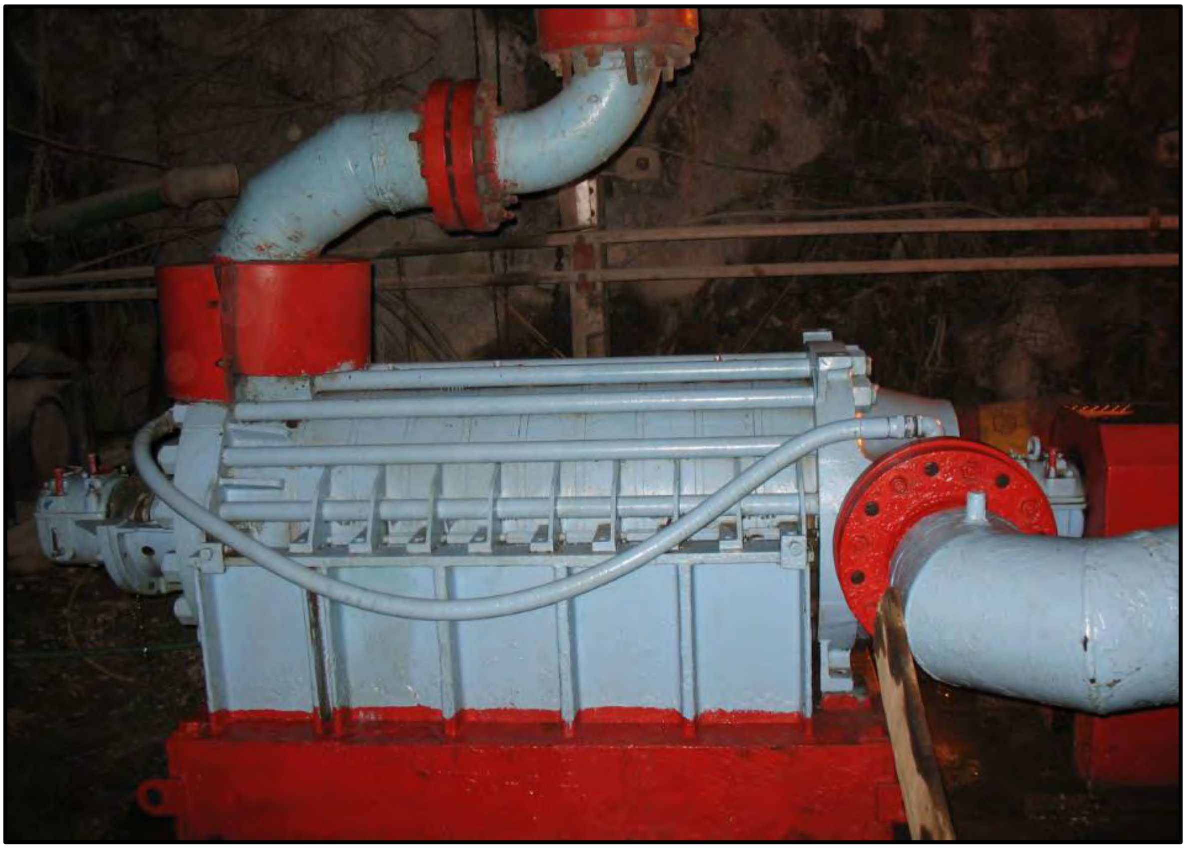


Figure 1-21: A typical multistage centrifugal dewatering pump [5]

The pump and pipe network arrangements influence the efficiency from one mine dewatering system to the next. The pumps at a water pumping station are usually placed in parallel and supply a common manifold as shown in Figure 1-22.

The flow rate of the water increases when a pump is added to a single discharge column shared with other pumps. Because the fluid friction increases when the flow rate increases, the total system water flow rate will be less than the sum of the individual pumps' capacity. Therefore, it is important to determine the maximum number of pumps the discharge column can accommodate without adversely affecting efficiency.

Figure 1-23 illustrates how the water flow rate is influenced when pumps are connected in parallel. To counter this side effect some mines have more than one column in their dewatering system.

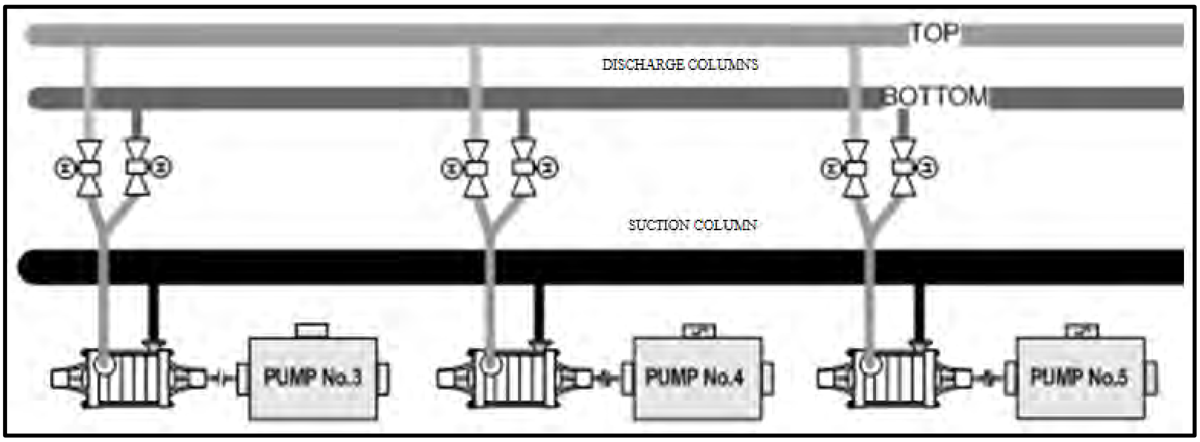


Figure 1-22: Parallel connection of dewatering pumps

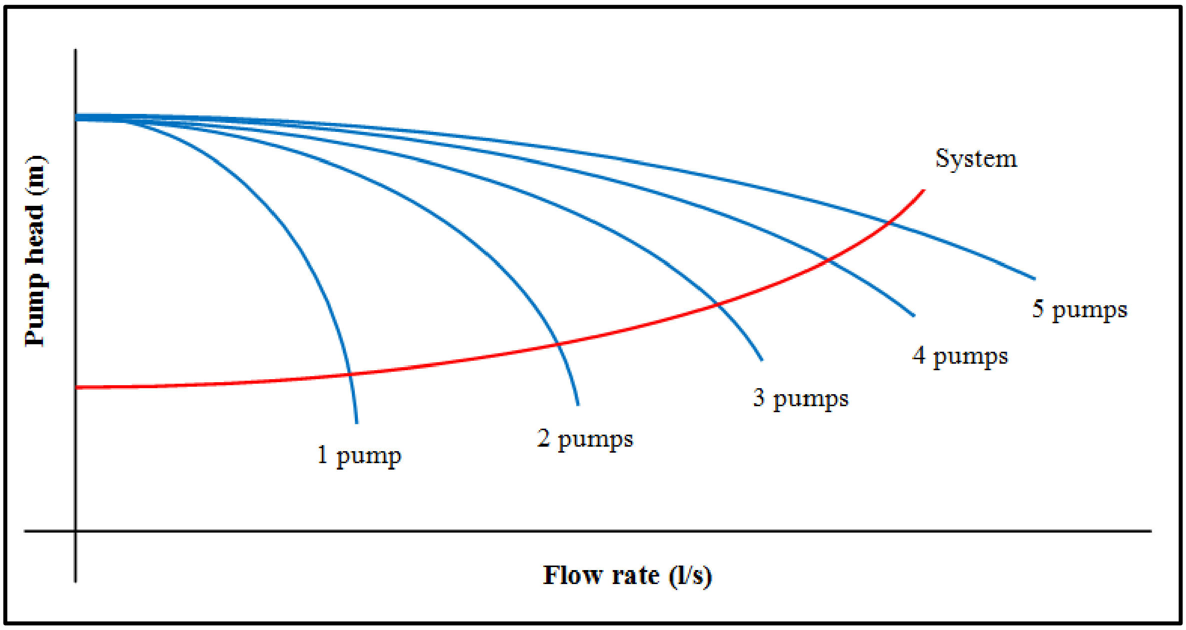


Figure 1-23: Flow rate of multiple pumps operating in parallel [13]

1.4 Techniques to reduce the water demand

1.4.1 Water demand

Mines consuming large amount of water are identified by comparing water consumption to the ore production. Vosloo [13] showed that the water consumed by a mine can be expressed and approximated as a linear function of the ore production, as shown in Figure 1-24.

Figure 1-24 shows that Mine E and Mine B consumes more water than the average mine per tonnes ore hoisted and Mine C uses only marginally more water than average. Therefore it can be assumed that water optimisation initiatives have more potential at these three mines than at the other mines. Botha [5] conducted a study regarding effective ways to reduce water in the mining industry. Leak management, stope isolation control and water pressure control were the three effective ways Botha [5] investigated.

In the mining industry many kilometres of pipe column supplies water from surface to the furthest and deepest working station in the mine, making leaking pipes a common problem. Due to the high pressure of the water in the pipes, even the smallest hole in a pipe will exert high volumes of water. The wasted water will be stored in an underground storage dam before being pumped back to surface.

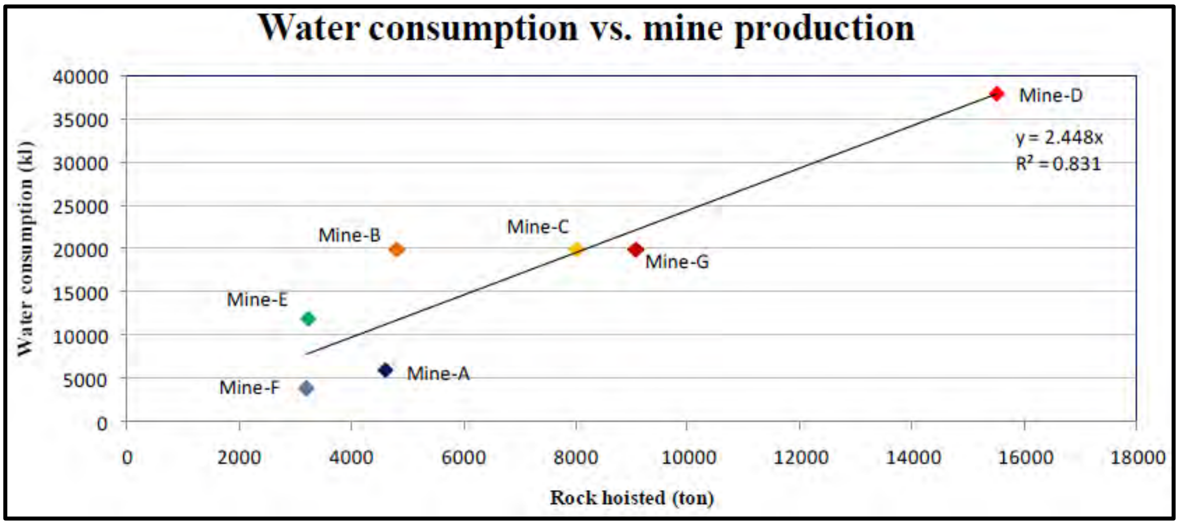


Figure 1-24: Graph showing water consumption (kl) as a function of minimum mine production (ton) [13]

Figure 1-25 shows the water leak flow rate and the cost price of wasted water as a function of the leak hole size. The data was obtained from a "save power" awareness board at one of Gold Fields (Pty) Ltd mines, see Appendix B.

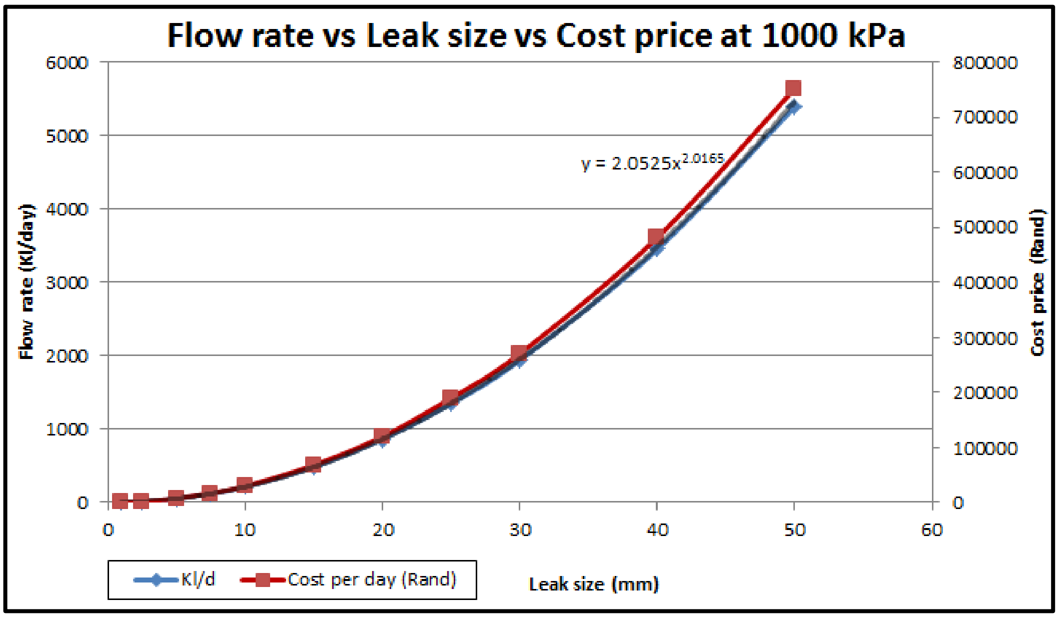


Figure 1-25: Graph showing flow rate (kl/day) and cost price (Rand) as a function of leak size (mm) at a pressure of 1000 kPa

The extra water requires more pumping operation and thus the electricity usage increases. Repairing pipe leaks on a regular basis will offer a significant reduction in electricity consumption. Water leaks can be identified with a visual inspection by a person on each underground level. A specialised portable hand held computer can also be used to log each leak's specific location and the extent of the leak. A report can be generated and distributed to the personnel responsible for the section. These reports and weekly feedback can increase the sustainability of repairing pipe leaks, resulting in cost saving.

Stope isolation control is another effective way to reduce water according to Botha [5]. The stopes are the areas were the actual work takes place. For example: mining, blasting, drilling and sweeping of the reef take place in the stopes. During blasting (15:00 to 18:00) a significant amount of water reduction can be achieved if the water fed to the stopes can be isolated. However, Botha [5] concluded that water pressure control remains the most effective solution to reduce water consumption.

Control valves, installed near the main supply column, reduce the waste water due to leaks as well as decreasing the volumes of water sent to the stope areas. The study will only focus on the use of control valves.

1.4.2 Effects of water pressure control

A few water pressure control initiatives were successfully implemented at some of the South African municipal water networks. These pressure control initiatives not only reduced the water wastage but reduced frequent system failures significantly [33].

From the equation below, derived from Bernoulli's theorem [34], it is shown that the flow rate through a hole is a function of the size and pressure of the fluid. Therefore it can be said that when the pressure of the fluid is reduced the flow rate will also be reduced [35].

$$q = C_V A \sqrt{\frac{2\Delta P}{\rho}} \qquad [m^3/s] \qquad \text{Equation 2}$$

Where:

- q = *Fluid flow [m^3/s]*
- C_V = *Flow coefficient [dimensionless]*
- A = *Area of leak size [m^2]*
- ΔP = *Pressure difference [Pa]*
- ρ = *Fluid density [kg/m^3]*

Vosloo [13] conducted a study regarding the relationship between pressure and flow rate at a typical mining level. Figure 1-26 shows that the flow rate increases with an increase of pressure.

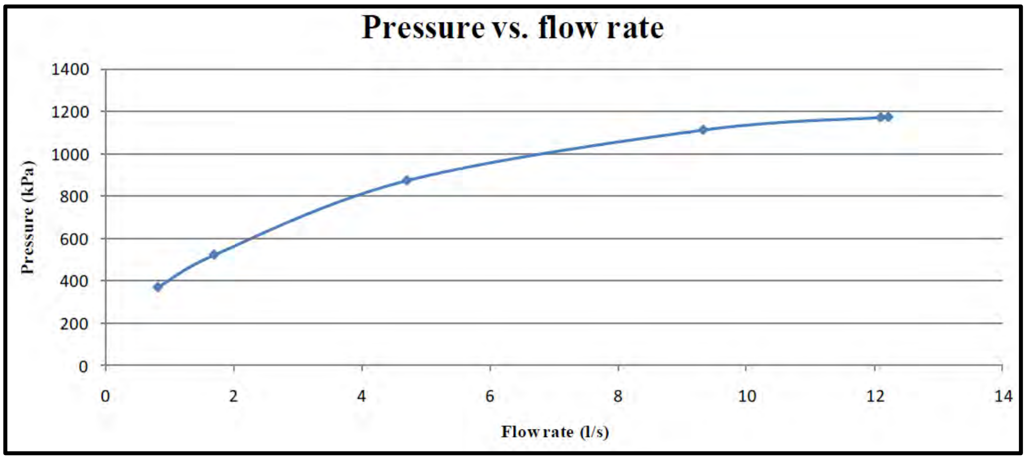


Figure 1-26: Graph showing the pressure (kPa) as a function of the flow rate (l/s) of water at a typical mining level [13]

PRV's installed on the underground levels are used to regulate the downstream pressure, allowing sufficient flow to equipment used in the stopes. Figure 1-27 shows the demand flow profile of a typical mine.

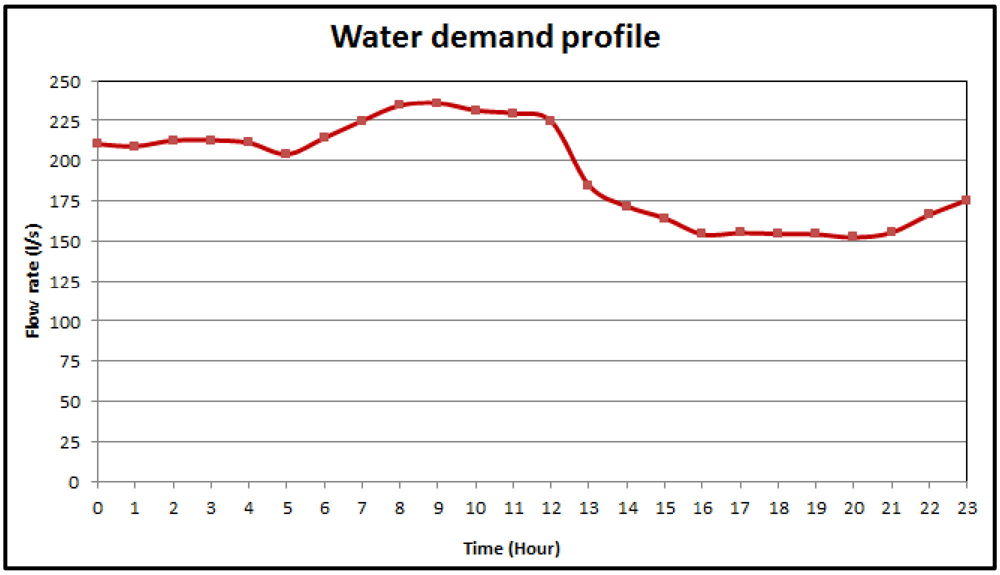


Figure 1-27: Graph showing the flow rate (l/s) for a typical mine over a 24-hour period

Figure 1-27 shows an increase in demand from 06:00 till 12:00 and from 22:00 till 03:00 the next morning. During these times production, sweeping and cleaning take place which demand high volumes of water for the equipment as well as for ventilation. The water demand decreases significantly from 13:00 till 21:00 when no production takes place.

In the study conducted by Vosloo [13], the downstream water pressure at the underground levels was reduced during the period from 15:00 till 20:00, as seen in Figure 1-28. The reduction in pressure had a significant effect on the supplied water flow rate. The flow rate reduction was on average 50 l/s for four hours which resulted in a total reduction of water consumption of approximately 720 kl.

By installing water pressure control valves, water supply schedules can be conducted according to mine shifts and pressure requirements. The valves can be controlled separately according to level specific requirements resulting in more water flow reduction and improved optimised system operation [5]. Valves can be closed completely on levels where no activity is scheduled or no water is required.

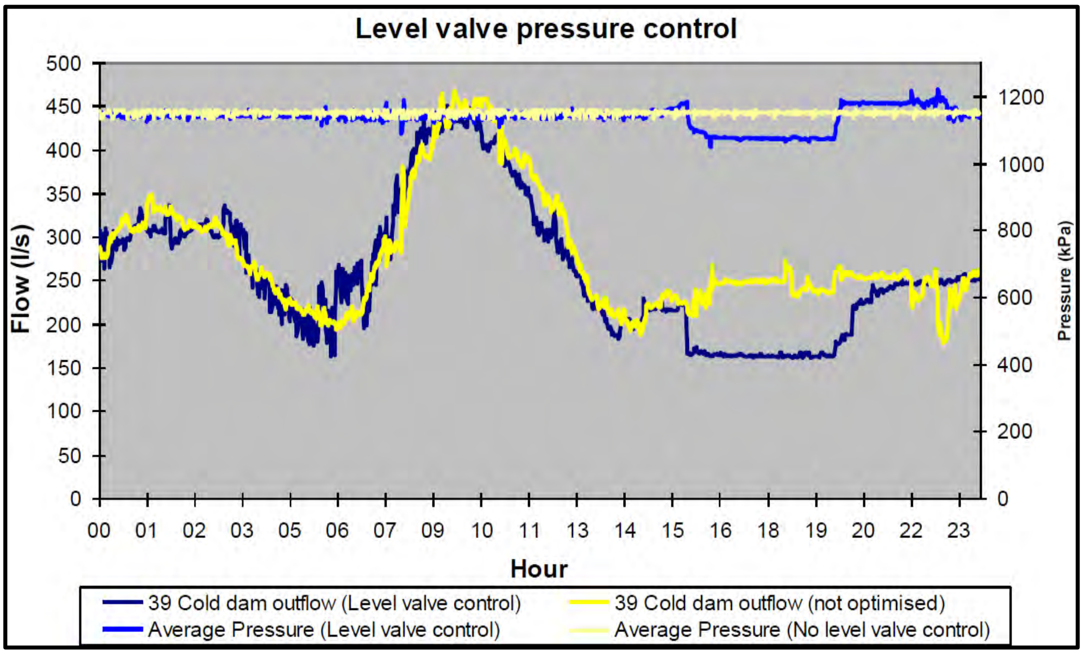


Figure 1-28: Graph showing the results of Vosloo's [13] pressure reduction study

When selecting a control valve to achieve the above mentioned control, primary constraints such as medium (water, steam or air), flow and pressure parameters must be identified [18]. The extent to which the valve will control these parameters improves the selection of the type and rating of the valve. Additional constraints must be taken into account when selecting a valve, such as cavitation, water hammer, flashing, safety ratings and control range.

Booysen [18] conducted a study regarding valve selection and concluded that the selection of a control valve requires a delicate compromise between various system constraints. Valve installation in the hazardous mining areas presents further challenges and constraints. An accurate indication of major system constraints can be identified by system analysis and simulation models [18].

1.5 Goal of the study

This dissertation investigates methods to select control valves for water reticulation systems. Valve selection needs to be investigated to ensure correct operation when installed in the reticulation system. Information from an energy efficiency project will serve as a case study. Effective valve control will result in energy savings.

1.6 Outline of the dissertation

Chapter 1

In Chapter 1 a brief background to South Africa's electricity generation and consumption is provided. Mine water reticulation systems (refrigeration plants, water supply, demand and dewatering systems) are discussed. The objectives and needs of the study are motivated and set.

Chapter 2

In Chapter 2 the need for control valves, valve constraints, valve calculations as well as system constraints will be discussed. The method of how valves are selected will be discussed.

Chapter 3

In Chapter 3 the development of an analytical valve selection model/method will be discussed. The identification of system components/parameters, data analysis and the use of simulation models will be discussed.

Chapter 4

In Chapter 4 the implementation of the analytical selection methodology on an energy efficiency project, which will serve as a case study, will be discussed. The results of the case study will be quantified.

Chapter 5

In Chapter 5 a conclusion regarding the outcome of the study and recommendations regarding further work are made.

2. CONTROL VALVES FOR WATER RETICULATION SYSTEMS

Summary

This chapter will serve as a literature survey for the study. The need of control valves, valve constraints, calculations and selection will be discussed. The present selection method will also be investigated.

2.1 Preamble

Various DSM projects aim to improve water reticulation systems in order to reduce the volume of water transferred. As part of the initiative control valves are required. Before a valve selection can be made the following must first be understood:

- Valve characteristic and constraints;
- Valve sizing (calculations); and
- Valve types.

2.2 Valve characteristics and constraints

2.2.1 Valve characteristics

Valves can be defined as a mechanism to change the flow and/or pressure of a medium in a system [36]. Devices normally used in combination with valves, for specific flow or pressure requirements are:

- Pressure transmitters;
- Flow meters;
- Actuators; and
- Controllers such as Programmable Logic Controllers (PLC).

The primary constraints influencing valve selection are: the type of medium (water, steam or air), flow and pressure parameters [18]. Figure 2-1 shows the standard valve flow characteristics for certain valve types. The extent to which the valve will control these parameters determines the application of the valve. Additional constraints must also be taken into account when selecting a valve, such as cavitation, water hammer, flashing, safety ratings and control range.

<u>Linear Flow:</u> A valve has a linear flow characteristic when the percentage valve travel (opening) is directly proportional to the flow rate (linear flow characteristic is presented by the blue line in Figure 2-1). For example, once the valve is at a constant opening of Δs the flow rate will be at a constant $(\Delta q \times C_V)$ of the maximum flow at a constant pressure drop, where C_V is the valve coefficient.

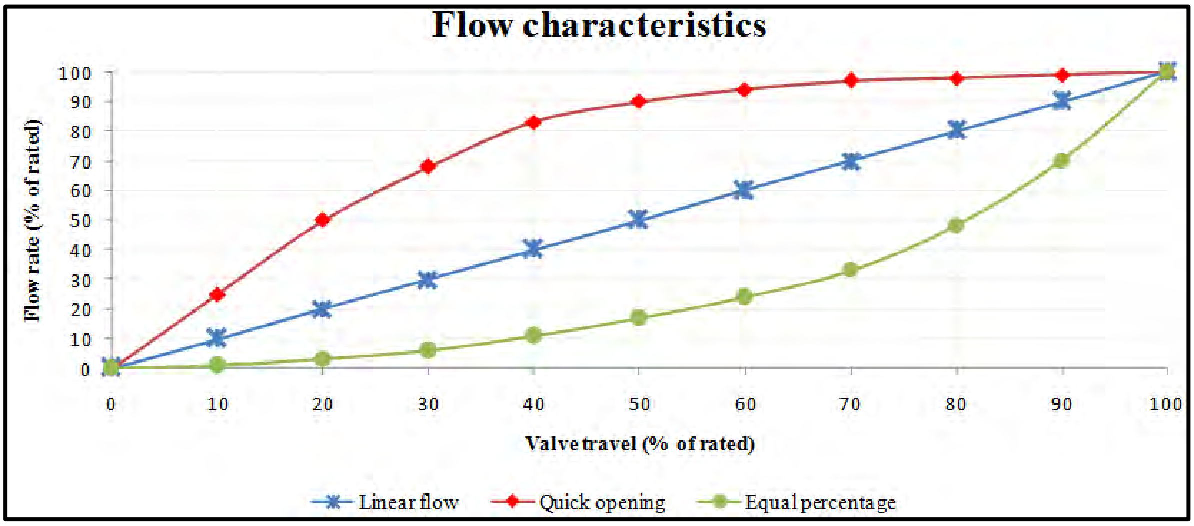


Figure 2-1: Standard flow characteristics found in valves [37]

Linear flow characteristics can be defined based on the relationship between the changes of rate of flow rate to valve travel [37] [38].

$$\frac{\Delta q}{\Delta s} \cong C_V \qquad \text{Equation 3}$$

Where:

Δs = *Percentage of valve travel*

Δq = *Percentage of flow rate*

<u>Equal Percentage:</u> A valve inherits an equal percentage flow characteristic when the percentage change in flow rate equals the percentage valve travel. Therefore, the valve initially gains a low increase in flow rate but gains more aggressively as the valve travel increases. For instance, there will be little change in the flow rate through the first stages of valve travel, resulting in a large flow rate increase as the valve travel increases [37]. Equal percentage is presented by the green line in Figure 2-1. Equal percentage flow characteristics can be defined based on the following relationship [37] [38].

$$\left.\frac{\Delta q}{\Delta s}\right|_{q=0} > C_V > \left.\frac{\Delta q}{\Delta s}\right|_{q=max} \qquad \text{Equation 4}$$

<u>Quick opening:</u> A valve inherits a quick opening flow characteristic when the maximum flow rate is achieved with minimal valve travel [37]. Quick opening is presented by the red line in Figure 2-1.

Quick opening flow characteristics can be defined based on the following relationship [37] [38].

$$\frac{\Delta q}{\Delta s}\bigg|_{q=0} < C_V < \frac{\Delta q}{\Delta s}\bigg|_{q=max} \quad \text{Equation 5}$$

2.2.2 Valve constraints

Cavitation: When water pressure through the valve falls below the vapour pressure of the liquid, vapour bubbles form (see Figure 2-2). These vapour bubbles implode as pressure recovery takes place, causing damage to valve and downstream pipework. This phenomenon is called cavitation.

Figure 2-3 shows the damages caused by cavitation on a plug valve [39]. Cavitation reduces valve performance and seat-sealing properties, resulting in flow leakage through the valve.

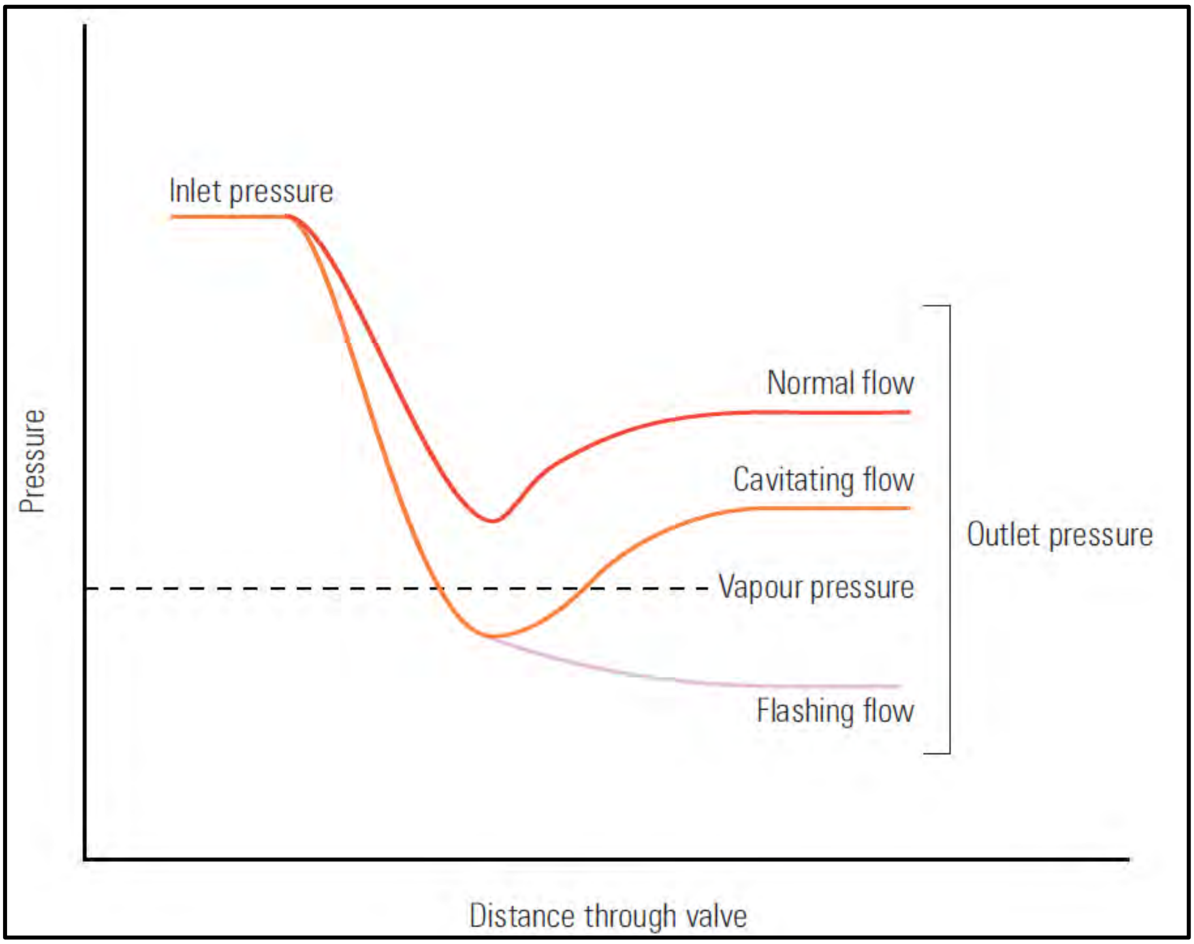


Figure 2-2: Pressure levels through a control valve creating cavitating and flashing flow [40]

Figure 2-3: Example of a valve cavitation [41]

Flashing: Flashing and cavitation are approximately the same phenomenon. However, cavitation starts at a much higher outlet pressure and the fluid returns to liquid state, while flashing stays below vapour pressure and does not return to pure liquid state. The result is destruction to the surface which is in contact with the medium as shown in Figure 2-4 [39].

