A strategy for potable water conservation in gold mines

SR Ngwaku

orcid.org/ 0000-0002-3226-6941

Dissertation accepted in fulfilment of the requirements for the degree *Master of Engineering in Development and Management Engineering* at the North-West University

Supervisor: Dr J Vosloo

Graduation: May 2020

Student number: 31557163

ABSTRACT

Title: A strategy for potable water conservation in gold mines

Author: Sheila Refilwe Ngwaku

Promoter: Dr JC Vosloo

Keywords Mine water, water consumption, conservation, benchmarking, potable water, intensity.

Water is a valuable resource in South African communities as well as industries. Mining operations require water for a variety of applications. The mismanagement of water results not only in the industry losing revenue but also in depleting South Africa's water resources. Mines make use of large quantities of both potable and non-potable water. Potable water is good quality water and a shared resource between communities and industries. Correct implementation and improvement of present mine water management strategies can reduce potable water usage in gold mines.

Mining operations have used several methodologies to improve potable water conservation. However, these methodologies focus on installing water treatment plants instead of water conservation practices, and even though this strategy to reduce the reliance on potable water from external sources has been proven to work, it is expensive and requires intensive maintenance. The installation of water treatment plants does not address the root cause of the high potable water usage in the mining industry. Improved water conservation practices can, therefore, postpone the need for investments towards water treatment facilities.

Literature shows that water conservation strategies require an integrated approach to saving water which includes the development of water balances, reporting water use, monitoring equipment conditions and recycling used mine water. Most literature focuses on recycling water; however, this is not the only solution to water conservation. Benchmarking operations and systems visually enables mine managers to realise water misuse and thus save water within the system effectively and efficiently. This will assist mines to identify segments in the mine that require more attention regarding water management and conservation.

Mines are traditionally benchmarked based on the mineral mined i.e. gold, platinum, copper, and others. This is because potable water needs for gold mines are different from those of platinum mines. The amount of mineral processed or mined is not the only variable that affects water use. A variety of factors influence potable water consumption. In this study variables for benchmarking potable water use are evaluated and used to set suitable benchmarks. Benchmarking introduces the need for intensive data management. Understanding the management of mining water is data-driven due to the vast amount of measurements required.

A holistic strategy that creates system performance awareness in terms of comparative water consumption was required. A strategy that efficiently identifies key failing systems in gold mines was needed. The scope of this study is limited to gold mines, and a strategy that isolates business units within gold mines was developed. Data was collected for all relevant operations, verified, and normalised by identification of variables to establish suitable benchmarks. These benchmarks assisted in identifying water savings opportunities. These opportunities led to the implementation of correct conservation measures for specific business units.

Eighteen mining operations were evaluated. The benchmarking methodology identified three key failing facilities that required further investigation into their water usage. These were the least performing operations. Water balances were developed to better understand the systems, various equipment was monitored and resulted in the identification of several leakages within the systems. A total water saving of approximately R17.7 million per annum was achieved and approximately 1 358 million litres of potable water was conserved per annum. The savings achieved are enough to provide more than 11 000 people in South African communities with water per day.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my Lord and saviour Jesus Christ for granting me favour, the knowledge and strength to complete this research study. For from Him and Through Him and to Him are all things. To God be the glory forever! Amen.

I would like to express my deepest gratitude to the following people:

- To my sister Relebogile Ngwaku, my mother and beautiful nieces, thank you for your continued support, your prayers and patience. This study would not have been possible without your loving support.
- To my loving partner Patrick Kadima, Thank you very much for your support and encouragement throughout the duration of my study. Thank you for standing with me in difficult times. My heartfelt thanks to you.
- To my friends Lesego Makaleng and Sibusiso Khoza, Thank you very much for the moral and technical support. You are highly appreciated.
- A special thank you to my academic mentors Mrs Maryke Janse van Rensburg and Dr Jean van Laar. Words cannot to express my gratitude for your continuous advice and guidance during my study period. Your valuable inputs and efforts to perfect this document were highly appreciated.
- Thank you to my colleagues Imar Schuin and Gert Abraham Herbest for conducting water audits in the mines and providing me with all the data I requested, without you, it would have been impossible to achieve savings in this study. Your assistance was highly appreciated.
- Thank you to Prof E. H Mathews for granting me this opportunity and supplying all resources needed to see this study through to completion. I am truly grateful.
- I would like to thank ETA Operations (PTY) Ltd and CRCED Pretoria for the financial support to complete this study.
- Thank you to my proof-reader Ms Pippa Marias.
- Thank you to my study leader Dr Jan Vosloo for guidance.

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LIST OF ABBREVIATIONS

AMD – Acid mine drainage

BPG – Best practice guidelines

CDP – Carbon disclosure project

COLS – Corrected Ordinary Least of Squares

DWS – Department of Water and Sanitation

GDP – Gross domestic product

ICMM – International Council on Mining Metals

IWRM – Integrated Water Resource Management

KPI – Key Performance Indicators

NEMA – National Environmental Management Act

NWA – Nation Water Act

OLS – Ordinary Least of Square

SCADA – Supervisory Control and Data Acquisition

TSI – Total Specific Intensity

VRT – Virgin rock temperature

WC/WDM – Water Conservation/ Water Demand Management

WCM – Water conservation management

WFN – Water footprint network

WRP - Water and Reclamation Plan

WSA – Water Service Act

WTP – Water Treatment Plant

WUL – Water use licence

ZLD – Zero liquid discharge

LIST OF TERMS

Benchmarks – A measure of performance against which other performance levels can be compared.

Intensity – Water consumed per unit of economic activity.

Non-potable water – Low quality untreated water from surface water resources or boreholes.

Potable water – High quality water that can be used for human consumption.

1 INTRODUCTION

1.1 WATER SCARCITY IN SOUTH AFRICA

South Africa is a semi-arid country with an average annual rainfall of only 500 mm per year [1]. This figure is well underneath the world average precipitation of 860 mm annually. The availability of water is becoming increasingly constrained in many South African areas; this is due to variables such as economic development and population growth. Water is a key natural resource and these constrains bring about a variety of concerns to all water consumers[2].

Water resource management emerges as one of the most noteworthy worldwide challenges of the 21st century [1], [3]. Based on the current situation of water, South Africa will experience a water deficit by 2030 [4]. Water demand will therefore exceed water supply. Increased industrialisation and urbanisation of South Africa's population continues to place a strain on South Africa's water supply.

Water plays a crucial role in South Africa's commercial sectors. All sectors directly or indirectly need water to function appropriately. As seen from Figure 1.1 below, there are three major sectors driving water demand in South Africa: the agriculture sector which is the most noteworthy at 63%, followed by the municipal sector at 26% and the industrial sector at 11%. The demand of water by these sectors is expected to increase by 1% annually until 2030 [4].

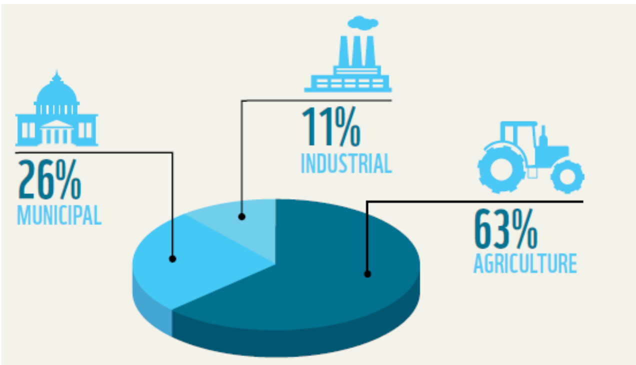

Figure 1.1: Drivers for increasing water demand in South Africa [4]

South Africa is known for its plenitude of mineral resources. South Africa has the world's fifth largest mining sector in terms of gross domestic product (GDP) [5]. In 2017, the mining industry contributed about 6.8% of total South African GDP in real terms, providing employment to 464 667 individuals [6]. This is an indication that the mining industry plays an important role in contributing to South African economy.

Despite the substantial contribution to the economy, water resources are at risk of being over exploited, in turn potentially resulting in negative impacts on the economy and ecology. The mining industry is a major contributor to the decline in water quality in many regions in South Africa [7]. Unless corrective measures are taken, the mining industry is expected to continue placing pressure on South Africa's scarce water resources.

The mining industry consumes only 5% of South Africa's total water [7], as shown in Figure 1.2. This percentage is a relatively small amount compared to other sectors, however, when mining takes place in water rare regions it can harshly impact local potable water supplies [8]. The water used by the mining sector is supplied either by the Department of Water and Sanitation (DWS) or by other water service providers.

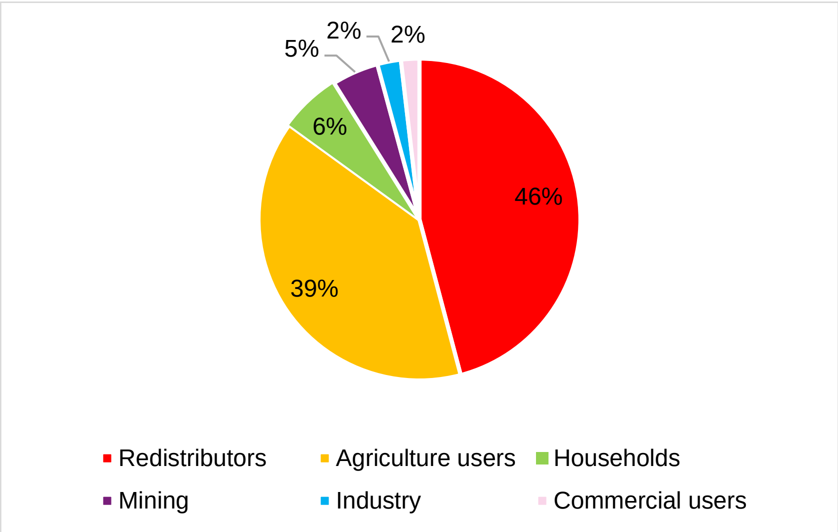

Figure 1.2: Water consumption distribution in South Africa's industries [10].

Existing South African ore reserves are continuously declining as they are being explored and extracted [11]. For mines to continue running, mining companies are forced to expand their operations to water-scarce regions. In water-scarce regions, mines are placing more pressure on already stressed water resources and the communities which depend on them. Figure 1.3 shows regions in South Africa that are water-scarce, as well as the locations of existing mines.

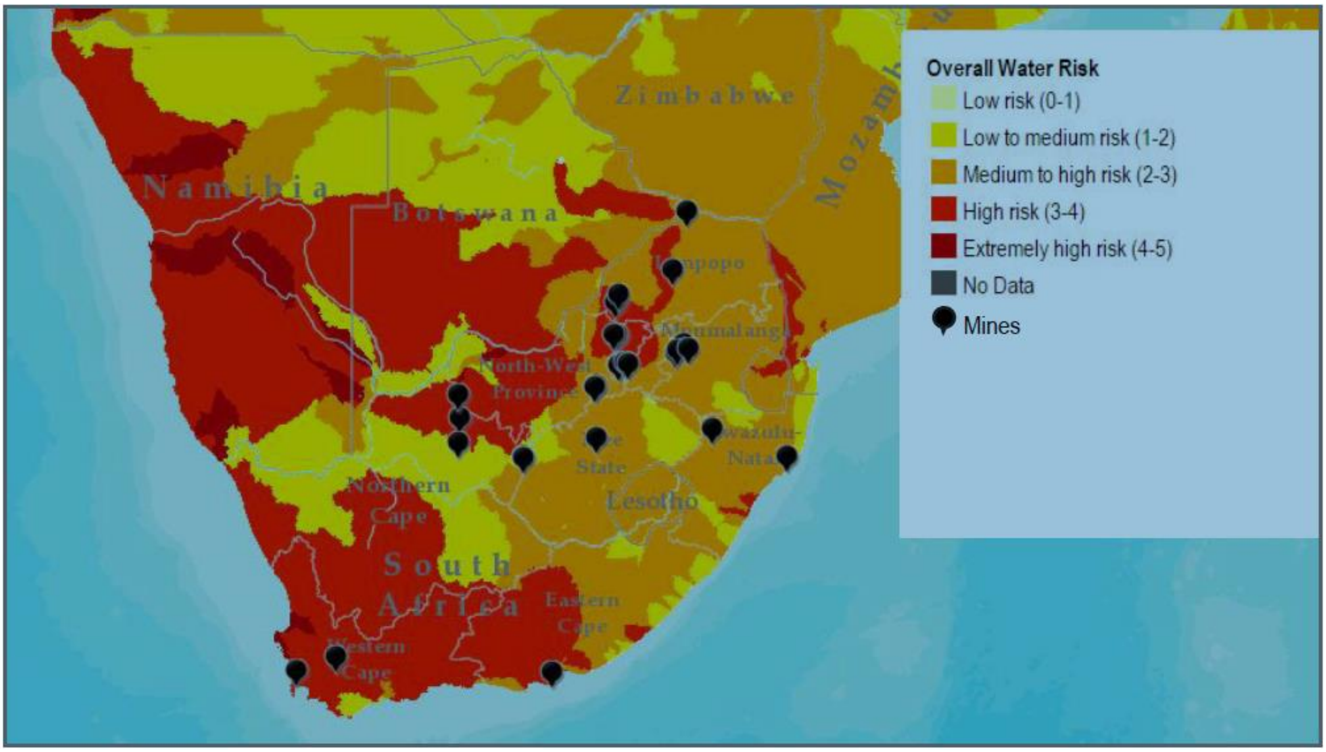

Figure 1.3: South African mines and water risk areas [12].

Many concerns across the mining industry have been raised because of the variability of water availability in South Africa [13]. As indicated in Figure 1.3, there is a high fraction of mines located in zones with medium to high water risks.

Water availability is highly reliant on the geographical location. Concerns with respect to water resources vary with climatic, hydrologic and hydrogeological variables [14]. Because of this spatial variability, the potential impacts due to mining will be different from region to region. Currently mines are developed in isolated locations where small to no water infrastructure exists [14].

Other water risks associated with mines include drought and flood occurrence as well as constrained access to water in these areas. To counteract these water risks, mining companies have incorporated recycling methods and multiple water abstraction methods. Although the bulk of water abstracted is from ground and surface water, alternative sources include, among others, potable water from district water bodies or municipalities, wastewater, or treated mine water[12].

The type of water utilised in the mining industry varies between users based on the type of mineral being mined, whether the operation is open-pit or underground. Hence the water consumption characteristics of an underground gold mine can differ significantly from that of an underground platinum or copper mine. The five main types of water used in the mining sector are [15]:

1. Potable water, which is water of good quality that is appropriate for human consumption, it is normally obtained from a water service provider or produced on site.
2. Raw water obtained from surface water on the site, or from a nearby surface water resource such as a river or dam or water supply scheme.
3. Underground water or groundwater from boreholes.
4. Process water produced from on-site activities such as water treatment plants.
5. Stormwater or rainwater collected on-site.

The bulk of the water abstracted by the mine should be non-potable water since most of the use-cases on mines do not require high quality water fit for human consumption [2], [16]. However, it is at times impossible for mining operations to use lower quality water to meet site consumption water demand if no lower quality water is locally available [16]. Figure 1.4 is an indication of water abstractions by a gold mine in South Africa. From this figure, it is clear that potable water is the major source for mines' primary activities.

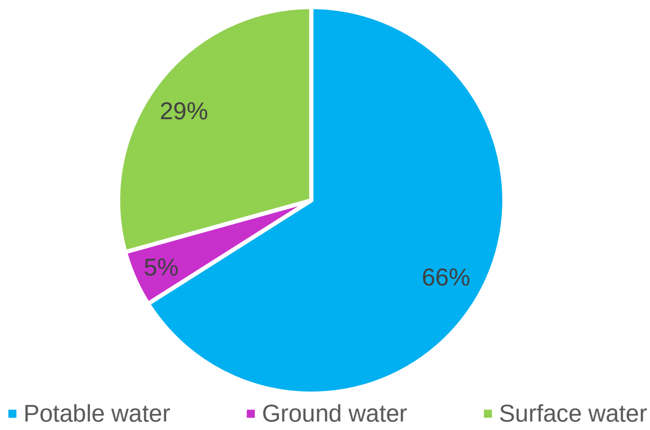

Figure 1.4: Water distribution for 18 gold mining operations [17].

A review of integrated annual reports of South African gold mining companies was conducted. It was found that only one mining company in South Africa reports its total water withdrawn by source categories. Integrated annual reports of other mining companies only report on total water withdrawn in a given year. This makes it difficult to establish the portion of potable water utilised by South African mines. Some of the integrated reports that were reviewed for different companies are in APPENDIX A. The important values are highlighted in red.

Historical references of water use for purposes of mining indicate that water has been alleged to be of low financial value [14].This has resulted in large volumes of water being purchased without management . [1]. The low cost of water per kilolitre plays a significant role in water mismanagement and overutilisation [18]. Table 1.1 gives water and electricity tariffs for different water boards and district municipalities.

Table 1.1: Municipality water tariffs [19].

Water board	Bulk water tariff (R/kL) 2018/2019	Electricity tariffs (c/kwh) 2018/2019
Sedibeng Water	5.66	160.44
Rand Water	6.1	163.34
Merafong Water	18.9	94.82

Table 1.1 indicates that the price of water and electricity varies greatly with location of the municipality. South Africa is a water-scarce country, and as such mines have a responsibility to ensure efficient water use [16]. Not only does potable water usage contribute to mining operational expenses, but it is also a shared resource between communities, industries and the ecology. Most mining operations do not require high-quality potable water and can therefore use water of lower quality. Potable water intake therefore can be reduced [16].

1.2 POTABLE WATER USAGE IN GOLD MINES

1.2.1 PREAMBLE

Mining processes rely heavily on water [13]. Water consumption in hard rock mines is ± 2 to 4 kilolitres per tonnes of rock milled, and is typically used in the following operations and activities [20]:

- Cooling of apparatus: Rock drills, diesel powered machines and drill steel.
- Dust control: All machinery must be sprayed with water to alleviate dust. Ore blasted is watered down before it is removed to avoid dust formation.
- Removal of heat in the surrounding environment.
- Water is used for transportation of material.
- Power source: water used in hydro-powered rock equipment.
- Employee amenity areas.
- Water for gold processing (elution and beneficiation processes).

The use-cases listed above can either be low-quality water or potable water. The mining activities that rely on potable water are listed below.

1.2.2 EMPLOYEE AMENITIES

Mine employees in offices, change houses, and hostels require water for drinking and sanitation. Potable water uses in these facilities vary from use in food preparations in mine canteens, to cleaning inside buildings as well as garden irrigation and recreational uses such as swimming pools [15].

Since mines are located in remote areas, mines often supply potable water to local businesses around the mines. These are third parties to the mine. Third parties pay the mine for water supplied. The water supplied to external third-parties is not used directly by the mine and is therefore subtracted from the total potable water used by the mine [21].

1.2.3 PROCESSING PLANTS

This is the section of the mine in which the mineral is separated from its ore [15]. Processing plants mainly receive their water from return water dams from the tailing's facilities. The processing plant mainly requires potable water within the elusion process because the water used must be of a certain pH and should be deionised [22]. Potable water is also used when insufficient water is recycled from the return water dams.