Figure 2-4: Example of damages caused by flashing flow [39]

Water Hammer: In the event of a sudden decease in flow velocity, water hammer occurs. A sudden decrease in flow velocity can happen for example, when a control valve plug gets stuck in the valve seat [42]. Due to incompressibility of water, pressure waves that can be 10 times higher than normal operating pressure, travels throughout the pipe network [39]. These pressure waves cause damages to downstream pipe networks and equipment as seen in Figure 2-5.

When water columns burst due to water hammer it can cause flooding of underground working levels which will require a shutdown of the level for repairs. Water hammer can be prevented when control valves are opened with a slow valve motion producing suitable thrust [39].

Figure 2-5: Example of damage to a pipe section due to water hammer [42]

Valve Noise: When valves are partially open large pressure drop and turbulence occur. This can result in vibration that induces valve noise. The noise caused by the vibrations can be damaging to human hearing. These vibrations could also damage valves and control equipment [39]. The vibrations caused by the turbulence are illustrated in Figure 2-6.

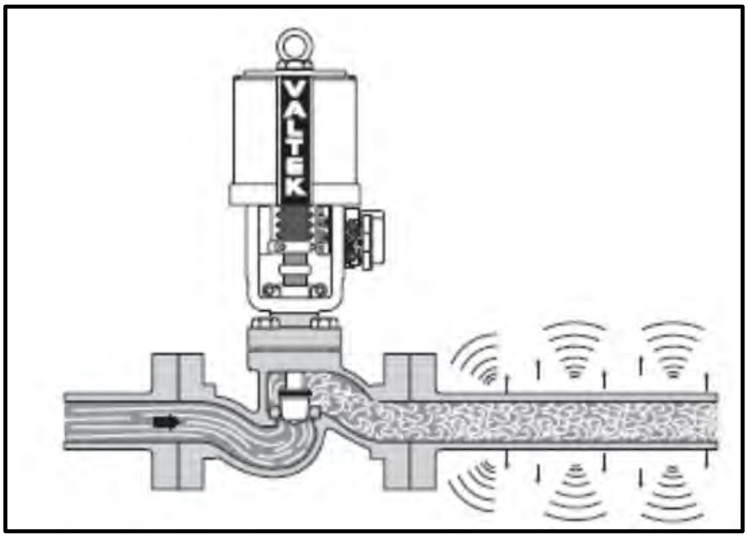


Figure 2-6: Turbulence cause vibrations resulting in valve noise [39]

2.3 Calculations for valve selection

The selection and correct sizing of a control valve must be based on the full understanding of the process. If a valve is sized too small the required flow rate will not be delivered. If a valve is sized to big the valve will be operated at low percentage opening which may result in instability. An ideal valve can be sized for a given application using a combination of calculations as guideline.

To gain the full knowledge of the process the following parameters need to be considered:

- The type of fluid (water, steam and air) and its thermodynamic characteristics;
- The required flow and pressure parameters; and
- The operating conditions (max, min and normal).

In this study only water supply applications valves will be considered. Valve sizing calculations are based on the Bernoulli equation [38] [35].

$$P_1 - P_2 = \frac{1}{2}\rho V_1^2 - \frac{1}{2}\rho V_2^2 \qquad \text{[Pa]} \qquad \text{Equation 6}$$

Where:

P_1 = Inlet pressure [Pa] (absolute)
P_2 = Outlet pressure [Pa] (absolute)
ρ = Fluid density [kg/m³]
V_1 = Inlet velocity [m/s]
V_2 = Outlet velocity [m/s]

Using the equation above, Bernoulli showed that when a fluid (water) flows through a hole, as seen in Figure 2-7, the velocity is directly proportional to the pressure difference. Bernoulli also calculated that the velocity is indirectly proportional to the specific gravity of the liquid.

The results of Bernoulli can be interpreted as follows:

- When the pressure differential (pressure drop) increases, the velocity increases; and
- When the density increases, the velocity decreases.

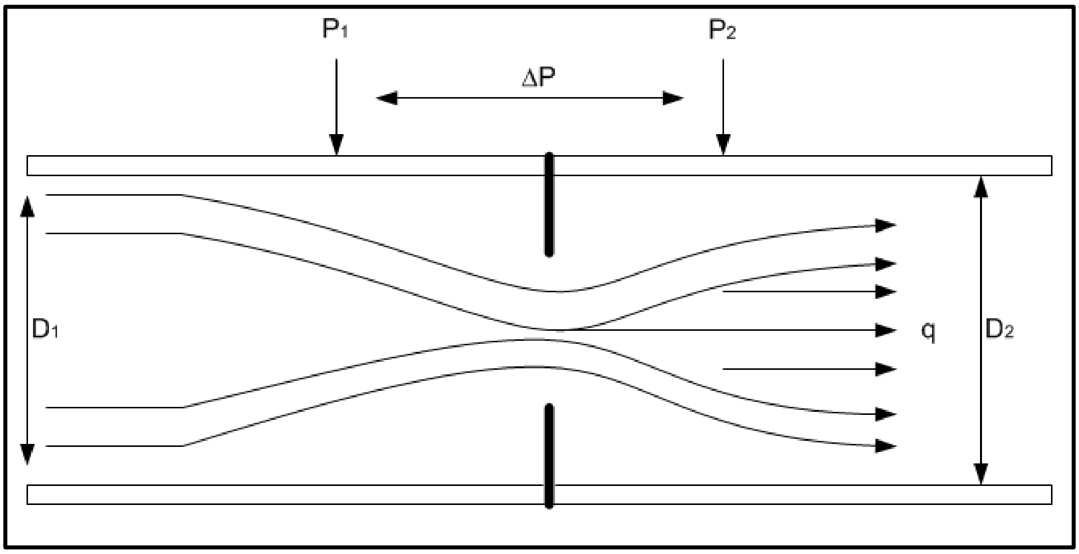


Figure 2-7: Diagram of liquid flow through a hole

The velocity of the fluid is directly proportional to the pressure differential but indirectly proportional to the density [37].

$$\Delta P \uparrow \ \ V \downarrow \qquad AND \qquad \rho \uparrow \ \ V \downarrow \qquad \text{Equation 7}$$

Where:

ΔP = *Pressure difference [Pa]*

V = *Velocity [m/s]*

ρ = *Fluid density [kg/m³]*

All these calculations can be simplified by using the valve flow coefficient, which combines all flow restriction (due to components inside the valve) into one value. The Fluid Control Institute (FCI) has developed a standard test model to determine flow coefficients among valve manufactures [38]. See Figure 2-8 for the FCI standard test model [37] [38].

$$C_V = q\sqrt{\frac{G}{\Delta P}} \qquad \text{Equation 8}$$

Where:

C_V = *Flow coefficient [dimensionless]*

ΔP = *Pressure difference [Pa]*

q = *Volumetric flow [m³/s]*

G = *Specific gravity [dimensionless]*

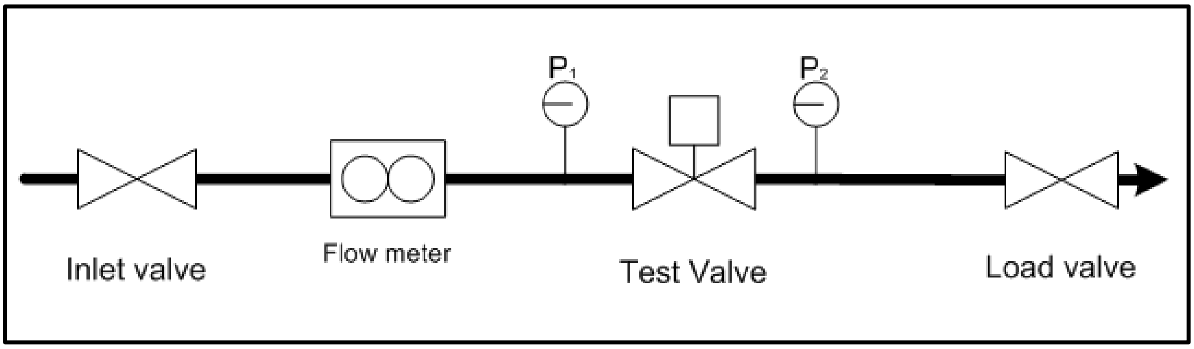


Figure 2-8: Standard FCI test model for flow coefficient measurement [38]

Appendix A provides a diagram displaying flow coefficient values at certain pressure drops and liquid flow.

As previously discussed, before an effective valve can be selected, appropriate process conditions need to be specified for:

- q = Volumetric flow [m^3/s];
- P_1 = Inlet pressure [Pa] (Absolute);
- P_2 = Outlet pressure [Pa] (Absolute);
- T = Temperature [K];
- G = Specific gravity [dimensionless];
- P_v = Vapour pressure [Pa]; and
- P_c = Absolute thermodynamic critical pressure [Pa].

The flow and inlet pressure depends on the system and needs to be measured with flow and pressure transmitters. The outlet pressure will depend on the installed valve setup and system characteristics. All standard conditions are 15° C and 101.3 kPa [37].

The following step of the valve sizing (selection) process is to solve for the desired flow coefficient value [37].

$$C_V = \frac{q}{N_1 F_P \sqrt{\frac{\Delta P}{G}}} \qquad \text{Equation 9}$$

Where:

C_V = *Flow coefficient [dimensionless]*

q = *Volumetric flow [m³/s]*

N_1 = *Equation constant [dimensionless]*

F_P = *Pipe geometry factor [dimensionless]*

ΔP = *Pressure difference [Pa]*

G = *Specific gravity [dimensionless]*

Where, N_1 is an equation constant (dependent on units used) and F_P is the piping geometry factor. The equation constant depends on the system unit type. These equation constants are provided in Appendix A. The piping geometry factor accounts for pressure losses due to pipe fitting such as elbows and reducers. If the inlet and outlet of a valve is equal, the pipe geometry factor equals one [37].

Most of the pipe geometry factors have been determined by valve manufactures. See Appendix A for pipe geometry factors. When the pipe geometry factor needs to be determined the following equation can be used [37].

$$F_P = \left[1 + \frac{\sum K}{N_2}\left(\frac{C_V}{d^2}\right)^2\right]^{-\frac{1}{2}} \qquad \text{Equation 10}$$

Where:

F_P = *Pipe geometry factor [dimensionless]*

K = *Head loss coefficient [dimensionless]*

N_2 = *Equation constant [dimensionless]*

C_V = *Flow coefficient [dimensionless]*

d = *Nominal valve size [mm]*

Where, N_2 is an equation constant and d represents nominal valve size. The $\sum$ K term is the sum total of all velocity head loss coefficients due to fittings attached to valve.

For example:

$$\sum K = K_1 + K_2 + K_{B1} - K_{B2} \qquad \text{Equation 11}$$

Where:

$\sum K$ = Total velocity head loss coefficient

K_1 = Resistance coefficient of upstream fitting [dimensionless]

K_2 = Resistance coefficient of downstream fitting [dimensionless]

K_{B1} = Bernoulli inlet coefficient [dimensionless]

K_{B2} = Bernoulli outlet coefficient [dimensionless]

Bernoulli coefficients can be calculated by the following equation [37]:

$$K_{B1} or\ K_{B2} = 1 - \left(\frac{d}{D}\right)^4 \qquad \text{Equation 12}$$

Where:

K_{B1} = Bernoulli inlet coefficient [dimensionless]

K_{B2} = Bernoulli outlet coefficient [dimensionless]

d = Nominal valve size [mm]

D = Pipe outside diameter [mm]

If the inlet and outlet pipe sizes are equal, then the Bernoulli coefficients are equal. The following equations can be used to determine K_1 and K_2 [37]:

$$K_1 = 0.5\left(1 - \frac{d^2}{D^2}\right)^2 \qquad \text{Equation 13}$$

$$K_2 = 1.0\left(1 - \frac{d^2}{D^2}\right)^2 \qquad \text{Equation 14}$$

The following step is to determine the maximum allowable flow and pressure drop over the valve. These values will be used to determine if choked flow is possible. Choked flow occurs when an increased pressure drop no longer provides an increase in flow rate [43].

The maximum flow rate can be calculated with the following equation [37]:

$$q_{max} = N_1 F_L C_V \sqrt{\frac{P_1 - F_F P_V}{G}} \quad [m^3/s] \qquad \text{Equation 15}$$

Where:

q_{max} = *Maximum liquid flow [m³/s]*

N_1 = *Equation constant [dimensionless]*

F_L = *Recovery factor [dimensionless]*

C_V = *Flow coefficient [dimensionless]*

P_1 = *Inlet pressure [Pa] (absolute)*

F_F = *Critical pressure ratio factor [dimensionless]*

P_V = *Vapour pressure [Pa] (absolute)*

G = *Specific gravity [dimensionless]*

Where, F_F is equal to the critical pressure ratio factor which can be obtained from the graph in Appendix A or following equation [37]:

$$F_F = 0.95 - 0.28\sqrt{\frac{P_V}{P_C}} \qquad \text{Equation 16}$$

Where:

P_V = *Vapour pressure [Pa] (absolute)*

P_C = *Absolute thermodynamic critical pressure [Pa] (absolute)*

The recovery factor F_L (without fittings) can be selected from the flow coefficient tables. However, if the valve is to be installed with fitting, F_L must be replaced with $\frac{F_{LP}}{F_P}$ where [37]:

$$F_{LP} = \left[\frac{K_1}{N_2}\left(\frac{C_V}{d^2}\right)^2 + \frac{1}{{F_L}^2}\right]^{-\frac{1}{2}} \qquad \text{Equation 17}$$

Where:

F_{LP} = *Combination between pressure and pipe geometry factor [dimensionless]*

K_1 = *Resistance coefficient of upstream fitting [dimensionless]*

N_2 = *Equation constant [dimensionless]*

C_V = *Flow coefficient [dimensionless]*

d = *Nominal valve size [mm]*

F_L = *Recovery factor [dimensionless]*

The maximum allowable pressure drop can be calculated from the following equation [37]:

$$\Delta P_{max} = {F_L}^2(P_1 - F_F P_v) \quad \text{[Pa]} \qquad \text{Equation 18}$$

Where:

ΔP_{max} = *Pressure difference maximum [Pa]*

F_L = *Recovery factor [dimensionless]*

P_1 = *Inlet pressure [Pa] (absolute)*

C_V = *Flow coefficient [dimensionless]*

P_V = *Vapour pressure [Pa] (absolute)*

When ΔP_{max} have been obtained it must be compared to the actual pressure drop ΔP. If ΔP_{max} is lower than ΔP, choked flow conditions will exist under the specified process conditions [37]. To overcome this choke flow condition, ΔP in the flow coefficient (C_V) equation must be replaced with ΔP_{max} [37].

When choke flow exists for the specified process conditions it can be determined if cavitation or flashing is the cause. As discussed in Section 2.2.2 cavitation occurs when a low pressure zone occurs downstream of the valve before pressure recovery (pressure higher than P_v) takes place. Flashing occurs when the outlet pressure is lower than P_v, but due to the high velocity vapour bubble implodes downstream. Figure 2-9 displays a diagram of liquid flowing through a valve with constant upstream pressure.

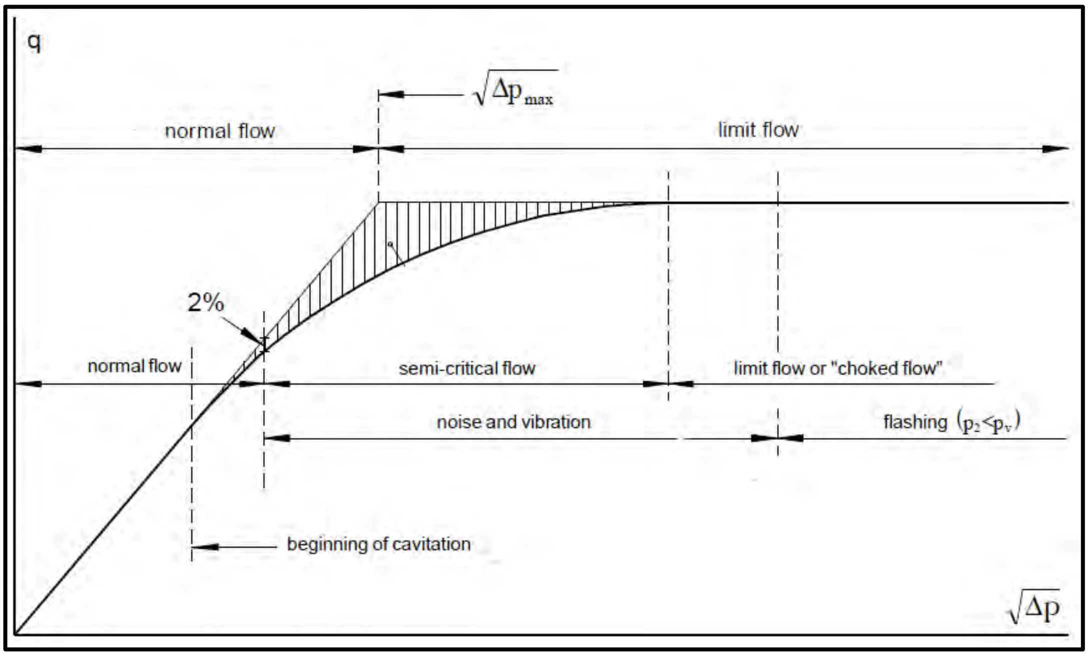


Figure 2-9: Diagram of liquid flow through a valve with constant upstream pressure [44]

2.4 Control valve types and present selection method

2.4.1 Valve types

A wide variety of control valves can be selected for a desired system specification. In this section the most commonly used (water application) control valves will be discussed.

PRV's: PRV's automatically reduce supply pressure to a pre-set (set-point) pressure if the supplied pressure is higher than the pre-set pressure (see Figure 2-10). The primary parts of the PRV's are the main valve; an upward-seating valve (that has a piston on top of its valve stem), an upward-controlling valve, a controlling diaphragm, and an adjusting spring and screw [36].

Ball valve: Due to a straight-through flow design, ball valves inherit a small pressure drop characteristic when fully opened. Figure 2-11 shows a typical ball valve. The ball valve provides control over a varied pressure range and has an equal percentage flow characteristic. However, due to the fixed characteristics, the valve is more liable to suffer from cavitation [37]. The valve is adequate for on/off situations with minimum maintenance.

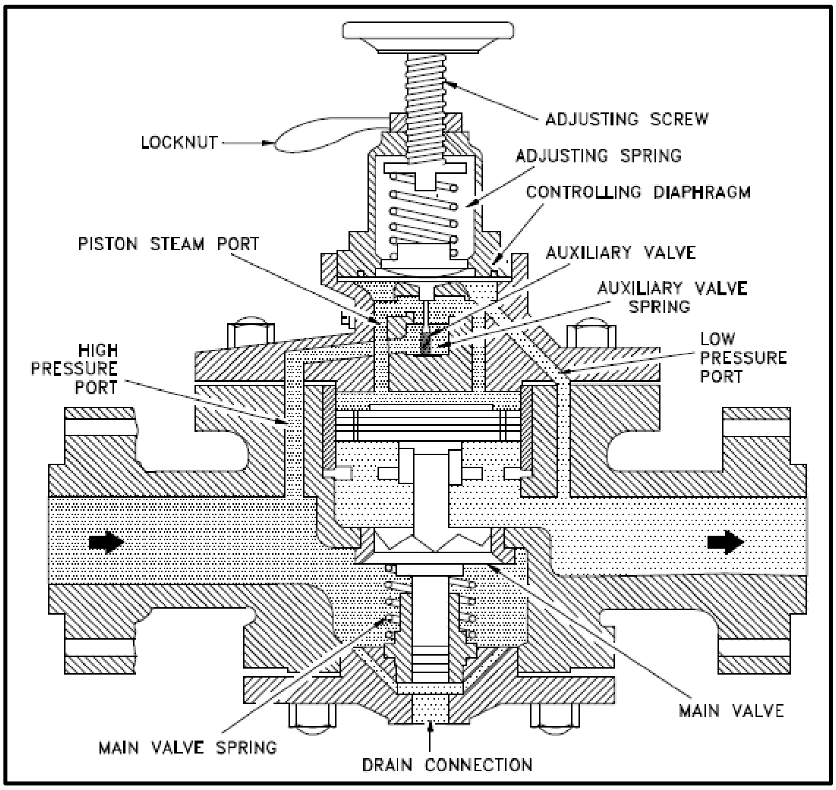


Figure 2-10: Cross sectional diagram of a pressure reducing valve [36]

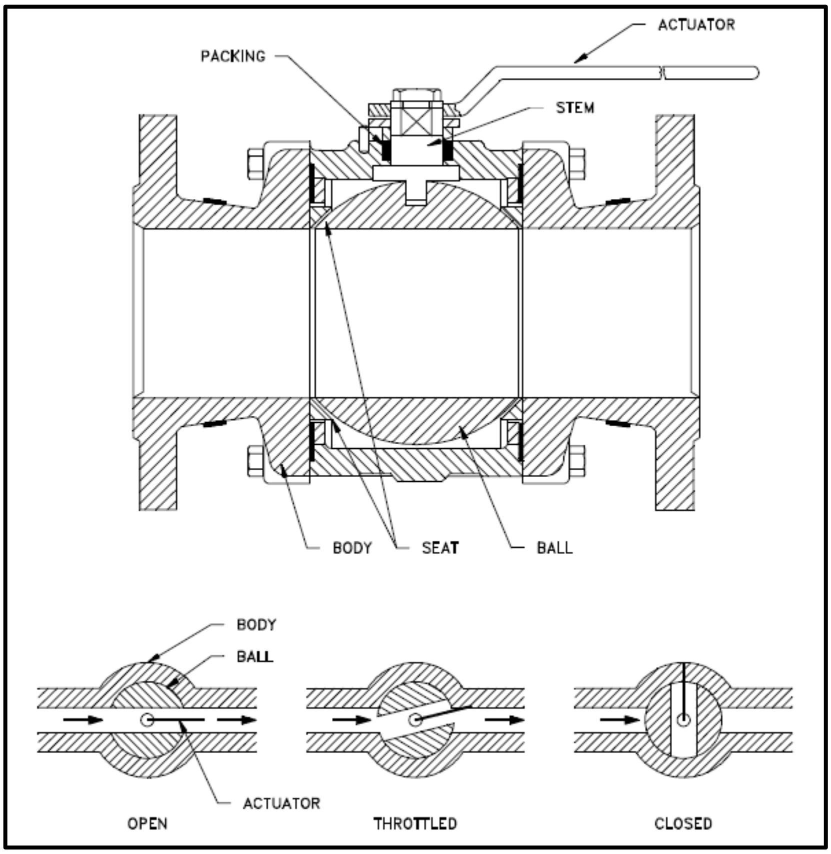


Figure 2-11: Diagram of a V-notch ball valve [36]

Butterfly valve: Due to the shape of the valve, minimum space is required for installation. Butterfly valves are widely used in different industries. Figure 2-12 shows a typical butterfly valve. The drawback of a butterfly valve is that for high pressure applications a larger actuator may be required. The butterfly valve characteristics are similar to a ball valve; equal percentage flow characteristic over a small pressure drop when fully opened [37].

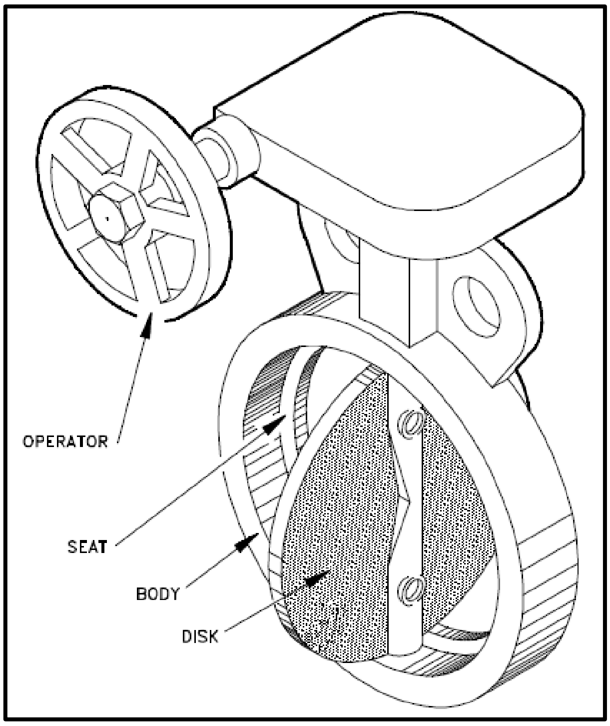


Figure 2-12: Diagram of a butterfly valve [36]

Globe type valve: Globe type valves are expensive compared to the ball and butterfly valves. However, in certain applications the globe valve characteristics makes it a more ideal choice. See Figure 2-13 for a typical globe type valve.

Special cages and trims can be constructed allowing changes to the valve characteristics. With these cages and trims the occurrence of cavitation, noise and vibration can be reduced or even nullified [45]. These cages and trims are ideal for high pressure and flow conditions situations where flashing, cavitation, noise and vibration become a concern. Figure 2-14 shows three different types of cages used in globe valves.

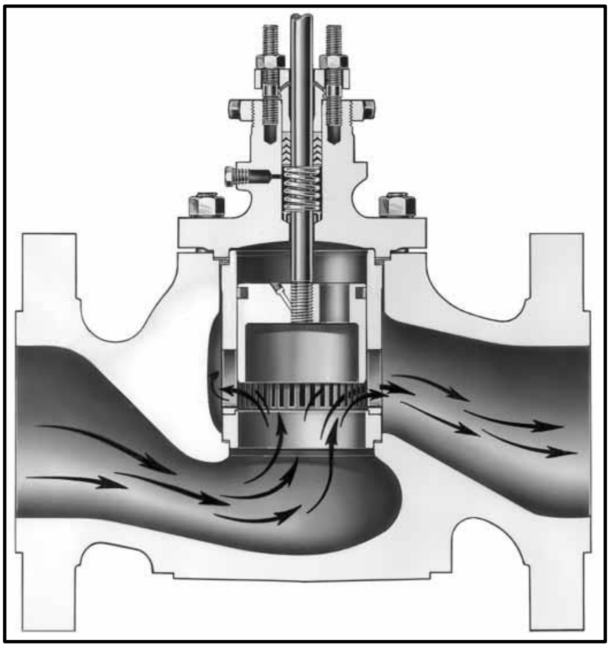


Figure 2-13: Image of a globe type valve [37]

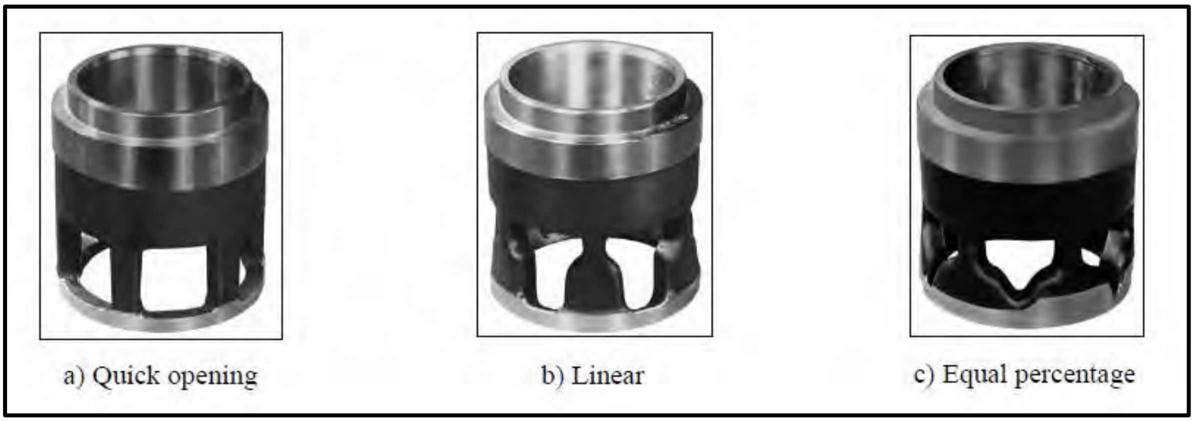


Figure 2-14: Image showing quick opening, linear and equal percentage cages in globe valves [37]

With energy efficiency initiative projects, control valves are required to control and optimise the system. Because of the high pressure experienced in the system, due to pressure control as discussed in Section 1.4.2, the pressure drop across an installed control valve will be high. The high pressure drop will increase the risk of cavitation in the valve. In an attempt to decrease the low pressure zone downstream, trims are installed and they will reduce the pressure in stages. This will prevent the pressure to decrease below the P_v. Figure 2-15 illustrates a typical multiple stage trim installed on water application valves.

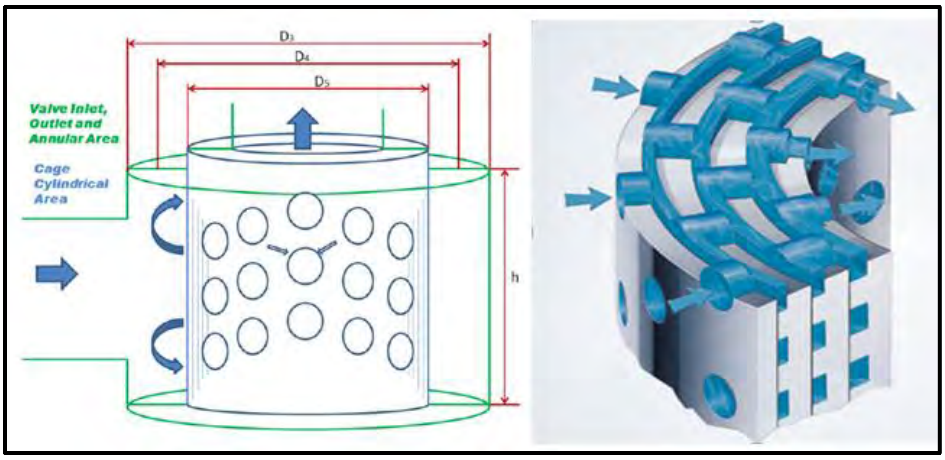


Figure 2-15: Multiple stage trim used to reduce cavitation effects [46]

The valve flow coefficient, Cv, provides an indication of the pressure drop over the valve for a specific flow and temperature. When a valve is operated at low percentage opening, the risk of cavitation will occur resulting in excessive wear. Figure 2-16 illustrates a standard globe valve Cv range as a function of various percentage openings.

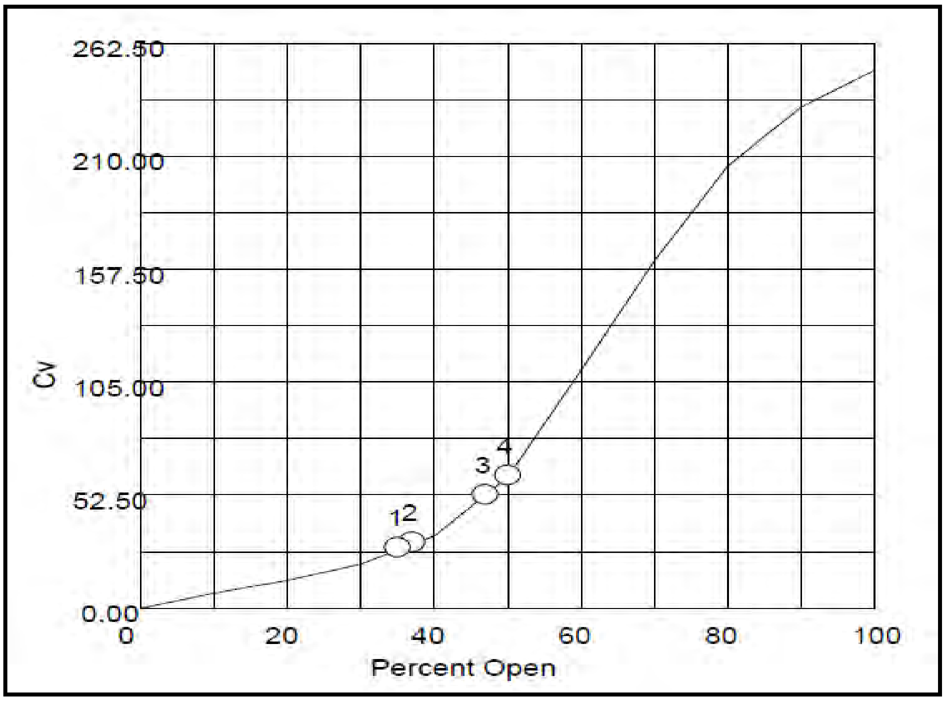


Figure 2-16: Graph showing the Cv range (0 to 263) as a function of a globe valve's opening (%) [18]

Cavitation can be reduced or eliminated by adding additional trims, as shown in Figure 2-15, to the valve configuration. Multiple trims will reduce the cavitation or direct the cavitation to minimise the damage. Figure 2-17 shows three trims diverting the cavitation away from the valve body.