1.2.4 MINING AREA

Gold can be mined through surface or underground operations[23]. This study mainly focuses on underground mines because over 95% of gold generation in South Africa comes from underground mining [24]. Water is used for extraction activities such as drilling, crushing of ore, conveyance, cooling of equipment and drinking.

In underground gold mining operations, most potable water is used as make-up water [25],drinking water and sanitation. When underground mining takes place, water needs to be removed from underground to reach the ore body or to prevent the mine from flooding. This process is known as dewatering. The dewatering system is a vital and exceptionally complicated system that should be efficiently managed [25]. Dewatered water is predominantly utilised for cooling underground. In occurrences where the volume of water diminishes, it is replaced by an addition of potable water from the municipal water board. The potable water received is termed make-up water.

The dewatering system supplies hot water from underground to several fridge plants and surface cooling towers [26]. Not all underground mines make use of refrigeration plants [27]. Where these refrigeration plants are used, however, water is pumped into an upper level dam from a lower station. The process continues until a point where water reaches the surface or is reused as surface water. On surface, water is sent to fridge plants to be cooled.

1.3 DRIVERS OF POTABLE WATER MANAGEMENT

1.3.1 PREAMBLE

The importance of water management and conservation was generally not regarded as a critical issue due to its low-cost implications, see Table 1.1. Threats of increased water scarcity have started raising concerns for water conservation. Water conservation is a key national priority [28]. Water experts have started warning the mining industry about possible water shortages and the need for sustainable water management. In South Africa, key indicators that have begun raising the importance of potable water management in the mineral sector are discussed in the sections that follow.

1.3.2 CORPORATE RESPONSIBILITY

Companies are becoming increasingly transparent about the economic, environmental and social impact caused by their daily operations [29]. This is termed sustainability reporting. In these reports, companies are required to disclose their total water withdrawn: this includes both potable and non-potable water [21]. Sustainability reports represent a company's commitment to a sustainable economy [30]. Companies publish integrated reports annually. Sustainability reporting is increasingly becoming a very important part of these reports. The integrated reports combine both financial and non-financial parameters [29], [31].

Sustainability reports ensure that companies consider their impacts on sustainability. The reports are viewed by both customers and stakeholders [30]. This form of transparency builds trust between companies and stakeholders. Due to these reports, companies are under pressure to do risk managements and continuously show improvements in efficiency through their Key Performance Indicators (KPIs). Potable water usage is one of these KPIs, highlighting the importance of effective water management.

1.3.3 ACID MINE DRAINAGE

South Africa has close to 6 000 abandoned mines as stated by the United Nations Environmental Programme [32].Unrestrained acid mine drainage (AMD) is caused by many of these mines [32]. The water flows into the rivers and springs which are used by residents and farmers. AMD is accountable for expensive environmental and socio-economic impacts. The latter results in water management moving up the value chain; for this reason a strategy for pricing water use charges was implemented [33]. With this strategy, mines could be required to pay an additional amount of money to address AMD [34].

1.3.4 LEGISLATION

Constitutionally, there are two fundamental acts that provide governance for the management of water resources in South Africa: The National Water Act (NWA, Act No. 36 of 1998) and the Water Service Act (WSA, Act No. 108 of 1997). The Acts provide the legislative framework for the management of overall water use, water resource management and water and sanitation in South Africa. Both of these acts fall under the boundary of the DWS regulated by the Minister of Water and Sanitation [35].

In addition to the Acts mentioned above, there are several associated frameworks that aid in defining the legislative frameworks. In South Africa, the National Water Resource Strategy 2 (NWRS2) was designed as a document to improve and guide governance in water management and sustainability [36]. Moreover, the NWRS2 addresses various needs, by setting out plans to ensure that there is equitable access to water for all South Africans while sustaining water resources.

The DWS's legislature helps ensure that the country's water resources are conserved, developed, utilised, managed, protected and controlled. For this reason, the NWA has set out general principles for regulating water use in section 21 of the Act [37]. This section lists all water use activities which require a Water Use Licence (WUL); this list clearly states that water that is discharged must be properly monitored for the WUL to be issued and encourages operations to recycle as far as possible. Any operation that fails to comply with the principles and regulations is liable for an offence and at a risk of a monetary fine or detainment [38].

The DWS has developed a National Water Conservation/Water Demand Management (WC/WDM) Strategy. WC/WDM is a crucial step in advancing the efficient use of water and requires organisations to develop and submit water conservation plans as part of their water use applications. Water use applications for individual operations should outline the degree to which water will be efficiently used. The monitoring and enforcement of the implementation of WC/WDM will receive specific attention. Mines are therefore under pressure to continuously improve their water usage in order to maintain their WUL [39], [40].

1.3.5 Operational costs

Gold mining is a major contributor to South Africa's economy. The country has reasonable advantage in terms of gold resources, but there are challenges that prevent South Africa from turning this advantage into a competitive advantage [24]. Some of these challenges are the decline in gold price, declining grades of gold deposits, and global financial crisis [24]. With the declining gold prices and ore grade comes increased costs and other constraints to productivity. The lower the ore grade, the greater the usage of water, electricity, reagents and other consumables [24].

Other challenges that contribute to the increase in operational costs include labour issues as well as increasing electricity tariffs. Employee strikes cause reduced productivity, which directly affects gold production [41]. The continuous increase in electricity prices is one of the major contributors to an increase in operational costs. These factors force operations to be more cautious of their commodity usage, since they are cost dependent.

1.4 Existing potable water conservation strategies

1.4.1 Preamble

The effective management of water is required in the gold mining industry, to overcome this, the mining sector and the DWS have made major efforts in creating standards to meet the requirement [42], [43]. The departments have adopted a series of Best Practice Guidelines (BPGs) on water management strategies, methodologies and instruments [42], [43]. These guidelines are aimed at ensuring potable water sustainability. Water rights have been legislated by the NWA. The NWA is the main framework for water management, as mentioned in section 1.3.4.

1.4.2 Water management

To enable improved and effective water management, the Integrated Water Resource Management (IWRM) method was introduced by the NWA. The method comprised of all aspects of water resources [44]. The concept of IWRM provides for both resource directed and source directed measures [45]. The aim of the resource directed measures is to manage and protect water resources and ensure sustainable utilisation, while the aim of source directed measures is to control the effects on the source through the prevention of water pollution.

The DWS has adopted a series of BPG for mines that are in line with international standards and concepts towards sustainable development. The guidelines are grouped by alphabets A, G and H [23]. BPGs in line with water management and conservation are prefaced with letter H, while those in line with general water management are prefaced G and those dealing with specific mining activities are prefaced by the letter A

The above-listed guidelines should be used by the mining industry as input for applying for water licences and other documents required by the Environmental Management Programs, Environmental impact assessment, closure plans, etc [39] . They should also serve as uniform basis for water management licensing process negotiations. These may also be used for prevention of penalties associated with water mismanagement.

1.4.3 WATER CONSERVATION

As a result of the high consumption of water in the mineral processing industry, the DWS requires mines to submit water conservation plans [39]. The NWA (Act 36 of 1998) accentuates the efficient management of water in South Africa through principles of IWRM [37]. The principles stipulated by the government seek to achieve equity, economic efficiency and ecosystem sustainability.

The National Environmental Management Act (NEMA) provides guiding legislation for environmental management in South Africa [46]. NEMA also describes a set of guiding principles leading the actions of the government that may influence the environment significantly. The principles need to be considered in all scopes of water management, including those related to water conservation.

The DWS has a role to promote, guide and assist with WC/WDM practices within the country [47]. As part of fulfilling this role, the directorate of water use efficiency has initiated the development of guidelines for WC/WDM for the mining sector in South Africa. The aim of the guideline is to assist the mining sector with the application of water conservation measures. The guidelines result in the compilation of the Water Conservation Plan [39].

According to the DWS, the BPGs should always be referred to when implementing potable WC/WDM. The relevant BPGs which support WC/WDM are listed in Table 1.2 below.

Table 1.2: BPG applicable for water conservation [39].

WC/WDM Phase	**Applicable BPG**
Phase 1: Assessment	BPG H2: Prevention of Pollution and impact minimisation.
	BPG G2: Salt and water Balance.
	BPG G3: Systems for monitoring water.
Phase 2: Planning	BPG H3: Water reclamation and reuse.
	BPG H4: Treatment of water.
Phase 3: Implement and manage	BPG G3: System monitoring.
	BPG H1: An integrated water management for mine water.

From Table 1.2, the measures that should be applied for water conservation according to DWS are further defined [39]. The three phases serve as a guideline for water conservation. Only BPGs that are related to the scope of this study will be used. Phase 1 and Phase 2 have guidelines that are most relevant to this study and are thus discussed in detail in the next section.

The BPGs cover a range of topics that can assist mining industries develop water management plans. These guidelines are for all water types, rainwater, surface water, groundwater and potable water. This study only focuses on potable water and will therefore make use of a few guidelines from the list. Guidelines that are applicable for potable water conservation in gold mines will be discussed thoroughly in the next section.

i. Water treatment (BPG H4, H2, H3)

Pollution prevention and minimisation of impacts (H2), water reuse and reclamation (H3), and water treatment (H4) fall under the same bracket and will be grouped together in this study. The output of all measures is water reuse and recycling. Mines require a certain degree of water treatment. Mining operations resort to this measure of water conservation because section 21(f) of the NWA states that water should be treated before disposal [37]. This measure is mainly taken to protect water resources [38].

Apart from the need to treat water because of regulations that are set for the water discharged to the environment, water treatment enables the reuse and recycling of water by the mine as documented in the Water and Reclamation Plan (WRP). Water reuse is an important measure that reduces potable water that enters the system. The higher the amount of water recycled and reused in the process the lower the water required from water resources.

Water recycling and reuse has been a widely used method of water conservation. When considering water management, focus must not only be placed on water recycling but should also encompass practical issues, behavioural issues and communication issues to enable a holistic approach in conserving water [48].

Many process industries utilise the principle of zero liquid discharge (ZLD) to maximise water conservation. This is a concept that uses water treatment methodologies to ensure that minimal water is injected in to the system as potable make-up water and no water is discharged [18]. ZLD focuses on waste-water reduction and pollution control; however, to fully conserve water, the volume of water used within the process should be minimised. This will realise full ZLD water minimisation.

A holistic approach to water conservation may delay the requirement of capital for dams and bulk water treatment works infrastructure. An interactive planning process should be used to determine the scope of work, the activities and required resources that must be prioritised for WC/WDM.

ii. Water balances (BPG G2)

Developing a good understanding of the specific mining process is the first step towards reducing water use in gold mines [8]. An accurate water balance should be completed before any attempt is made to save water [49]. This entails the understanding of all the streams in the mine system.

Water accounting is defined as a reporting methodology that quantifies the total volume of water withdrawn by the mine, the consumption of water within the operation, and the water that is discharged [2]. Mine operations have several activities and therefore many water streams; making it challenging to know exactly where a mining operation's water is being consumed. Mines depend on creating water balances to manage water consumption and achieve sustainability.

The most fundamental building block for mine water management is a water balances and salt balances [39]. Salt balances are used for mass conservation while water balances are used for water conservation. The two balances are used together when there is a need to calculate unknown flows [39].Without an accurate water balance, it is impossible to conduct planning, assessment, execution and management of WC/WDM at a mine. Water balances can be used for the following [39]:

1. Auditing water usage from incoming streams.
2. Identification of high consumption and wastage.
3. Identification and quantification of water imbalances.
4. Identify unexpected discharge and leakages.
5. Identify sources of pollution and quantify volumes of polluted water.
6. Simulate and assess different water management strategies for execution.

Balances must be updated regularly and used as a dynamic tool to ensure water use is optimal. The water accounting framework gives definitions for input-output water balance models. From the framework, input water is defined as the total amount of water which is received by the organisation. It includes both potable and non-potable water. Output water is defined as the total amount of water removed from a facility after it has performed all duties. There is also diversion water which is not important for this study. Diversion water flows into the system without being utilised by operational facility. Only important flows that are consumption related should be included in the water balance [50].

iii. Equipment Monitoring (G3)

A well designed and effective monitoring programme is an essential component of the WC/WDM measures in all mines [39]. Any plan to manage water should ensure that all existing facilities are maintained. Botha [51] identified three techniques that may be used to reduce the usage of water in deep-level mines:

- Isolation of mine stopes.
- Pressure control.
- Management of leaks.

In this study, the main focus will be leak detection since the reticulation of water in mines consist of long pipelines transporting water from the surface to the deepest levels in a mine and development areas [51], [52]. The most common problem related to pipes in mines is leaks. This is because these pipes are exposed to extreme conditions. Figure 1.5 depicts most common factors that can be evaluated for leak control.

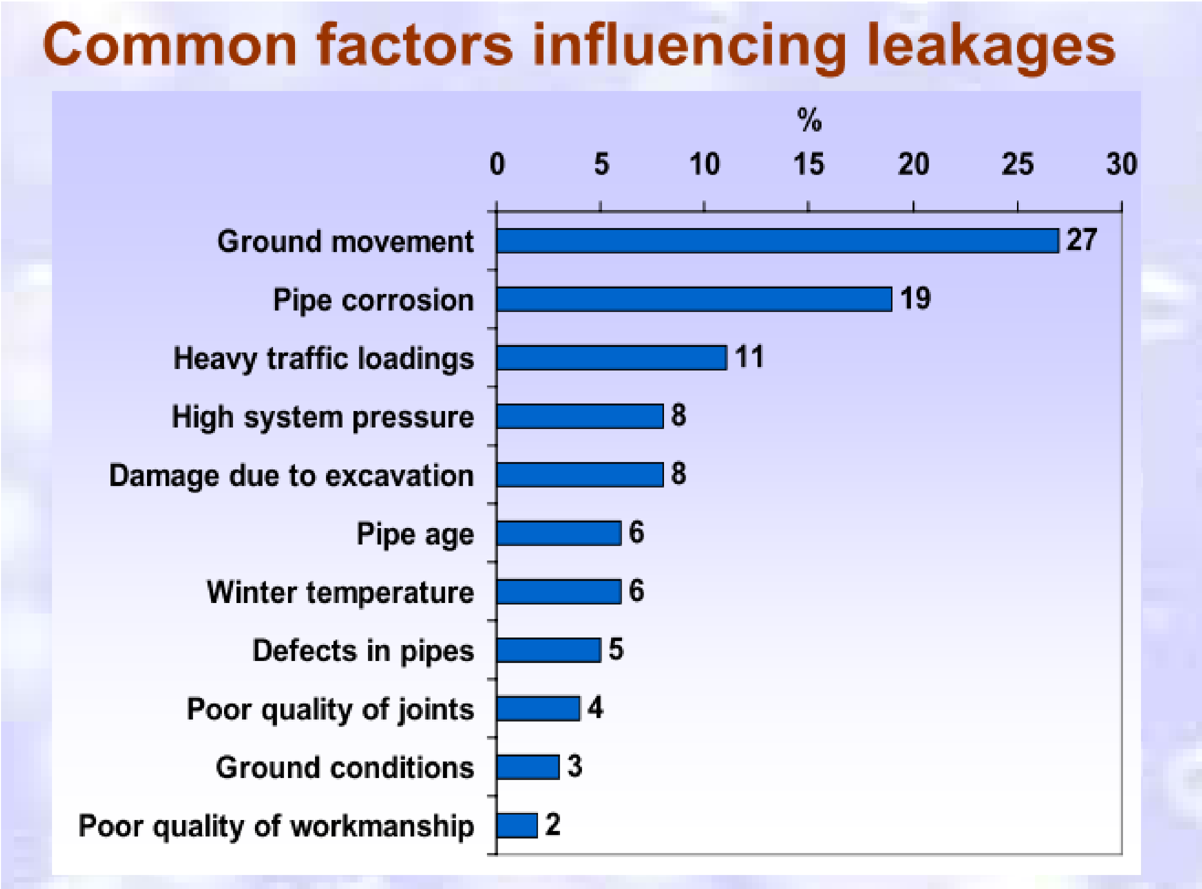

Figure 1.5: Factors influencing pipeline leakages [52].

Large amounts of water can be lost if no monitoring is undertaken. The volume of water lost through a leak is influenced by, amongst other factors, the pressure of water flow. At a high pressure, even the smallest leak may cause large quantities of water loss. Pressure-reducing valves are used to lower the pressure of water underground. 1 000 kPa is the maximum pressure to keep flow underground [51].

1.5 IDENTIFICATION OF POTABLE WATER CONSERVATION OPPORTUNITIES

1.5.1 PREAMBLE

It was previously stated in Section 1.2.4 that mines are unique and have unique operating conditions. Water use depends on many factors [53], [54]. It is important to fully assess an operation before any measure can be applied to save water in a facility. Measures of water conservation have already been discussed in section 1.4.3; knowing the correct measure to follow and when to implement it will save time and cost.

To identify if there is a need for better water management practices in a mine, a way of measuring performance should be identified. There is a call for transparency and disclosure on water use and management from all consumers globally [16]. The mining and metals industry should be at the forefront of water performance transparency and reporting considering their high dependency on water [16].

There has been progress on water reporting and disclosure over the years. Mining operations have started reporting their performance through numerous existing water reporting standards such as CEO Water Mandate, Carbon Disclosure Project (CDP) and the Global Reporting Initiative (GRI) [16]. Although mining companies report on one or more of these, companies are not yet necessarily reducing their water withdrawals [16], [55]. This is because the reports do not consider the industry’s specific material water practices, degree of water use and risks. The reports have limited information/analysis of actual water use data [56].

The reports focus on aspects such as total water withdrawn by source, the sources that are affected by withdrawal, percentage and total amount of water reused and recycled as well as the total water discharged by destination and quality. The reports are mainly for promoting compliance and not precisely water management [56].

The International Council on Mining and Metals (ICMM) is working on providing a more holistic framework for understanding water risks and opportunities for the mining industry. The ICMM has developed a guide to support the industry in making meaningful reports. It has defined a set of standardised water performance metrics to assist the mining industry with better water governance, water management and more transparent water reporting [16]. The performance metrics are tabulated in Table 1.3.

Table 1.3: Water performance metrics [16].

Performance metric	**Definition**
Withdrawal	The amount of water received by the mine operation from the environment or a third-party supplier.
Discharge	The amount of water removed from an operational facility to the environment or third party.
Efficiency	The proportion of water reused and recycled by the site to reduce the overall consumption.
Consumption	A quantity that describes the volume of water utilised by the operation and not returned to the environment or third party.

The metrics should be used to measure performance in the context of sustainable development. The metrics tabulated in Table 1.3 are aligned with the Mineral Council of Australia and the Water Accounting Framework. The strength of the framework is that it allows mines to account for water used [50].

In addition to the performance metrics tabulated in Table 1.3 above, it is recommended that companies calculate a water-intensity metric. The water-intensity metric provides more insight of the water consumed per unit of product [16]. Integrated reports of various mines in South Africa use intensity to measure performance. The aim of each operation is to ensure that intensity decreases annually: this is deemed good performance [57].