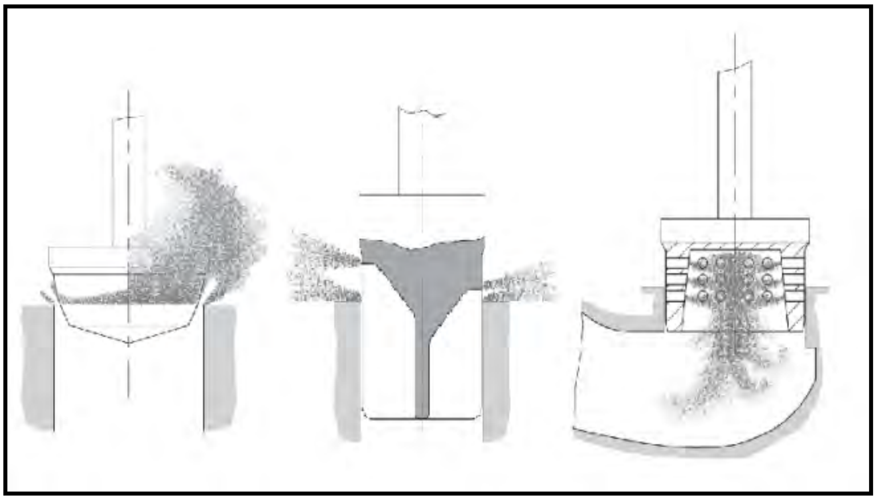


Figure 2-17: Image of Cavitation and three limited trims [47]

Additional trims will however affect the valve control range. Figure 2-18 shows a similar valve as in Figure 2-16, but with a 6 stage linear trim. Using multiple stage trims the valve control curve at small valve openings are minimised. Figure 2-18 illustrates the Cv range as a function of different percentage openings when trims are used.

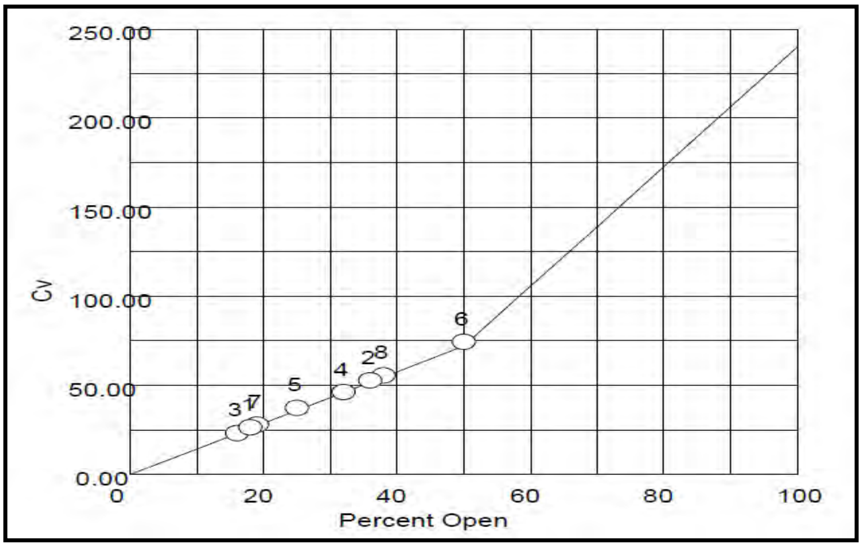


Figure 2-18: Graph showing the Cv range (0 to 250) as a function of a globe valve's opening (%) with multi trim valve control [18]

2.4.2 Present selection method

In every valve selection, process information is exchanged between the sales engineer and site engineer. The site engineer requires a valve for a specific application and provides the sales engineer with system parameters, for example: flow and pressure parameters. The sales engineer uses these parameters to specify a valve. The system parameters including a valve type will be pre-selected and used as input variables for a calculation sheet. All the equations discussed in the previous sections are typically preprogramed in the calculation sheet.

The calculation sheet provides the sales engineer with the various outputs, for example: whether the valve will experience cavitation or flashing conditions, noise levels and maximum allowable pressure across the valve. Based on this information the sales engineer will then propose a valve to the site engineer. The disadvantage of this selection process is that the valve manufacturer only matches the sample constraints. This is a problem because when the control valve is installed in a mine water reticulation network, the entire system characteristics change. The selected valve may no longer be suitable for the specific application. This may cause instabilities or damages in the system, resulting in production loss.

2.5 Conclusion

Control valves perform a vital role in the control of water reticulation systems. It is important to understand the underground process to ensure that the correct valve for the specific application is selected.

When control valves are not selected correctly it could lead to cavitation, flashing, water hammer and valve noise, resulting in severe consequences.

3. ANALYTICAL CONTROL VALVE SELECTION METHODOLOGY

Summary

To ensure a more effective valve selection both system and valve constraints need to be investigated. A system analysis methodology will be developed. The system analysis methodology will discuss the analytical selection process by means of data analysis and simulation models.

3.1 Preamble

Selecting a control valve involves selecting various components that make up a valve in order to satisfy system and control constraints [37]. Good control valve selection will result in effective control of the pressure and flow rates. The selection process used by valve manufacturers will be discussed. An investigation regarding a more effective valve selection process will be conducted.

3.2 System analysis methodology

When selecting (sizing) a control valve, valve manufacturers use system flow and pressure parameters. Different components, namely: valve type, body size, orifice size and trim are selected to satisfy these flow and pressure parameters. These components are pre-selected from the manufactures' tables, based on the output of various calculations.

The calculations are all incorporated into a calculation sheet which determines whether the valve will experience severe flashing or cavitation effects. If either of these conditions can occur a new valve type or body size is selected. The calculation sheet also determines the maximum allowed pressure drop across the valve and noise levels. In the Occupational Health and Safety Act and Regulation 85 of 1993 (OHS act) noise level may not exceed 85 dB [48]. When noise levels exceed this maximum the cage operator (on-setter) cannot hear the alarm bells. If noise levels are a potential problem the valve installation position should be moved away from the shaft vicinity. Figure C-7 in Appendix C shows a typical valve calculation sheet.

The disadvantage of this selection process is that valve manufacturers only address valve constraints and not system constraints. The manufacturer also often uses data received from the client without fully understanding the requirements. With DSM projects, system characteristics are changed by introducing additional control components. The aim of this study is to investigate a more effective way to select control valves, satisfying valve and system constraints, resulting in a more effective valve solution.

Systems analysis is the process of scrutinising measured (empirical) data in order to develop a good understanding of the functionality of the system, as well as identifying problems and analysing possible solutions. In an attempt to understand both valve and system constraints a system analysis methodology was developed. The methodology is divided into three sections as seen in Figure 3-1. After completing the methodology the result will be a set of valve constraints.

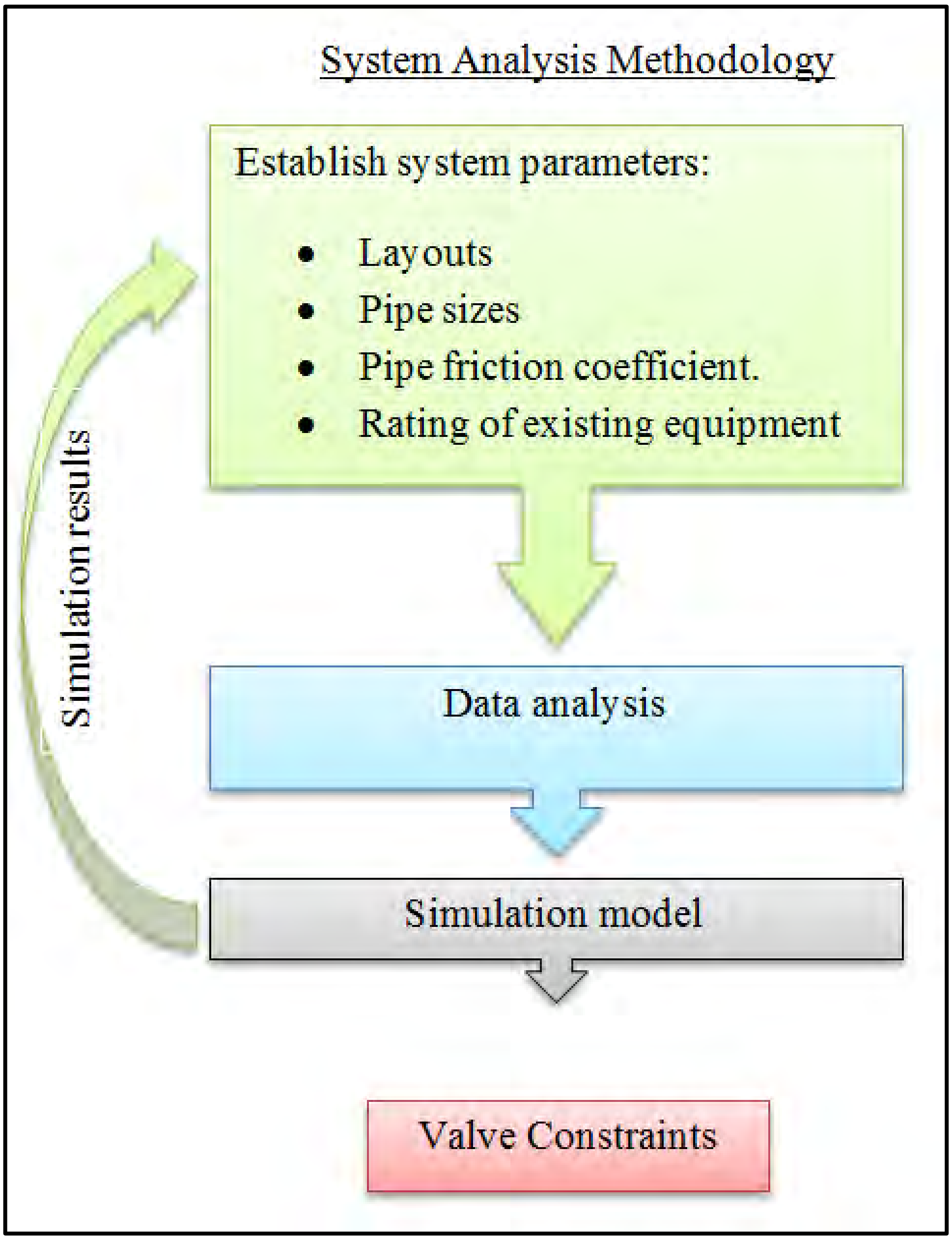


Figure 3-1: Flow diagram of the system analysis methodology

The initial step of the methodology is to identify all available system components and to collect data. The collected data must be measured data for a time period during which the mine operation had no unscheduled interruptions. In an attempt to comprehend the complexity of the system a simulation model can be developed based on the analysed data. The results of the simulation model need to be compared to system parameters and analysed data to ensure a valid model.

Based on the analysed data, different scenarios can be simulated using the simulation model to determine new valve parameters (characteristics).

3.3 Establish system components

The initial step of the methodology is to identify all the system components, for example: layout of water system, pipe size and pipe friction coefficients must be identified. Below is a list of a typical mine's system components and their characteristics:

- Pipe size;
  - Size (approximate length 3500 m and diameter 200 mm)
  - Resistance coefficient (obtain from measured data)
- Control equipment; and
  - PRV's and NGD (rated at 30 MPa)
  - Control and isolation valves
- Users
  - Drills (approximately 450 kPa)
  - Cooling cars
  - BAC (approximately 250 l/s)
  - Sweeping

Data can be collected by means of flow meters and pressure transmitters, seen in Figure 3-2, Supervisory Control and Data Acquisition (SCADA) systems, historian databases, specification sheets and design/layout drawings. In the case where system data is not available, portable instrumentation can be used to take measurements. Data can be logged over different time increments. Data logged over shorter time increments will give a clearer indication of system operations.

Figure 3-2: A pressure transmitter installed on underground levels

A basic layout of a typical mine water reticulation system is illustrated in Figure 3-3. The mine consists of two vertical shafts, the Main-shaft and the Sub-shaft, which are joined on Level 22. Figure 3-3 shows pipe lengths, existing valve Cv's and the height between different underground levels.

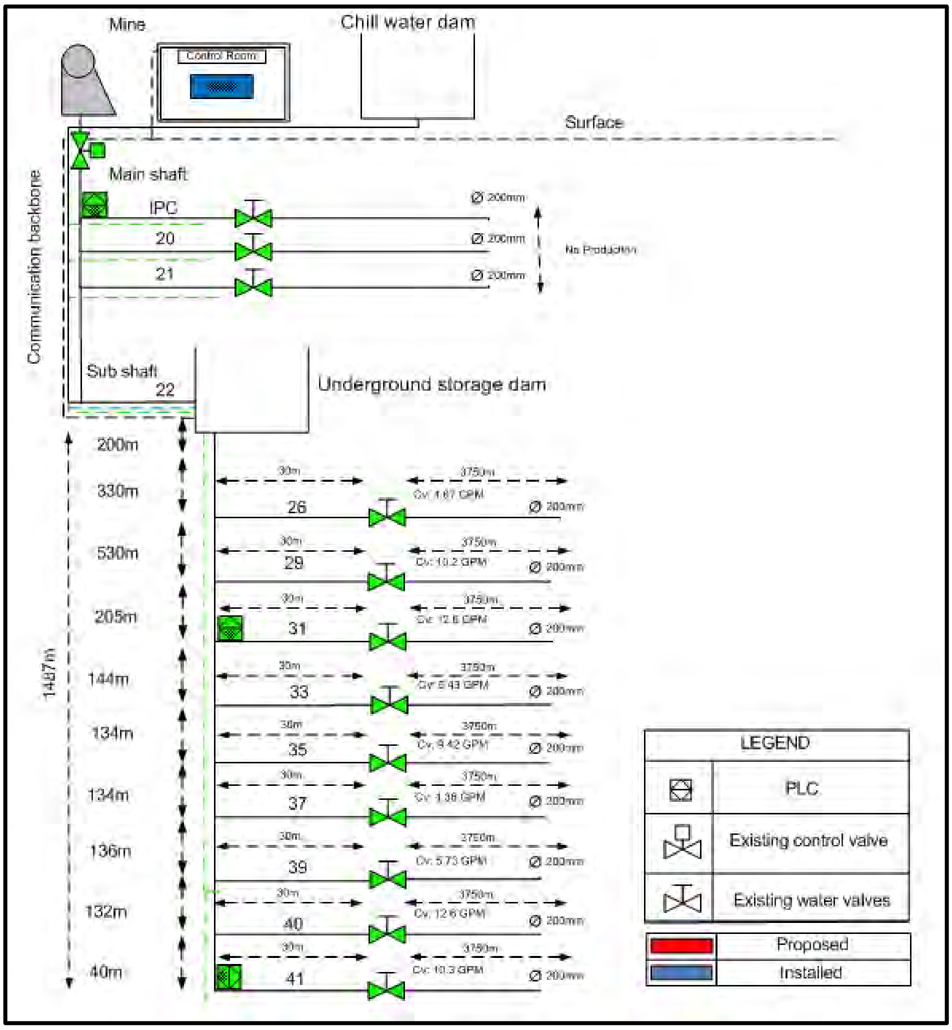


Figure 3-3: Layout of a mine water reticulation network

3.4 System data analysis

All available data must be analysed in order to understand how the system functions. Figure 3-4 and Figure 3-5 show flow and inlet pressure variations on specific mining Levels 35, 39 and 40 for the mine illustrated in Figure 3-3. These variations show different pressure and flow requirements of equipment throughout the day.

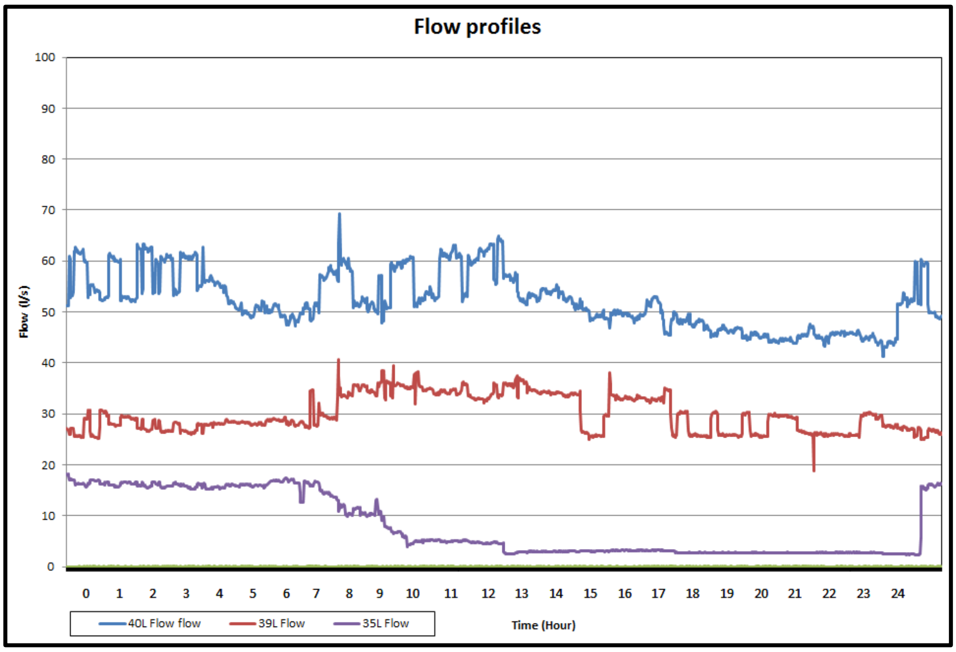


Figure 3-4: Graph showing flow rate (l/s) logged for levels over a period of 24 hours

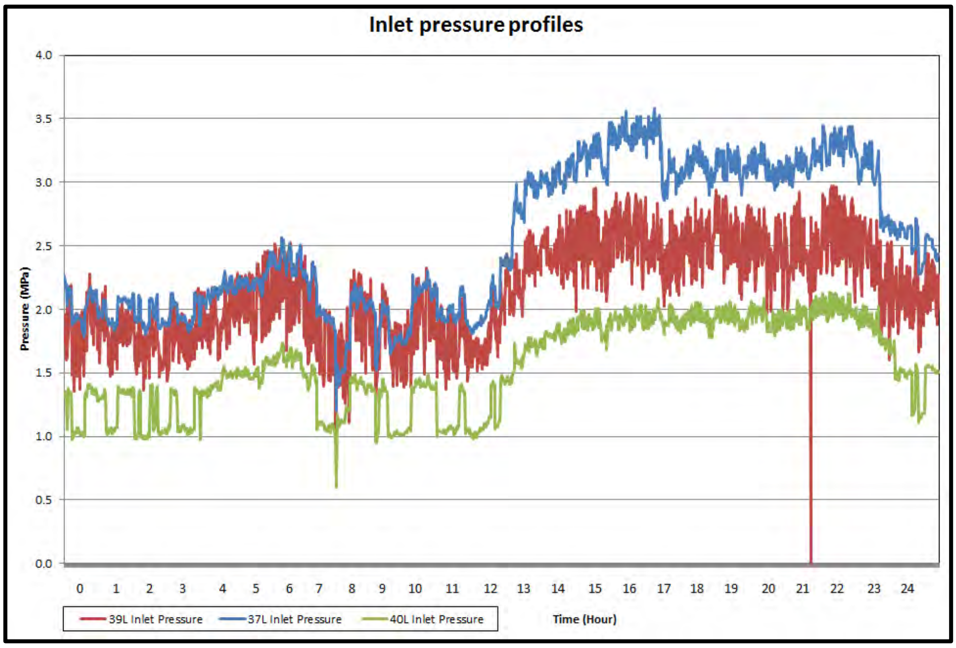


Figure 3-5: Graph showing pressure data (MPa) logged for levels over a period of 24 hours

A common error is to measure the average flow and pressure values, as illustrated in Figure 3-6, and use it as inputs for the valve manufacture selection process. The problem of using the average system flow and pressure ranges is that it hides the effects of fluctuations.

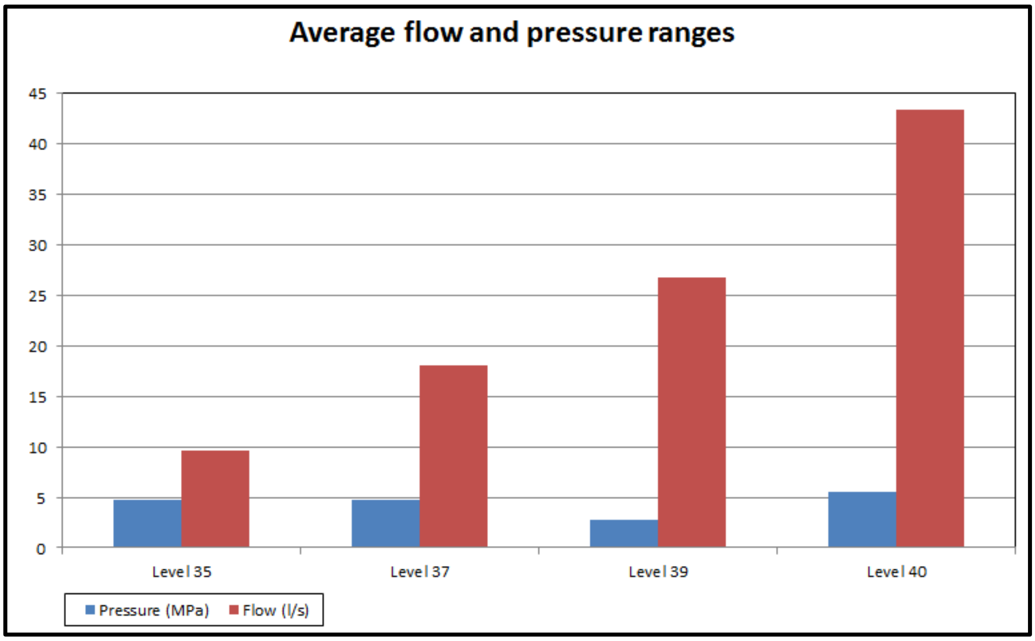


Figure 3-6: Average flow and pressure range

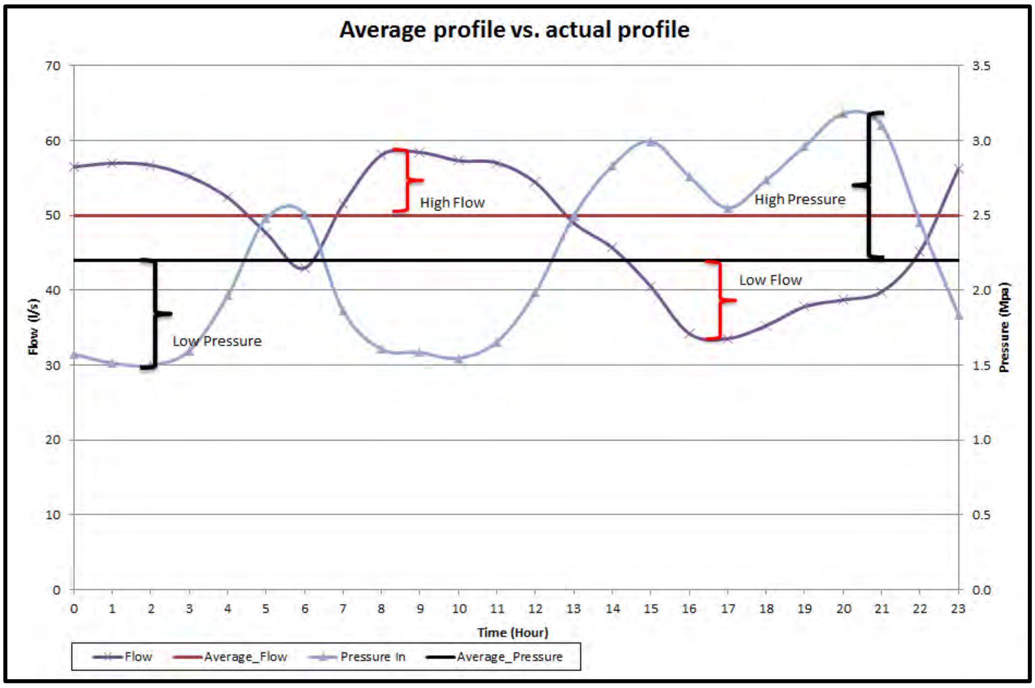


Figure 3-7: A profile of the flow and pressure for an underground level over a period of 24 hours.

Figure 3-7 shows the flow and pressure data on an underground level for a general work day. The disadvantage of basing valve selection on the average system data is that it hides the effects of fluctuations as seen in Figure 3-7. Selecting a valve based on average values may result in a valve not being able to control the flow and pressure during extreme conditions. The impact of the valve selection is shown in Figure 3-8.

Assume the manufacturer selected condition C (Figure 3-8) as input set for their calculations. The valve will only be adequate within the range of A and B (depending on control range). Parameters A and B represent the extreme operation conditions for the valve. Condition A indicates a low flow, high pressure and condition B a high flow, low pressure condition. Because the minimum and maximum conditions of the valve do not fall close to the minimum and maximum values of the system parameters, the valve will not operate as required for the entire range of the system parameters, conditions 1 and 2.

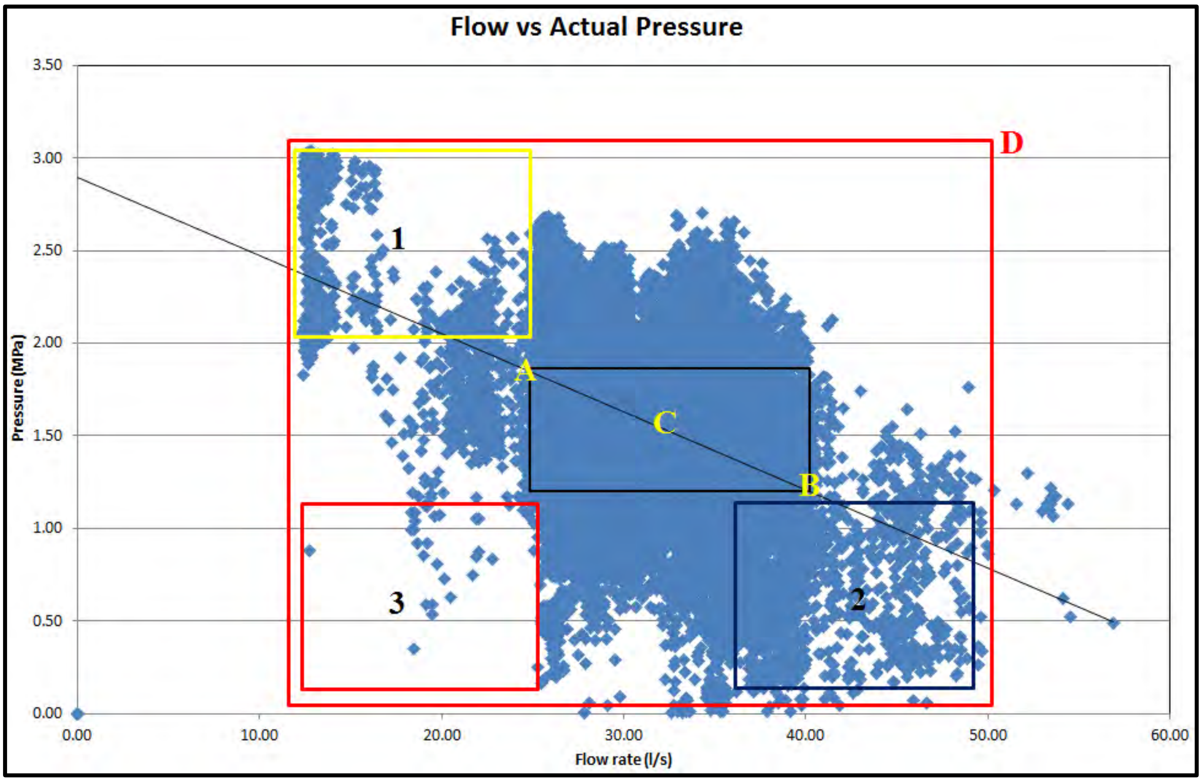


Figure 3-8: Scatter plot of upstream pressure (MPa) as a function of flow rate (l/s) for a level

An additional problem is that the valve will be used to change system operations once it is installed. The new valve must still be able to function properly under the new system constraints. Possible system changes could be (see Figure 3-8):

- A reduction in flow could shift system operations from condition C to a region similar to condition 1;
- A reduction in pressure could shift system operations from condition C to a region similar to condition 2; and
- A reduction in pressure and flow could shift system operations from condition C to a region similar to condition 3.

These possible changes in the system characteristics indicate that a valve selected specifically for condition C will no longer be suitable.

3.5 Simulation model

3.5.1 Simulation software

KYPipe is a widely used and trusted hydraulic analysis model in the world [49]. Pumps, junctions, variable pressure supplies, regulators, active valves, turbines, on/off valves and different meters can be included in simulation models to simulate real life system operations. KYPipe is a validated and verified simulation package and was used for this study.

A pre-implementation simulation is defined as a simulation model to simulate and predict a system's behaviour, prior to the design and installation of a system. To comprehend how the uncertainties discussed in Section 3.4 will affect the new system characteristics and existing equipment, a simulation model must be developed using KYPipe.

3.5.2 Building the simulation model

The simulation model, as seen in Figure 3-9, emulates system operations based on several system configurations.

The system's configurations are:

- Pipe length;
- Pipe diameter;
- Pipe resistance;
- Underground elevation change;
- Location of demands/inflow points; and
- Location of valves and fittings.

A fixed demand node is the end point of a pipe section, indicated by the orange arrows in Figure 3-9. The flow demand (l/s) is based on the equipment situated on the specific level. The demand of the node changes over time, indicating the operational changes throughout the day. A junction node is a node where two or more pipes meet or where flow is removed or added to the system indicated by the grey arrows in Figure 3-9.

Elements, indicated by blue and yellow arrows in Figure 3-9, represent active valves and regulators with flow coefficients. Valve travel (%) and fixed pressure (MPa) specifications can be incorporated respectively. The simulation can have configurable elements representing components like PRVs. This is to ensure a suitable replication of the system operations.

The simulation model needs to represent the actual behaviour, and not the average behaviours of the system operation. It is thus essential to configure simulation elements representing certain components in the simulation model by allocating numerical values. These numerical values (inputs) must be obtained from proper measurements taken from the actual system.

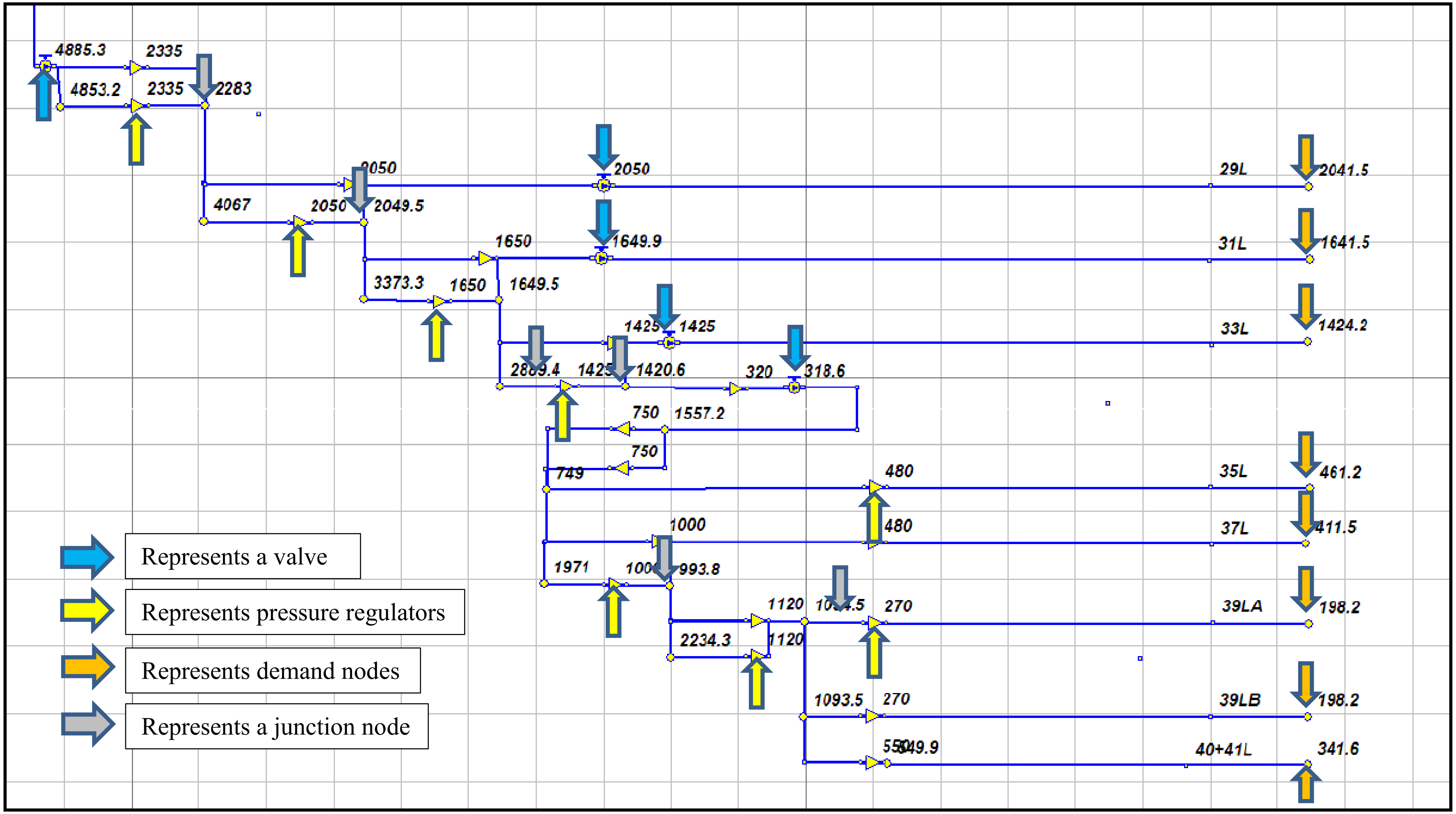


Figure 3-9: Image of a simulation model with pressure values

An increase in pipe resistance, due to old or decayed pipes, can have a significant effect on the entire system. The resistance for a pipe can be obtained from a reference table based on details such as length, material and age. However, this requires an inspection of the entire system which is unpractical. To simplify the process, the resistance coefficient of pipe sections can also be calculated with equation 19 [35].

Measurements can be obtained from existing or portable measurement equipment. The pressure difference can be obtained by changing the flow rate (demand), as seen in Figure 3-10. The measured data can be substituted in the equation [50] to calculate the pipe resistance.

$$P_1 - P_2 = \Delta P = \rho \times K \times \frac{V^2}{2} \qquad \text{[Pa]} \qquad \text{Equation 19}$$

Where:

- P_1 = *Inlet pressure [Pa] (absolute)*
- P_2 = *Outlet pressure [Pa] (absolute)*
- ΔP = *Pressure difference [Pa]*
- ρ = *Fluid density [kg/m³]*
- K = *Resistance coefficient [dimensionless]*
- V = *Velocity [m/s]*

Velocity can be calculated by [50]

$$V = \frac{q}{A} \qquad [m^3/s] \qquad \text{Equation 20}$$

Where:

- q = *Liquid flow [m³/s]*
- A = *Area of leak size [m²]*
- V = *Velocity [m/s]*

When the simulation model is verified it is an understandable and comprehensive representation of the system functionalities.

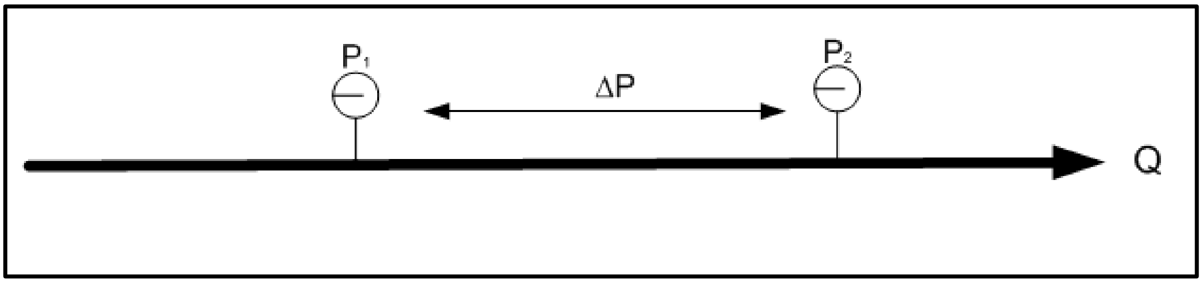


Figure 3-10: Diagram of a pipe resistance test

3.5.3 Using the simulation model

The simulation model can be used as follows:

- To simulate various system or control scenarios (based on project scope and control strategy); and
- To determine changes in system characteristics/parameters due to newly installed equipment or control valves.

The entire system renders on two scenarios, as mentioned above. These system characteristics and parameters are given to the valve manufacturer to reselect (size) the valve from their catalogue. Constraints, for example: valve size, rating and control curves (range) etc., must also be adhered to. A more effective valve solution may even reduce or eliminate existing system constraints.

Once the system control philosophy has been successfully simulated the predicted system data (flow and pressure) can be analysed. A new set of variables can be determined using the analysis method discussed in Section 3.3. The simulation results can be used to identify the uncertain "extreme" scenarios, for example:

- Low flow, high pressure; and
- High flow, low pressure.

3.6 Conclusion

There is a disadvantage when using the valve selection process of the valve manufacturers. When average data is used to select a valve this valve will most likely not be suitable for all system parameters. In an attempt to satisfy both valve and system constraints, a system analysis methodology was developed. The first step of the methodology is to analyse all the available data in order to understand the system functionality.

When all the system parameters and specifications have been identified, a simulation model can be developed in an attempt to understand the complexity of the system. This simulation model must be verified according to proper measurements taken from the actual system. This will ensure that all the system constrains are mitigated before an optimised and effective solution is proposed.

Selecting the effective valve solution may even resolve or eliminate the inherited problems of the system. After the new system has been successfully simulated using the simulation model, the resulting data can be used to select a control valve that will satisfy all constraints.

4. IMPLEMENTATION AND RESULTS

Summary

In this chapter the analytical valve selection methodology will be implemented. Different valve scenarios will be simulated with the help of a simulation model. The results and energy savings will be quantified.

4.1 Preamble

Before an effective water optimisation strategy can be implemented, a complete system analysis should be conducted to identify various system constraints. These system constraints need to be considered before an effective valve solution can be developed. In Chapter 3 a system analysis methodology was developed to assist the selection of an effective valve solution. In this chapter the implementation of the methodology will be discussed by means of an energy efficiency project implemented at a deep-level gold mine. The energy saving obtained due to valve control will also be quantified.

4.2 Case study

4.2.1 Background

The mine in the case study consists of two vertical shafts, namely Main-shaft and Sub-shaft, which are joined on Level 23. A section of the mine is illustrated in Figure 4-1.

To protect the underground equipment the high water pressure needs to be reduced. The existing NGD control valves, installed in the underground levels, are used to regulate the pressure. The control levels of the existing NGD valves were limited and the valves had to be serviced regularly due to cavitation damage. A specification sheet regarding the NGD valves can be seen in Appendix B.

The aim of the project was to reduce the amount of water sent underground and subsequently reducing the amount of water that has to be dewatered (pumped back to surface). Installing control valves on several strategic points throughout the system reduced the amount of water sent underground.

In order to reduce the amount of water the following control philosophy was implemented:

- The control valve on Level 26 will reduce the supplied chill water to a minimum of approximately 140 l/s.
- Level 29-40 control valves will be controlled on a set-point, reducing the pressure and flow to working stations.

As part of the project requirements to control the water reticulation, several levels were equipped with PLCs, flow meters and pressure transmitters. The effects of pressure set-point control strategy were tested in the mine by changing the downstream pressure using the existing NGD control valves. To change the downstream pressure the pressure set-point was adjusted using the mine's SCADA system.

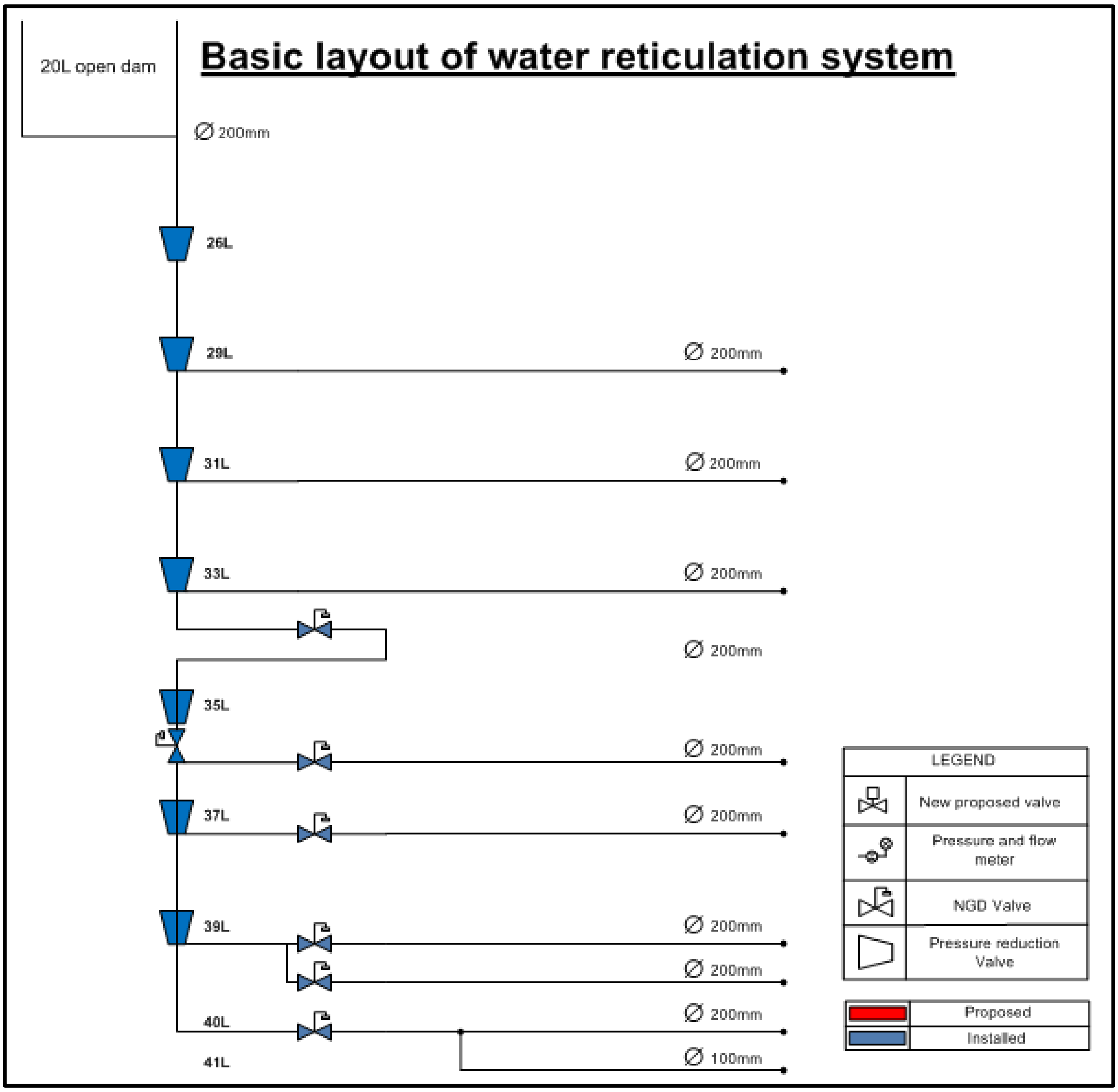


Figure 4-1: A layout of the mine water reticulation system

The control philosophy mentioned above was programmed into the control platform which is connected to the mine's SCADA server via an Object Linking and Embedding for Process

Control (OPC) connection. A layout of the mine‘s supply water reticulation was constructed on the control platform shown in Figure 4-2.

The initial control valve selection was made using the manufacturers methods as discussed in Chapter 3. A 200 mm and several 100 mm valves were identified as suitable control valves. See Appendix B regarding specifications of the control valve.

The scope of the project included decommissioning the existing NGD valves and installing the new selected globe control valves. Figure 4-3 illustrates the proposed solution. The proposed solution was to install the 200 mm globe control valve on Level 26.

Figure 4-1 shows that chilled water is supplied from a storage dam situated on Level 20. The 200 mm globe valve will be used to control the main water supplied to underground levels. A 100 mm globe valve will be installed on each working level. This will allow further flow reduction to the lower underground areas. The lower level control also stabilises the system by preventing the main column from draining.

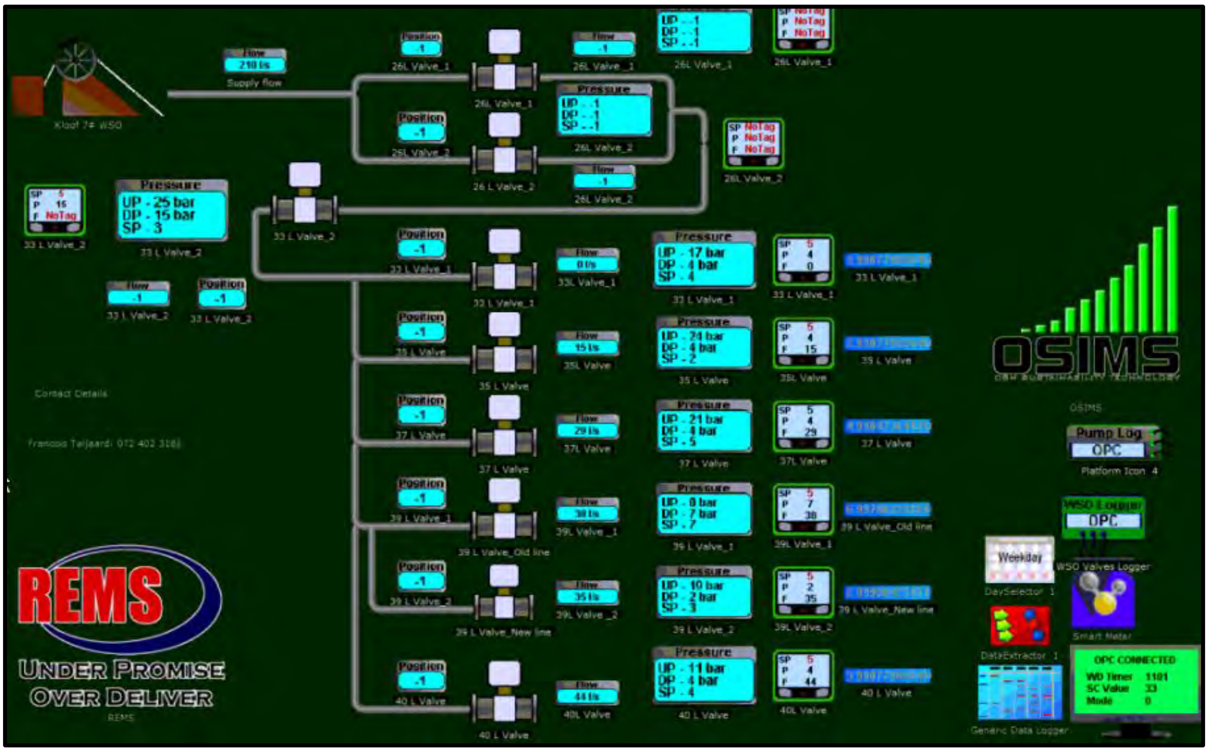


Figure 4-2: Control platform screen shot

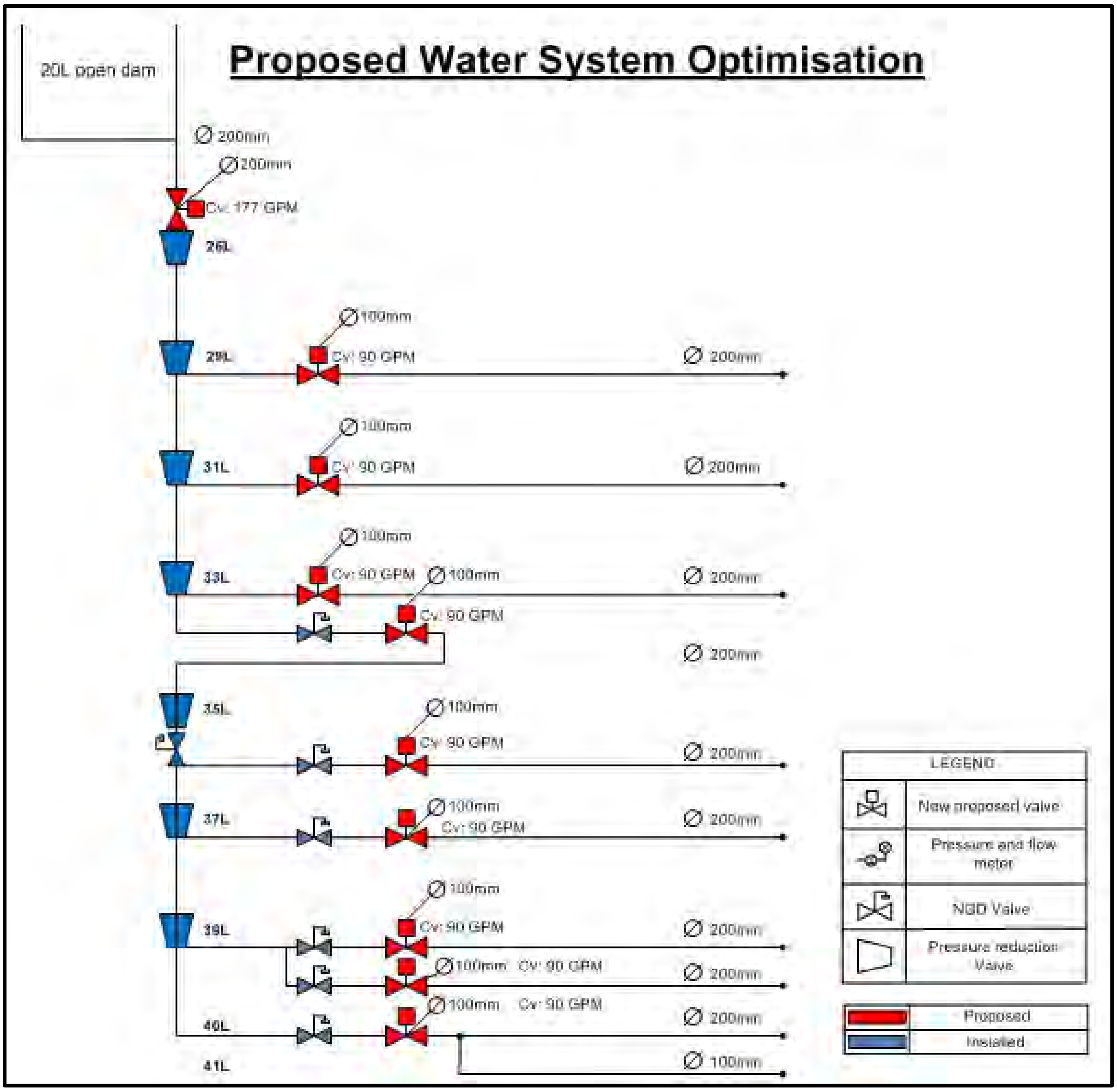


Figure 4-3: Proposed water supply initiative

4.2.2 Problem statement

Control valves are required to reduce the amount of water sent to the underground levels. The contractor selected the control valves based on sampled system data. This resulted in an incorrect valve selection for the system. Globe control valves were selected for durability and stable control.

After commissioning the first 100 mm globe control valve on Level 29, the downstream water pressure decreased to an unacceptable low pressure at the stope area. The control valve was subsequently removed by mine personnel.

Mine personnel claimed that the 100 mm globe control valve was too small and restricted the water flow too much, resulting in a downstream pressure reduction. They refused to install the rest of the control valves.

To solve the problem a system analysis methodology was implemented. The system analysis methodology involved the following:

- Establishing system parameters and collecting data;
- Analysing data;
- Developing a simulation model; and
- Testing scenarios.

The system analysis methodology investigated both valve and system constraints to enable a good understanding of the functionality of the system. To further comprehend the impact of change to the system, a simulation model was developed. The simulation model was verified using measured system data to ensure a suitable solution.

4.3 Application of the analytical control valve selection model

4.3.1 Establishing system parameters

The initial step of the system analysis methodology was to establish all system components and parameters. These system components and parameters were as follows:

- Layouts (see Figure 4-4);
- Pipe sizes and valve ratings (diameter 200 mm, 5 MPa upstream and 1.2 MPa downstream);
- Valves and ratings (PRV's and NGD, rated at 4 MPa);
- Length of a typical level (6000 m, see Figure 4-4); and
- Existing users (Rock drills, cooling cars and sweeping).

A layout of the mine's water reticulation system is illustrated in Figure 4-4. All the above parameters were identified through site inspections or available data. A layout showing the entire Level 40 is illustrated in Figure 4-5.

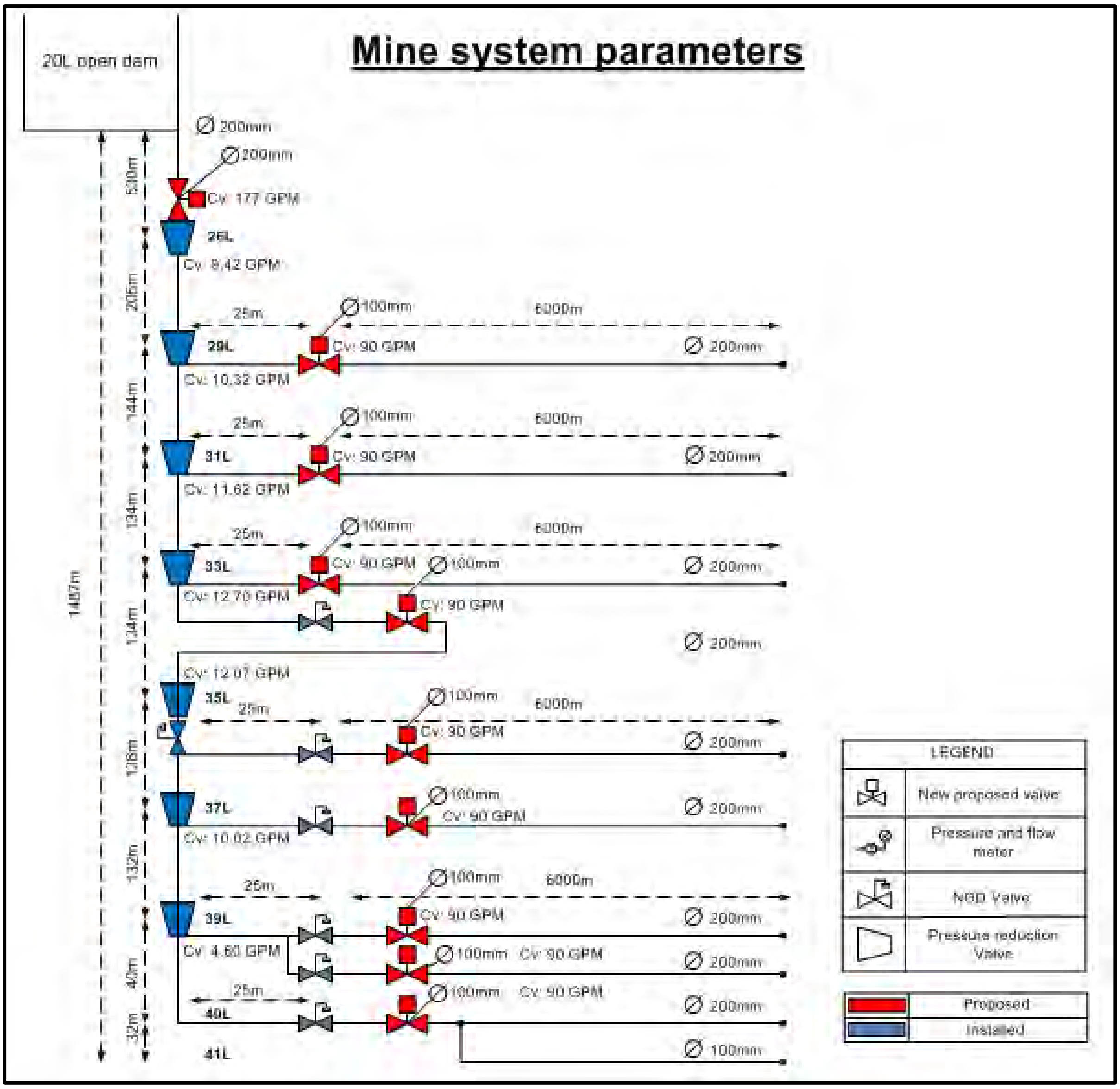


Figure 4-4: Layout of water reticulation network showing system parameters

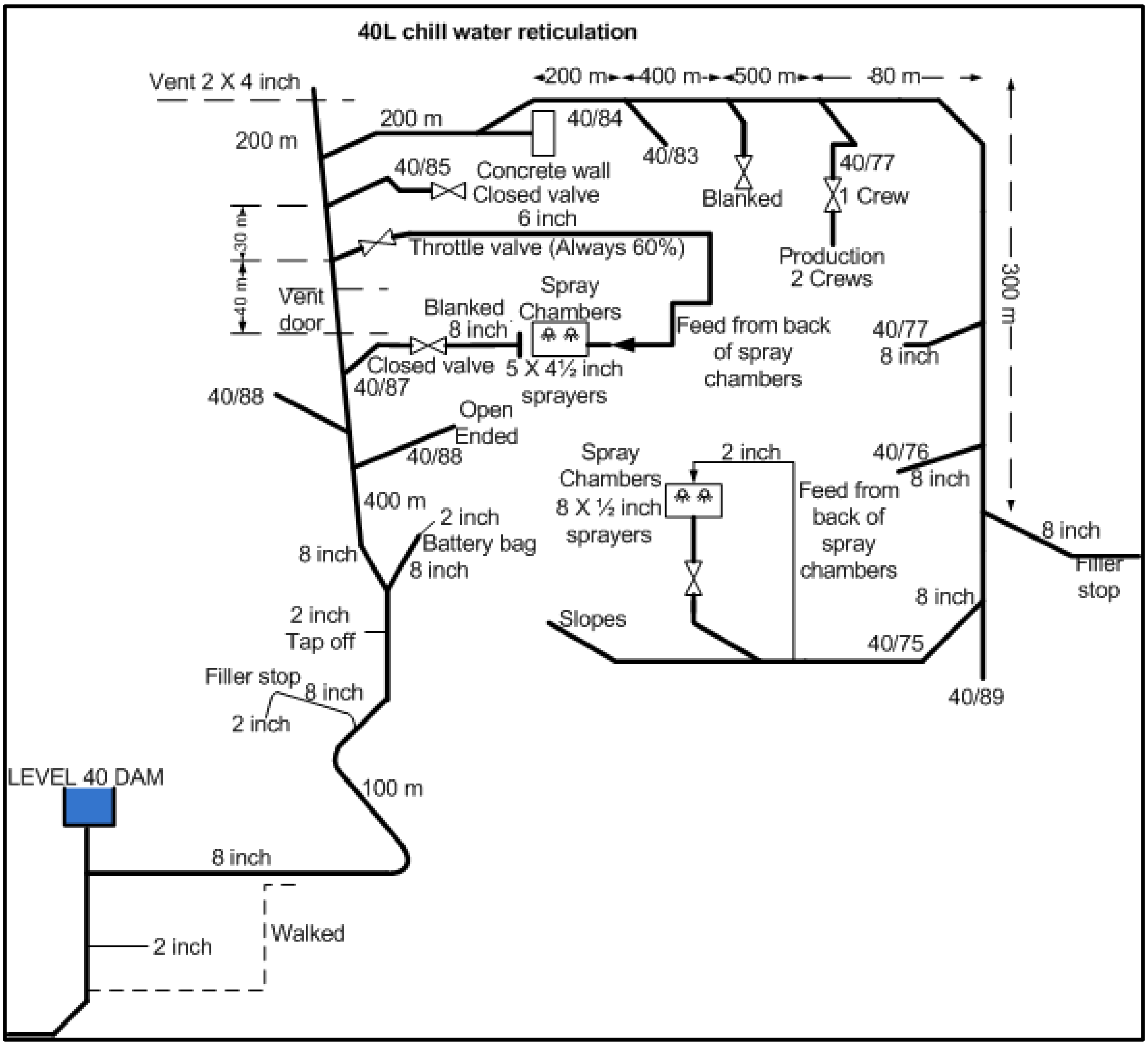


Figure 4-5: Example of an underground level

4.3.2 Data analysis

To understand the system functionality all the available data had to be analysed. Correcting the location and accuracy of the pressure and flow transmitters allowed sufficient data to be recorded. In the case of incomplete data or unavailable instrumentation, portable instrumentation was used.

The analysed data shows flow and pressure fluctuations throughout the system (see Figure 4-6 and Figure 4-7). These fluctuations could be caused by the NGD valve located on Level 40. Changing the opening speed of the valve is too dynamic. The result is water hammer causing severe pressure and flow fluctuations propagating throughout the system.

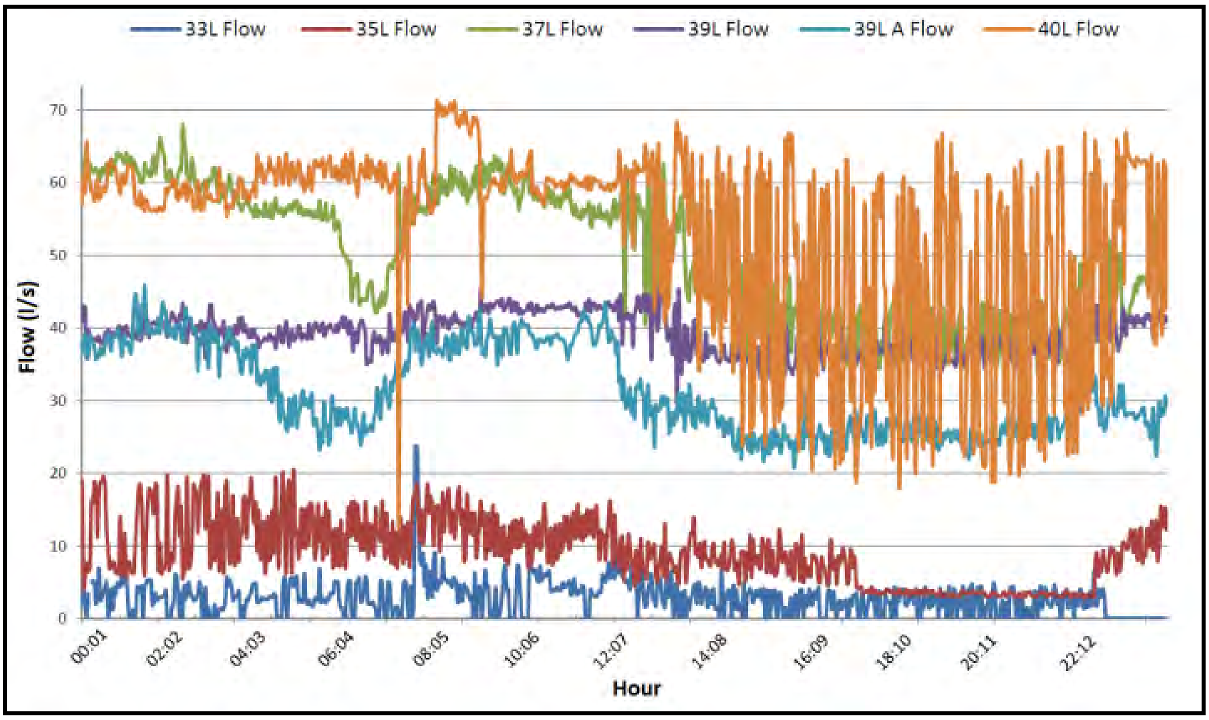


Figure 4-6: Flow data measured for specific underground levels

The data analysis revealed that the system is unstable due to these fluctuations which complicated the valve selection process even more. Selecting an effective control valve solution may reduce or eliminate the instability of the system.

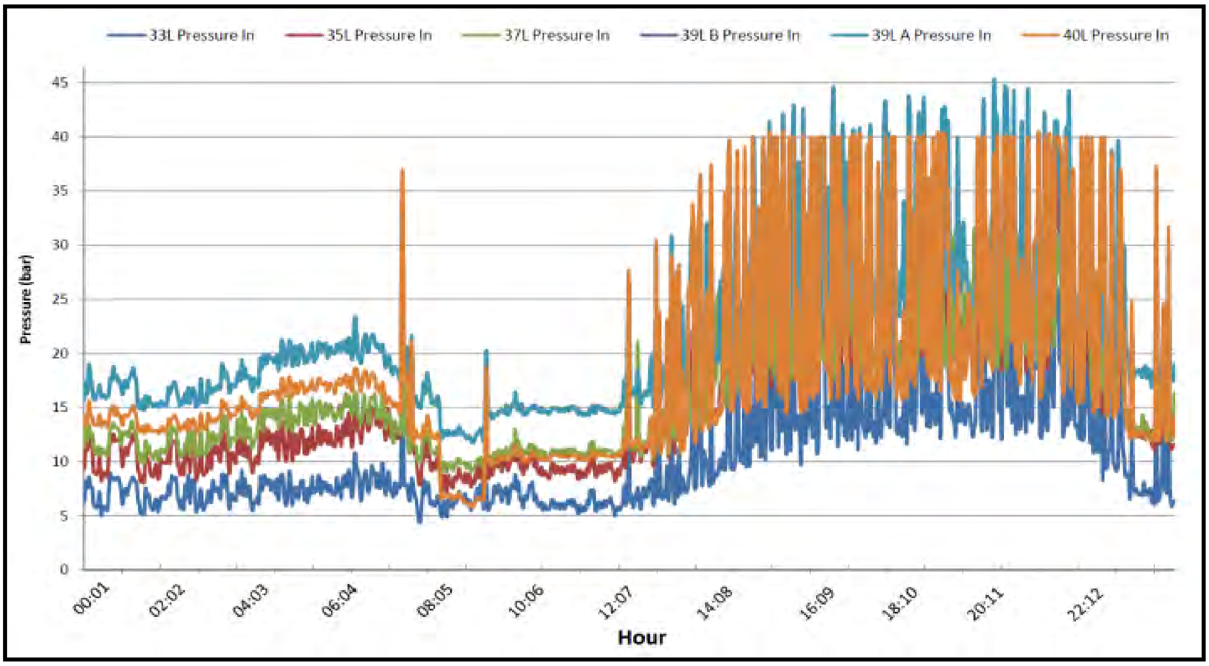


Figure 4-7: Pressure data measured for specific underground levels

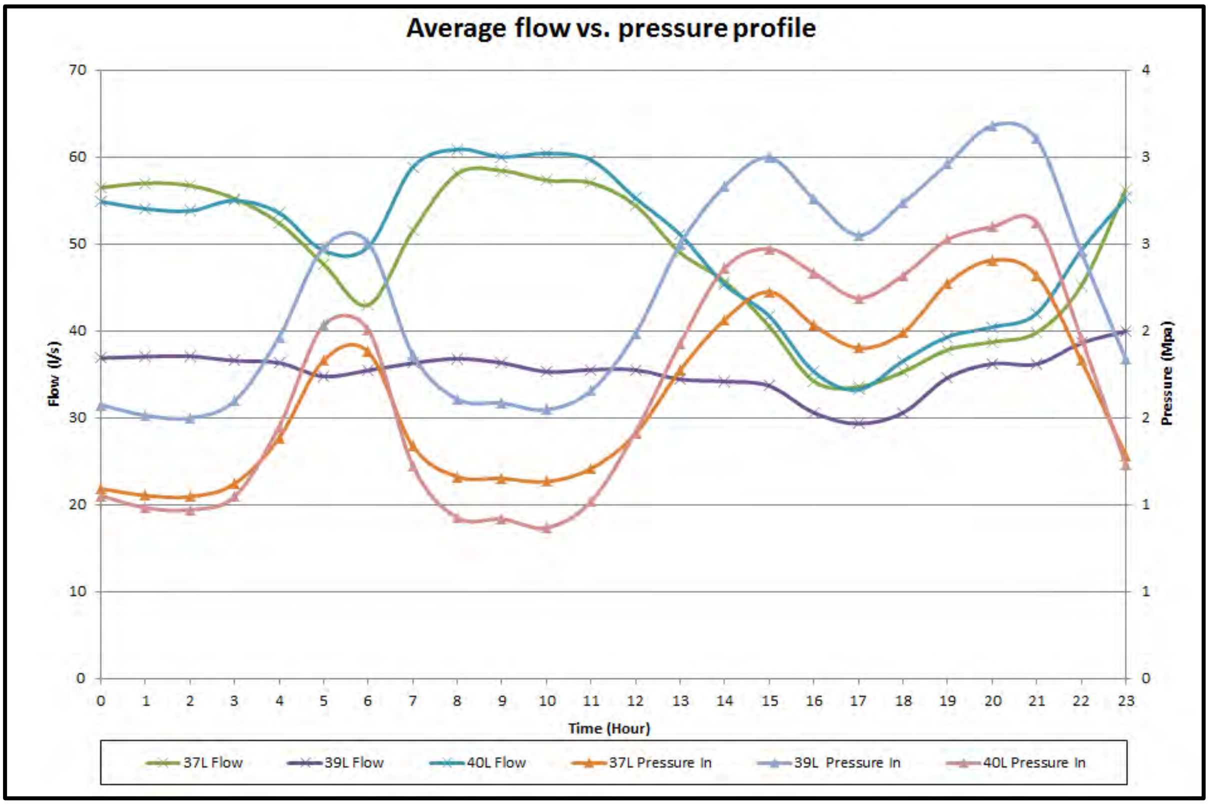


Figure 4-8: Flow rate compared to pressure for a level

This average data (see Figure 4-8) does not include the irregularities seen in Figure 4-9. Condition A in Figure 4-9 indicates the flow and pressure parameters used by the contractor during the initial globe control valve selection process. Figure 4-9 illustrates data points over a one month period. It also shows that the selected globe valve will only be suitable for conditions similar to A.