1.5.2 BENCHMARKING APPROACH

A key component in evaluating performance and efficient water use management is to establish benchmarks [58]. Performance metrics can be used for benchmarking; however, prior to benchmarking it is vital to note that water use is heavily dependent on site setting and resource type. This study focuses on how to use the water-intensity metrics for benchmarking. Benchmarking is an important step in evaluating usage and comparing it with similar mining operations' characteristics [57], [59].

Benchmarking can be defined as a method of assessing the performance of a system against a reference performance [58]. Firms specialising in system benchmarking have proven that process benchmarking is an efficient way of assessing process improvements and efficiency [57]. A clear understanding of shortcomings or achievements of an operation can be established through comparing its performance against similar operations [57], [58]. Average and frontier benchmarking are two of the most common benchmarking methodologies [60].

The methodology used for benchmarking is dependent on the purpose for benchmarking [57]. Average benchmarking may be used if the aim is to compare average performance of similar cost [61]. Average benchmarking is subdivided into different methods. The Ordinary Least Square (OLS) method is the one that is widely used. OLS is a technique that is regression-based. This function obtained from the OLS methodology can represent any performance indicator i.e. cost or production.

Frontier benchmarking is a form of average benchmarking. In frontier benchmarking, the OLS technique is modified to become Corrected Ordinary Least Square (COLS). COLS is implemented by lowering the regression function found by OLS while maintaining the gradient of the line. This results in a more accurate benchmark . [61] Frontier benchmarking methods also includes linear programming methods such as the Data Envelopment Analysis.

There are two benchmarking methodologies used in the wastewater and water usage sector. The two methods are metric benchmarking and process benchmarking [62]. Metric benchmarking numerically evaluates an organisation's performance. Metric benchmarking usually makes use of performance indicators that identify sections that need improvement (e.g. number of people employed, level of leakages, water supply, etc) [62], [63].

Making use of metric benchmarking to numerically assess performance levels; segments of the operation with an apparent performance gap can be identified [62]. Metric benchmarking requires an understanding of descriptive factors, such as geographical location, physical features, population and atmospheric conditions – all essential to understanding the performance gap. Metric benchmarking includes evaluating data trends against target level of performance. KPIs for metric benchmarking include:

- Supply coverage.
- Water usage and production.
- Water lost before reaching the customer (Non-revenue water).
- Metering all facilities, etc.

Process benchmarking is defined as a method of identifying the exact facilities that need improvement by comparing them against excellent performing facilities [62]. The concept of process benchmarking is widely understood as a methodology to learn best practice. Process benchmarking allows for an organisation to identify key failing processes and compare them to best performing organisations. This benchmarking methodology requires complete transparency with their selected partner companies [62], [64]. Process benchmarking seeks improvement by examining processes that were identified to be weak when compared to partner companies.

Process benchmarking takes in to account all constraints and circumstances that exist within an organisation and investigates measures that are suitable for achieving best practice for a specific section in an organisation. Examples of processes analysed in process benchmarking include the following:

- Domestic waste treatment plants.
- System maintenance.
- Research and development.
- Management of energy, etc.

Both metric benchmarking and process benchmarking indicate that factors affecting water use need to be thoroughly investigated in order to fully assess the performance of an operation through benchmarking. In South Africa, the only report that has documented the determination of water use benchmarks in mines is the benchmarking document released by the DWS [65]. This report categorises mines according to the minerals processed. From the document, it is seen that water used is influenced by the mineral mined i.e. gold, platinum or coal etc. This means that water needs for a gold mine cannot be compared to those of a platinum mine.

Although the benchmarking report [65] provided a thorough overview of water use per unit product being mined, it also states that many factors or variables influence water use. It is therefore important to fully evaluate all sections that use water in gold mines in order to normalise benchmarks. In Section 1.2 of this document, potable water usage was divided into different water use categories. The following Chapters outline the main water uses in the different categories and factors that influence water use in the categories.

1.5.3 Employee amenities

At a mining operation, potable water is generally used for drinking, cooking, bathing and sanitation for employees and contractors [15]. Mines are mostly situated in remote areas out of urban areas; for this reason, mines have the responsibility to install water systems on site. Miners often must travel from far to get to the operations. To avoid transportation cost and late arrivals, the mine provides hostels for its employees with the above water supplies.

Water consumed at offices, change houses and used for irrigation are not metered as often and is generally considered insignificant if leaks do not occur. In this study, the focus is mainly on residential areas occupied by mine employees. There is a high risk of water wastage since employees do not pay for their water consumption and do not need to conserve this resource.

The DWS uses the per capita consumption (litre/capita/day) to benchmark water consumed by South African residents in various municipalities [66]. This benchmark enables them to identify provinces that consume more water per capita. Per capita can be defined as the average water usage by each person of a population. To normalise water use in hostels, the number of people occupying the hostel will be used. This will give an idea of how much water is approximately consumed per person per day.

1.5.4 PROCESSING PLANT

Literature that categorises gold processing plants according to water use was limited. However, in order to compare gold processing plants with each other, the process followed for the beneficiation or extraction of gold must be the same. If the process is similar it can be assumed that the amount of water required by the process should be similar.

The processing plants used in this study belong to the same umbrella company. Ore is treated at the gold plant on site. Milling is the first step of gold extraction, followed by leaching the ore with cyanide, carbon in pulp concentration, and the absorption of carbon by electrowinning. The process does not result in the production of pure gold. The resultant product is called dorè and is dispatched to Rand refinery for purification on a weekly basis [67].

Breitung-Faes and Kwade [68] conducted experiments to investigate appropriate operation parameters for quantifying energy usage based on mills. It was found that the energy consumed in gold processing is greatly influenced by operation parameters such as mill size and mill geometry. This means that the bigger the mills the more energy is consumed. There is no study available to prove that this parameter influences water use in gold mines.

Interviews will be conducted on site to determine if there is a relationship between water and mill size. Logically, higher volume processes require more water as water occupies space.

Data on mill sizes at the operations investigated was not available and this parameter could not be used. For example, process equipment is generally designed with an optimal water use range and straying from this range could lead to a change in the efficiency with which water is used. With no data on mill sizes in the operations. There was no proof that mill sizes affect water use.

Interviews were conducted with metallurgists and environmental officers at different operations. Two questions were asked in these interviews:

1. Does ore grade influence water used for gold processing?
2. What parameter or variable can be used to measure water use efficiency in plants?

The answer to the first question was no, water used is mainly influenced by the amount of material being treated, while ore grade is influenced mainly by the region in which gold is mined and does not affect water in any way. The variable that can be used to normalise water use was said to be tonnes treated. The of tonnes milled greatly influences water use for processing.

1.5.5 MINING AREA

Benchmarking potable water use underground has not been fully explored. However, a number of papers have investigated the determination of energy/electricity benchmarks for gold mines and will be discussed below. As stated by the international Performance Measurement & Verification Protocol Committee 2001 [69], energy savings and water savings are one and the same thing in a sense that the implementation of energy efficiency programs result in water savings . This means that principles used for energy savings may be applied for water savings.

Van der Zee [70] undertook a study which aimed to determine electricity cost risks and opportunities in gold mining operations. One of the objectives of Van der Zee's research was to benchmark electricity usage in various systems of deep-level gold mines. The study outlined elements that may be utilised to determine accurate benchmarks for energy consumption in mines. Van der Zee was successful in benchmarking mines with respect to the elements tabulated in Table 1.4. Only high energy using systems were investigated. The resulting savings were validated by case studies [70].

Table 1.4: Fundamentals of benchmarking (adapted from [57], [70]).

Elements of benchmarking	**Description**
Mine revenue contribution	The grade of Ore(g/t)
	Mine turnover reported
	Operational costs
Size of the mining operation	Number of levels of production
	The number of shafts in the mine
	The number of people employed by the mine
Production and Electricity consumption	The quantity of gold produced
	Total electricity used per year
Mine Depth of the mine	Deep (< 3 000 m)
	Shallow (< 2 000 m)
	Ultra-deep (> 3 000 m)
Mining technology	Conservative mining
	Mechanised mining

Tshisekedi [71] also conducted a study on energy consumption in South African mines namely, gold and platinum mines, in this study electricity consumption was also benchmarked. Tshisekedi obtained overall yearly electricity usage data and gold production from mining operations; with data collected, energy intensity for each mine was calculated in kWh/tonne. Tshisekedi used the following criteria for benchmarking:

- Mine production.
- The depth of the mine.
- The impact of production on the environment Degree of mechanisation.
- Efficiency.
- Degree of automation.

Both Tshisekedi [71] and Van der Zee [70] established that electricity utility depends on the depth of the mine. In order to substantiate this, underground processes needed to be investigated that are related not only to electricity but to water use.

According to literature, high underground temperatures are one of the major day-to-day challenges faced by South African mines. This creates uncomfortable to dangerous conditions for mine workers [72]. Cooling systems are designed to overcome this challenge. Cooling requires water and is one of the most important applications of water in underground mines [70], [72], [73]. The uncomfortable underground conditions are caused by the virgin rock temperature (VRT) which increases when mine depth increases. The VRT can reach up to 70 °C [72].

Depending on the location of the mine; the VRT of deep-level mines in South Africa increases by about 12 °C per kilometre. [25]. Figure 1.6 below shows how the VRT is influenced by the depth of the mine in different regions in South Africa [51], [74] .

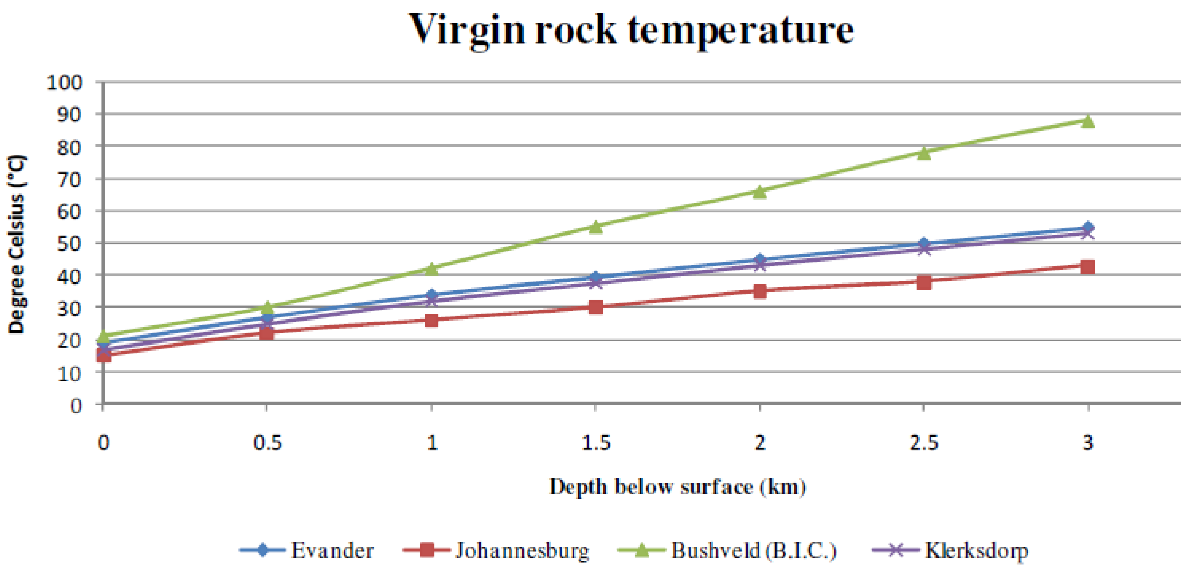

Figure 1.6: The effect of depth on VRT (adapted from [51], [74]).

Since underground cooling and ventilation depend on water, it can be concluded that as mine depth increases, water required also increases. According to Tshisekedi [71] , the depth of the mine is one of the parameters that must be taken into consideration when benchmarking water used underground. By calculating the average intensity of each mine and classifying it by depth, the efficiency of the mine within its depth category can be determined [57], [71]. This is a benchmark.

Benchmarks, such as these, give awareness of how a system is performing. Being able to calculate benchmarks allows for better decision-making. It allows for computable performance indication using input and output variables to achieve efficiency [57].

Benchmarking is becoming more mainstream in determination of process performance [75]. Benchmarking will help ensure that the performance of an organisation is assessed fairly. Benchmarking should be considered a critical step when measuring, designing and identifying performance metrics.

1.6 SUMMARY OF THE LITERATURE

Several researchers have attempted to address water management in the mining industry. Table 1.5 gives a summary of literature relevant to this study. Categories compared in Table 1.5 include general water management, potable water management, water recycling, the use of water balances, equipment monitoring, benchmarking and compliance. These categories are compared because they can assist in achieving a holistic water management strategy that does not only focus on water recycling and compliance but considers all measures that can assist the mining industry with water conservation.

Table 1.5: A summary of relevant literature focusing on water management and mining.

	Water management	Potable water management	Water recycling	Water balance	Equipment monitoring	Benchmarking	Gold mining	Compliance
[1]	Addressed	Addressed	Addressed	Addressed	Not addressed	Not addressed	Not addressed	Not addressed
[7]	Addressed	Not addressed	Addressed	Addressed	Addressed	Not addressed	Addressed	Not addressed
[8]	Addressed	Not addressed	Addressed	Addressed	Addressed	Not addressed	Addressed	Not addressed
[11]	Addressed	Not addressed	Addressed	Addressed	Not addressed	Not addressed	Addressed	Addressed
[12]	Addressed	Not addressed	Addressed	Not addressed	Not addressed	Not addressed	Addressed	Addressed
[15]	Addressed	Addressed	Addressed	Addressed	Addressed	Addressed	Not addressed	Not addressed
[16]	Addressed	Not addressed	Addressed	Addressed	Not addressed	Addressed	Addressed	Addressed
[18]	Addressed	Not addressed	Addressed	Not addressed	Addressed	Not addressed	Not addressed	Addressed
[21]	Addressed	Addressed	Addressed	Addressed	Not addressed	Not addressed	Addressed	Addressed
[48]	Addressed	Addressed	Not addressed	Addressed	Addressed	Addressed	Not addressed	Not addressed
[51]	Addressed	Not addressed	Not addressed	Addressed	Addressed	Not addressed	Addressed	Not addressed
[62]	Addressed	Addressed	Addressed	Not addressed	Addressed	Addressed	Not addressed	Addressed
[63]	Addressed	Not addressed	Addressed	Addressed	Not addressed	Addressed	Not addressed	Not addressed
[64]	Addressed	Addressed	Addressed	Not addressed	Addressed	Addressed	Not addressed	Addressed
[65]	Addressed	Addressed	Addressed	Addressed	Not addressed	Addressed	Addressed	Addressed

Red	Not addressed
Green	Addressed

From Table 1.5, it can be seen that a number of studies have looked at water management in the gold mining industry, however, these studies mainly focus on water recycling, water balances and water compliance. There are limited studies that have benchmarked water use, particularly in the mining industry. There is therefore a need for a holistic strategy to conserve potable water in gold mines. A holistic strategy entails benchmarking water use to identify water savings opportunities, monitoring equipment, recycling water, as well as ensuring that mines are compliant with all environmental regulations.

Ranchod *et al* [1] used tailored water footprint networks to identify high water consumers in the platinum mining industry. This study looked at blue water which is water sourced from groundwater, rainfall and lakes and not particularly potable water. The methodology was used to quantify direct and indirect water use across the mining process. Detailed water balances were used to investigate water use within the operation. The methodology revealed that the largest consumption of water in platinum processing was due to evaporation. Measures such as covering tailings to recover and recycle water were proposed.

To assess mine water use in the platinum mining industry and thus achieve water conservation, Haggard [7] published a study on water foot-printing. Water foot-printing can be used to quantify water used within a process. According to this study, areas in the system where water needs to be reduced can be determined by using a water footprint network. The method proves to be successful; however, in the study Haggard only looked at tailing's facilities, smelters and concentrators. The shortcoming is that the systems investigated may not be the only areas where water needs to be reduced.

Gunson *et al* [8] identified options of reducing, reusing and recycling water in the mining industry. The study demonstrates where these measures have been implemented globally to reduce water used by the mining industry. Six scenarios were evaluated to investigate water savings options. The water savings options included evaluating water loss due to tailings evaporation, filtered tailings disposal, tailings thickening as well as pre-sorting ore before milling. Water recovered from these options was recycled which reduced the amount of water introduced to the system. The method also showed that combining savings options will result in more water savings for the mining industry.

Toledano and Roorda [11], looked at models, opportunities and challenges affecting the mining industry interms of water conservation . The study showed that mining companies primarily use water recycling techniques to reduce their water footprint. Water recycling and reuse is the only measure proposed in this study due to stringent environmental regulations related to water discharged by mines.

Lugalya [12], Investigated the role of climate stress in water management within the mining industry. From the study, it was seen that mines face many climate-related water risks and there should be actions taken by mining companies to mitigate water risks. The study also revealed that mines manage water as a reactive response and not a proactive response. From the study, the author states that mines have incorporated recycling methods to counteract water risk, however mines should have a plan to manage climate-related water risks. The study did not provide a specific measure that should be applied to manage water to counteract climate risks.

The Stakeholder Accord on Water Conservation [15], developed a guideline to assist the mining sector with baseline target setting. The guideline identifies individual water savings opportunities in the mining industry. The individual conservation opportunities ranged from assessing water in the extraction area, in the beneficiation area, tailings, assessing water use in employee amenities and many more. The study explains the role of setting targets and achieving water savings opportunities through target setting. The study also proposes the use of benchmarks to compare facility performances. The measures considered to conserve water include; water recycling, lowering evaporation and monitoring leaks.

ICMM [16], developed a guide to assist the mining industry in making transparent and consistent water reports. The guideline looked at metrics that can be used to discribe an operation's performance. The metrics include water withdrawal, quality of water discharged, recycling ratio, water consumed by facilities, and water intensity calculation. According to the guideline, water-intensity can be used for benchmarking.

Barrington [18] investigated practical methodologies of achieving water conservation in the process industry. The use of water auditing techniques to analyse water flows was thorougly examined. In the study, equipment auditing proved to be a simple yet effective method to conserve water. Water conservation measures implemented in the study also include; reusing water in process units, using rainwater as an ulternative source and encorporating water treatment practices to minimise water discharged.

Seneviratne [48], investigated practical appoaches to water conservation in organisations. The investigation resulted in a six step aproach of conserving water. The steps include a development of a conservation plan, appointing a designated water conservations manager, gathering baseline data and reviewing previous water usage to determine water use benchmarks. The forth step involves identification of improvement opportunities by use of orgasation water balance, followed by developing a plan that prioritises opportunities in order to know which improvement methodology should be implemented first for example leak management. The last step was to report results obtained.

Botha [51], conducted a study to optimise water use in deep-level gold mines. The aim of the study was to reduce water wastage while reducing electricity consumption. In the study, Botha identified three techniques that can be used to reduce water use in gold mnes.The three techniques identified include stope isolation, leak management and supply water pressure control. The study mainly focused on equipment monitoring and resulted in significant water savings.

References [62], [63] and [64], suggested enhanced utilisation of data in water utilities. The aim of the studies was to show that water consumers should use data obtained from processes to implement efficient water management strategies. The studies looked at the use of process and metric benchmarking to measure water performance in organisations. Although these methods are effective, the authors acknowledge that they may present several inconveniences. These include difficulty finding suitable parameters to compare data, finding a set of water consumption indicators and actual data management.

The benchmarking report [65], was thoroughly discussed in preceding sections. The document was developed by the DWS for assisting the mining industry in setting water use benchmarks. The document also provides measures that may be used to conserve water after determining benchmarks.

1.7 DATA MANAGEMENT OF POTABLE WATER MEASUREMENTS

Benchmarking is data-driven and in a complex operation like gold mines, data is measured daily and transferred through different departments. The data is therefore error-prone because many transfer errors could occur. Benchmarks are set for important decision-making. Data needs to be verified to ensure correct decision-making.

Mining companies have multiple operations in multiple regions. Therefore, high volumes of data from different sources must be gathered, transferred, consolidated and analysed daily [76]. The management of data in gold mines is complex because some systems used for data collection are automated while others are manual. Data is mostly exchanged in a form of multiple Excel spreadsheets [77]. The information source inputs can either be automated or manual.

Management of data is essential to ensure that all data received is accurate and error-free. Ebrahim [31] conducted a study for improving the quality of environmental data in gold mines. The study suggests that the origins of each data point need to be investigated before data can be reported. The origins of data can be traced back to a specific reporting chain. A reporting chain for any organisation consists of a source document, summary and resulting value. The arrows in Figure 1.7 indicate points of communication between the person taking actual water measurements, summaries created by their manager and final figures reported for evaluation.

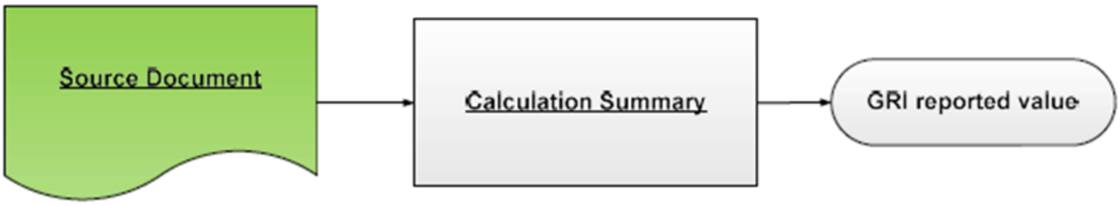

Figure 1.7: Reporting chain (adapted from [31]).

Since mine data is used for a variety of important reports, making business decisions based on poor data will affect the company significantly. Janse van Rensburg *et al.* [77] also created a standard data tree structure that aims at ensuring environmental data integrity and quality. The method uses data automation and a combination of the double entry and proofreading techniques. There are two methods of verification, proofreading and double entry [31]. The framework suggests that data should be standardised, centralised and verified before any decision-making can be concluded from this the data.

1.8 Need for the study

South Africa is a water-scarce country. South African gold mines utilise large amounts of potable water from surrounding municipalities which is a shared resource. Additionally, gold mines are under pressure to improve their potable water footprint due to numerous factors like corporate responsibility, financial constraints and legislative frameworks. Strategies for gold mines to reduce their potable water consumption therefore need to be developed. It was found from literature and legislation that mining industries are mainly focusing on water treatment, water recycling and reporting. There is therefore no holistic strategy for potable water conservation in the gold mining industries.

1.9 Study Objectives

The primary objective of this study is to develop a holistic strategy for saving potable water in gold mines. The objectives of the study are listed below;

- Develop a strategy for effective potable water conservation in gold mines.
- Implement the developed strategy.
- Measure, report and discuss results.

1.10 DISSERTATION OVERVIEW

Chapter 1

Chapter 1 gives a background of South Africa's water resources and how they are consumed within the mining industry. The knowledge gap within literature was clearly stated, mainly that current water conservation techniques in gold mines are isolated in nature and do not make use of a holistic approach as part of their standard operational activities. Guidelines that were developed by the DWS as well as other sources are also presented in this chapter.

Chapter 2

In Chapter 2, the strategy for conserving potable water is defined with the use of literature and guidelines. A Step by step procedure is provided to explain how the methodology should be carried out.

Chapter 3

In Chapter 3, the implementation and results of the study are discussed. Two mines were used as case studies to test the water reticulation optimisation methods. The savings achieved from the three case studies are used to validate the methodology.

Chapter 4

Chapter 4 gives the conclusion of the research as well as the findings. From chapter 4, it is seen that the objectives of the study were met, and the strategy proved to be successful. Significant savings were achieved although expected benchmarks were not met. Recommendations for future work are also provided.

2 DEVELOPING A CONSERVATION STRATEGY

2.1 PREAMBLE

The objective of this chapter is to develop a holistic strategy to assist the gold mining industry to identify underperforming facilities using benchmarking techniques. After a facility has been identified, a detail investigation is done to identify inefficiencies.

Although the methods discussed in Chapter 1 are effective to an extent, they are not efficient. This is due to these methodologies only focusing on water treatment and recycling and not addressing mismanagement. With large amounts of data available at different measurement points, managers are finding it difficult to identify where operational issues are located in the system. Managers therefore rely on recycling water since it reduces potable water intake. Recycling water assists mines in complying with legislations that are in place regarding water discharged and recycling.

Water recycling results in large volumes of water being reused and thus reducing the need for large quantities of inlet potable water. Water recycling is important in mining industry, it is however not the only methodology that should be used to conserve water. Chapter one proved that there are other methodologies that can conserve potable water.

The steps that will be followed to conserve water in gold mines by means of benchmarking and inefficiency identification are shown in Figure 2.1. These steps are derived from literature and shortcomings identified in Chapter 1. The first two steps involve data management, followed by determination of performance indicators. The final steps involve reporting of the associated benchmarks and savings.

The benchmarks calculated are aimed at prescribing possible solutions of saving water efficiently and to indicate areas of focus. Each step of the solution process is discussed in the following sections.

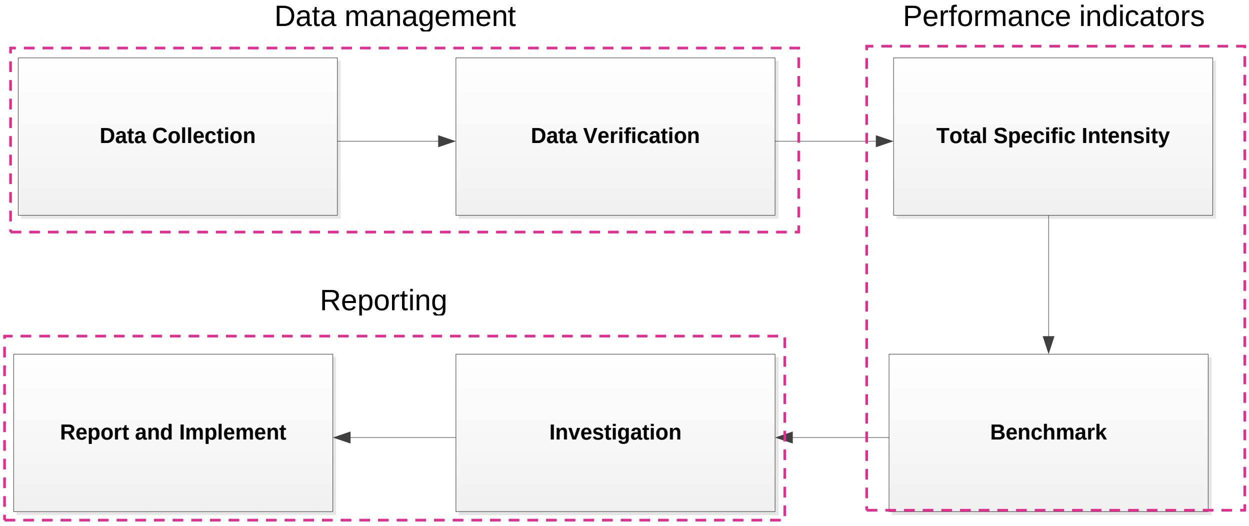

Figure 2.1: Water conservation strategy.

2.2 DATA MANAGEMENT

i. Collection of data

In Section 1.7 the importance of data management was emphasised. The first step towards efficient data management is to collect relevant data and source documents. Ebrahim [31] investigated the importance of knowing the origins of data and knowing the correct reporting chain. A data reporting chain is a network of processes that describe flow of information needed to generate goods or services [78]. Prior to this, however, an investigation of which source documents are available is required, followed by deciding the type of data values necessary [71], as well as deciding on the reporting period. According to Booysen [79], 12 months is an acceptable period for decision-making since it captures all seasonal effects. The process is represented by Figure 2.2.

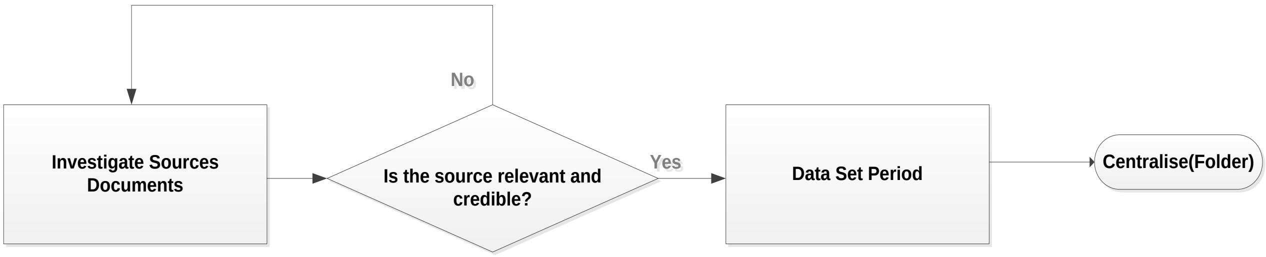

Figure 2.2: Data collection process.

The first step of the data collection process is to investigate all information sources. Information sources are written or electronic documents that have information of any transaction and may verify the completion of data [31]. Information sources may have varying formats and might be stored as different file types. There are a variety of information sources available from several departments. In addition to investigating these, the data custodians or people responsible for sources need to be investigated. The data custodian should be the mine personnel who directly uses and generates the data. The personnel must have a clear understanding of the origins of data and reasons for reporting the specific data points. Electronic sources are also credible due to their minimal error possibility.

Step 2 in Figure 2.2 allows the user to evaluate which source documents are necessary and credible for reporting. The most credible sources have been identified to be contracts or invoices because they are legal documents. Both contracts and invoices involve third-party companies. Contracts are binding documents and should be honoured. Invoices are more credible because they reflect dates by which products were purchased as well as the quantity purchased.

The third step highlights the importance of selecting the appropriate data period for decision-making. According to the Energy Savings Management Guide [80], it is important to select the amount of historical data that accounts for all seasonal trends. Baseline calculations requires data that extends to at least 12 months to account for these seasonal effects. The source documents should therefore be collected for a minimum of one calendar year.

The last step of the process shown in Figure 2.2 is the centralisation of data. This means that data is located in one place or folder. Data centralisation helps the reporter keep track of all the sources they have, and it allows data to be easily accessible to individuals that need it. This is an important step because it promotes efficiency.

Ebrahim's reporting chain method shown in Figure 1.7 is expanded by the process represented in Figure 2.2. The complete data reporting process is shown in Figure 2.3.

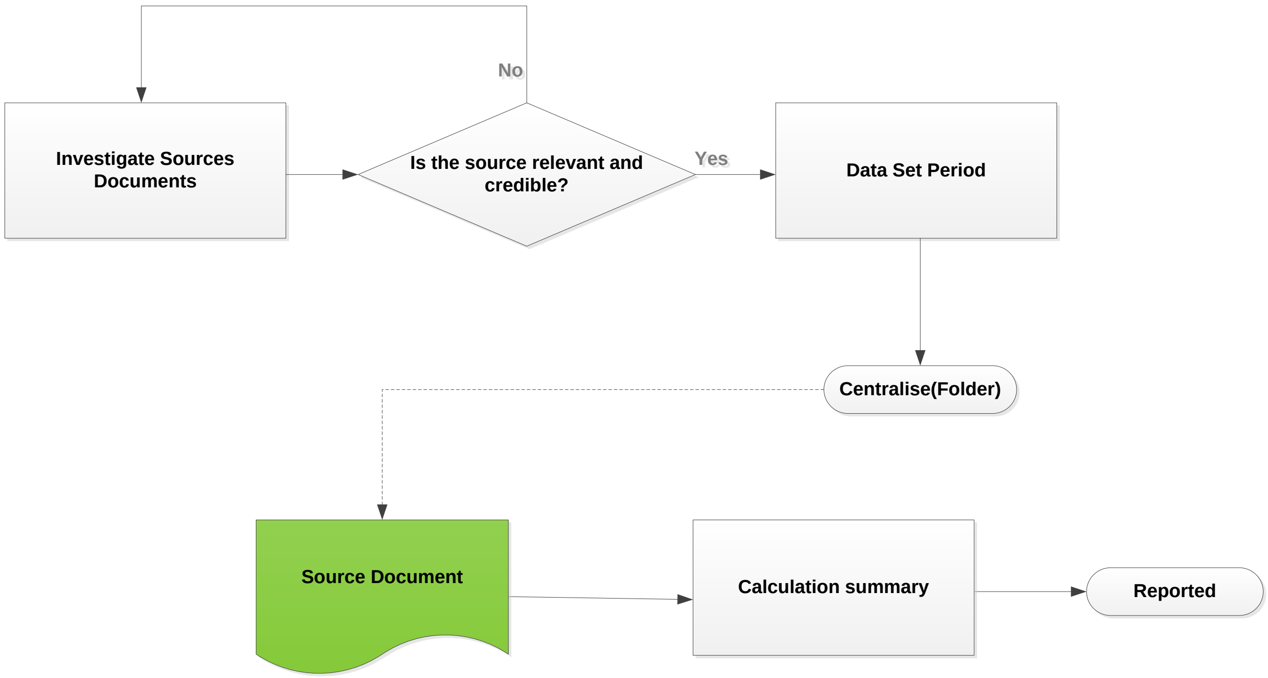

Figure 2.3: Data reporting process.

Following all the steps in Figure 2.2, the correct source documents are selected and centralised. The correct source document is highlighted green in Figure 2.3. Between reporting and the correct source document is a calculation summary. A calculation summary is a document that is used for calculations and capturing values. Recording values on summaries is done for efficient communication between departments.

With the reporting chain expanded, the person responsible for reporting can have a better understanding of data reported, and whether correct and relevant data is being reported. This process also allows the reporter to make important decisions about the data: that is, the period for which the data should be reported, and which data set is necessary for reporting.

The reported value comes from calculation summaries in most instances. In summaries, third-party users are subtracted from the invoiced amounts and values are adjusted according to the needs of the reporter. This may involve unit changes (kilograms to tonnes) or multiplication by emission factors.

ii. Data verification

In order to ensure that data reported is accurate enough for decision-making and ultimately benchmarking, a process that can assist in identifying issues with data reported needs to be followed. In Section 1.7, it was briefly discussed that there are two data verification methods. These methods do not require automation although automation would yield better results that are also less prone to human error.

The two methods that will be considered in this study to ensure accuracy in the data reported are proofreading and double entry verification. Proofreading consists of a comparison between inputs of information against the source of the data [31] . Double entry of data involves two parties independently processing source data and comparing the two outputs [31]. The comparison performed in each method results in the identification of errors. Proofreading will be used in this study because it can be completed by one person. The disadvantage of this method is that it is more prone to error but can be used in cases where only one individual is assigned to perform verification.

More than one person can create a calculation summary. The summary is linked directly to reporting. The calculation summary is error prone. Figure 2.4 shows the verification step. The verification step is necessary to ensure that the data in the summary is correct before reporting. Verification is completed using the proofreading method. If the value on the summary does not match the source document, the figure reported on the summary is changed to match the source document.

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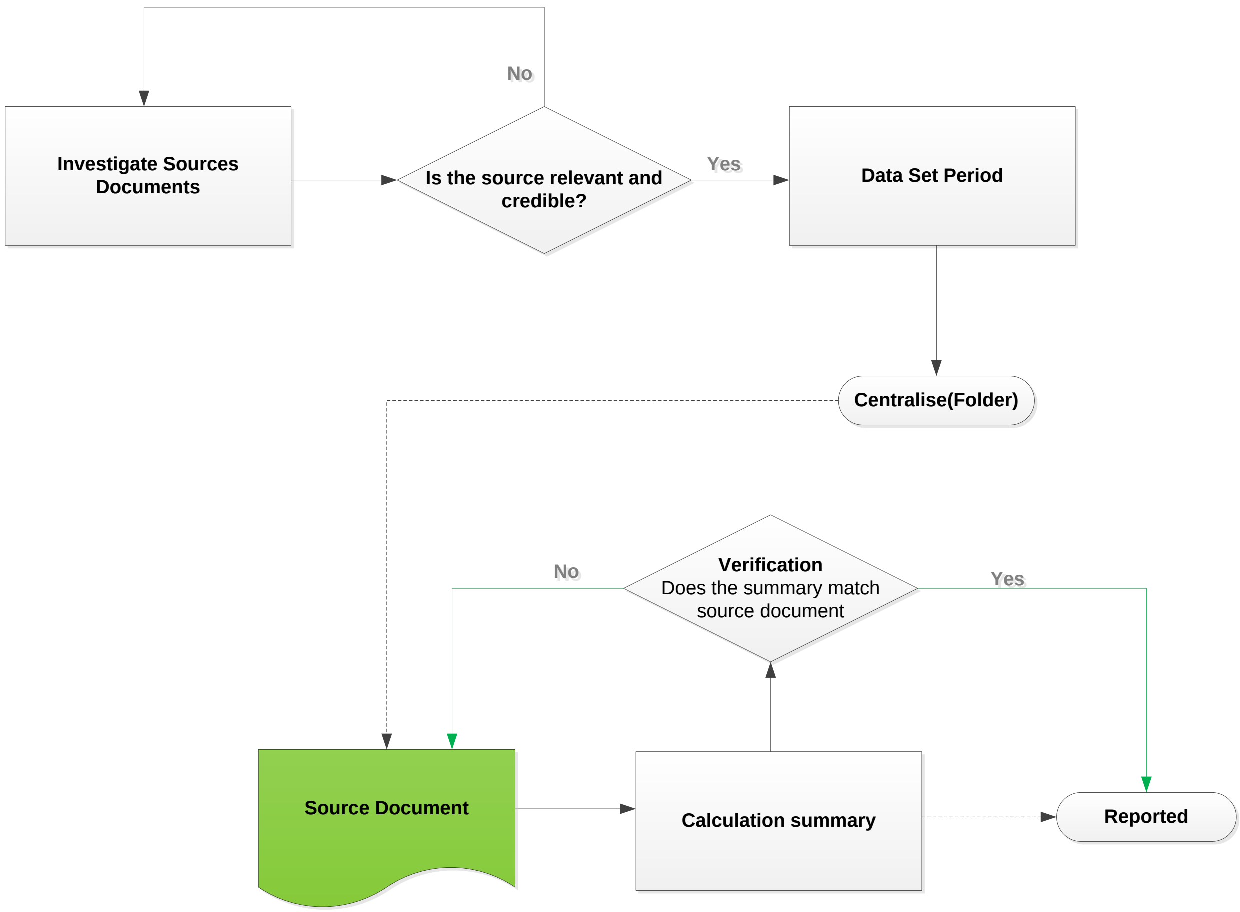


Figure 2.4: Data verification process.