When the manufacturer installed the selected 100 mm globe control valve, all the system characteristics changed, resulting in extreme conditions similar to conditions 1 or 2 shown in Figure 4-9.

To better understand the effect of this unknown condition on the system characteristics and existing equipment, a simulation model was developed.

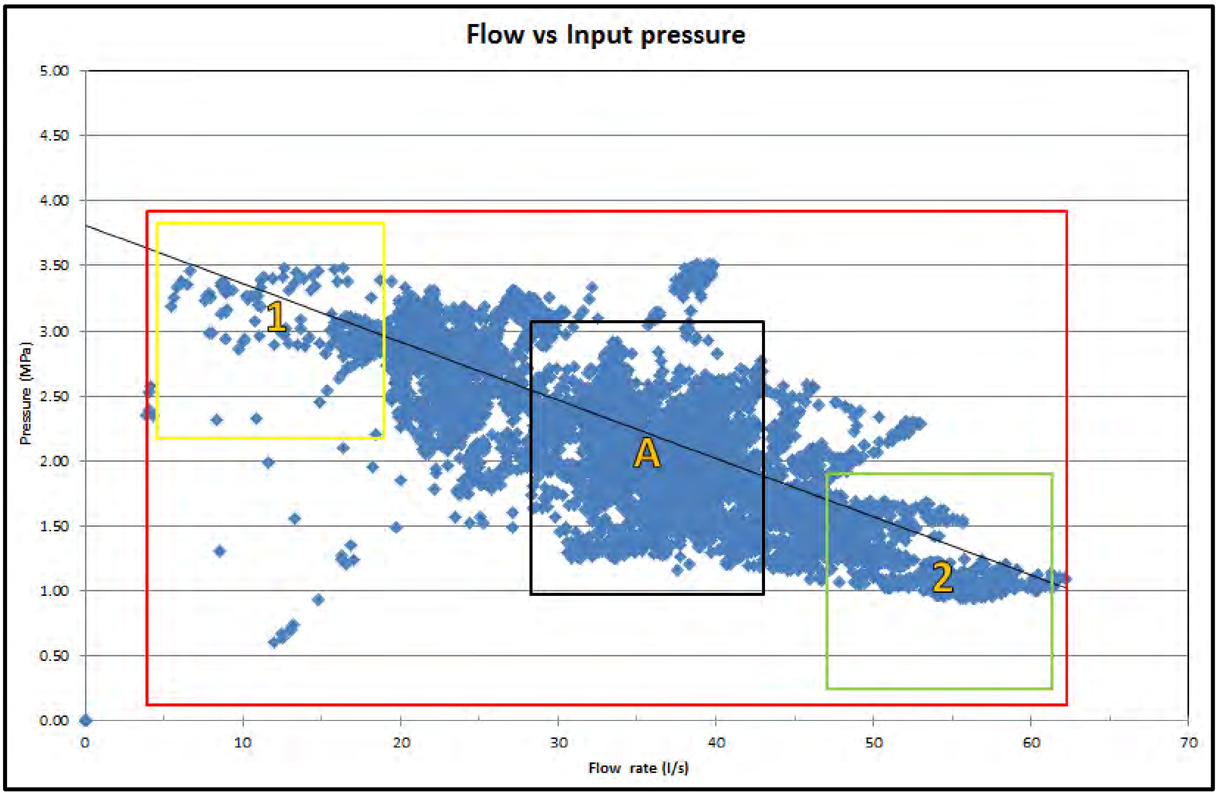


Figure 4-9: Average flow compared to pressure profiles for specific levels

4.3.3 Simulation model

The simulation model was verified using measured/recorded system data (see Appendix B). The data sample was taken during a period when the mine operated without any unscheduled interruptions. The logged data was analysed to obtain flow and pressure profiles for levels where accurate instrumentation was installed.

The data revealed that most of the mine water is used between 06:00 and 11:00 during the drilling shift. Flow and pressure data for Levels 29 and 31 were not obtainable due to a lack of instrumentation. Data from existing flow meters on the surface and in the main column at Level 35 was used to calculate the water consumption. The results showed that 80% of the mine's water was consumed below Level 35, meaning that it can be been assumed that the remaining 20% of the mine's water was consumed on Levels 29 and 31.

Several PRVs are situated throughout the water reticulation network. The flow coefficient of the PRVs was unknown and the valves could not be simulated using the models available in the simulation database. However it was known that the valve's downstream pressure was half of its upstream pressure. In order to simulate the behaviour of the PRVs a pressure sustaining valve (PSV) was used in the simulation model. With the use of PSVs the simulation model accurately simulates the behaviour of the mine's water reticulation network.

The flow characteristics of the NGD valves were also unknown. PSVs were again used to emulate the NGD control valves in the simulation model. The NGD valve's downstream set-point values were used as input variables for the PSV. The simulation data verified that the pressure output of the PSVs was within acceptable tolerances compared to the actual logged data.

Figure 4-10 illustrates a simplified simulation model developed to represent the mine's complex water reticulation network. Each node represents the water demand (in l/s) as verified by logged data. A 24-hour demand profile was entered for each level. The results of the simulation model, before any changes have been made, are shown from Figure 4-10 to Figure 4-12.

The simulation results for Levels 29 and 31 could not be verified due to a lack of actual logged data. The results for the other levels were similar to the actual logged data. Because the simulation model was verified it could now be used on the levels below Level 35.

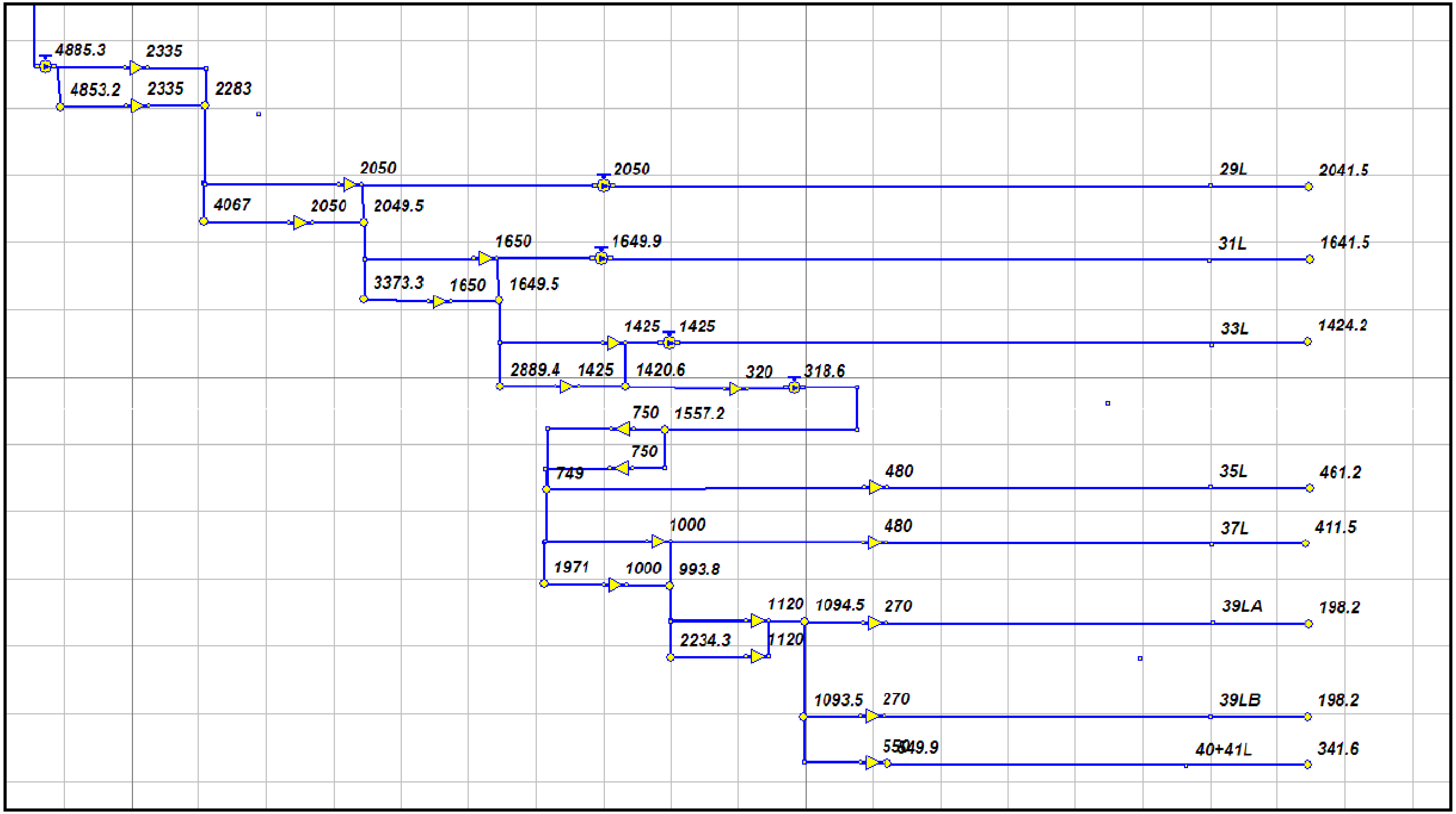


Figure 4-10: Simulation model of actual system before optimisation

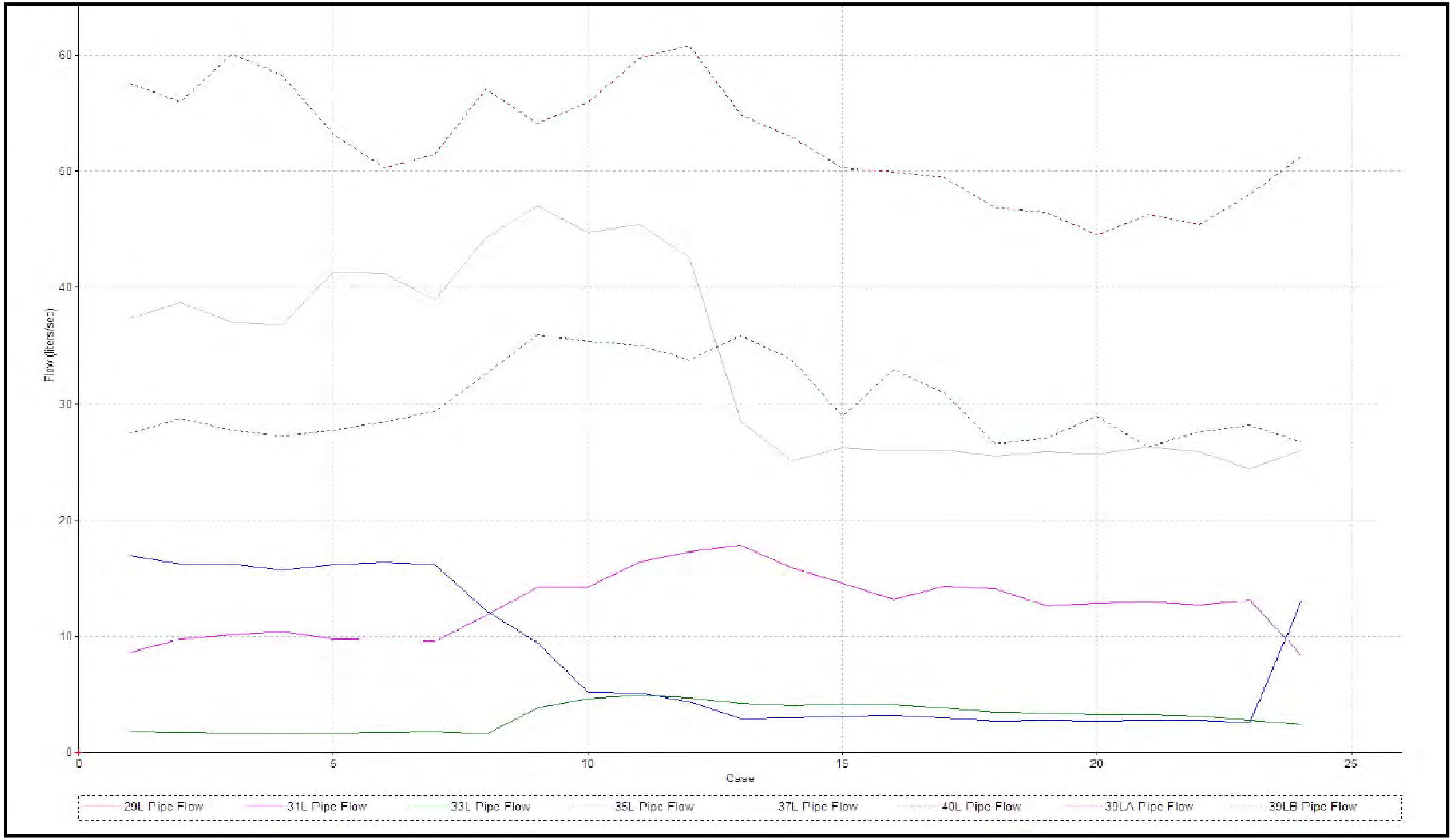


Figure 4-11: Flow demand profile of simulation model

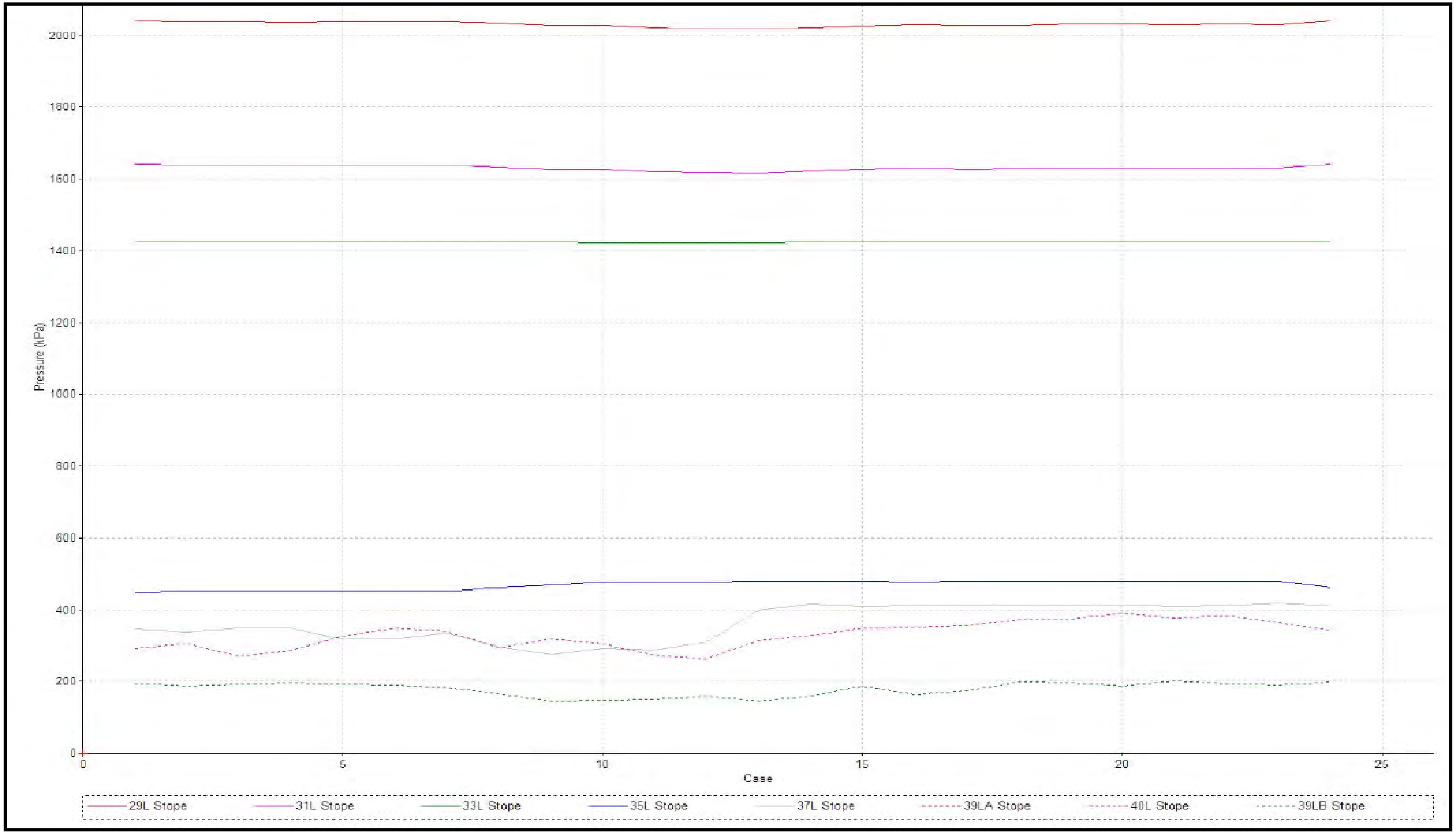


Figure 4-12: Pressure profile of simulation model

4.3.4 Simulation scenarios

Personnel at the mine believed that the pressure reduction occurred after the commissioning of the initial globe control valves. To determine the effect of the original valves on the system and to establish new parameters for selecting a new valve, a few scenarios were simulated:

Table 3: Scenario description and expected outcomes

Scenario	Description	Expected results
1	System operation with proposed valves.	Will the original proposed valves work?
2	Active system with fixed pressure inputs.	Select new valve and monitor valve travel for system data.
3	Active system with minimum pressure inputs.	What size valve will satisfy minimum pressure conditions?
4	Active system with maximum pressure inputs.	What size valve will satisfy maximum pressure conditions?
5	System operation with two valves.	Minimum and maximum conditions too much for single valve. Test alternative configurations to reduce pressure.
6	Operation with maximum acceptable flow.	What will the impact of the new valve solution be during drill shift?

Scenario 1:

The simulation model was adapted to include the originally proposed globe control valves. All of the valves' flow coefficients were set according to the valve specification (see Figure 4-5) and all other valves were in a fully opened position. The proposed control valves were incorporated into the simulation model and were 100% open.

The simulation layout and results are shown in Figure C-1 and Figure C-2, see Appendix C. The negative pressure values shown below Level 33 are because of an existing valve situated between Levels 33 and 35. The pressure drop over the valve is of such a magnitude that the downstream components of the system cannot function within the resulting input pressure.

Scenario 2:

The characteristic values of a new valve were entered into the simulation model as described in the previous paragraph. All of the pressure values for the system were calculated by the simulation.

The simulation software calculated the values for: the pressures at each valve as a function of the static head (vertical height) before the valve, the water flow through the valve, the valve's resistance to flow and the PRV outputs.

The valves' opening positions were varied throughout the day (over a 24-hour period) to determine whether the valves were able to control the downstream pressure according to the mine's requirement. Figure C-3 shows the system layout and results for the simulation. The valve positions were as follow:

Table 4: Valve percentages to achieve original pressure

Time	Level 37 [%]	Level 39 A [%]	Level 39 B [%]	Level 40 [%]
14:00	45	48	48	64
15:00	47	42	43	60
16:00	47	47	47	60
17:00	47	45	45	60
18:00	46	40	40	58
19:00	46	40	40	58
20:00	46	42	42	56
21:00	46	40	40	57
22:00	46	41	42	57

<u>Scenario 3:</u>

The system was updated to use manually entered input pressures instead of calculated input pressures. The aim of this simulation was to determine the valves' output during a "low pressure condition" for the various flow demands of the day. The valves were all set to be 100% open. Results of the simulation model can be seen in Figure C-4 (See Appendix C). Figure C-5 illustrates the level pressures throughout a 24-hour period, representing one day.

The simulation identified Level 39 as a potential problem area. The high flow going into the level resulted in an average pressure drop of more than 100 kPa. The high flow and large pressure drop could have instigated cavitation or water hammer effects.

Scenario 4:

The function of this simulation scenario was to determine the valves' output during a "high pressure condition" for the various flow demands during the day.

Each valve had a fixed opening position (see Table 5) for the 24-hour simulation. To limit the downstream pressure to less than 1500 kPa, the opening positions were:

Table 5: Percentage valve opening to limit pressure below 1500 kPa

Level 37 [%]	Level 39 A [%]	Level 39 B [%]	Level 40 [%]
31	30	30	40

Figure C-6 shows the system layout and results of the simulation model. The new valves will be able to effectively restrict high input pressures from propagating to downstream sections. High input pressures need to be reduced in order to protect the equipment used at underground stope areas.

Scenario 5:

The simulation model was updated with two valves (installed in parallel) replacing the existing NGD valve. The aim of this simulation was to test the possibility of installing two smaller valves in the mid-shaft column.

The system was simulated with the valves in a 100% open position. The simulation layout is illustrated in Figure C-7. The results in Figure C-8 indicate that the resulting pressure is below the operational pressure. It is therefore not feasible to replace the existing mid-shaft NGD valve with two smaller valves in parallel.

Scenario 6:

A scenario was simulated where the demand on Levels 37 to 40 was individually increased to determine the effect of increased flow on the level's pressure. The maximum flow was determined by increasing the flow until visible pressure reduction. The theoretical maximum flow for Levels 37 to 40 is shown in Table 6.

Table 6: Maximum allowable flow and corresponding pressure

	Level 37	Level 39 A	Level 39 B	Level 40
Maximum allowable flow [l/s]	50	55	50	70
Theoretical pressure [kPa]	500	551	566	545

4.3.5 Simulation results

The water reticulation system of the mine in the case study was used as the basis for the simulations. Different scenarios were simulated to determine the behaviour of the system and to anticipate the effects of the control action. The simulation results will allow a more effective way of identifying new valve parameters. The following conclusions were made:

- It is not feasible to replace the existing NGD valves with the originally proposed globe control valves due to a decrease in operational pressure;
- To ensure a desired pressure on each level, the valve travel should be at an minimum of 40%;
- A 200 mm valve with C_V of 179 (with a 100% opening) will satisfy minimum pressure conditions. Level 39 will experience difficulty with low pressure in the event of a low pressure input scenario;
- A 200 mm valve with C_V of 355 (with a variable percentage opening) will be able to restrict the downstream pressure to below 1500 kPa during a high pressure input scenario; and
- It is feasible to replace the existing NGD valve between Levels 33 and 35 with a high flow rate valve.

The simulation results and data analysis provided a set of pressure and flow constraints for the mine. This set of constraints was used as the primary criteria for the contractor to select the new valves. The calculated results of the valve manufacture can be seen in Appendix C. The constraints consisted of three sections: minimum limit, normal operation and maximum limit. Lists of these constraints are given in Table 7.

Table 7: Valve specific parameters

	Input pressure range [kPa]	Typical input pressure [kPa]	Output pressure range [kPa]	Flow range [l/s]	Typical flow [l/s]
Level 37					
Normal	1000 - 3000	2000	500 - 100	20 - 40	24
Max limit	N/A	4000	1500	N/A	20
Min limit	N/A	1000	500	N/A	50
Level 39 A + B					
Normal	1000 - 3000	1600	500 - 100	25 - 40	20
Max limit	N/A	4000	1500	N/A	25
Min limit	N/A	800	500	N/A	42
Level 40					
Normal	1000 - 2000	1200	500 - 100	40 - 60	44
Max limit	N/A	3000	1500	N/A	40
Min limit	N/A	800	500	N/A	65

The final proposed solution was to install a fixed ratio valve in series with the existing NGD valve as seen in Figure 4-13. The fixed ratio valve will reduce the high inlet pressure to a sustainable outlet pressure allowing the NGD valve to regulate the downstream pressure while avoiding cavitation or water hammer.

Valve selection will be less complex without the hazard of cavitation and water hammer, allowing for a robust low maintenance valve to be specified. The valve assembly is illustrated in Figure 4-14.

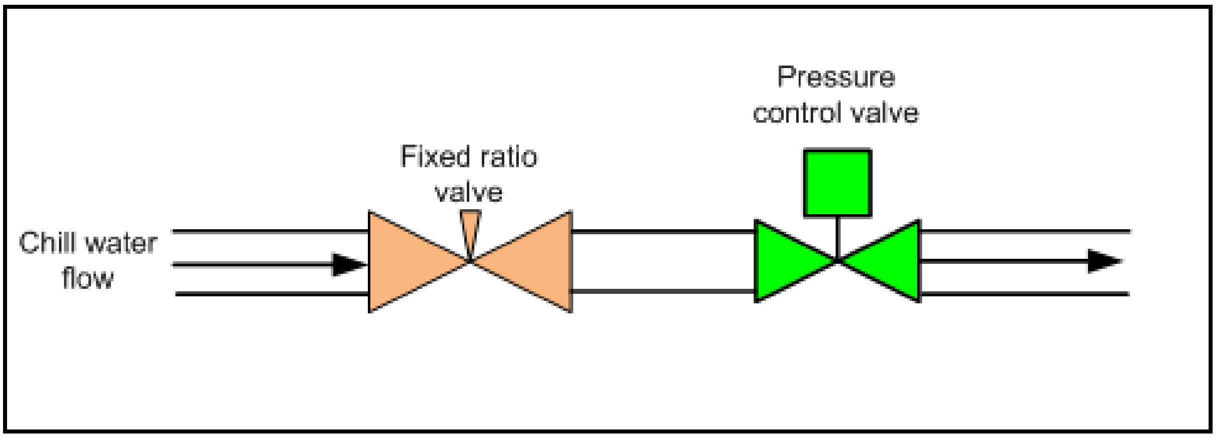


Figure 4-13: Proposed valve configuration for the underground levels

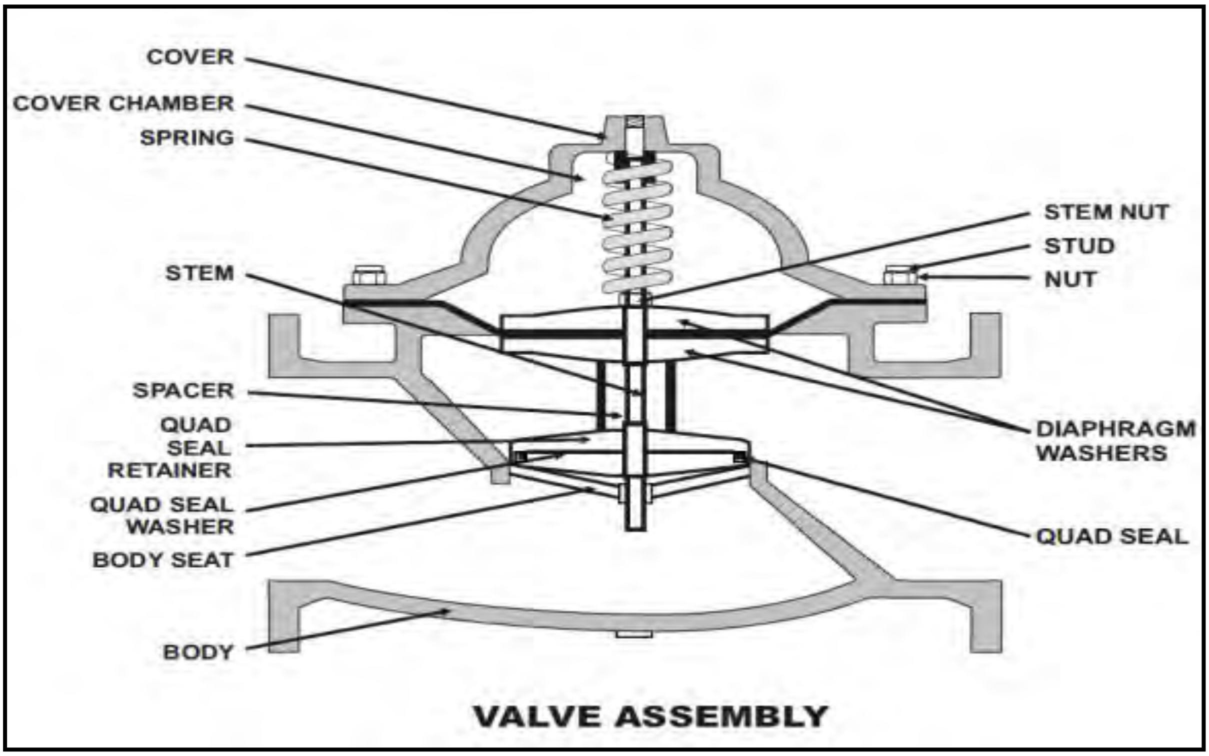


Figure 4-14: New proposed valve assembly [50]

4.4 Case study implementation and results

4.4.1 Valve specification parameters and implementation

After determining an effective valve solution, installations could continue. A basic layout of the new proposed solution is illustrated in Figure 4-15.

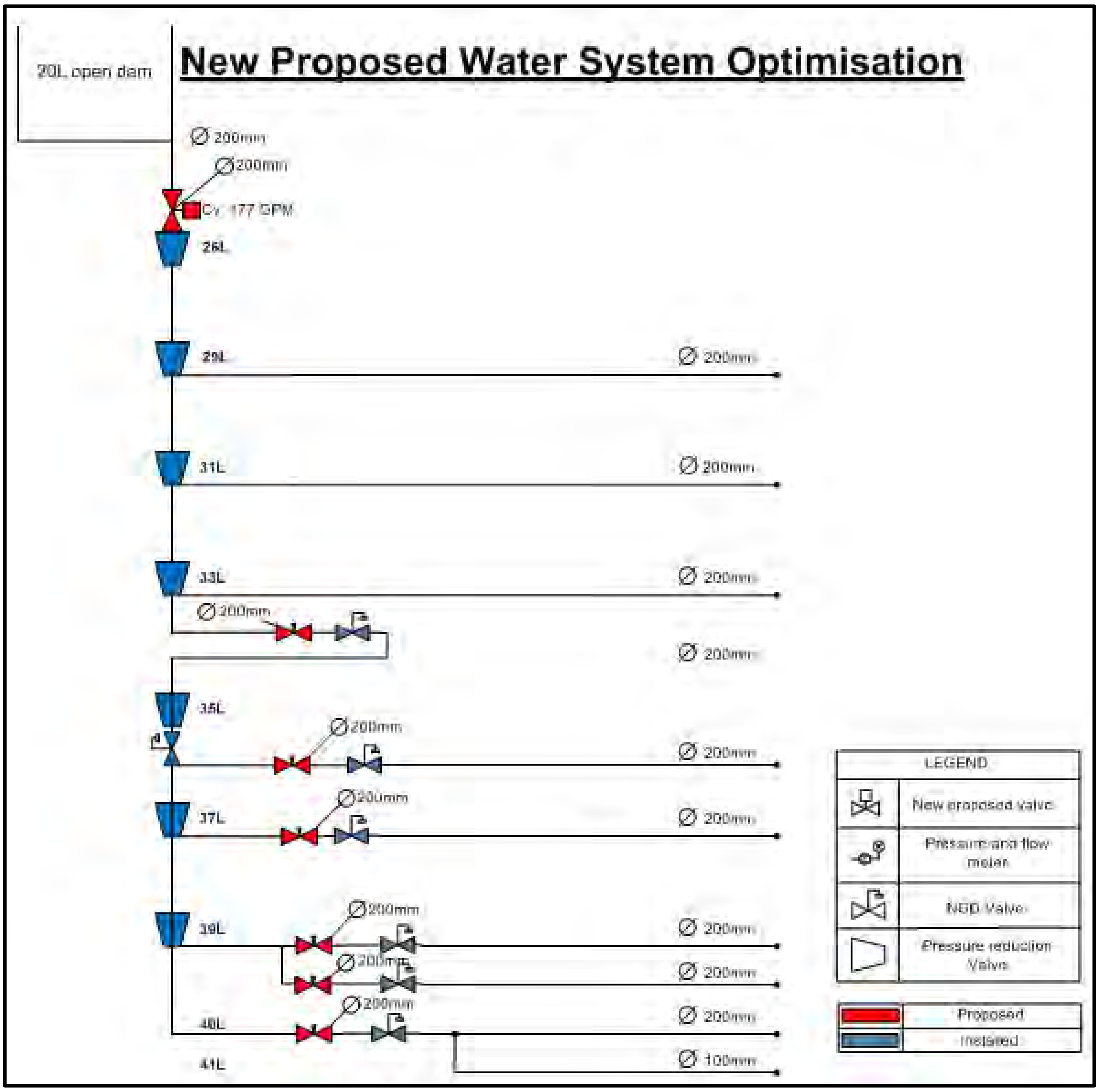


Figure 4-15: New proposed solution

A few days after the Level 26 control valve was installed the maximum possible flow through the valve was limited to 180 l/s, but subsequently the flow gradually decreased to 150 l/s. The mine subsequently removed the valve. When the valve was removed and inspected, debris was found inside the trim which caused the flow restriction. The water quality of the case study mine is considered to be a major constraint as seen in Figure 4-16. The multi stage trim would eventually block due to any insoluble particles in the water. This unforeseen problem will make any valve with internal trims unsuitable for use in the mining industry.