2.3 PERFORMANCE INDICATORS

i. Total specific potable water intensity

The first step of the analysis is to calculate the Total Specific Intensity (TSI) to examine how total potable water for the system is influenced by ore mined for each operation. This will give a picture of how an operation is performing relative to other operations.

A water user that is efficient can be defined as user that achieves the desired production outcome using the minimal amount of water required for that outcome [15]. The level of financial gain associated with the amount water used, and an indication of absolute water use are key factors required to measure water use efficiency.

Water intensity relates absolute potable water use over a defined period to the mine output [15]. As indicated in previous sections, in mines, mine output is measured in “tons per annum”, ‘ounces per annum’ for precious metals. Total specific potable water intensity of a mine is measured in “kilolitres per tonne”.

TSI gives an understanding of how the mine is performing. It does not necessarily show where a mine is using more water and where water is being misused. Calculating TSI gives an indication of whether an operation is performing efficiently. It does not specifically show areas that one should focus on to conserve water. If the TSI of an operation decreases it implies that the operation is performing better than previously, however it implies the opposite if the intensity increases.

In this study, the total specific intensity calculation is used to give an overall idea of how an operation is performing without normalising data and evaluating data fairly. Before the intensity can be calculated, the total potable water for an operation must be calculated. Total potable water excludes the potable water supplied to third parties. Equation 1 gives this calculation.

$$\text{Water consumption} = \sum \text{Invoice amount(kL)} - \text{water supplied to third-party} \qquad (1)$$

TSI can be calculated using equation 2 below.

$$TSI = \frac{Total\ water\ consumption\ [kL]}{Total\ product\ [tonnes]} \qquad (2)$$

ii. Benchmarking

Water efficiency means using less water to produce the same amount of services or useful output. Efficiency indicators are used to indicate the water consumption performance. Benchmarking is a tool that can be used to assess performance. The objective of this section is to benchmark water use at gold mines.

The first step for benchmarking is identifying KPIs for water use. KPIs can be established for several reasons, either to measure performances for individual processes within an operation or to measure performance of an entire site. Mines are normally multi-product mines, meaning that intensity can be calculated at the end of intermediate processes or at the finished product [15]. Therefore, it is important to first develop an understanding of water requirements within an operation, together with all characteristics of an operation.

The DWS, in collaboration with the Chamber of Mines, commissioned a project to undertake the setting of water conservation targets for the mining sector. A literature review conducted by the Department revealed that no country in the world has set water use efficiency targets for the mining sector [65]. The methodology used by DWS followed four steps which are discussed in depth below. The Department used both metric and process benchmarking to determine targets.

According to the study, setting mine water use benchmarks is a four-step method summarised in Figure 2.5.

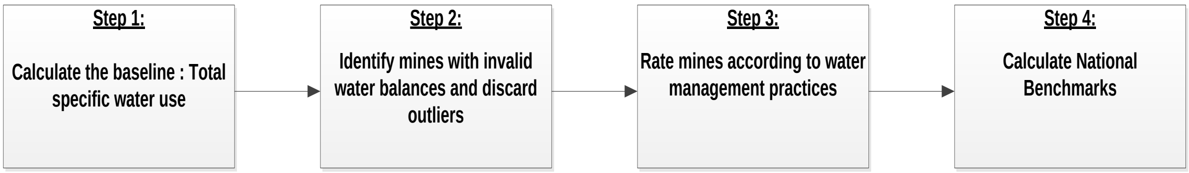


Figure 2.5: Process of calculating water use benchmarks.

Step 1: Computation of current baseline: Total Specific Water Use.

In this step, all potable water data obtained from the mine is used. The baseline is calculated without consideration of outliers and different mine characteristics. Equation 1 is used in this step.

Step 2: Remove Invalid or Poor Water Balances.

In this step, mines are classified according to the availability of complete water balances. The mines that have incomplete water balances are discarded and cannot be used for benchmarking. Outlier mines are also discarded in this step. According to the Department, mines with extremely high (> 400% of average) or low (< 25% of average) specific water used should be discarded. This is done because the figures are considered unrealistic.

The overall total specific water use per commodity can now be calculated based on valid water balances.

Step 3: Rate mines in terms of Water Management Practices.

Water use benchmarks are determined using mines that can demonstrate that effective water management practices are being implemented. In this step, five critical aspects are looked at:

1. Status of water balances
2. Frequent month to month update of monitoring data into computerised system

3. The constant use of water balance information in decision-making for water management
4. Existing water conservation plan
5. Use of DWS BPG

Step 4: Computation of Benchmarks

Only the best performing mines are used to determine the final benchmark. An average of at least the top three mines of a specific commodity may be used as a benchmark.

The method was slightly adapted in this study, this is illustrated in Figure 2.6. In this adaptation, outliers are considered and discarded if necessary.

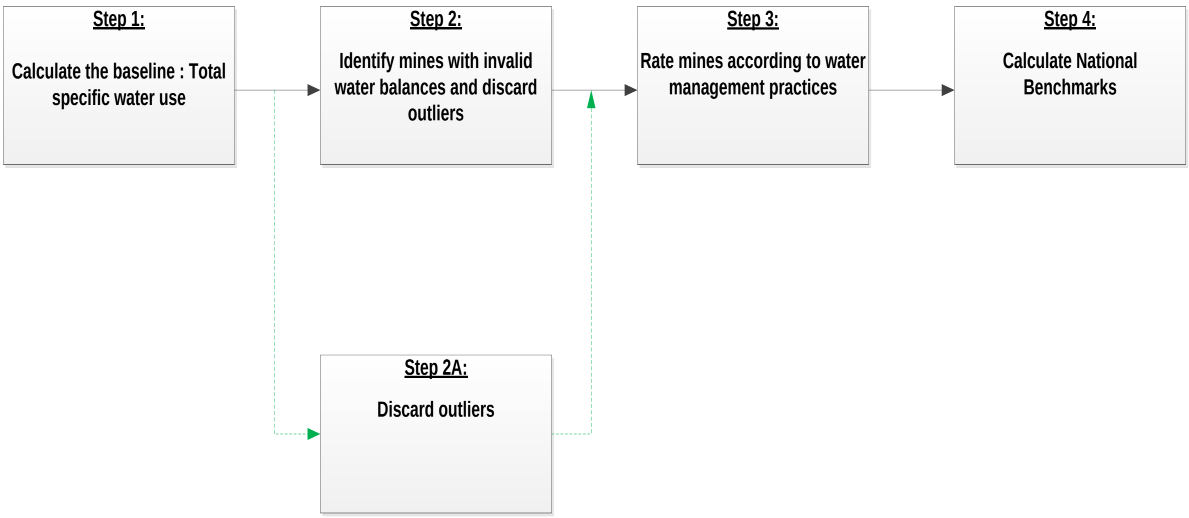


Figure 2.6: Applicable methodology

Gold mining operations have minimal metering available to establish complete water balances. It is infrequent that an operation with perfect water balances will be found. In cases where water balances are incomplete, Step 2A can be applied; this is excluding the first part of the second step as prescribed by the DWS. Only using the second part which is determining outliers by means of the lower (< 25% of average) and upper limit (> 400% of the average).

When benchmarking, making fair comparisons between mines is important, and logical comparisons can be achieved by normalising data and comparing mines in such a way that all variables can be considered. In this study, instead of considering the entire operation for benchmarking, the mine water data can be divided into sections where possible. An investigation was carried out to understand factors influencing mine potable water use in the Chapter 1.

Lai and Lu [81] calculated carbon emission benchmarks by normalising data. When the aim is to normalise data correlation, analyses are carried out to identify an appropriate parameter for normalising the utility in question [81]; second, to identify whether there exists any relationship between the characteristics to enable just comparisons to be made between the normalised data points. Finally, benchmark values may be calculated for total normalised potable water use.

The benchmarking process discussed in this chapter is applicable to all mine business units in Chapter 1, and potable water use in gold mines was evaluated. It was found that each operation can be split into three sections, namely: water for mining, water for the processing plant, and water to residential areas. The mine also supplies water to third parties, but for the purpose of this study, third-party water is excluded because the mine has limited control on how third parties use their water. The business unit split is shown in Figure 2.7 below.

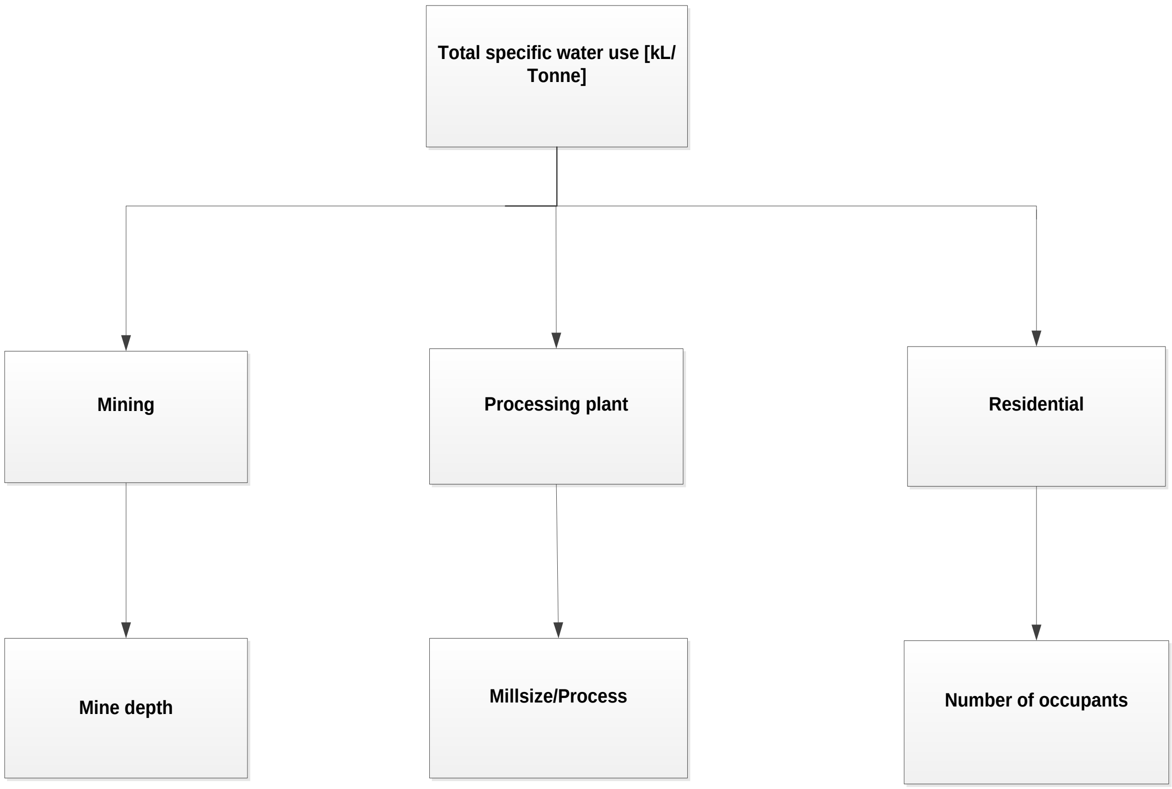


Figure 2.7: Data normalisation categories

Splitting operations result in data accuracy and more credible benchmarks. This split should work for any mining company but can also be expanded depending on the data available at an operation. The equations that follow represents the benchmark calculations at each business unit: the mine benchmark, followed by the plant benchmark and, lastly, resident's benchmark.

$$Intensity_{Mine} = \frac{Mine\ \ water\ [kL]}{Rock\ mined\ [tonnes]} \tag{3}$$

The intensities are grouped according to different mine depths so that small mines are not compared to bigger mines as Figure 2.7 suggests.

$$Intensity_{Plant} = \frac{Water\ to\ plant\ [kL]}{Tonnes\ treated} \tag{4}$$

Similarly, plants with the same mill size and follow the same process must be grouped together and a benchmark is calculated per operation.

$$Intensity_{Residentials} = \frac{Water\ consumed\ [kL]}{Number\ \ of\ occupants} \tag{5}$$

2.4 REPORTING

i. Investigate

After benchmarks for different systems have been calculated, a detailed investigation can be completed. The investigation involves understanding each process that requires water use and the persons at the operation that will assist with information, for instance the foreman. The key points that are investigated are those facilities that were identified to be the least performing according to the benchmarking methodology. This is the part of the process that will show the person responsible for water conservation where focus must be placed to reduce water wastage.

To verify that the data reported, and benchmarks calculated are correct, an investigation that involves two assessments must be carried out. The first is the development of a water layout, this gives an indication of where the water is utilised. The second assessment is a detailed water audit. This entails identification of leaks in the system and making use of equipment that can identify anomalies in the line or system. As a part of the investigation, calibration certificates of all meters should be provided.

The various operations on a gold mine are different and have different potable water needs: some operations depend only on potable water from the municipality whilst other operations get water supplies from natural resources and water treatment practices. A detailed water layout gives an indication of total water withdrawn, where it was withdrawn and what it is used for in an operation. A water layout gives a clear picture of what an operation looks like and all water lines involved.

To develop a detailed water layout, access to the mine operations must be provided by the mine personnel: this can be environmental officers or operation foreman or any mine personnel that understands water flow in the operation. The following main information needed to be obtained from mine personnel in order to design a detailed layout for the operation is:

1. A plan of the site, location and description of existing services on site.
2. The function of the premises and types of activities carried out.
3. Drawings of buildings, showing points that require water supply.
4. The quality of water.
5. The presence or absence of meters.

With all the five information points addressed, a detailed water layout for each operation can be designed. The water layout generated should be approved by the persons responsible for water conservation and reporting onsite. The water layout or balance includes all input water streams and all output streams.

Investigations that involve detailed water audits can take place once the layout is complete and therefore provide all necessary information of potable water use. The water consumption data is obtained through monthly water meter readings. The accuracy and reliability of the meter reading data is critical as it provides the basis on which the water consumption is investigated and analysed. Therefore, the meters and subsequent readings need to be investigated for data credibility by means of calibration certificates.

To assure the accuracy of the readings, an electrical instrument that can measure flow without turning off water supplied to the mine is needed. Ultrasonic flow meters may be used for this purpose. There is a range of ultrasonic flow meters suited for different applications. A flow meter that was selected was a clamp-on ultrasonic flow meter. The meter works without being drilled on to the pipe, this reduces cost of installation.

During the investigation step, it is also important to examine the facilities that are grouped together. Reprocessing plants cannot be compared to main processing plants. All factors influencing water use and characteristics of each facility must be thoroughly investigated. These factors include the type of ore mined, number of occupants and many other factors as mentioned in Section 1.2.

It was stated in the first chapter that leaks are the greatest source of potable water loss. Investigation should be carried out to identify leaks on the system. With the water balance and layout available, lines can be walked to identify leaky pipes. Leaks are, however, not the only cause of water loss. The presence of meters in the pipeline should be investigated. This will enable the identification of meters that are malfunctioning.

ii. Report and implement

Investigation in the mine may be carried out by any individual who understands the mining processes and the benchmarking process. However, prior to implementation, the mine personnel responsible for water conservation should generate pre-implementation and change-control reports that will be submitted to all decision makers: these include engineers, operation managers and foreman. This ensures that if a pipeline, for instance, needs to be closed, it will not affect the system and that all parties agree to changes that should be done in the system.

The report will be sent to site personnel depending on the period of data or benchmark period. In this study, monthly benchmarks are calculated and therefore reports will be sent out monthly. The reports will outline five main principles, namely the situation at the operations; tasks or measures that should be taken; the person who must take action; cost implications; and expected results.

The report should have a complete water layout of the system and should have detailed information of where the problem was identified, the main causes of the problem and how the problem can be solved. Most problems include maintenance and repairs. The cost implications involved in developing the solution should be clearly stated in the report. Practical solutions to the problems should clearly be explained.

There are different budgets for different facilities and business units within the mine. The report should therefore be sent to the correct department so that the budget can be allocated correctly.

With all managers informed of the possible solution to the potable water problem, implementation can take place. Processes must be closely monitored to ensure that production is not impacted and that all parties that need to receive water are accommodated. The savings achieved can then be quantified and reported. The savings achieved may be used to validate that the solution indeed works.

2.5 CONCLUSION

In this chapter a strategy to conserve water was adapted and developed based the DWS guidelines and other sources. This strategy requires six steps to be followed in order to yield accurate results. The six steps are further grouped into three main categories: data management, performance indicators and reporting. The methodology allows for the person responsible for water conservation to be able to identify areas in the system that require attention before attempting to conserve any water. It also shows that recycling water is not the only solution to conserving water in gold mines. It may reduce pollution, but it does not necessarily save water lost within the system. The results achieved after the methodology has been implemented will be used to validate the study.

3 IMPLEMENTATION AND RESULTS

3.1 PREAMBLE

In this Chapter, steps from Chapter 2 are followed to attain the final benchmark figures for potable water use in different sections of the mine. The benchmarks are used to identify the performance of an operation at different sections of the mine. Case studies will be selected according to the performance of the different operations i.e. the least performing operation will be selected as a case study. Measures that should be taken to conserve water will be investigated and implemented according to the needs of specific operations.

3.2 DATA MANAGEMENT

i. Collection of data

The processes for data collection were discussed in Chapter 2 and depicted in Figure 2.3. The same process was followed for data collection and reporting. Eighteen mining operations were evaluated. The operations include mineshafts and processing plants. A series of interviews with site personnel were conducted on mine sites. This was to fully understand information sources available and from whom data must be collected. Figure 2.7 showed how the operations are separated for benchmarking. According to site personnel, data needed is unique for each section of the mine. Table 3.1 summarises sources required and relevant sources.

Table 3.1: Data required per section.

Mine section	Data required	Relevant source
Mining	Potable water figures	Municipal invoices and third-party reading
	Mine depth	Mine integrated report
	Rock mined figures	Supervisory Control and Data Acquisition (SCADA) report
Processing plants	Potable water invoices and third-party meter readings	Municipal invoices and third-party reading
	Type of processing plant	Mine integrated report
	Tonnes milled/treated	SCADA report
Employee amenities (hostels)	Potable water meter readings	Consumption meter readings
	Number of occupants	Site report (Human resource department)

Data for financial year 2018 (July 2017 to June 2018) was obtained from the environmental officers at all 18 operations. Eleven of these operations are mineshafts while seven are processing plants. The financial year for the mine operations used in this study starts in July 2017 and ends in June 2018. This means that data for 12 months was evaluated and used.

Potable water data and production data were received from environmental officers on site. The origin of this data was thoroughly investigated as Figure 2.3 suggests. Potable water information sources were received in the form of invoices, meter readings (summaries and meter photos) and third-party consumption. An example of an invoice received at the mine is attached in APPENDIX B. In this invoice the figure for the total potable water purchased is highlighted red. This is the figure used for potable water consumption before the subtraction of third-party users.

Production data was received in SCADA reports. In all operations, a SCADA system is installed. This is a control system that makes use of computers, networked data communication, field instruments (measurement devices and Programmable Logic Controllers) and interfaces for high-level process supervision and management [82].

The SCADA system reports production data daily and stores it in a specific folder on the system. Environmental officers receive this data monthly from the control room. SCADA reports are translated into metal accounting reports and contain all data for the mining process. An example of the metal account report used is attached in Figure 2 of APPENDIX B. The important information is highlighted red in the report. These are tonnes treated and rock mined. This is sensitive data as it contains information of how the mine is performing in terms of profit. A metallurgical clerk is employed in all operations to extract production data for reporting.

ii. Data verification

In Chapter 2, proofreading was selected as the verification method to be used in this study. As shown in Figure 2.4, verification is a step between source document and the summary provided by the environmental officer. This section is specifically for potable water data. Production reporting uses a computerised system and errors are minimal. Water meters are not linked to any system, the electrical foreman takes readings on the meters only once a month. Meters can stop working at any given time. If the meter stops in the middle of the month, water data can be lost, and incorrect figures may be reported.

Data was verified before any analysis could take place. Several discrepancies were found within the data and were corrected to ensure that the data is as accurate as possible. A typical example of a common error is shown below. Figure 3.1 is a picture of the meter reading taken by a mobile application used by the mining company. This application allows the user to enter the meter reading into the system. The image is used for verification of the meter reading.

Figure 3.1: Meter reading from the mobile application.

Table 3.2 indicates final figures reported by the engineering foreman at a specific operation. As can be seen comparing the foreman's data in Table 3.2 and the mobile application image, the foreman reported 771 811 instead of 771 914, this means that the utility for that month was under-reported. Incorrect conclusions would be made regarding the data and the cost of the company. Therefore, verification is important.

Table 3.2: External third-party meter readings from foreman.

Property description	May`18	June`18	Consumption
Business Unit 1	139 848	139 932	84
Business Unit 2	21 151	21 361	210
Business Unit 3	231 785	232 246	461
Business Unit 4	913 572	917 077	3 505
Business Unit 5	449 653	452 852	3 199
Business Unit 6	8 554	8 715.7	161.7
Business Unit 7	373 384	Locked	0
Business Unit 8	38 524	38 524	0
Business Unit 9	705 622	708 465	2 843
Business Unit 10	770 633	771 811	1 178
Business Unit 11	60 961	60 963	2
Business Unit 12	659 775	65 977	0

Business Unit 13	342 635	344 384	1 749
Business Unit 14	locked	Locked	
Business Unit 15	13 770	21 150	7 380
Business Unit 16	6 135	9 090	2 955

All potable water data received was verified and checked against meter readings. Errors were identified during the verification step and subsequently reported and fixed. Using proofreading, the summary was compared to meter readings. The errors found are reported in Table 3.3;

Table 3.3: Summary of values reported with errors

Property description	Meter reading (photo)/source	Reported figure	Error percentage
Business unit 10	883 323	888 323	1%
Business unit 12	792 955	762 953	4%
Business unit 23	330	360	8%
Business Unit 1	164 904	48 185	71%
Business Unit 2	22 110	64 020	189%
Business unit 3	238 079	75 050	68%

Errors below 0.5% were excluded, the highest error that was found was 189%, for auditing purposes this is referred to as material error. Some errors were as a result of using the incorrect source. The table validates that proofreading can be used to verify data.

3.3 DETERMINING TOTAL SPECIFIC INTENSITY AND BENCHMARKING OPERATIONS

The third and fourth step of the strategy are calculating TSIs and benchmarks respectively; the process was fully described in section 2.3. TSI is calculated to give an overall indication of how operations are performing relative to each other, while benchmarking holistically evaluates all systems to identify poor performing facilities. TSI is an important step of evaluating if there are any problems in the system.

3.3.1 TOTAL SPECIFIC INTENSITY

A top to bottom approach is followed as outlined in Chapter 2. First the TSIs are calculated for each operation. The TSI values are obtained by using equation 2 and plotted in Figure 3.2.

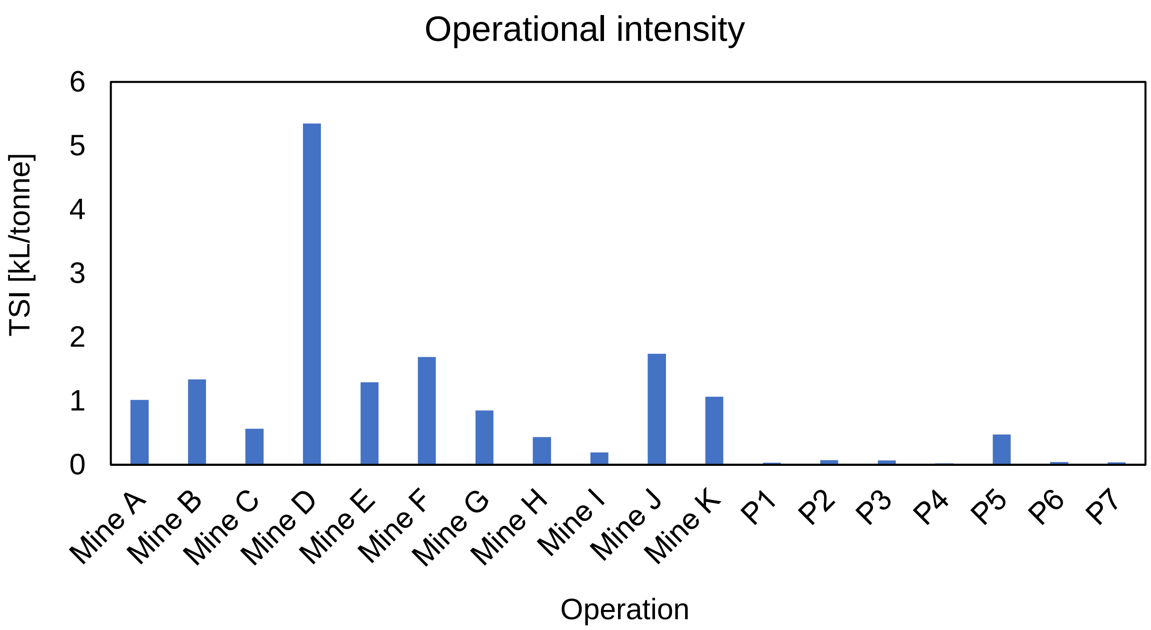


Figure 3.2: TSI for each operational facility

From Figure 3.2, it can be seen that Mine D is the worst performing operation because it has the highest TSI figure. TSI clearly indicates which facility utilises high volumes of water and could be possibly wasting water. Although this can assist with water management at Mine D, it does not clearly identify where in Mine D the problem is. This therefore results in many resources being needed and time to identify exactly where the problem occurs in mine D. TSI is therefore not an efficient method for decision-making in terms of measures that must be taken to conserve water, but it is useful in identifying operational facilities that are least performing. Benchmarks still need to be calculated using the methodology in Chapter 2.

3.3.2 BENCHMARKING

The four steps for benchmarking described in section 2.3ii were followed. It is important to note that the procedure deviated from the steps where necessary.

With all the data points available, steps stipulated by the DWS were followed.

- Step 1:

  The total analysis of water in the mine was completed and discussed in section 3.3.1. This step gives an overall idea of how mining operations in this study are performing. It does not give a clear understanding of where conservation methods should be applied.

- Step 2:

  All the 18 operations had water balances. These water balances consisted of meter readings of the inlet potable water streams, potable water consumers and water discharged where applicable. The completeness of the water balances could not be confirmed because the water balances were old, and chances of system changes are high. Therefore, all mining operations were used for analysis, none of the operations were discarded based on incomplete water balances. Water balances of the operational facilities were of the same standard. Step 2A of Figure 2.6 was followed. Operations were discarded based on the presence of outliers.

- Step 3:

The first criterion was not applicable to all mines because all the mines had unverified water balance layouts; critical mines will be discussed in the case study section. All environmental officers, however, confirmed that they follow water conservation practices. There is a regular monthly update of monitored data, ensuring meter readings are taken. All operations make use of DWS's BPGs.

Mines that are already issued with a water-use licence use water conservation plans as part of their efficiency initiatives. No mines were discarded based on conservation practices.

- Step 4:

The benchmarking report from the DWS was only used as a guideline. Final benchmarking figures were determined using methods discussed in section 2.3 ii. Aggregating process according to similarities and using the average intensity of the selected operations as a benchmark.

The guideline also stated that the most accurate water use efficiency benchmark can be calculated using the average intensity of at least the top three performing mining operations within the commodity group. In this study a benchmark will be calculated the same way where possible, depending on the number of mines that suit a certain category. Benchmarks are calculated per mining section as explained, Figure 3.3 is copied from Chapter 2 to explain the following subsections.

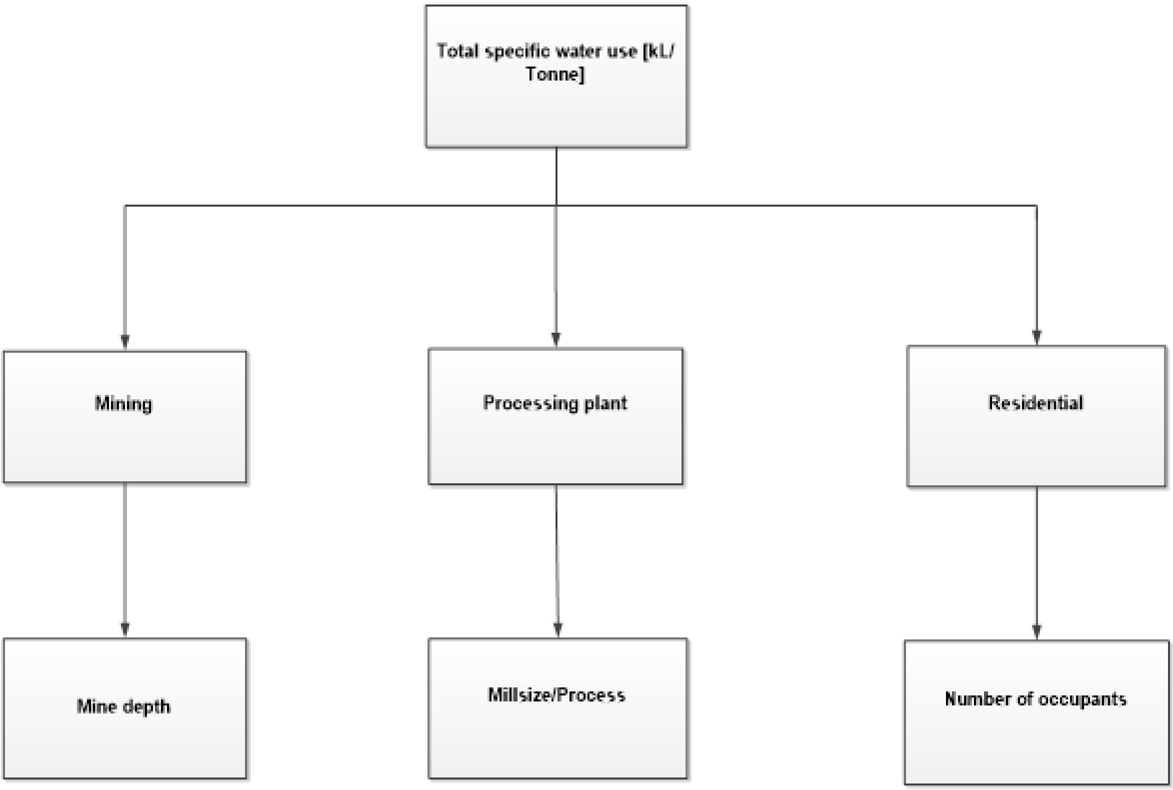


Figure 3.3: Data normalisation (from Chapter 2).

3.3.3 Mining

Tshisekedi [71] and Van der Zee's [70] findings were used to categorise mines according to their depth. Table 3.4 illustrates these categories, where shallow mines are said to be mines with a depth of less than 2 000 metres. Mines exceeding 2 000 metres but are lower than 3 000 metres are said to be medium depth mines while mines with the depth that is greater than 3 000 metres are said to be deep. The depths are only used as categories, equation 5 is used to determine the intensity and therefore benchmark.

Table 3.4 shows all the categories, the mine intensity in kilolitres per rock mined and the calculated benchmark. Without this way of categorising mineshafts, Mine I would have been found to be the best performing mine because it has the lowest intensity. But this mine is the shallowest mine and such a conclusion cannot be made. The average intensity per category is recognised as a benchmark.

In the medium section, Mine D has the highest intensity. This means that Mine D is not performing well according to other mines in this category. The intensity of Mine D was therefore not included in the determination of the final benchmark of this category. At least three mines were used as the guideline stipulates.

Table 3.4: Categorising mines in terms of their depths

Depth	Mines	Intensity [kL/tonne]	Benchmark
Shallow (< 2 000 m)	Mine I	0.19	0.94
	Mine F	1.69	
Medium (< 3 000 m)	Mine A	1.01	1.02
	Mine B	1.34	
	Mine C	0.57	
	Mine D	4.30	
	Mine E	1.29	
	Mine G	0.85	
	Mine K	1.07	
Deep (< 4 000 m)	Mine H	0.43	1.09
	Mine J	1.74	

An irregularity is noted in the deep mine category; Mine H has an intensity that is less than the benchmark of medium mines. This may be due to a variety of reasons. One reason may be as a result of Mine H being situated in a non-arid region. A region is said to be non-arid when it is not characterised by severe lack of available water. This means that water supplied to underground is not only potable but from other non-potable water sources.

3.3.4 Residents

Residential areas occupied by mine workers are more susceptible to high water usage. This is primarily because of a lack of education on water use, as well as unreported maintenance issues such as continuously running showers, malfunctioning toilets and many more. People occupying hostels are not expected to pay for their water use since they are supplying a service to the mine, and this leaves room for water wastage.

In order to find a suitable benchmark for hostel water use, identification of outliers was needed. This is because hostels were only normalised based on the number of occupants. According to an article published by Hunt and Rogers [83], an appropriate benchmark for domestic water use must show how much water is being consumed (Litres), by whom (person) and time period (day). Other critical factors that may be used to normalise water use in hostels include the size of the hostels. Oversized hostels might give room for underutilised infrastructure which might lead to poorer maintenance.

The benchmark was calculated using the number of occupants in this study as it is a globally recognised method. The DWS suggests that outliers are values greater than 400% of the average water use and lower than 25% of the average water used [65]. Figure 3.4 was used to identify outlier hostels.

Not all the mines evaluated in this study have hostels, so only mines that have hostels are plotted. The hostel name coincides with the mine name. This means that the hostel at Mine A will also be referred to as Mine A. Figure 3.4 and Figure 3.5 represent hostels.

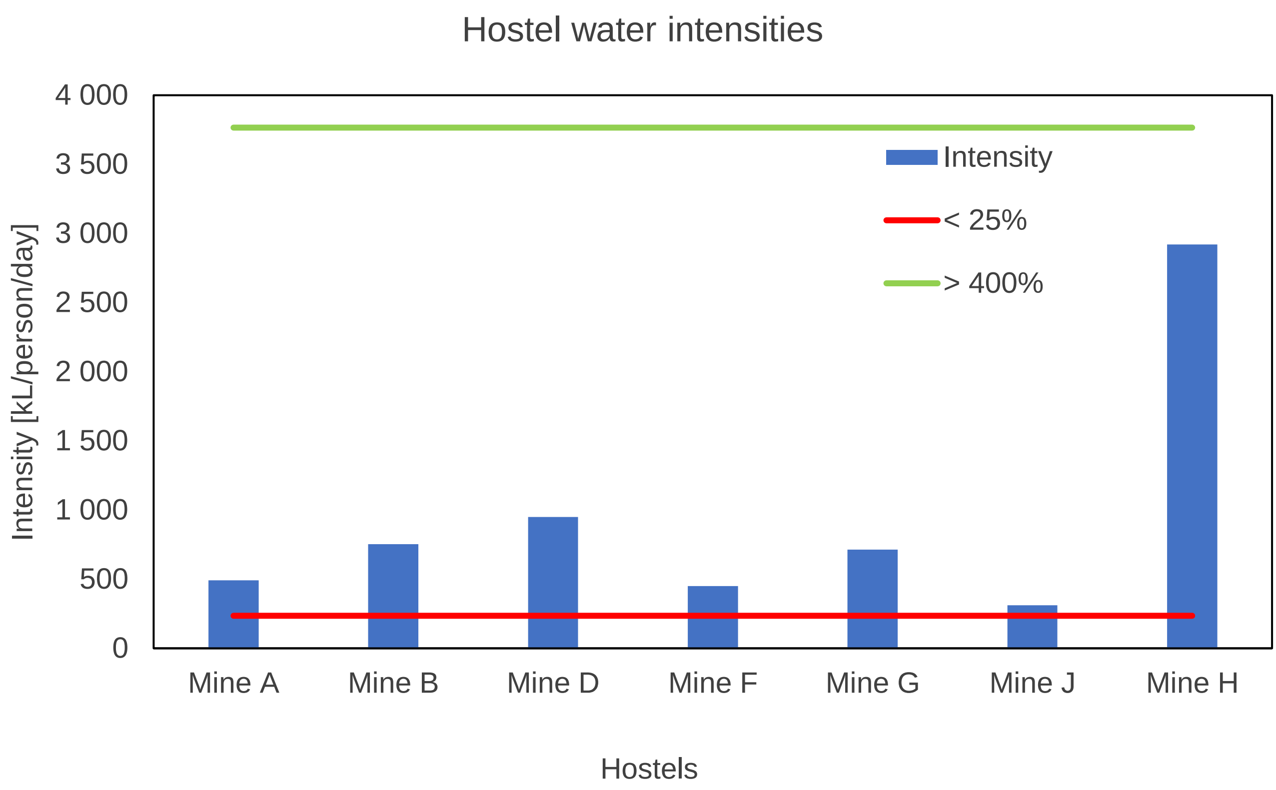


Figure 3.4: Hostel water intensities in kL per number of occupants from sample mine data.

All mines except Mine H are well below the 400% line and above the 25% line and are therefore used to calculate the benchmark. The average benchmark was calculated to be 611.49 L/person/day. This figure is above the national water consumption benchmark of 235 litres per person per day [66] .

The benchmark can be seen in Figure 3.5. Four mines are above the hostel benchmark; however, Mine H is the one that is more concerning and should be investigated further.