Figure 4-16: Level 26 block due to particles in mine water

Alternative approaches such as bypass sections, custom valve design and multi valve installations were investigated. The final solution was to install the proposed globe control valve in parallel with an electric actuated gate valve as shown in Figure 4-17. The 200 mm globe control valve will only be controlled when the gate valve has closed (during the blasting shift). If the globe valve becomes blocked again, it would not decrease the total supplied water sent underground. This solution will provide a more sustainable installation.

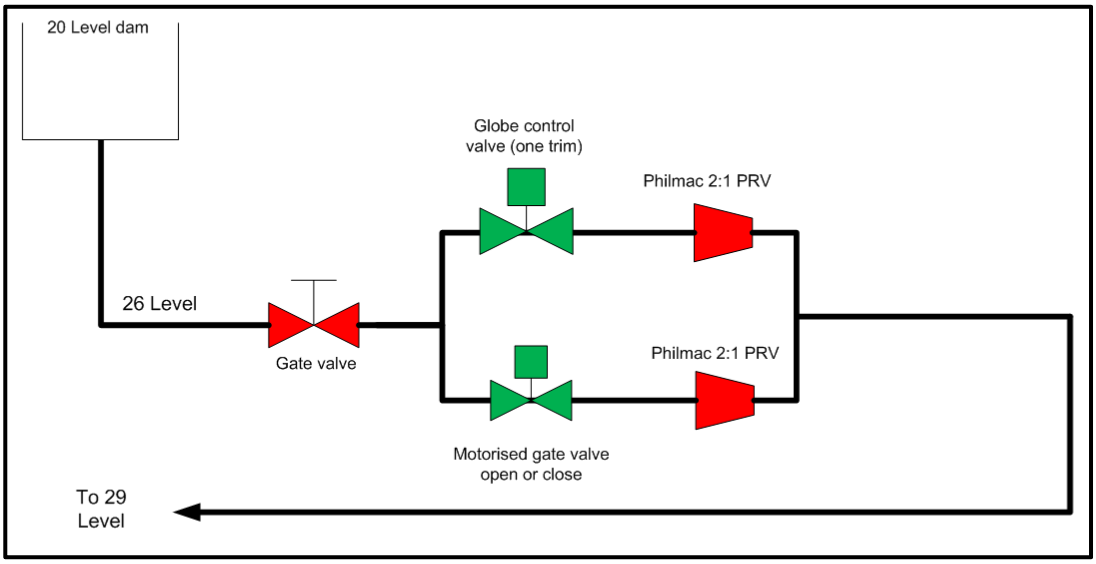


Figure 4-17: Level 26 new valve installation configuration

4.4.2 Case study results

The mine consumes on average 20 Ml water per day. The water consumption profile for a typical mine production day is shown in Figure 4-18. From this figure the two mine shifts (drilling and sweeping), and their variant water demands, can be identified. The maximum water demand occurs during the drilling shift from 06:00 till 12:00 and during the sweeping swift from 22:00 till 04:00 the next morning.

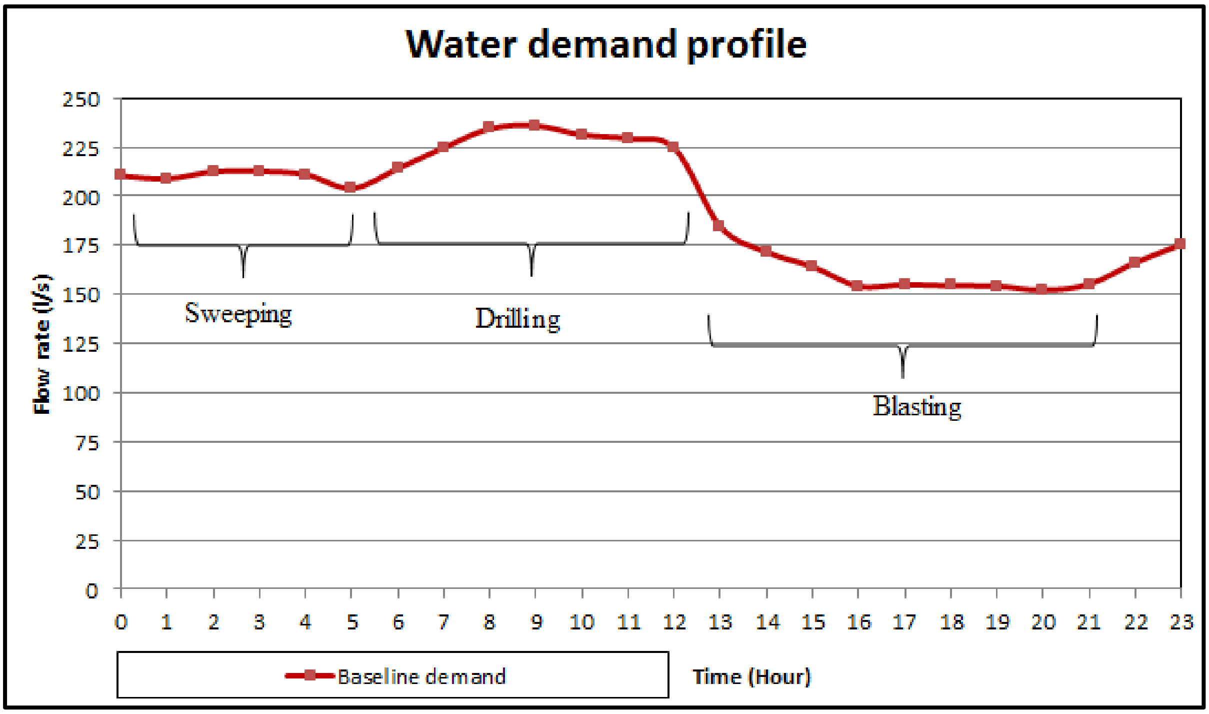


Figure 4-18: Water demand profile for the mine used in case study

With the new control a significant decrease occurred in the amount of water flow, see Figure 4-19. The performance of the project was measured over a three month period. During the first month the average water reduction was 3.4 Ml per day resulting in an average weekday power reduction of 3.6 MW.

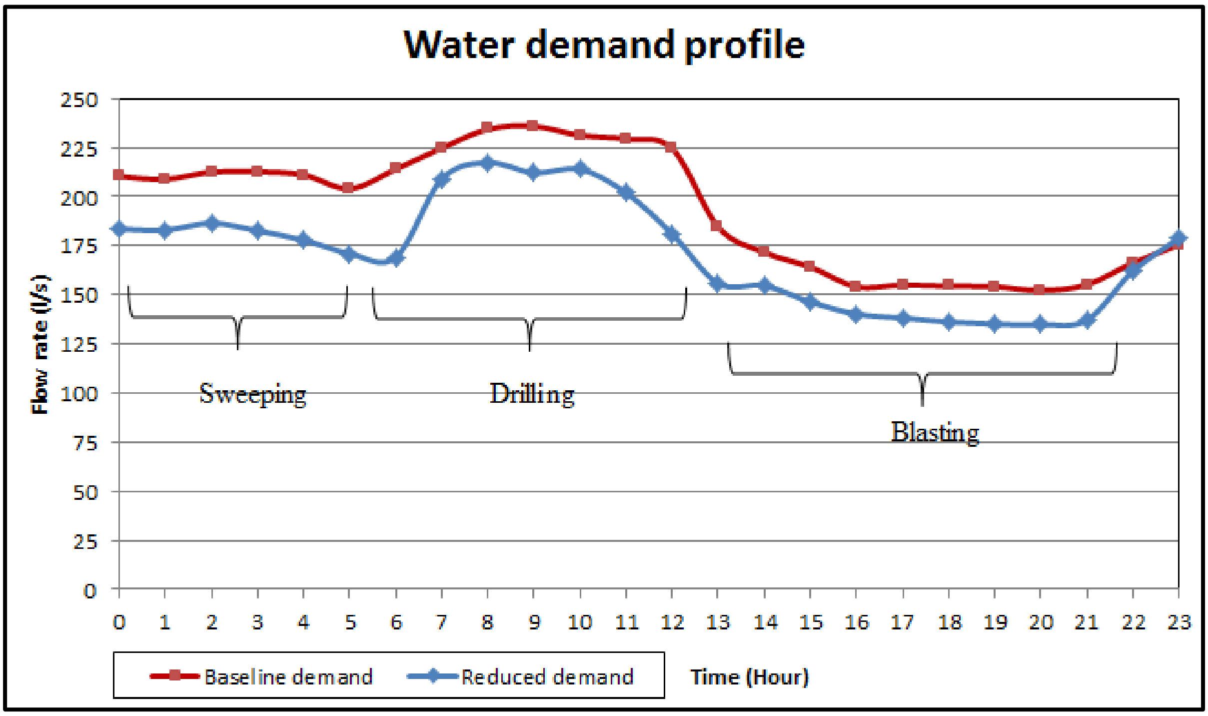


Figure 4-19: Reduction in flow rate due to pressure control

4.5 Energy savings resulting from valve control

If the water supply to the underground levels can be reduced, the water required to be pumped back to surface will also be reduced, resulting in significant electrical energy savings. Reducing the water pressure showed a significant reduction in water flow demand reducing the electrical power demand. Figure 4-20 shows the average reduction in electrical power.

The performance of the project was verified over a three month period. Table 8 shows the electrical power, monetary and water usage savings achieved over this three month period. The financial impact of the water reduction is calculated using the average off-peak and standard electricity cost rates, because less electrical power is consumed during Eskom's peak periods.

The financial impact of the reduction in electrical energy consumption in the summer was R34 268 per day for the three month period. This will result in a monthly saving of approximately R693 230, based on 22 workdays per month.

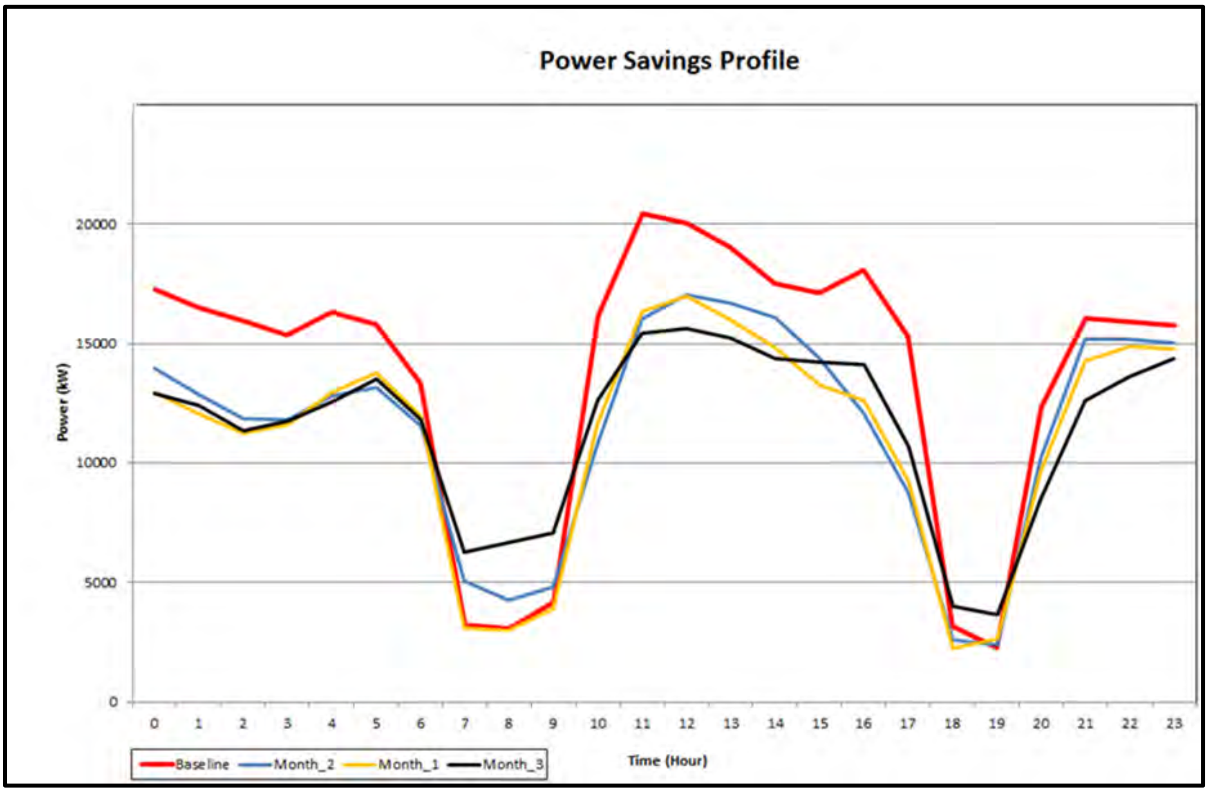


Figure 4-20: Graph showing the electrical impact (kW) of water pressure control over a period of 24 hours

Table 8: Results after using valve control for a period of three months

Description	Target	Month 1	Month 2	Month3	Average over the three months
Average weekday power reduction [MW]	1.65	3.607	3.95	3.086	3.548
Evening peak power reduction [MW]	N/A	3.607	3.95	3.086	3.548
Total reduction in energy consumption [MWh]	N/A	2515	2475	1878	2289
Total reduction in energy cost [R]	N/A	747 881	753 887	577 921	693 229.67
Total reduction in water usage [Ml]	N/A	3.395	3.341	2.536	3.09

4.6 Conclusion

An energy efficiency project implemented at a mine served as a case study for this investigation. The aim of the project was to reduce the amount of water sent underground, subsequently reducing the amount of water to be pumped back to surface. After the first valve problem a system analysis approach was chosen. The analysed data revealed that approximately 80% of the water consumed was below Level 35. In order to comprehend the behaviour of the system a simulation model was developed.

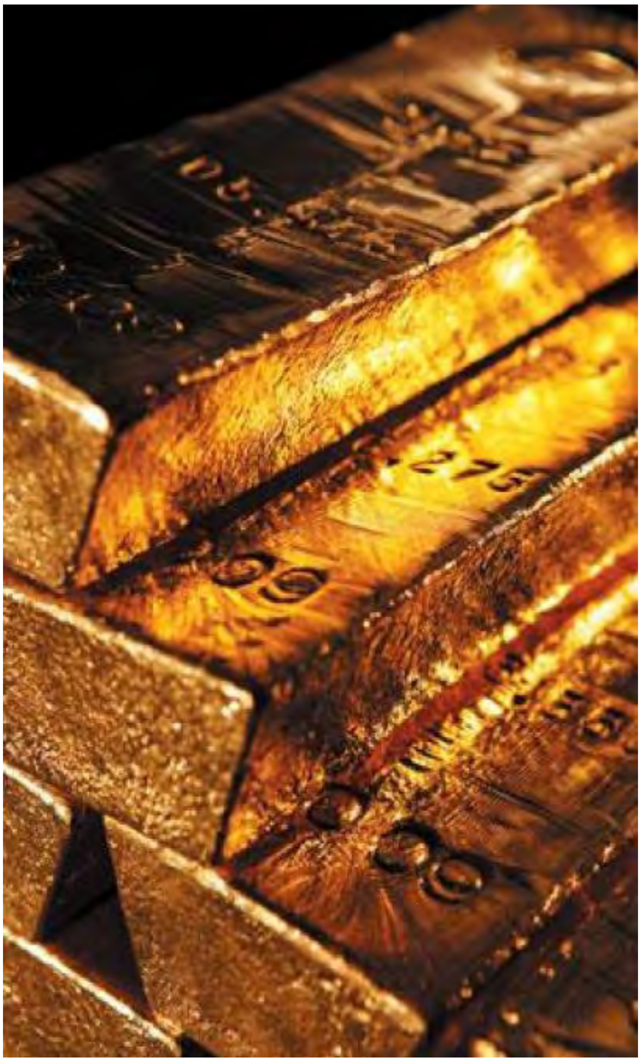
Different scenarios were simulated to anticipate the effects of the control action. The simulation model revealed a decrease in pressure was caused by an existing NGD control valve situated in the main feed column between Levels 33 and 35. The final proposed solution was to install a fixed ratio valve in series with the existing NGD valve. The fixed ratio valve will reduce the high inlet pressure to a sustainable outlet pressure, allowing the valve to regulate pressure while avoiding cavitation or water hammer effects.

In an attempt to solve the problem regarding the levels below Level 35, different scenarios were set and verified with the help of a simulation model. Different scenarios were simulated and concluded that the 100 mm globe control valve would not have caused a flow or pressure decrease, as stated by mine personnel. However a single valve could satisfy all the various project specific constraints. Two identical valves installed in series were selected as the most effective solution due to the high pressure. At this high pressure one of the valves will reduce the pressure to an acceptable controllable pressure. The second control valve will be able to reduce the downstream pressure and flow while avoiding cavitation.

After an effective valve solution was identified and implemented, significant energy savings were achieved. The expected target for the project was to reduce the water supplied to the mine with 2 Ml per day and achieve an average power saving of 1.6 MW daily. After a three month testing period a daily average saving of 3.1 Ml water and 3.55 MW reduction in electrical power was achieved.

The reduced water consumption resulted in an additional 45% electrical energy saving. An additional 40% overall performance in water reduction was achieved by implementing the water supply reduction (energy efficiency initiative) study.

5. CONCLUSION AND RECOMMENDATIONS



Summary

In this chapter an overview of the study will be discussed followed with an conclusion. Recommendations will be specified for further studies.

5.1 Conclusion

South Africa has experienced difficulty in sustaining a steady electricity supply. It was also revealed that the South African mining industry consumes a significant amount of the electricity supplied by Eskom. Investigating the mining industry's energy usage identified the water reticulation systems as a major electricity consumption section. Incorporating water supply optimisation initiatives in the South African mining industry, offers a significant potential to reduce the electricity consumption.

The water reticulation system has three categories, namely the refrigeration system, supply system and the dewatering system. The investigation revealed that mine water is used primarily for cooling, drilling and sweeping purposes.

An investigation to the possibility of reducing the water supplied to underground levels via water pressure control was done. As the depth of the mine levels increase the water pressure also increases. PRVs reduce high water pressure distributed to various mining areas in a complex water supply network. Water flow and pressure can be managed and controlled by installing the correct control valves at appropriate positions throughout the water reticulation system. Correct valve selection is subject to various constraints in order to ensure an effective solution.

An investigation into the valve selection revealed that the selection of an effective control valve requires a compromise between different system constraints. Additional constraints, such as cavitation, water hammer, flashing, and control range, must be taken into account when selecting a valve. The investigation also revealed that valve manufacturers, when sizing a valve, do not include both valve and system constraints in their calculations.

The disadvantage regarding the "traditional" selection process can be overcome by using system analysis. An investigation into a system analysis approach revealed that a simulation model can be developed using data analysis and system parameters. The simulation model will show the behaviour of the system and anticipate the effects of the control action.

Valve installation in the hazardous mining areas presented further challenges and constraints which cannot be specified by a simulation model. However, it is extremely important to include system specific constraints to ensure an effective valve selection.

After an effective valve selection had been made, power savings could be achieved. The expected target for the case study was to reduce the mine's daily water supply with 2 Ml and achieve an average power saving of 1.6 MW. After implementing the valve solution and optimising the water supply system, a 3.1Ml water reduction was achieved including a power saving of 3.55 MW.

Installing a control valve can provide the capability to reduce the water consumption on underground levels. Selecting the correct valve is important especially in the mining industry where high pressures could lead to damage, resulting in production losses. Various types of valves used for water pressure control was discussed, as well as the common problems encountered in high pressure valve applications.

5.2 Recommendations for further work

In this study the effects of reducing the water supply were investigated. Additional water reducing techniques: leak management and stope isolation have not been implemented on the case study. Further investigation could be conducted on implementing water supply reduction in combination with the additional techniques in a mine.

It is recommended that the potential of a load shifting initiative project (pump automation) combined with a water supply optimisation be investigated. It was also seen that the actual energy reduction exceeded the expected energy reduction. The reason for this was not investigated during the study. This could also be included in further studies.

6. REFERENCES

[1] E. Abdelaziz et al., “A review on energy saving strategies in industrial sector,” *Renewable and Sustainable Energy Review,* vol. 15, no. 2011, pp. 150 -168, Sept. 2010.

[2] H. Zhang, *Optimal sizing and operation of pumping systems to achieve energy efficiency and load shifting.* Pretoria, South Africa: University of Pretoria, 2011.

[3] *Energy Accounts for South Africa: 2002 - 2009*, Statistics South Africa, Pretoria, 2012.

[4] *Power Generation from Coal*, Int. Energy Agency, Paris, France, 2010.

[5] A. Botha, “Optimising the demand of a mine water reticulation system to reduce electricty consumption,” M.Eng. thesis, Dept. Mech. Eng., North-West University, Pretoria, 2010.

[6] *Power conservation Programme (PCP) rules*, NERSA, Pretoria, South Africa, 2008.

[7] E. de Lange, “The impact of increased electricity prices on consumer demand,” M.BA. thesis, Gordon Inst. of Bus. Sci., University of Pretoria, Pretoria, 2008.

[8] *Eskom Tariff Book*, Eskom, Sandton, South Africa, 1 April 2011.

[9] Eskom. (2009, Aug.). Annual report. [Online]. Available: http://www.eskom.co.za/annreport09/ar_2009/downloads/eskom_ar_2009.pdf.

[10] M. Begemann, “Integrated and syncronised approach to DSM initiatives,” M.Eng. thesis, Dept. Mech. Eng., University of KwaZulu-Natal, Durban, South Africa, 2009.

[11] *Energy Efficiency case studies.* National Business Initiative, Johannesburg, 2008.

[12] N. De Kock, “Optimising the load shift potential of the clear water pumping system on a South African Gold Mine,” Dept. Elect. and Electron. Eng., North-West University, Potchefstroom, South Africa, 2005.

[13] J. Vosloo, “A new minimum cost model for water reticulation systems on deep mines,” Ph.D. thesis, Dept. Electrical. Eng., North-West University, Pretoria, 2008.

[14] L. Prinsloo. (2009, Oct. 23). Eskom's DSM initiatives yield significant savings. *Mining Weekly* [Online]. Available: //www.miningweekly.com/article/eskom-dsm-programme-supporting-savings-in-the-mining-sector-2009-10-23.

[15] M. Creamer. (2009, Feb. 09). World's new deepest mine `safe, cheap' - AngloGold. *Mining Weekly* [Online]. Available: //www.miningweekly.com/article/worlds-new-deepest-mine-safe-cheap-anglogold-2009-02-09.

[16] D. Stanton, "Development and testing of an underground remote refigeration plant," International Platinum Conference, The South African Inst. of Mining and Metallurgy, 2004.

[17] D. Stephenson, "Distribution of water in deep gold mines in South Africa," *Int. J. Mine Water,* vol. 2, no. 2, pp. 21-30, 1983.

[18] W. Booysen et al., "Selection of control valves on water optimisation projects," presented and the *Int. Consortium University Entrepreneurs*, Cape Town, 2011.

[19] J. Vosloo et al., "Case study: Energy savings for a deep-mine water reticulation system," *Applied Energy,* vol. 88, no. 1, pp. 328-335, 2011.

[20] F. Lloyd and P. Cronje, "Refrigeration systems for a deep-level mine," in *Int. Deep Mining Conf.*, Johannesburg, 1990, pp. 1333-1346.

[21] P. Jansen van Rensburg, "The development of a refrigeration system at depths between 3 500 and 4 500 meters below surface," in *Int. Deep Mining Conf.*, Johannesburg, 1990, pp. 1357-1363.

[22] M. Biffi and D. Stanton, "Cooling power for a new age," in *3rd Int. Platinium Conf. 'Platinium in transformation'*, Sun City, South Africa, 2008, pp. 239-248.

[23] M. Den Boef, "Assessment of the national DSM potential in mine underground services," Ph.D. thesis, Dept. Mech. Eng., North-West University, Potchefstroom, South Africa, 2003.

[24] AngloGold Ashanti. (2008). AngloGold Ashanti's response to the power crisis [Online]. Available:http://www.anglogold.co.za/subwebs/informationforinvestors/reports08/power-crisis.htm.

[25] J. van der Walt and A. Whillier, "Considerations in the design of integrated systems for distributing refrigeration in deep mines," *J. South African Inst.Mining and Metallurgy,* pp. 109-124, 1978.

[26] M. Biffi, "Ventilation strategies to meet future needs of the South African platinum industry," in *2nd Int. Platinum Conf. 'Platinum Surge Ahead'*, Sun City, South Africa, 2006, pp.59-66.

[27] HPE Hydro Power Equipment. (2012, Aug.).. *HPE Hydro Power Equipment* [Online]. Available: http:/www.hpesa.com/vv-pressurereducing.html.

[28] Manos Engineering. (2012, Sept.). Manos Engineering Mine Cooling [Online]. Available: http://www.manos.co.za/.

[29] H. Hansen et al., "Speciation and leachability of copper in mine tailings porphyry copper mining: Influene of partical size," *Chemosphere,* vol. 60, no. 10, pp. 1497-1503, 2005.

[30] S. Tein, "Demand side management on an intricate multi-shaft pumping system from a single piont of control," Dept. Elect. and Electron. Eng., North-West University, Potchefstroom, South Africa, 2006.

[31] J. Calitz, "Research and implementation of a load reduction system for a mine refrigeration system," M.Eng. thesis, Dept. Mech. Eng., North-West University, Potchefstroom, South Africa, 2005.

[32] J. de la Vergne," Hard Rock Miners Handbook, 3de ed. North Bay, Ontario, Canada: MeIntosh Engineering, 2003.

[33] R. Mckenzie and W. Wegelin, "Implementation of pressure management in municipal water supply systems," Miya Luxemburg, Pretoria, 2009.

[34] F. White, "Viscous flow in ducts," in *Fluid Mechanics*, New York: McGraw-Hill, 2008, pp.413-417.

[35] Munson et al., *Fundamentals of Fluid Mechanics*, 5th ed. New York: Wiley, 2006.

[36] *Mechanical Science, Valve Fundamentals*, PDHengineer, Houston, TX, 2009.

[37] *Valve Control Handbook.* LLC Fisher Control Int., Marshalltown, Iowa, USA, 2005.

[38] EMERSON, "Valve Sizing Calculations (Traditional Method)," EMERSON, Marshalltown, Iowa, USA, 2005.

[39] P. Skousen, "Common Valve Problems," in *Valve Handbook*, New York: McGraw-Hill, 2004, pp. 338-373.

[40] Spirax-Sarco Limited, "Module 6.3: Control valve sizing for Water System," Spirax-Sarco Limited, Cheltenham, Gloucestershire, UK, 2003

[41] Kentintrol. (2012, Aug.). Servere Service Valves. [Online]. Available: http://www.kentintrol.com/product_info/products/severe_service_valves.

[42] Cycle Stop Valves. (2012, Aug.), Constant Pressure Pump Control Valves. [Online]. Available: http://cyclestopvalves.net/csvtechinfo_10.html.

[43] D. Macdonald, "Practical Control Valve Sizing, Selection and maintenance", IDC Technolodies Pty Ltd, West Perth, Western Australia, 2008.

[44] *Handbook for control valve sizing*, PARCOL S.P.A., Via Isonzo, Milan, Italy, (2012).

[45] W. Rahmeyer et. al, "Cavitation testing results for a tortuous path control valve," presented at the Fluid Engineering Conf., Rancho Santa Margarita, SC, 1995.

[46] A. Grace and P. Frawley, "Experimental parametric equation for the prediction of valve coefficient for choke valve trims," *Int. J. Pressure Vessels and Piping,* vol. 2, no. 88, pp. 109-118, 2011.

[47] A. G. Samson, "Technical Information - Cavitation in Control Valves", in Mess-Und Regeltechnik Weismullerstrabe, Frankfurt, Germany, 2003

[48] *Guidance on 2011: Mining Charter Report,* Chamber of Mines of South Africa, Johannesburg, 2010.

[49] KYPIPE. (2010). *KYPIPE* [Online]. Available: http://www.soltechltda.com/pdf/SoftWare_Modelacion_de_Redes_KyPipe_2010.pdf.

[50] *Baker Automatic Control Valves*, Premier Valves, Alberton, South Africa, 2007.