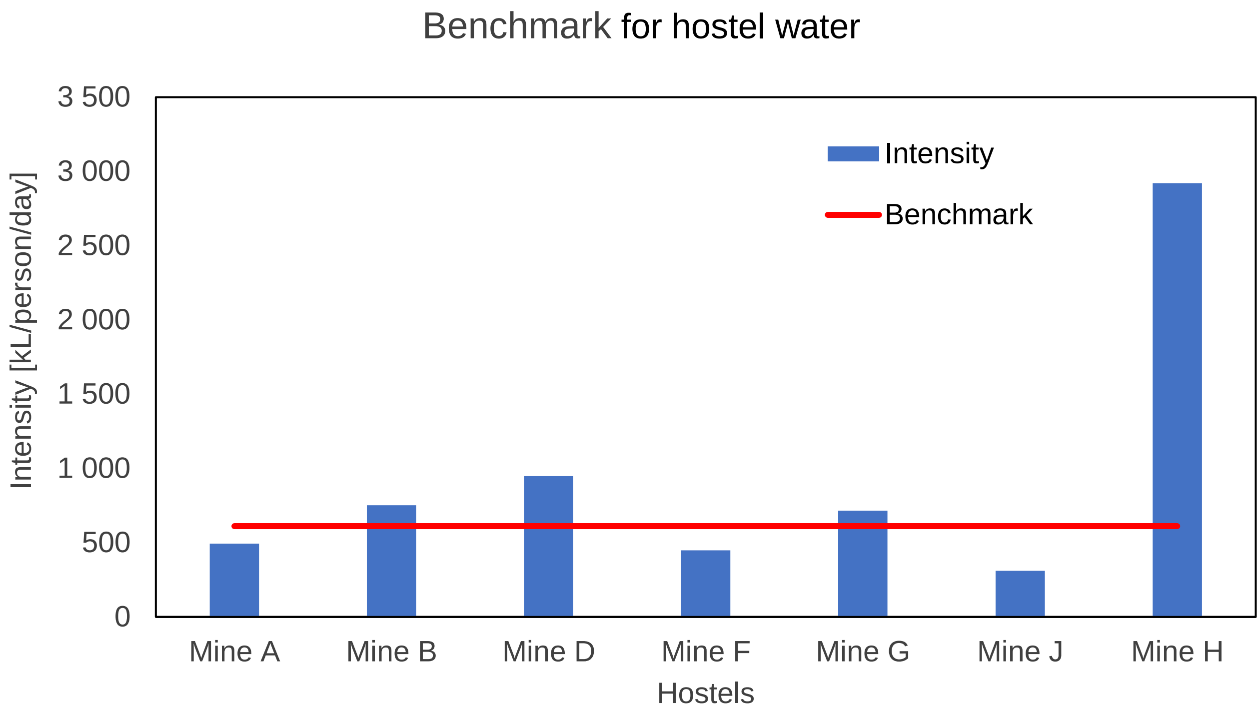


Figure 3.5: Final benchmark for hostel water usage.

3.3.5 Processing plants

Water consumed by the processing plant was normalised using tonnes treated. Some plants are independent from the mineshafts, while others receive tons from more than one mineshaft, for this reason a new naming convention is used. There are seven plants and are named P1 through P7. Table 3.5 maps out which processing plant receives ore from which mine.

Table 3.5: Plant to Mine mapping.

Plant name	Mine providing ore
P1	Mine F
P2	Mine C
P3	Mine A, Mine B, Mine D, Mine E and Mine G
P4	Mine I
P5	Mine H
P6	Reprocessing plant (Tailings reclamation)
P7	Reprocessing plant (Tailings reclamation)

Figure 3.6 below shows all the plants for which data was available. Outliers had to be identified before processing plants that are suitable to be used for the determination of benchmarks can be selected. This is done in line with step 2A of the determination of benchmarks set by the DWS.

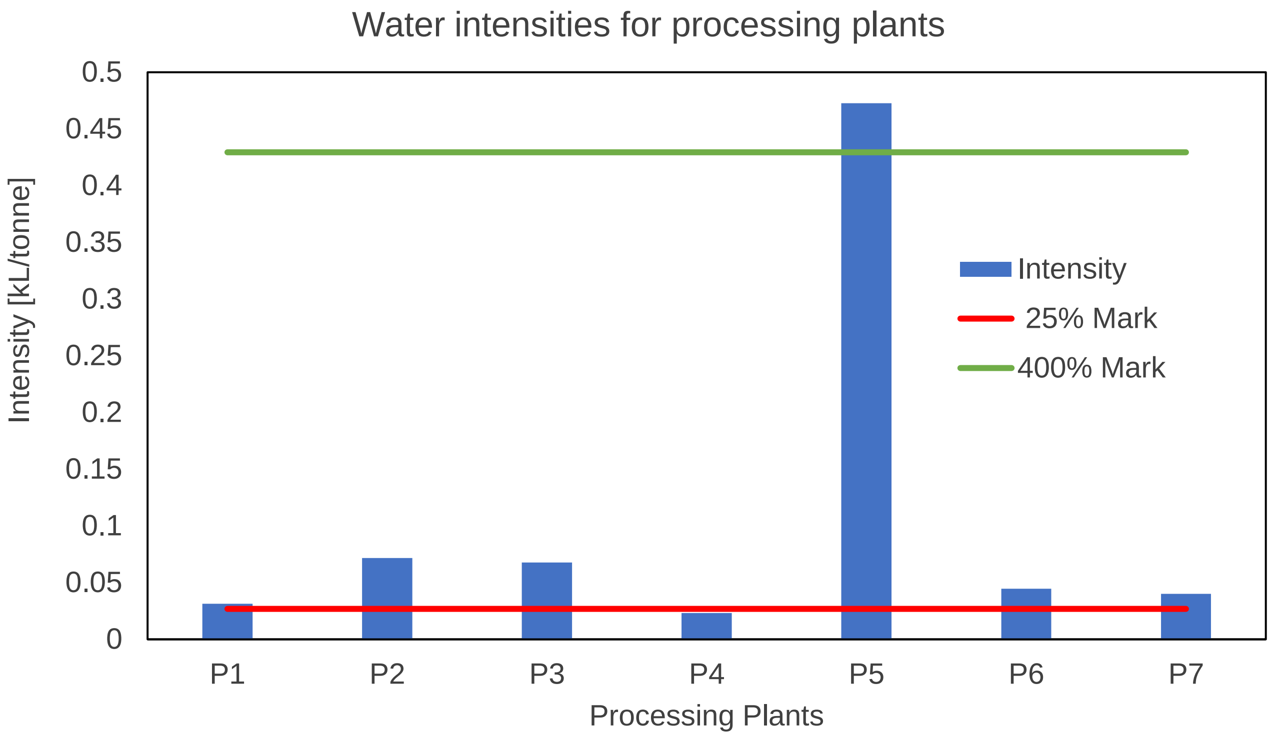


Figure 3.6: Processing plant intensities in kL per tonnes processed from sample mine data.

P5 proves to be an obvious outlier since it has an intensity that is above 400% of the average intensity. P1 and P4 are below 25% of the average and may also be outliers, however P5 may be influencing this result. P5 is removed from the population to identify if P1 and P4 are actual outliers. From Figure 3.7, it can be seen that P1 and P4 do not fall under the 25% mark and should not be classified as outliers.

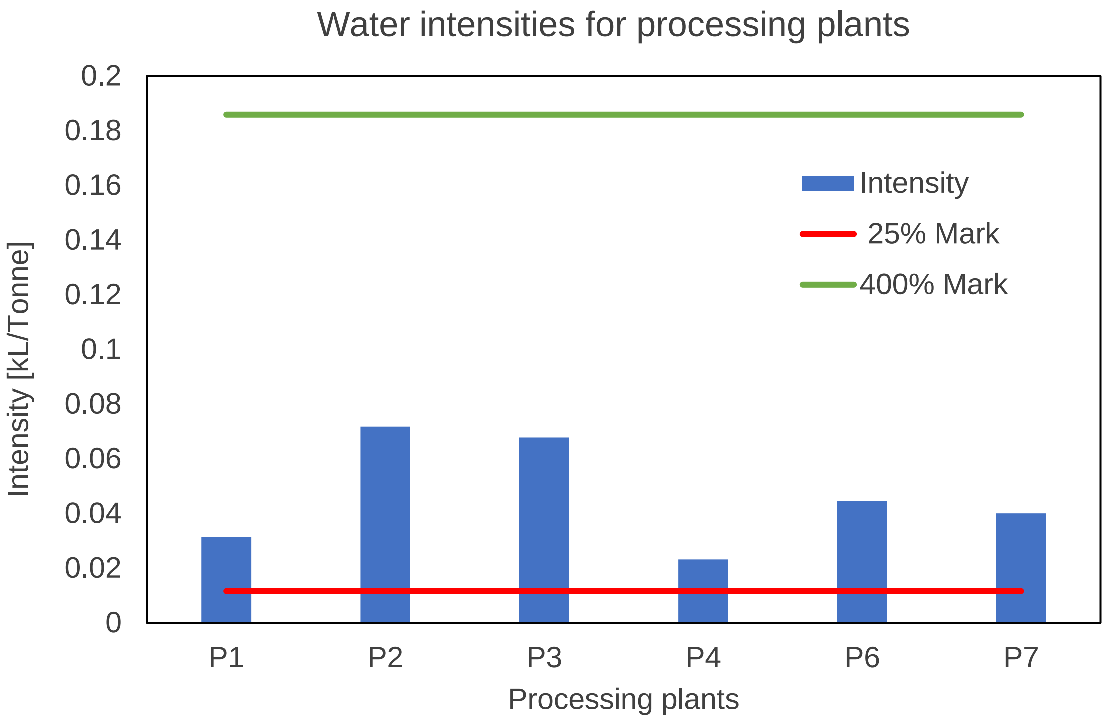


Figure 3.7: Processing plant intensities in kL per tonnes processed excluding P5.

All plants excluding P5 may be used to determine the benchmark since Figure 3.7 shows that they are not outliers. From Table 3.5, It was seen that not all the plants assessed are the same. P1 through P5 process ore from mineshafts, while P6 and P7 are reprocessing plants. Reprocessing plants receive material that is already crashed and has been pre-treated. Water needs for reprocessing plants and normal plants are not the same. Figure 3.8 shows the benchmark calculated excluding P5, P6 and P7.

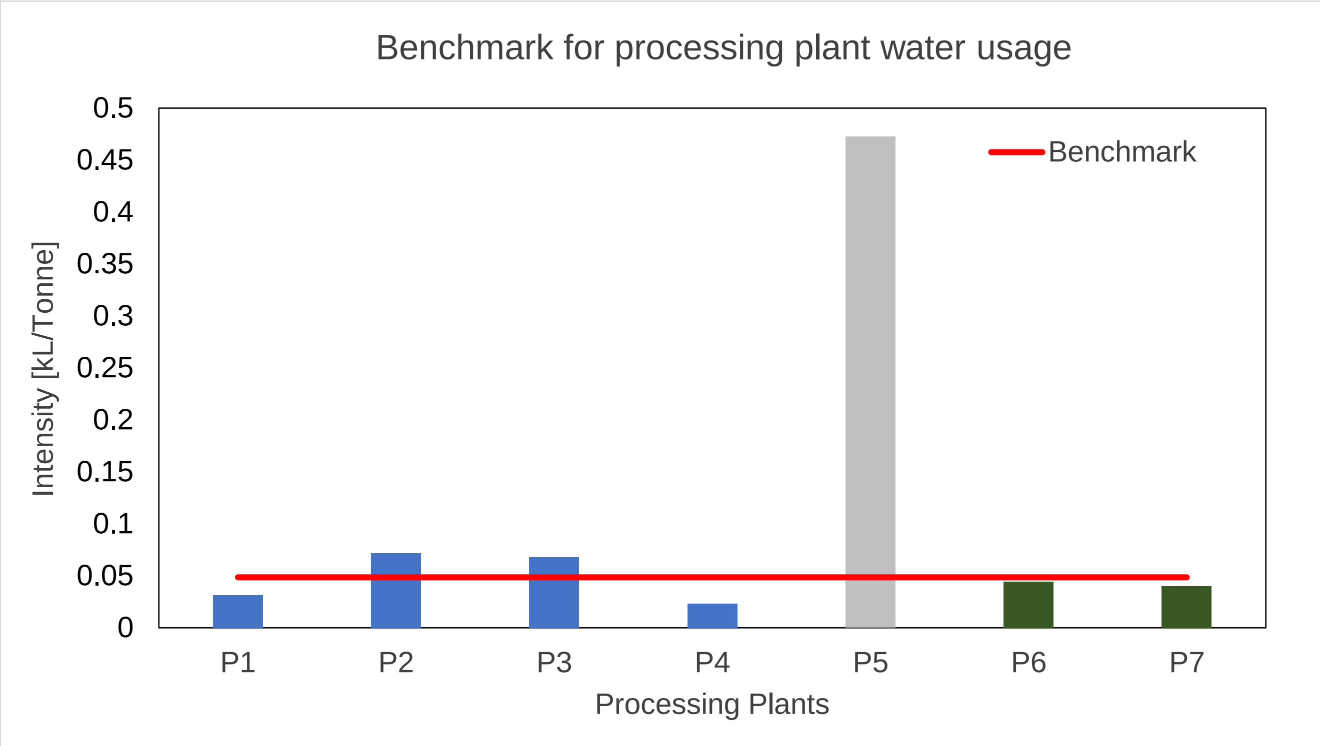
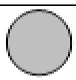
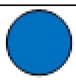
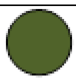


Figure 3.8: Final benchmark for processing plants.

Table 3.6 gives detailed description of what each colour represents.

Table 3.6: Plant classification

Plant colour	Description
	Outlier Plant (above 400%).
	Plants that receive Ore directly from a mineshaft/s. The ore still requires milling, these plants are called normal plants in this study.
	These are reprocessing plants; no milling is required since the reef has been processed before.

The benchmark was therefore calculated using P1, P2, P3 and P4. Although P2, P3 and P5 exceed the benchmark, P5 is the more concerning operation.

3.3.6 BENCHMARKS

The purpose of determining benchmarks was to ensure that conservation methods are applied to the correct operational facilities of the mine and to identify water savings opportunities. The benchmarks help identify operations that are least performing in the different categories. The selection of case studies was made according to the calculated benchmark. Table 3.7 gives a summary of the case studies selected and the calculated benchmarks.

Table 3.7: Case study selection

Category/Section	Benchmark	Selected case study	Selected case study intensities
Mining	1.02 [kL/tonne]	Mine D	4.3 [kL/tonne]
Hostels	611.49 [L/person/day]	Mine H	3 191 [L/person/day]
Plant	0.05 [kL/tonne treated]	P5	0.59 [kL/tonne treated]

For the mining category, only Mine D stands out with an intensity that is four times higher than the intensities in its depth category. This means that further investigations need to be made, and implementation of possible measures need to be taken. Hostel at Mine H and P5 belong to the same operation but will not form part of the same case study since they have unique cases. Mine H hostel had an intensity of 3 191 L/person/day and the plant had an intensity of about 0.59 kL/tonnes treated. These figures are well above the benchmarks calculated and will therefore need further investigations.

3.4 IMPLEMENTATION AND RESULTS

This section describes the application of the last steps of the six-step strategy, namely investigation, implementation and reporting that all fall under section 2.4 of the dissertation. The following subsections combine section (i) and (ii) of 2.4. These steps are only applied to the mines that were found to be the worst performing from the use of benchmarks.

The operations belong to one umbrella company and have the same managers; all environmental managers, foreman and engineers were informed on the results from benchmarking their operations. Both the benchmarking procedure and Table 3.7 were sent to all decision makers. Details of how the case studies were investigated and implementation are discussed in the sections that follow. Permission was granted by decision makers to solve current problems as efficiently as possible.

3.4.1 CASE STUDY 1

Mine D has two surface shafts (the east and the west shafts). Mining is conducted to a depth of 2 365 metres. Ore is transported 7 km away for processing. This deep-level operation conducts mostly dispersed mining on the Basal Reef with around a quarter of its mining activities involving remainder pillar extraction.

Mine D is located in South Africa's Freestate Province. According to Figure 1.3, Mine D is in a medium to high water risk area, this means that the availability of non-potable water is limited. Mine D, therefore, receives most of its water from potable water supplies around the mine.

It was identified that the main problem or irregularity is at the shaft because the shaft intensity was four times the intensity of other mines in its depth category. Mine D supplies its ore to P3, which also receives ore from four other mineshafts. P3 was not identified as a concerning processing plant and will not be part of the case study. Water use is divided between the mining section and hostel section. The hostel consumed 948 L/ person/day. This figure is just above the benchmark and does not give reason for concern. However, it can be investigated further.

To begin with the investigation section, a water balance layout was constructed and reviewed in depth as section 2.4i suggests. The water balance layout in Figure 3.9 shows all pipelines leaving the water service provider to the shafts and where water is distributed within the shaft.

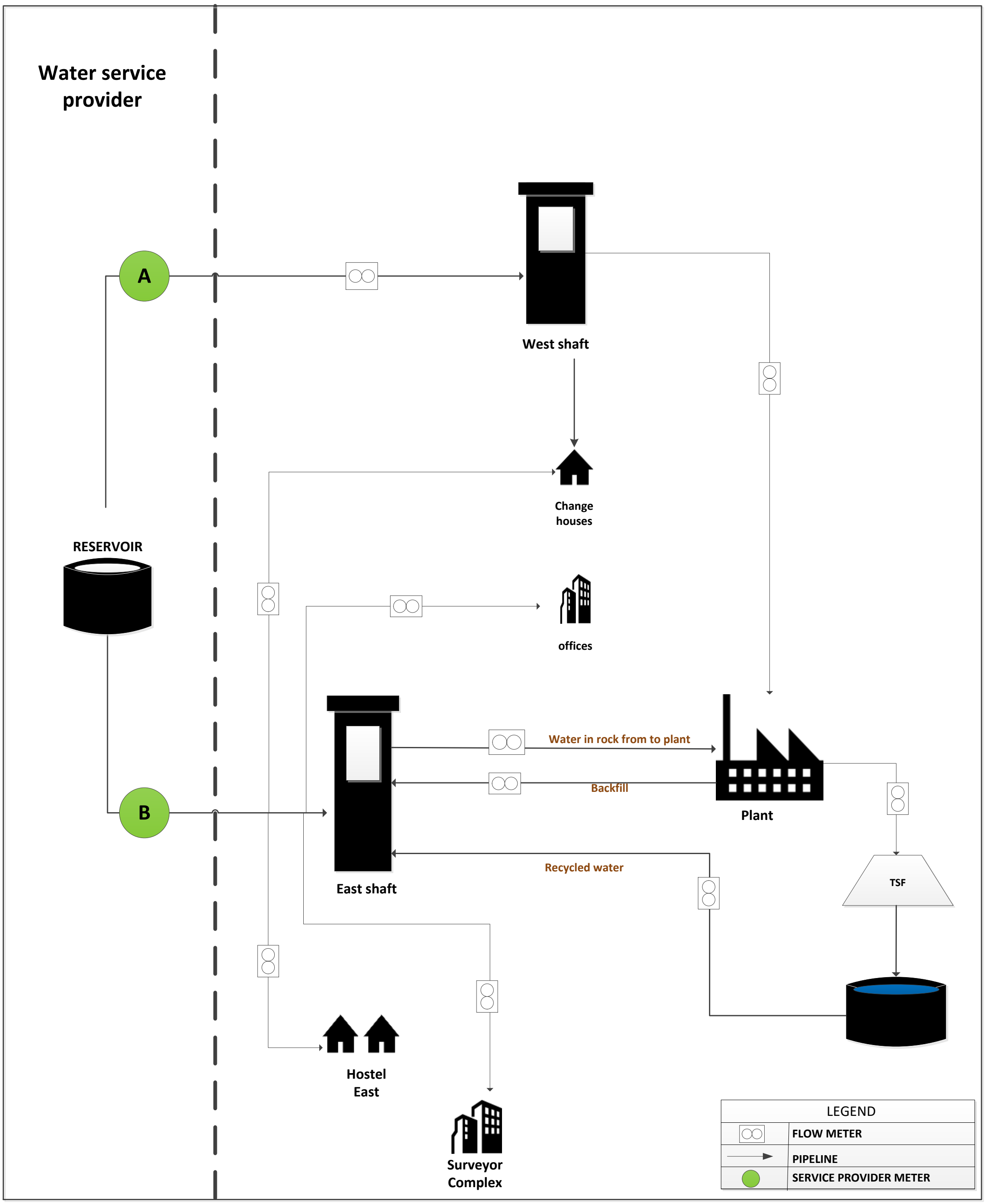


Figure 3.9: Mine D potable water distribution layout.