APPENDIX A: FLUID DYNAMICS

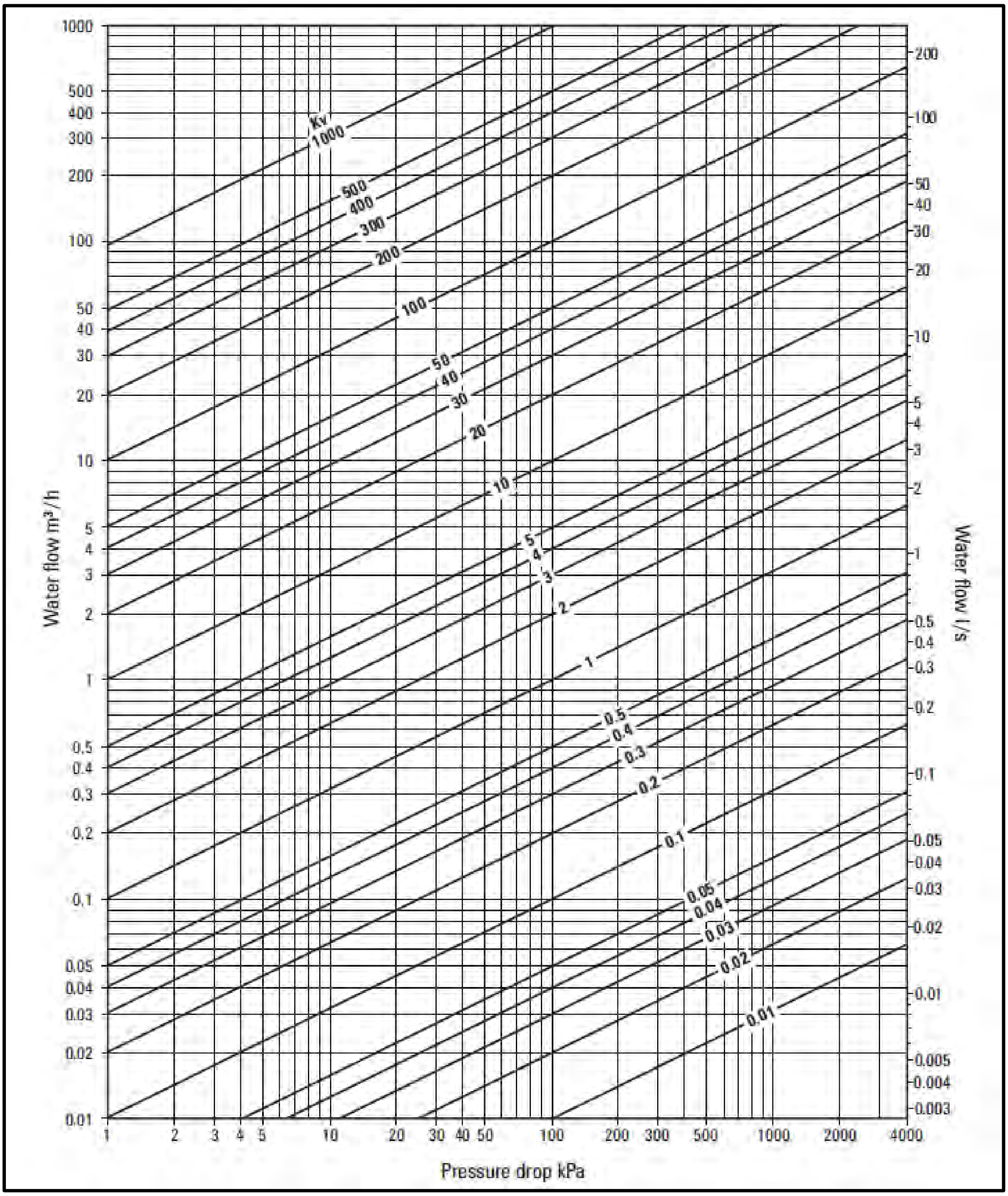


Figure A-1: Data diagram showing the water flow coefficient as a function of pressure drop [41]

		N	w	q	$p^{(2)}$	γ	T	d, D
N_1		0.0865	- - -	m^3/h	kPa	- - -	- - -	- - -
		0.865	- - -	m^3/h	bar	- - -	- - -	- - -
		1.00	- - -	gpm	psia	- - -	- - -	- - -
N_2		0.00214	- - -	- - -	- - -	- - -	- - -	mm
		890	- - -	- - -	- - -	- - -	- - -	inch
N_5		0.00241	- - -	- - -	- - -	- - -	- - -	mm
		1000	- - -	- - -	- - -	- - -	- - -	inch
N_6		2.73	kg/h	- - -	kPa	kg/m^3	- - -	- - -
		27.3	kg/h	- - -	bar	kg/m^3	- - -	- - -
		63.3	lb/h	- - -	psia	lb/ft^3	- - -	- - -
$N_7^{(3)}$	Normal Conditions $T_N = 0°C$	3.94	- - -	m^3/h	kPa	- - -	deg K	- - -
		394	- - -	m^3/h	bar	- - -	deg K	- - -
	Standard Conditions $T_s = 15.5°C$	4.17	- - -	m^3/h	kPa	- - -	deg K	- - -
		417	- - -	m^3/h	bar	- - -	deg K	- - -
	Standard Conditions $T_s = 60°F$	1360	- - -	scfh	psia	- - -	deg R	- - -
N_8		0.948	kg/h	- - -	kPa	- - -	deg K	- - -
		94.8	kg/h	- - -	bar	- - -	deg K	- - -
		19.3	lb/h	- - -	psia	- - -	deg R	- - -
$N_9^{(3)}$	Normal Conditions $T_N = 0°C$	21.2	- - -	m^3/h	kPa	- - -	deg K	- - -
		2120	- - -	m^3/h	bar	- - -	deg K	- - -
	Standard Conditions $Ts = 15.5°C$	22.4	- - -	m^3/h	kPa	- - -	deg K	- - -
		2240	- - -	m^3/h	bar	- - -	deg K	- - -
	Standard Conditions $T_S = 60°F$	7320	- - -	scfh	psia	- - -	deg R	- - -

Figure A-2: Image of a table showing equation constants [41]

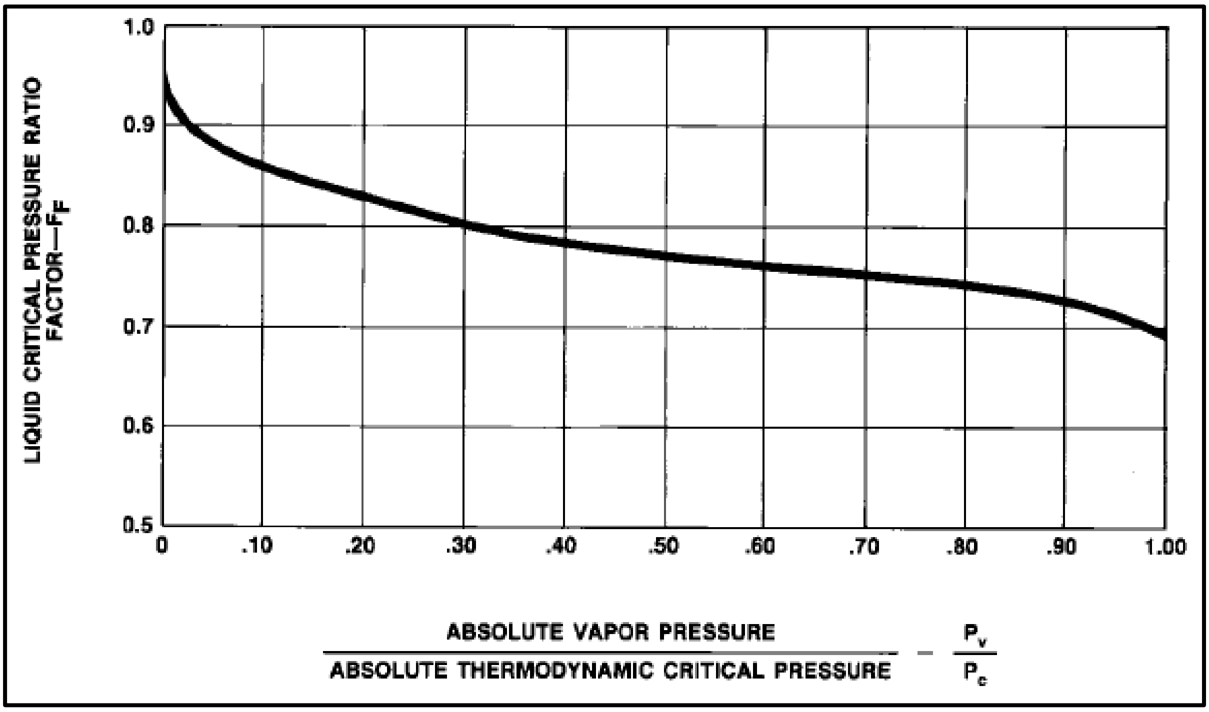
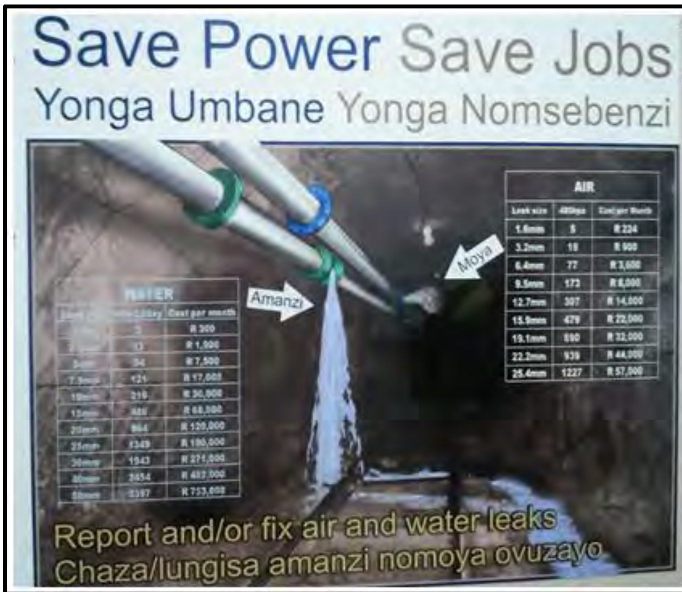


Figure A-3: Datasheet graph of liquid's critical pressure ratio factor [41]

APPENDIX B: VALVE SPECIFICATIONS AND MEASURED DATA

Table B-1: Cost per day compared to leak size

Leak size [mm]	[Kl/day]	Cost per day [R]
1	2	300
2.5	13	1 900
5	54	7 500
7.5	121	17 000
10	216	30 000
15	486	68 000
20	864	120 000
25	1349	190 000
30	1943	271 000
40	3454	482 000
50	5397	753 000



Leak size (mm)	Kl/day	Cost per day (Rand)
1	2	300
2.5	13	1900
5	54	7500
7.5	121	17000
10	216	30000
15	486	68000
20	864	120000
25	1349	190000
30	1943	271000
40	3454	482000
50	5397	753000

Figure B-1: Save power awareness board at one of Gold Fields (Pty) Ltd mines

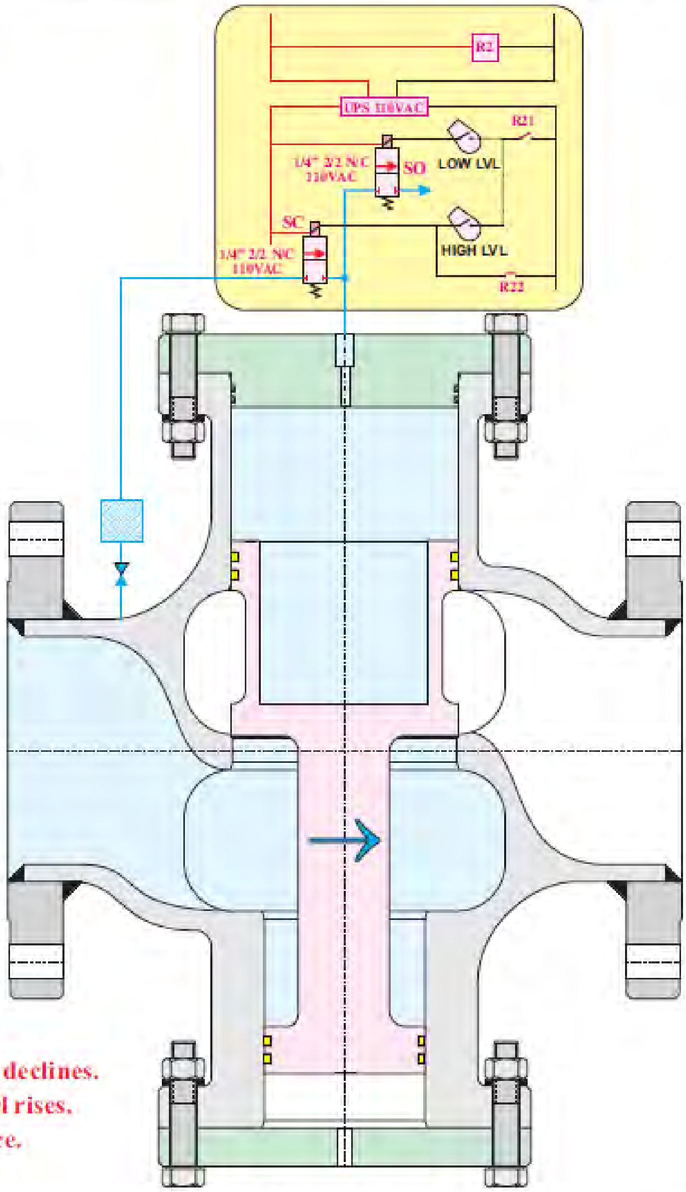
P.O. BOX 76266
WENDYWOOD 2144
SOUTH AFRICA

TEL +27 11 802-8351
FAX +27 11 802-8350

Website - www.ngd.co.za
E-mail - info@ngd.co.za

NGD VALVES

ISOLATING, SAFETY & CONTROL VALVES
RESERVOIR LEVEL CONTROL VALVE



LOW LEVEL

Low level switch contact closes

High level switch is opened and Low level switch is closed. Solenoid valve SO is activated while solenoid valve SC is deactivated

Water vents from the closing compartment

Level control valve is opened.

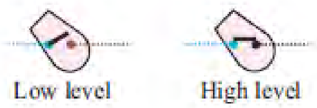
HIGH LEVEL

Low level switch contact stays opened.

High level switch closes. Solenoid valve SC is activated while solenoid valve SO is deactivated

Water enters the closing compartment

Level control valve closes



Note!
The LCV stays closed while the water level declines.
The LCV stays opened while the water level rises.
The LCV closes on power failure occurrence.

AREA OF APPLICATIONS

The N.G.D reservoir level control valve controls the water level by opening or closing the valve on low or high level conditions in the reservoir. The valve can be actuated by the line-fluid pressure or alternatively by compressed air, hydraulically or electrically.
The valve is used in: -

- Industrial Water Systems
- Municipal Water Supply Systems
- Pump Stations
- Mine Water Reticulation
- Petro-Chemical Plants

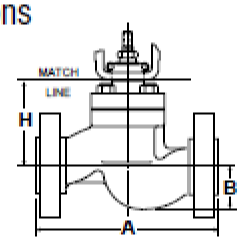
PRINCIPLES OF OPERATION

The N.G.D reservoir level control valve's actuator is a natural and integrated part of the valve. This type of actuator is ideal for relatively clean line-fluid. The line-fluid pressure actuates the valve and no external power source is required.

The piloting is done by combination of solenoid valves and suspended type level switches, which are compatible with the line fluid and the system pressure.

Figure B-2: Specification sheet regarding NGD valves

Valtek Mark One
Dimensions



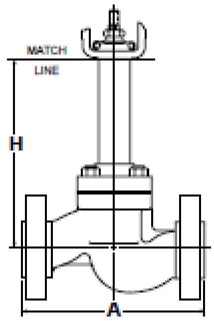


Table 19: Globe Body Dimensions – Class 150, 300, 600 (in. / mm)

Body Size (inches)	A								B		H				Clearance Above Actuator Required for Disassembly	
	ANSI / Globe*		ANSI / ISA**								Standard Bonnet		Extended Bonnet			
	Class 150, 300, 600		Class 150		Class 300		Class 600									
½ & ¾	8.5	216	7.3	184	7.6	194	8.1†	206†	1.5	38	3.8	97	8.3	212	2.5	64
1	8.5	216	7.3	184	7.8	197	8.3	210	1.8	44	3.8	97	8.3	212	2.5	64
1½	9.5	241	8.8	222	9.3	235	9.9	251	2.3	59	5.2	132	9.7	246	4.0	102
2	11.5	292	10.0	254	10.5	267	11.3	286	2.3	57	5.4	138	9.9	252	4.5	114
3	14.0	356	11.8	298	12.5	318	13.3	337	3.4	86	6.8	172	12.3	312	5.8	147
4	17.0	432	13.9	353	14.5	368	15.5	394	5.2	133	8.4	214	13.9	354	7.5	190
6			17.8	451					5.5	139	10.1	256	15.6	395	10.0	254
6					18.6	473	20.0	508	5.8	146	12.3	311	17.8	451	10.0	254
8			21.4	543					7.1	180	12.5	318	18.0	457	10.9	277
8					22.4	568	24.0	610	7.5	190	14.4	365	19.9	505	11.4	290
10			26.5	673					8.4	214	14.1	359	19.6	498	11.9	302
10					27.9	708	29.6	752	8.9	227	14.1	359	20.6	524	12.1	308
12			29.0	737					9.6	243	14.1	359	19.6	498	12.6	320
12					30.5	775	32.3	819			16.3	413	22.8	578	12.6	320

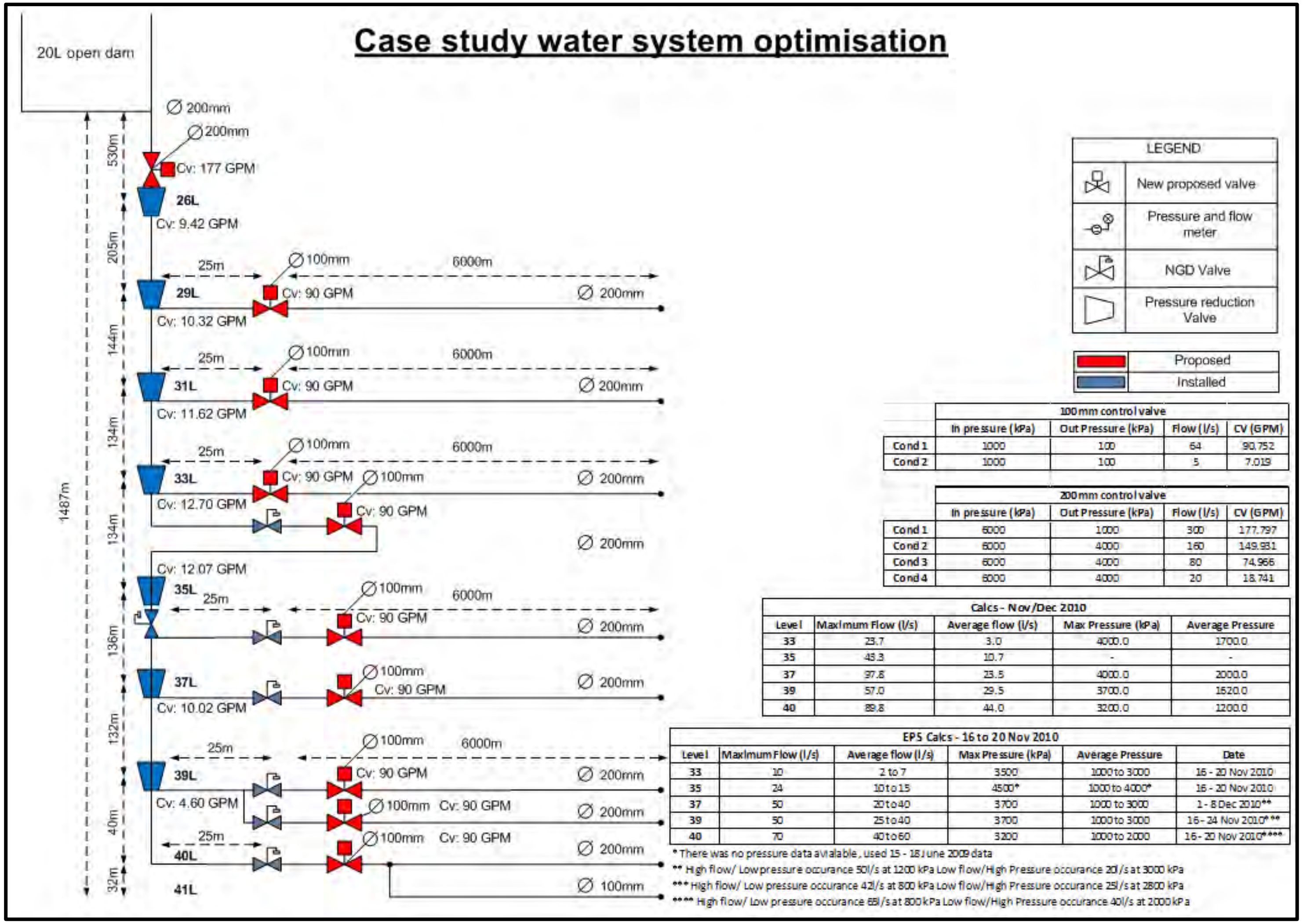
* Flowserve standard per ANSI / ISA S75.20, 1992 ** Per ANSI / ISA S75.03, 1985 †For screwed end use 8.3 / 210

Table 20: Globe Body Dimensions – Class 900, 1500, 2500 (in. / mm)

Body Size (in.)	A				B				H								Clearance Required for Disassembly			
	Face-to-Face*								Standard Bonnet				Extended Bonnet							
	Class 900, 1500		Class 2500		Class 1500		Class 2500		Class 900, 1500		Class 2500		Class 900, 1500		Class 2500		Class 900, 1500		Class 2500	
1	11.0	279	12.0[2]	305[2]	1.8	44	1.8	44	5.6	143	6.8	173	10.1	257	11.3	286	3.6	90	3.6	90
1½	13.0	330	15.0[1]	381[1]	2.7	68	2.4	60	8.7	220	8.7	221	13.2	334	13.2	334	5.6	141	5.6	141
2	14.8	375	15.8	400	2.8	71	3.0	77	8.7	220	8.7	221	13.2	334	13.2	334	6.1	154	6.1	154
3	18.1	460	26.0[1]	660[1]	4.2	106	3.7	94	11.4	289	12.9	328	18.4	467	19.9	506	8.4	214	8.3	211
4	20.9	530	29.0[1]	737[1]	4.4	113	5.4	138	12.4	316	14.6	371	19.4	496	21.6	549	9.7	246	10.7	272
6	30.0[2]	762[2]	34.0[1]	864[1]	7.2	183	7.3	184	19.4	493	17.4	442	26.4	671	27.3	692	12.2	309	13.6	344
8	32.8	832	40.3	1022	9.4	240	10.3	262	18.6	473	24.3	616	24.2	613	31.3	794	16.7	424	17.8	451
10	39.0	991	50.0	1270	11.2	284	10.0	254	21.9	556	26.0	660	28.9	734	33.0	838	18.3	465	19.5	495
12	44.5	1130	56.0	1422	14.0	356	12.9	327	26.6	675	28.0	711	33.6	852	35.0	889	19.4	492	20.5	521
14	49.5	1257							24.8	629			31.8	806			20.5	521		

* ANSI / ISA S75.15, 1987; (1) Per ANSI / ISA S75.16, 1987; (2) Flowserve standard

Figure B-3: Specification sheet regarding proposed globe valves



	100mm control valve			
	In pressure (kPa)	Out Pressure (kPa)	Flow (l/s)	CV (GPM)
Cond 1	1000	100	64	90.752
Cond 2	1000	100	5	7.019

	200mm control valve			
	In pressure (kPa)	Out Pressure (kPa)	Flow (l/s)	CV (GPM)
Cond 1	6000	1000	300	177.797
Cond 2	6000	4000	160	149.931
Cond 3	6000	4000	80	74.966
Cond 4	6000	4000	20	18.741

Calcs - Nov/Dec 2010				
Level	Maximum Flow (l/s)	Average flow (l/s)	Max Pressure (kPa)	Average Pressure
33	23.7	3.0	4000.0	1700.0
35	43.3	10.7	-	-
37	97.8	23.5	4000.0	2000.0
39	57.0	29.5	3700.0	1620.0
40	89.8	44.0	3200.0	1200.0

EPS Calcs - 16 to 20 Nov 2010					
Level	Maximum Flow (l/s)	Average flow (l/s)	Max Pressure (kPa)	Average Pressure	Date
33	10	2 to 7	3500	1000 to 3000	16 - 20 Nov 2010
35	24	10 to 15	4500*	1000 to 4000*	16 - 20 Nov 2010
37	50	20 to 40	3700	1000 to 3000	1 - 8 Dec 2010**
39	50	25 to 40	3700	1000 to 3000	16 - 24 Nov 2010***
40	70	40 to 60	3200	1000 to 2000	16 - 20 Nov 2010****

* There was no pressure data avialable, used 15 - 18 June 2009 data
** High flow/ Low pressure occurance 50l/s at 1200 kPa Low flow/High Pressure occurance 20l/s at 3000 kPa
*** High flow/ Low pressure occurance 42l/s at 800 kPa Low flow/High Pressure occurance 25l/s at 2800 kPa
**** High flow/ Low pressure occurance 68l/s at 800 kPa Low flow/High Pressure occurance 40l/s at 2000 kPa

Figure B-4: Measured data used to verify simulation model and scenarios

APPENDIX C: SIMULATION SCENARIOS

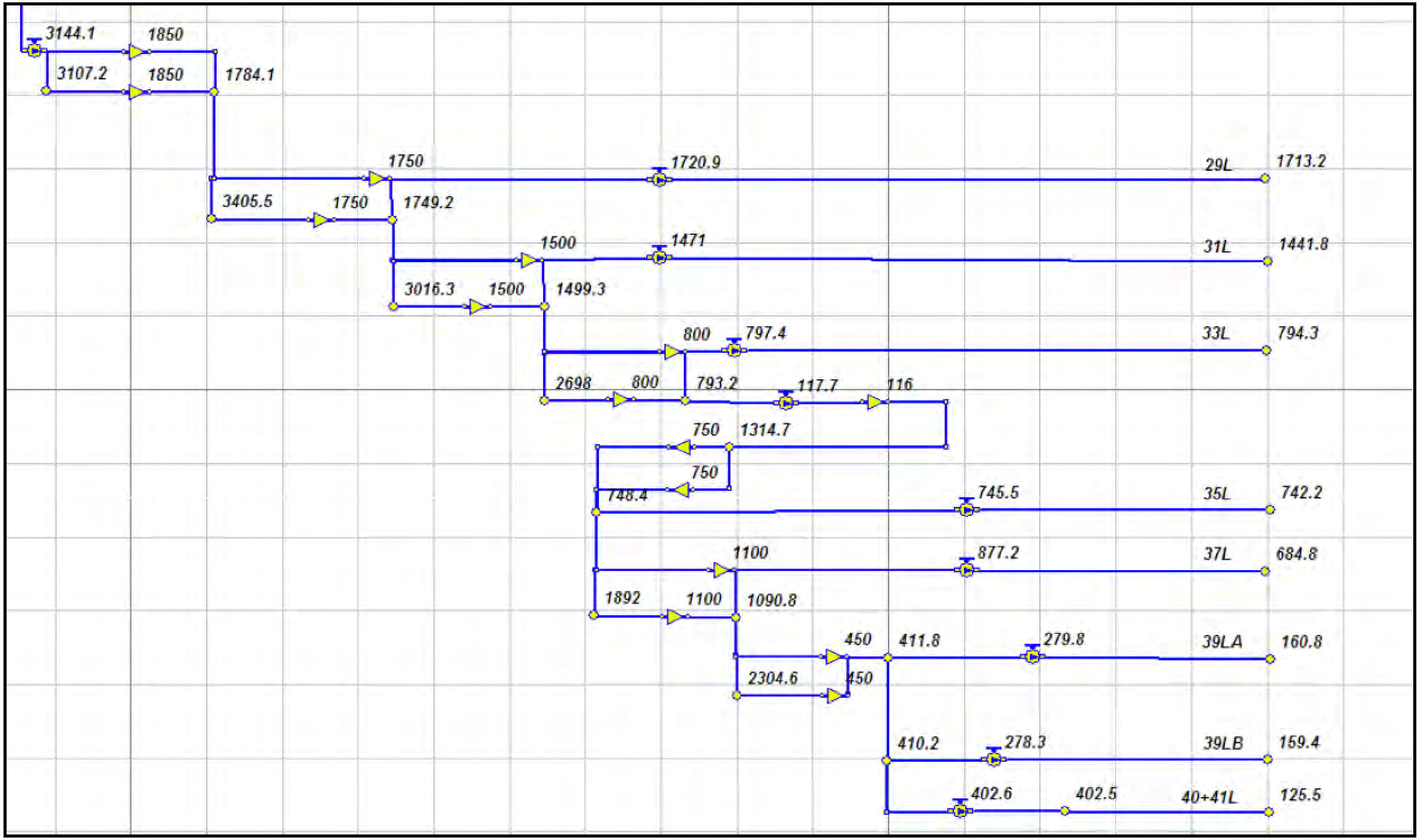


Figure C-1: Image showing the simulation layout of active system with pressure inputs

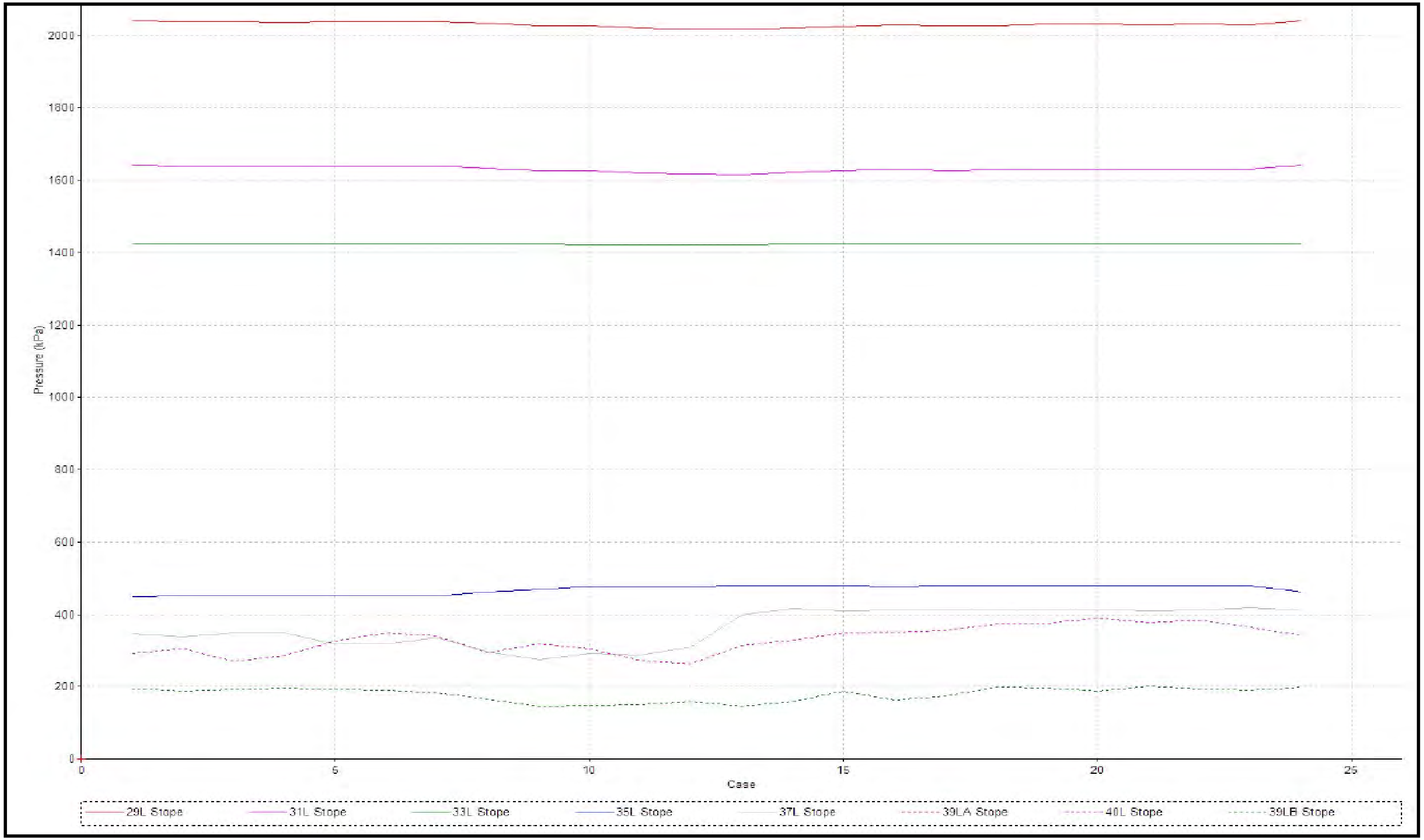


Figure C-2: Graph showing system pressures (kPa) as a function of pressure inputs

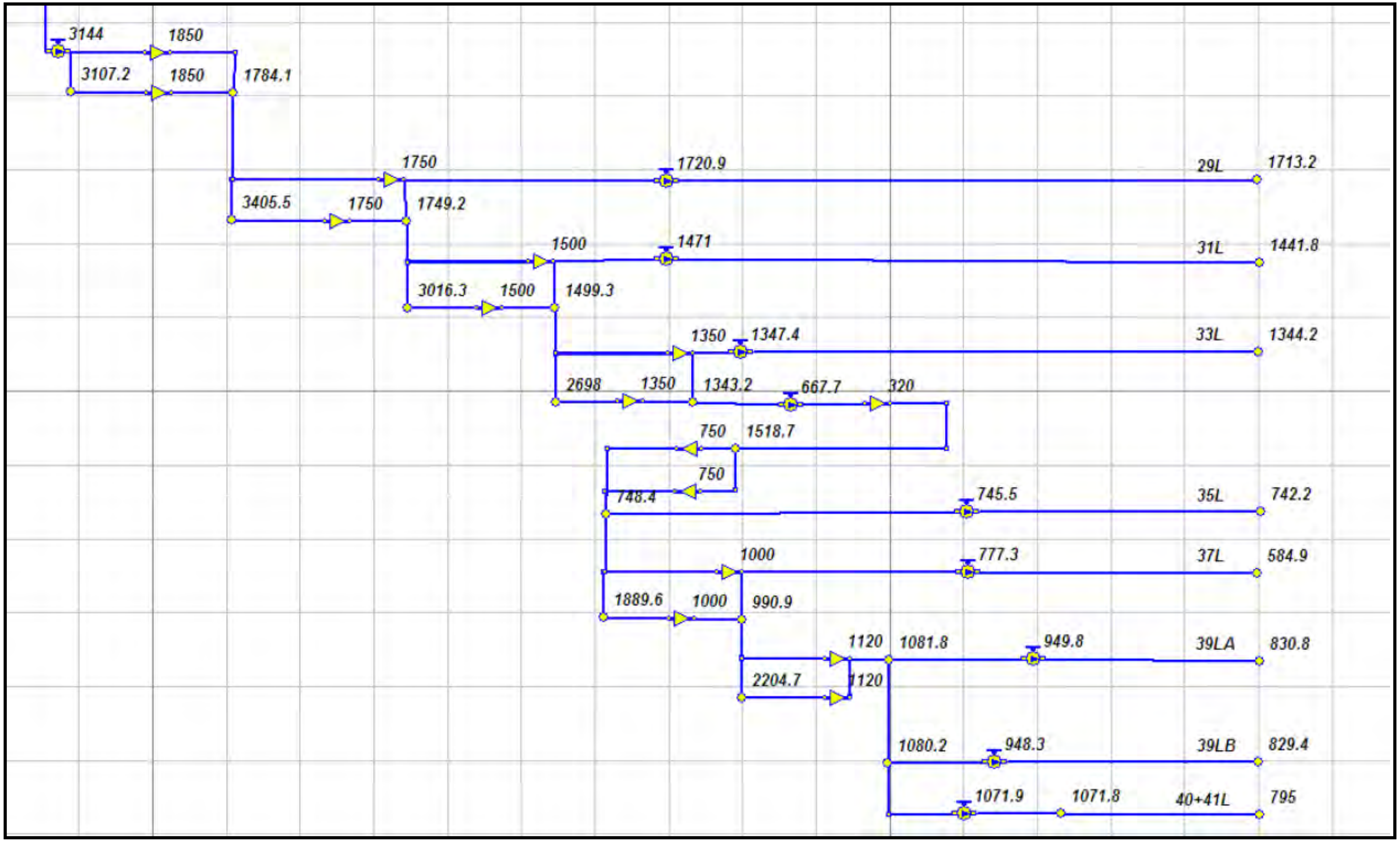


Figure C-3: Simulation layout of active system with calculated pressure inputs

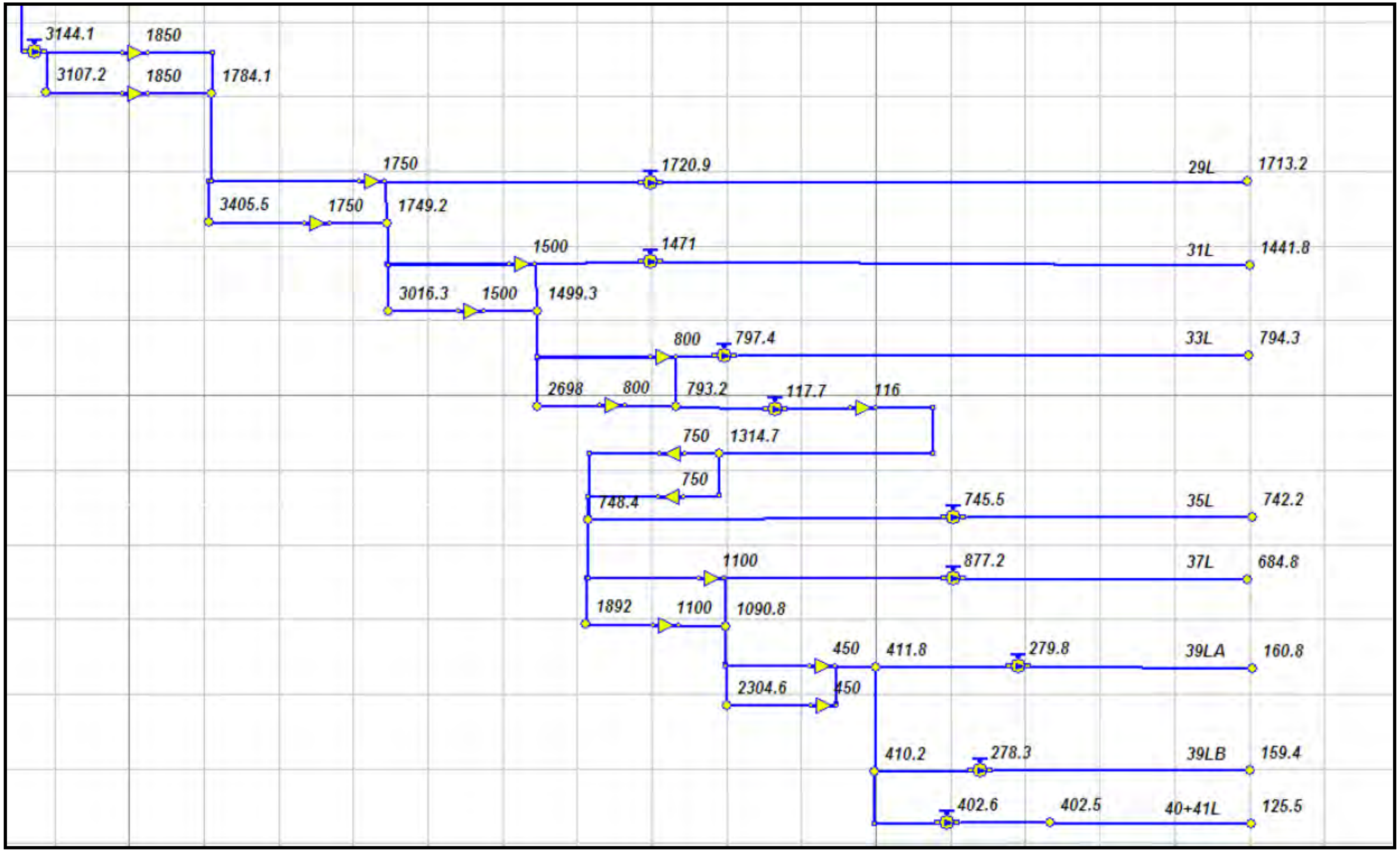


Figure C-4: Simulation layout of active system with minimum pressure

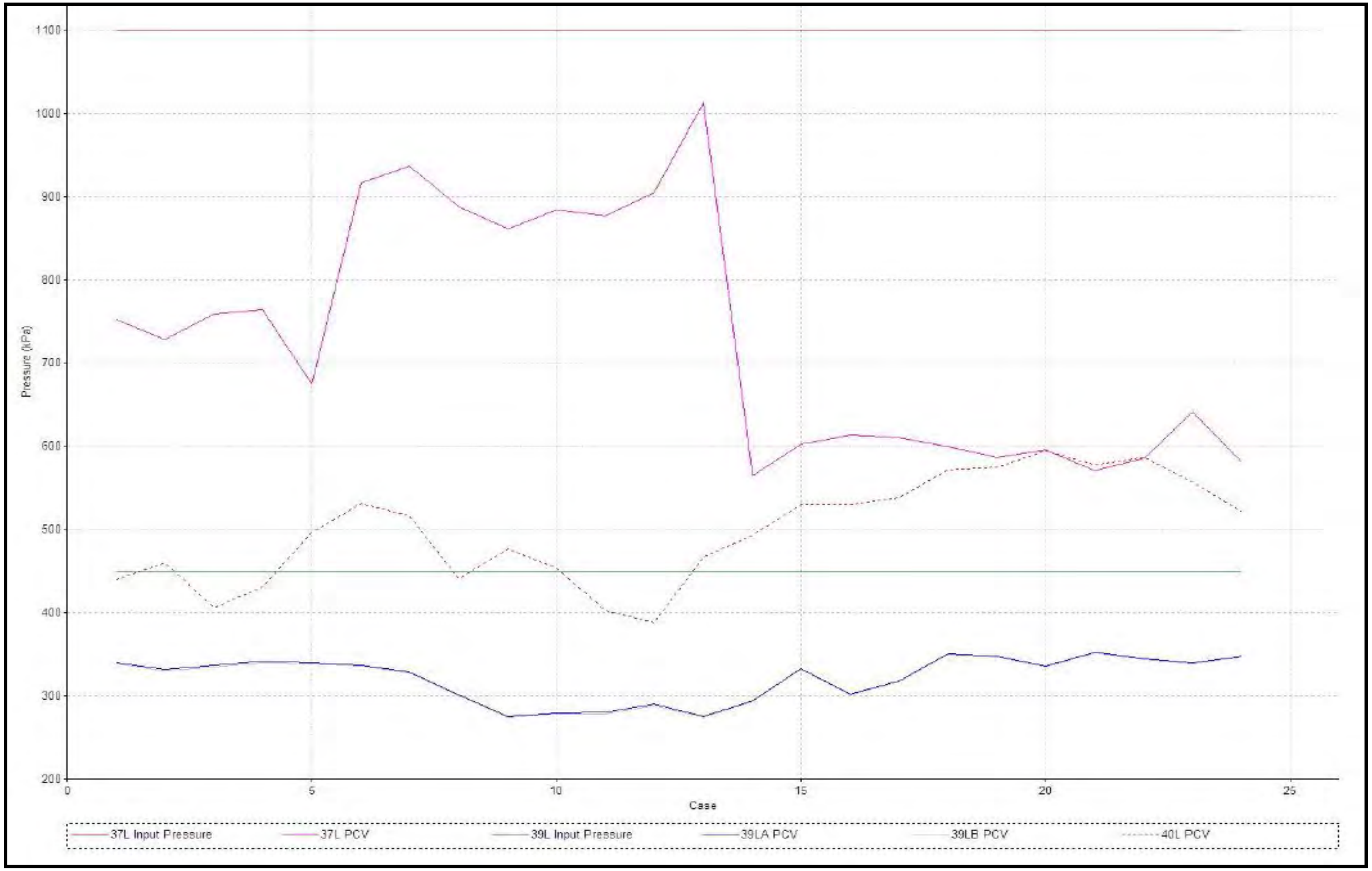


Figure C-5: Graph showing system pressures (kPa) as a function of minimum pressure inputs

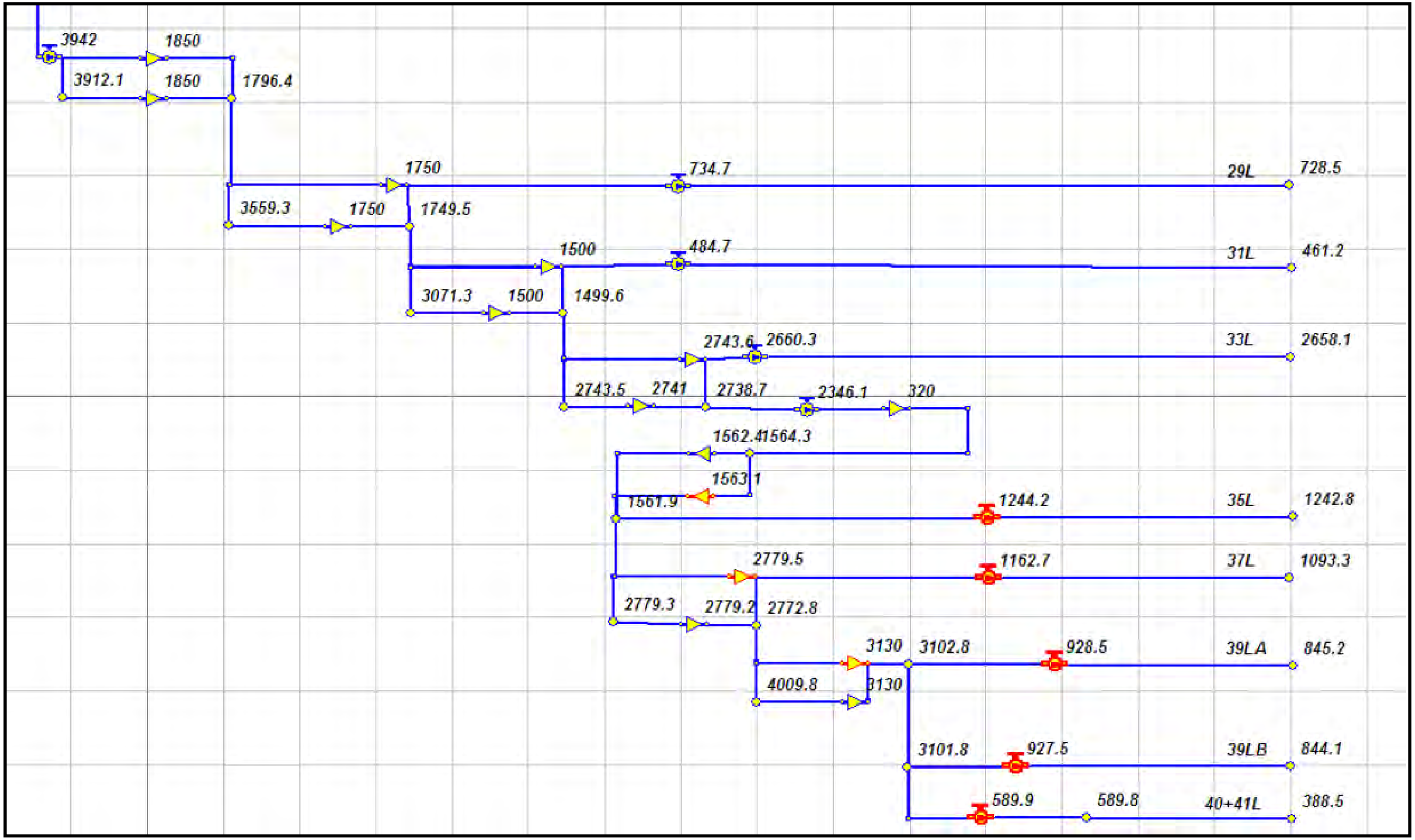


Figure C-6: Image of a simulation layout of an active system with maximum pressure inputs

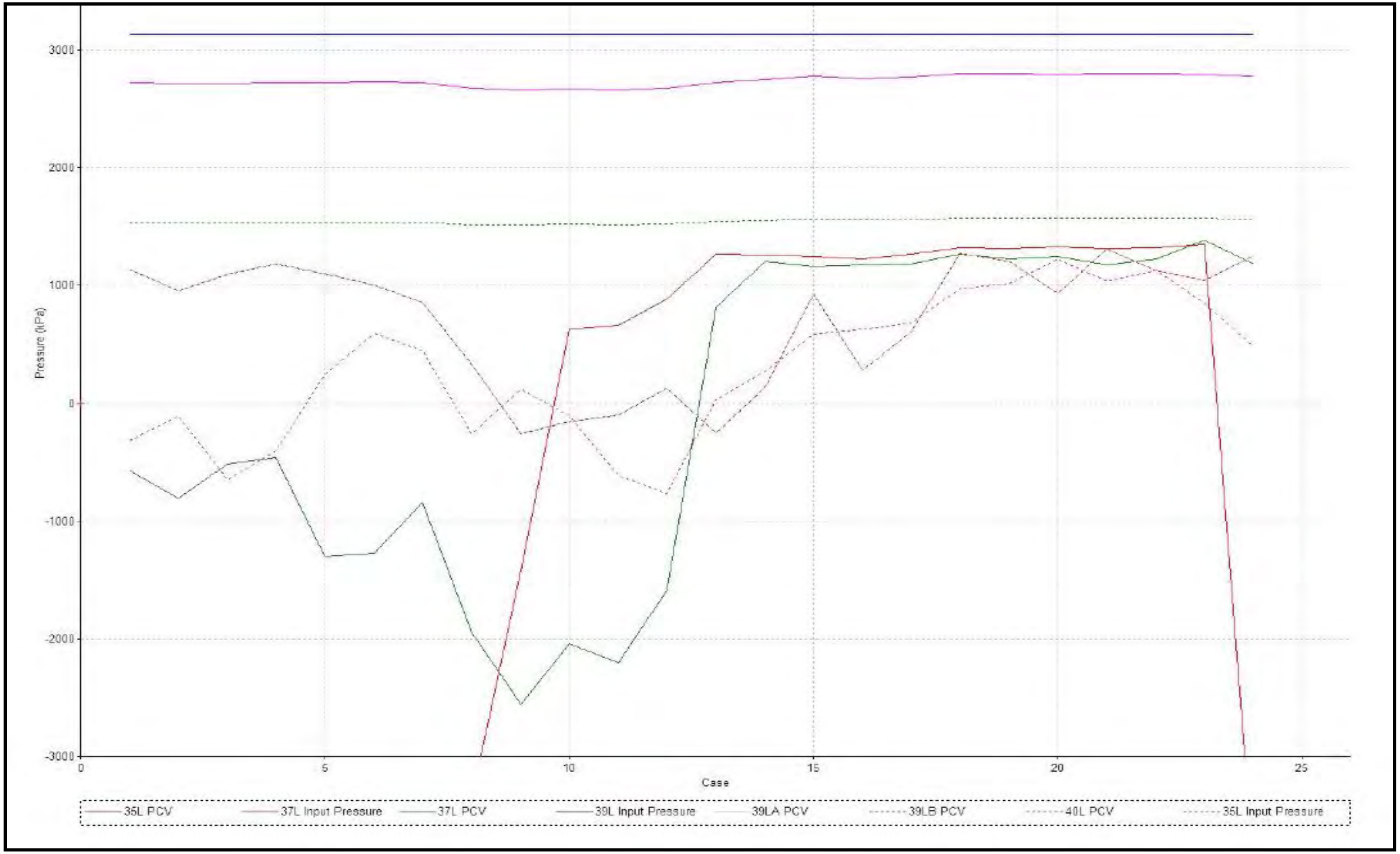


Figure C-7: Graph showing system pressures (kPa) as a function of maximum pressure inputs

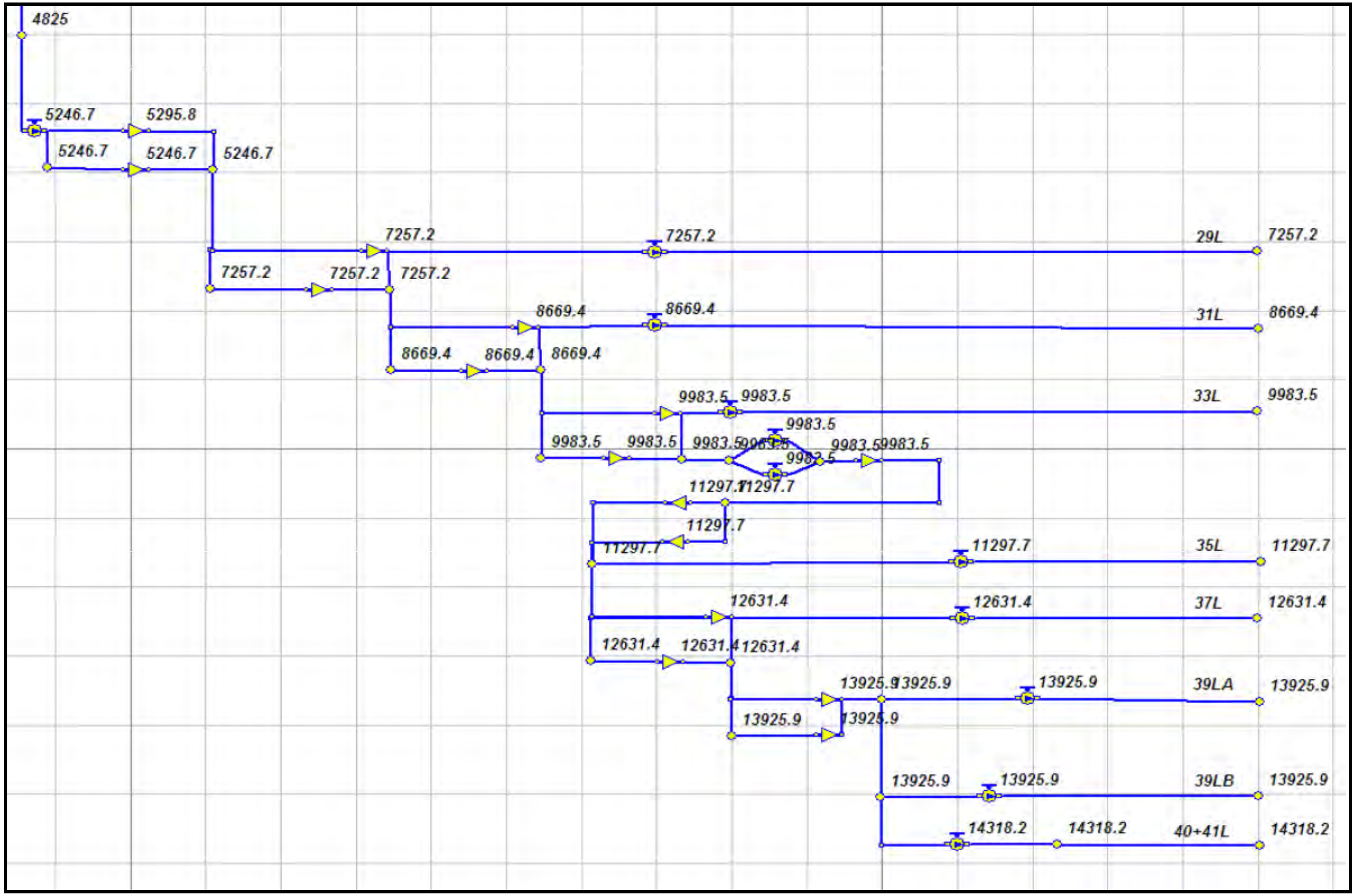


Figure C-8: Image of a system simulation layout

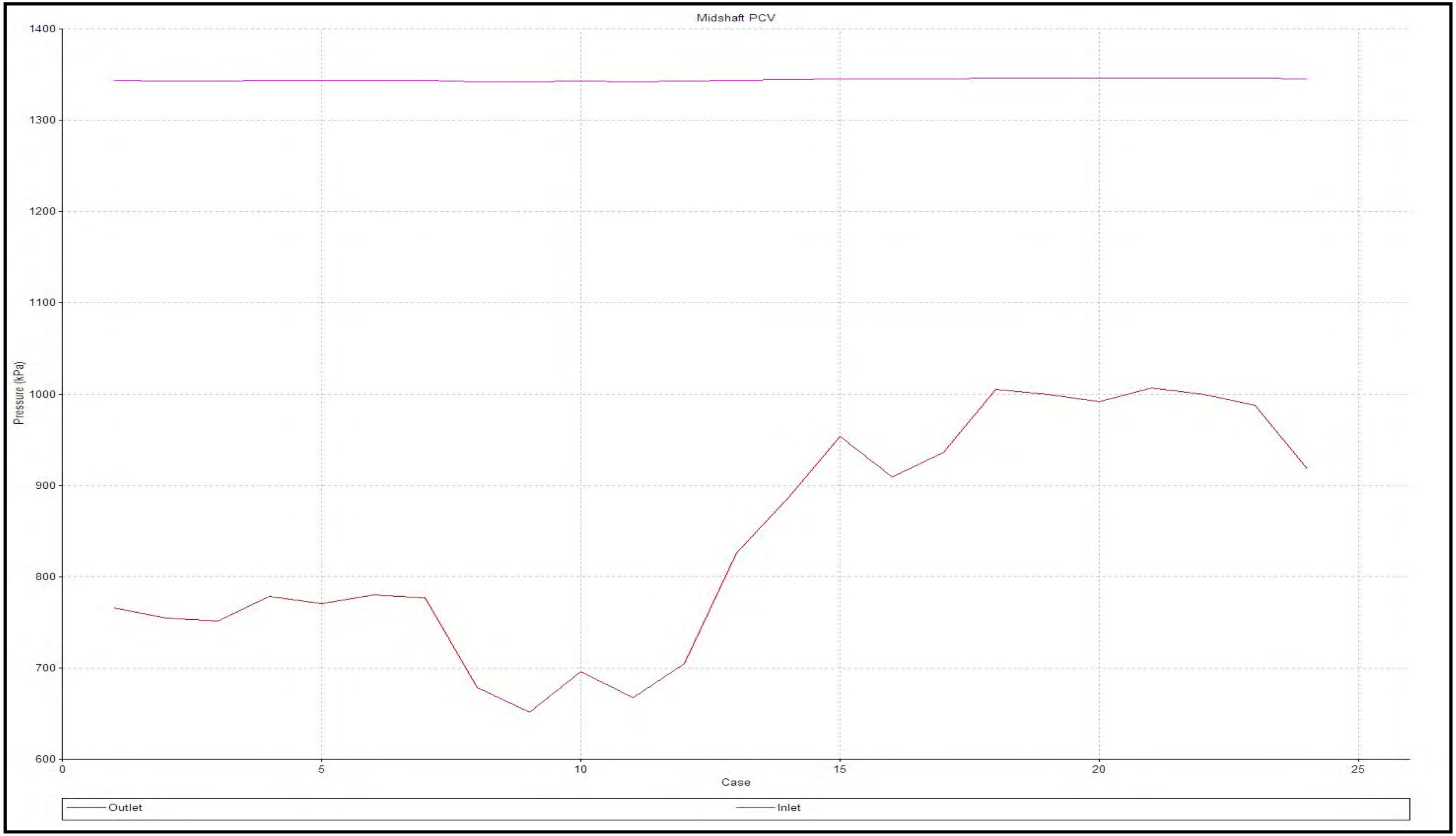


Figure C-9: Graph of the mid-shaft parallel valve pressure (kPa) as a function of flow input

FLOWSERVE

Detail Information
Prepared By :
Flowserve Corporation
Springville Utah

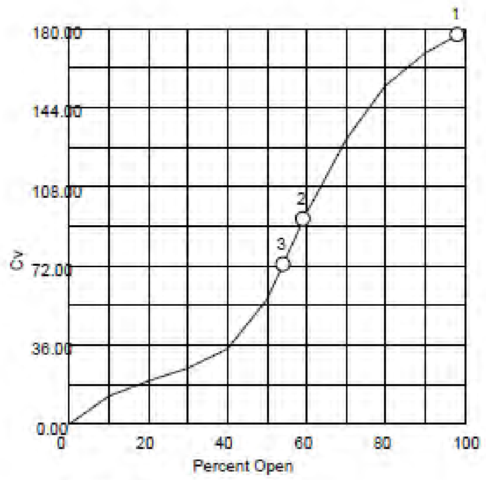
Customer : Iritron
PO # :
Serial # : .001
Rev/By : 0.0/hduplessis
Application :

Project : latest Info
Proj Num :
Contract # :
Alternate :

Valve Tag # : Level 37
Page # : 1
P&ID :
Line :
Date / Ver : 2011-01-19 /10.0.1.6250

4.00 in (Trim : 3.50 Cv:179) CL300 Mark One Standard Globe

		Cond 1	Cond 2	Cond 3							
Process Data											
Temp	(°C)	20.000	20.000	20.000	---	---	---	---	---	---	---
P1	(bar (g))	28.000	28.000	28.000	---	---	---	---	---	---	---
P2	(bar (g))	27.500	22.200	21.700	---	---	---	---	---	---	---
Liq Flow	(l/s (std))	28.500	53.200	43.500	---	---	---	---	---	---	---
Gas Flow	(1000 Nm³/h)	----	----	----	---	---	---	---	---	---	---
Visc	(cSt)	0.000	0.000	0.000	---	---	---	---	---	---	---
VP	(bar (g))	-0.991	-0.991	-0.991	---	---	---	---	---	---	---
DP	(bar (g))	0.500	5.800	6.300	---	---	---	---	---	---	---
DpC	(bar (g))	20.299	22.902	19.800	---	---	---	---	---	---	---
Vel	(m/s)	3.517	6.566	5.369	---	---	---	---	---	---	---
Noise	(dBA)	< 70.0	< 70.0	< 70.0	---	---	---	---	---	---	---
Flow Cap	(Cv)	177.218	93.414	72.838	---	---	---	---	---	---	---
Stroke	(Percent)	98	59	54	---	---	---	---	---	---	---
Info		---	---	---	---	---	---	---	---	---	---
Detailed Miscellaneous Information											
FP		0.947	0.984	0.990	---	---	---	---	---	---	---
FL		0.837	0.889	0.826	---	---	---	---	---	---	---
FR		1.000	1.000	1.000	---	---	---	---	---	---	---
Sg		1.000	1.000	1.000	---	---	---	---	---	---	---
K		---	---	---	---	---	---	---	---	---	---
Xt		---	---	---	---	---	---	---	---	---	---
Z		---	---	---	---	---	---	---	---	---	---
FD		0.990	0.561	0.503	---	---	---	---	---	---	---
MWT		---	---	---	---	---	---	---	---	---	---
Detailed Cavitation (Sigma) Information											
Sigma		57.982	4.998	4.602	---	---	---	---	---	---	---
Sigma MR		2.091	1.943	1.998	---	---	---	---	---	---	---
PSE		1.171	1.171	1.171	---	---	---	---	---	---	---
SSE		1.036	1.031	1.029	---	---	---	---	---	---	---
Sigma V		2.156	2.117	2.201	---	---	---	---	---	---	---
Sigma P		2.366	2.174	2.237	---	---	---	---	---	---	---



Flow Direction : Flow Over
Trim Characteristic : Equal Percent
Trim Type : Unbalanced
Retainer : Standard

DB rev - 967 : 2011-02-28

Fluid: Water
Type: : Full   State: : Liquid
Owner: Perform   Fluid List : Standard
Vp Equation : Antoine

Critical Pressure (PSIA) : 3208.200000
Critical Temperature (°R) : 1165.100000
Reference Specific Gravity : 1.000000
Molecular Weight : 18.020000
Specific Heat Ratio : 1.330000
ReferenceTemperature (°R) : 527.400000
Vp-A : 14.357900   Vp-B : 6869.520000
Vp-C : -83.030000
Minimum Temperature (°R) : 495.000000
Maximum Temperature (°R) : 1164.600000
Bulk Modulas (lbf/in²) : 340000.000000

Detailed Actuator Information

Electric Actuator   Actuator : 100   Spring : Standard
Seatload Required(Class IV)   9 Kg/Cm (2445 N)
Actual : 159.31 Kg/Cm   Failed : 69.61 Kg/Cm

Units of the grid are : N

Fluid + Friction	Throttling Stiffness	Open to 30%	30% to Close and Shut Off	Off Seat and Close to 30%	30% to Open
Cond 1	310	2034	1724	-1246	-1556
Cond 2	3599	2034	-1565	2043	-1556
Cond 3	3909	2034	-1875	2353	-1556
Cond 4	---	---	---	---	---
Shutoff	---	---	-15341	15818	---
P1=P2=0	239	239	239	239	239
Act+Spr	11056	29200	28199	19376	17041
Act-1+Spr	5488	13673	13125	10464	9188
Spring	---	4684	3683	---	---
Spring-1	---	---	---	---	---

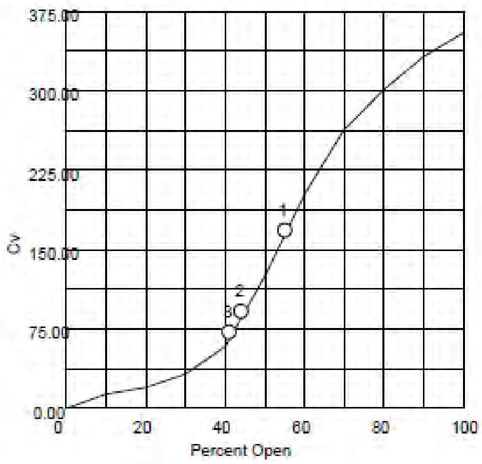
Figure C-10: Datasheet of a valve calculation values for Cv = 179

FLOWSERVE

Detail Information	Customer : Iritron	Project : latest Info	Valve Tag # : Level 37
Prepared By :	PO # :	Proj Num :	Page # : 2
Flowserve Corporation	Serial # : 002	Contract # :	P&ID :
Springville Utah	Rev/By : 0.0/hduplessis	Alternate :	Line :
	Application :		Date / Ver : 2011-03-01 /10.0.1.6250

6.00 in (Trim : 5.00 Cv:355) CL300 Mark One Standard Globe

		Cond 1	Cond 2	Cond 3							
Process Data											
Temp	(°C)	20.000	20.000	20.000	---	---	---	---	---	---	---
P1	(bar (g))	28.000	28.000	28.000	---	---	---	---	---	---	---
P2	(bar (g))	27.500	22.200	21.700	---	---	---	---	---	---	---
Liq Flow	(l/s (std))	28.500	53.200	43.500	---	---	---	---	---	---	---
Gas Flow	(1000 Nm³/h)	----	----	----	---	---	---	---	---	---	---
Visc	(cSt)	0.000	0.000	0.000	---	---	---	---	---	---	---
VP	(bar (g))	-0.991	-0.991	-0.991	---	---	---	---	---	---	---
DP	(bar (g))	0.500	5.800	6.300	---	---	---	---	---	---	---
DpC	(bar (g))	22.192	11.330	9.028	---	---	---	---	---	---	---
Vel	(m/s)	1.563	2.918	2.386	---	---	---	---	---	---	---
Noise	(dBA)	< 70.0	< 70.0	< 70.0	---	---	---	---	---	---	---
Flow Cap	(Cv)	168.343	92.040	72.181	---	---	---	---	---	---	---
Stroke	(Percent)	55	44	41	---	---	---	---	---	---	---
Info		---	---	---	---	---	---	---	---	---	---
Detailed Miscellaneous Information											
FP		0.997	0.999	0.999	---	---	---	---	---	---	---
FL		0.875	0.625	0.558	---	---	---	---	---	---	---
FR		1.000	1.000	1.000	---	---	---	---	---	---	---
Sg		1.000	1.000	1.000	---	---	---	---	---	---	---
K		---	---	---	---	---	---	---	---	---	---
Xt		---	---	---	---	---	---	---	---	---	---
Z		---	---	---	---	---	---	---	---	---	---
FD		0.537	0.359	0.303	---	---	---	---	---	---	---
MWT		---	---	---	---	---	---	---	---	---	---
Detailed Cavitation (Sigma) Information											
Sigma		57.982	4.998	4.602	---	---	---	---	---	---	---
Sigma MR		1.992	2.252	2.365	---	---	---	---	---	---	---
PSE		1.171	1.171	1.171	---	---	---	---	---	---	---
SSE		1.072	1.061	1.058	---	---	---	---	---	---	---
Sigma V		2.315	2.624	2.756	---	---	---	---	---	---	---
Sigma P		2.329	2.628	2.759	---	---	---	---	---	---	---



Flow Direction : Flow Over
Trim Characteristic : Equal Percent
Trim Type : Unbalanced
Retainer : Standard

DB rev - 967 : 2011-02-28

Fluid: Water
Type: : Full   State: : Liquid
Owner: Perform   Fluid List : Standard
Vp Equation : Antoine

Critical Pressure (PSIA) : 3208.200000
Critical Temperature (°R) : 1165.100000
Reference Specific Gravity : 1.000000
Molecular Weight : 18.020000
Specific Heat Ratio : 1.330000
ReferenceTemperature (°R) : 527.400000
Vp-A : 14.357900   Vp-B : 6869.520000
Vp-C : -83.030000
Minimum Temperature (°R) : 495.000000
Maximum Temperature (°R) : 1164.600000
Bulk Modulas (lbf/in²) : 340000.000000

Detailed Actuator Information

Electric Actuator   Actuator : 100   Spring : Standard
Seatload Required(Class IV)   13 Kg/Cm (5240 N)
Actual : 159.31 Kg/Cm   Failed : 69.61 Kg/Cm

Units of the grid are : N

Fluid + Friction	Throttling Stiffness	Open to 30%	30% to Close and Shut Off	Off Seat	Close to 30%
Cond 1	633	6037	5404	---	-4676
Cond 2	7345	6037	-1308	---	2036
Cond 3	7978	6037	-1941	---	2669
Cond 4	---	---	---	---	---
Shutoff	---	---	-29421	30149	---
P1=P2=0	364	364	364	364	364
Act+Spr	11056	29200	28199	19376	17041
Act-1+Spr	5488	13673	13125	10464	9188
Spring	---	4684	3683	---	---
Spring-1	---	---	---	---	---

Figure C-11: Datasheet of valve calculation values for Cv = 355