This is the overall water balance and does not show the intricate details of how water is supplied within the shafts. It was identified that water to the hostels is not the main problem. The water sent to the offices is assumed to be insignificant. However, it is important to follow the pipelines going to these destinations to ensure that there are no leaks and that meters are functional. A boundary was drawn around the shaft area since it is the area of focus as stipulated by the benchmarking methodology and case study selection.

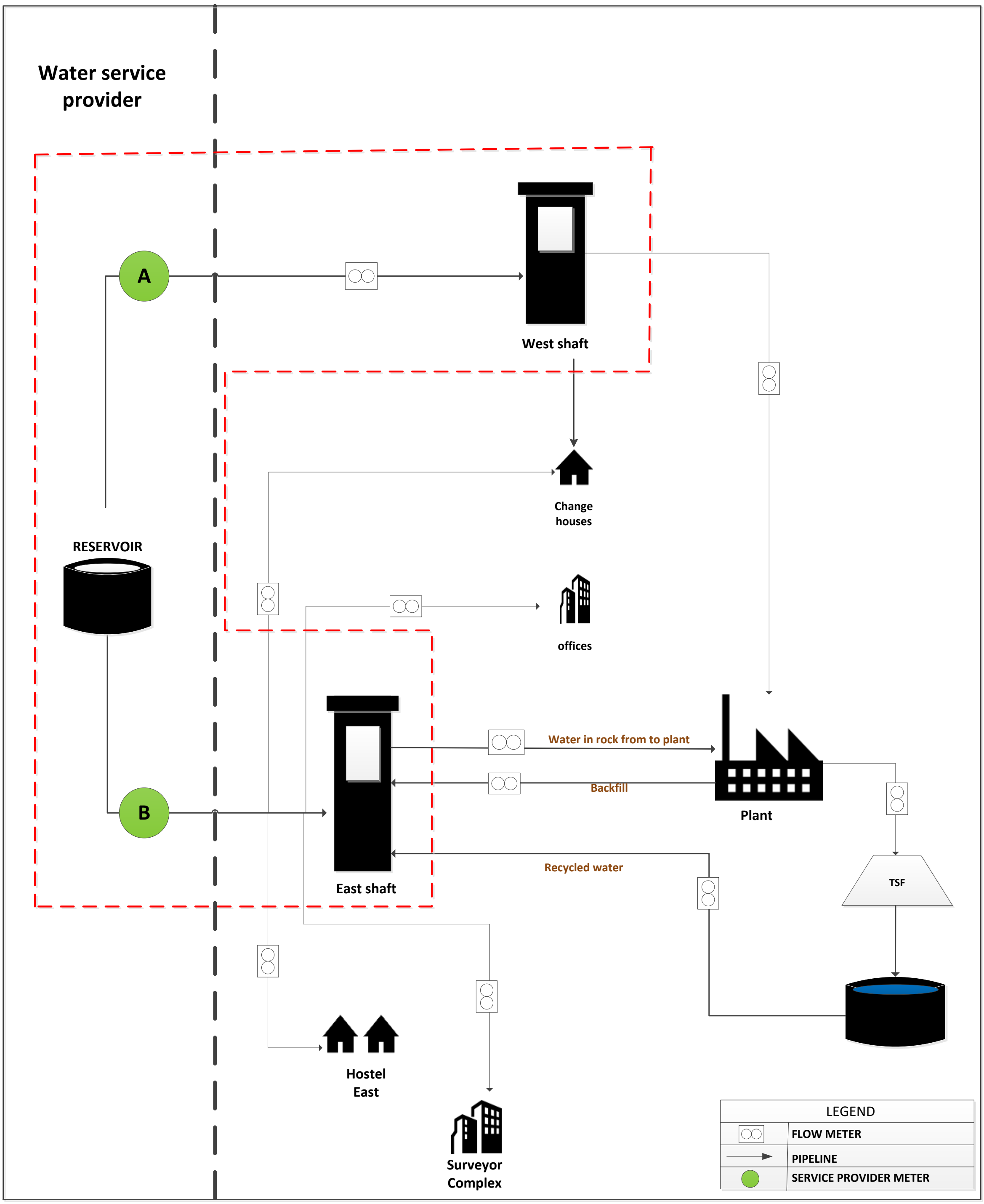


Figure 3.10 : Boundary of focal points for Mine D.

Invoices are known to be valid source of information and are mostly used as information sources by the mining industry [31], [84]. Although invoices are trusted, caution should be taken when relying on invoices. Mine D receives water from the municipality using two pipelines. These pipelines are A and B as indicated in the water layout in Figure 3.10. Meter A supplies potable water to the west shaft and is located 3.14 km from the shaft itself. While the meter B is located about 2.9 km from the east shaft.

The distance between the shaft and the municipal water supply makes it possible for delay in in response-times for leaks. It was also discovered that the pipeline was located 0.5 m underground next to an untravelled road. This further limit access to the pipeline for inspections and complicates the execution of routine maintenance. The invoices from the service provider showed that high volumes of water are being consumed by the mine. This, however, did not make sense because the operation hoists an average of 23 000 tonnes per month and is close to its closure. This is a relatively low figure compared to other mineshafts.

There were no secondary meters at the shaft inlet to prove that the volume reported by the service provider is correct. Due to low amounts of tonnes produced, ultrasonic meters were placed at the shaft inlets in March 2019. The ultrasonic meters are labelled west meter and east meter in Figure 3.11, while the service provider meters are labelled A and B. The ultrasonic meters proved that there were water flow differences between water received by the shafts and water reported on the invoices. Further investigations needed to be made to understand the difference in readings. A detailed water audit was conducted. Figure 3.11 also shows the two pipelines evaluated. The two colours are used to show that meters A and B are independent from each other and that water doesn’t flow in the same pipeline.

Figure 3.11: Mine D pipeline representation.

A comparison of meter readings provided by water service provider and readings at the shaft was implemented. This enabled the investigator to see if there are any significant leakages within the system. The data was observed for a period four months. The meters were monitored weekly and results are summarised in Table 3.8.

Table 3.8: Meter reading comparison

Week	**A [kL]**	**West meter [kL]**	**% Difference**	**B [kL]**	**East meter [kL]**	**% Difference**
Week 1	475	2	99%	17 610	17 570	0%
Week 2	544	9	98%	18 330	15 990	15%
Week 3	70	17	75%	19 080	18 120	5%
Week 4	68	2	97%	18 770	17 620	7%
Week 5	89	12	86%	18 230	17 630	3%

Table 3.8 above clearly indicates the discrepancy between meter A that belongs to the service provider and the west meter; it also shows the discrepancy between meter B and the east meter. Leaks were discovered during the water audit.

Figure 3.12 illustrates all the water leaks identified between the two measurement points.

Figure 3.12: Leak locations.

Six leaks were identified on the pipeline to the west shaft. Only one leak was identified on the pipeline going to the east shaft. All identified leaks were closed by the instrumentation foreman. The before and after pictures are shown in Table 3.9.

Table 3.9: Implemented repairs

Before		
After		

3.4.2 SAVINGS ACHIEVED

The project began after the determination of benchmarks using financial year 2018 data. Financial year 2019 data was used for investigation, implementation and development of strategy. Although the project took place from July 2018 to June 2019, savings were only achieved towards the end of the project. Figure 3.13 shows when implementation took place and the continuous decline of water usage.

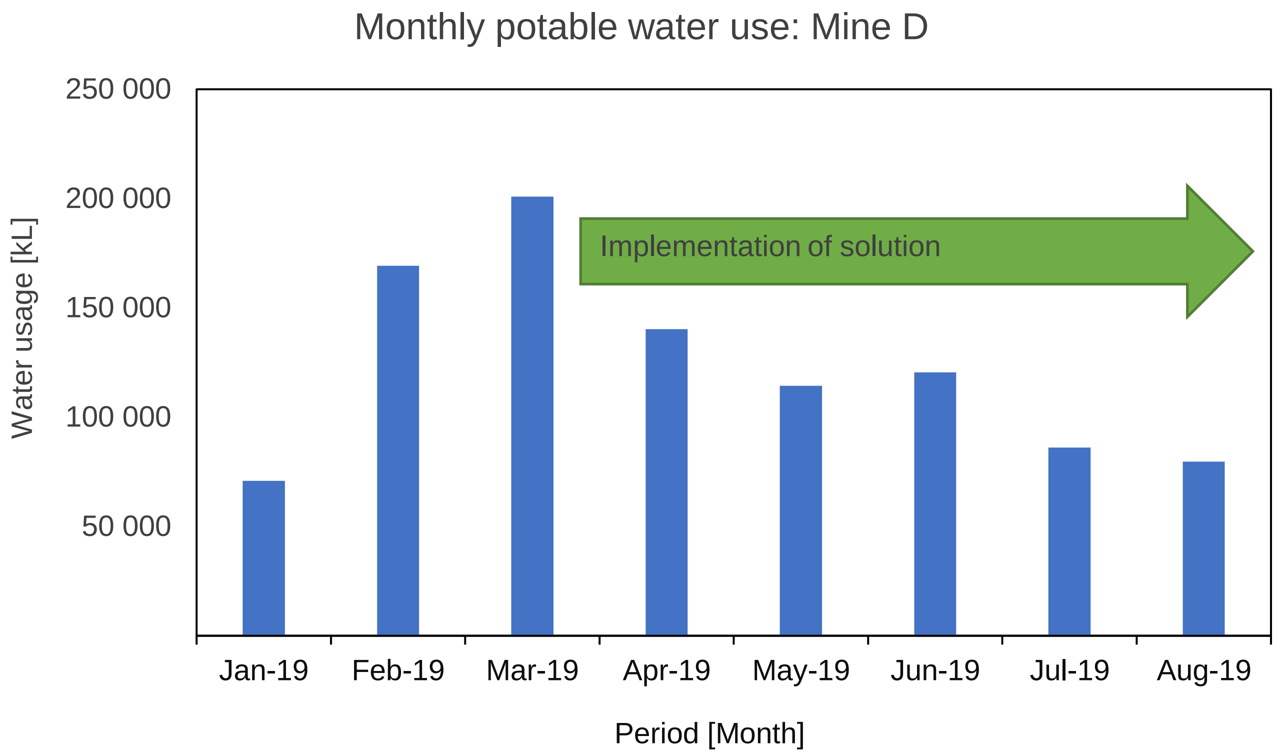


Figure 3.13: Mine D water usage in kL per month.

Figure 3.13 indicates that the conservation strategy was effective. The strategy was only implemented in March 2019 and a continuous reduction in water consumption was realised. In order to quantify the savings achieved, a comparative parameter must be selected. From Figure 3.13, the water consumed in March 2019 can be used to compare water use before and after strategy implementation. However, to be more conservative, historical data is used to identify whether the March 2019 water consumption could indeed be used as a baseline. Historic data for the three months before implementation is evaluated and shown in Figure 3.14.

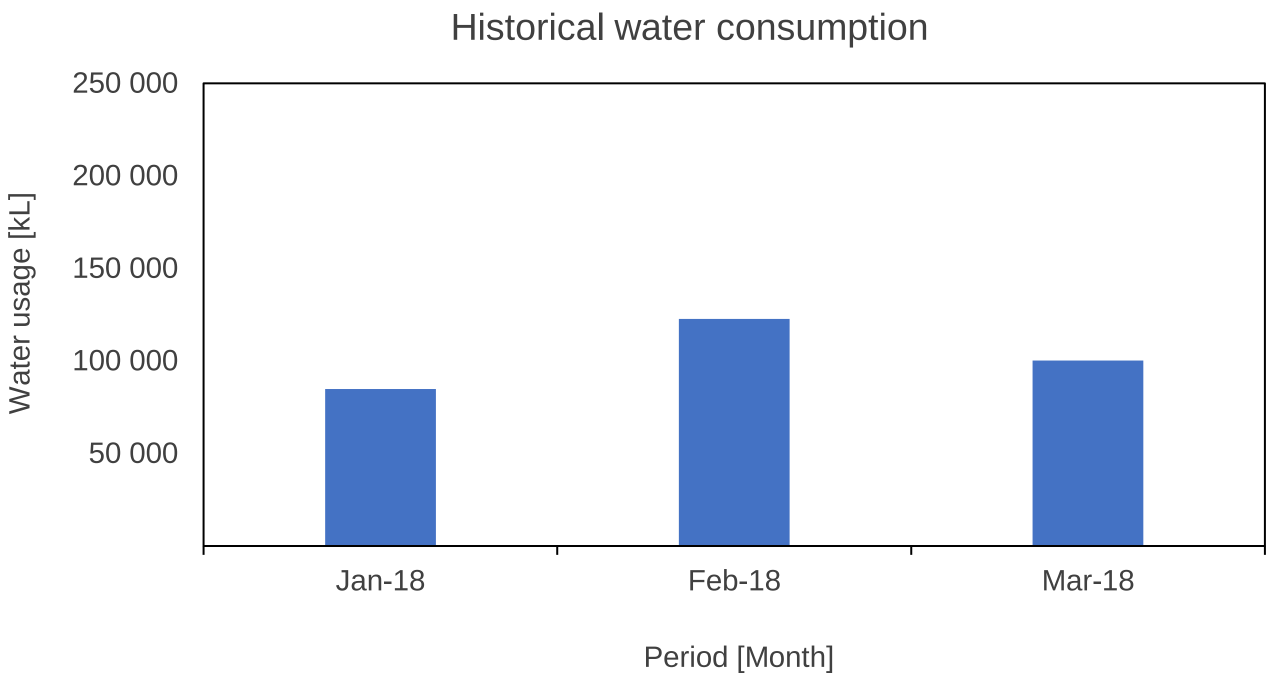


Figure 3.14: Historical water consumption of Mine D

A month-to-month comparison between 2018 and 2019 data was conducted. Using Figure 3.14, and Figure 3.13 it can be seen that the January 2018 and January 2019 water consumption values are similar, no irregularity is noted in the comparison. When comparing February 2018 consumption and February 2019, February 2018 is lower than 2019 water consumption. Similarly, March 2018 data was compared to March 2019 data. It can be seen that the March 2019 water consumption is much higher than the March 2018 water consumption. Also, in 2018 the water consumption over the three months were very similar in quantity. This is not the case for January to March in 2019.

From the analysis discussed above, it is clear that Mine D was performing poorly in February 2019 and March 2019. If the strategy was not implemented, it can be assumed that the following months would have followed the same trend. Since no irregularity was found in the January to January comparison. The average consumption during February and March 2019 can be used as a conservative baseline. Figure 3.15 shows the baseline plotted as well as the monthly water consumption of Mine D.

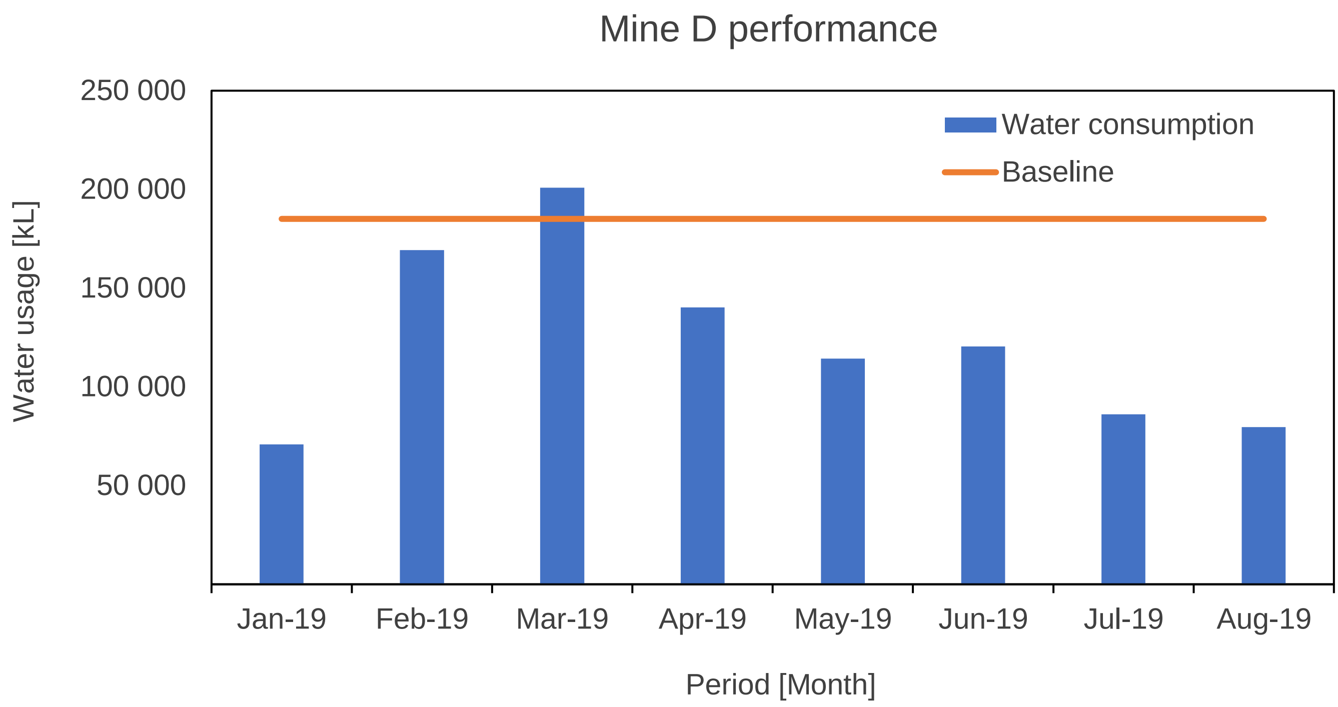


Figure 3.15: Mine D performance against the baseline.

With the baseline defined, water savings can be quantified. Figure 3.16 shows savings achieved graphically.

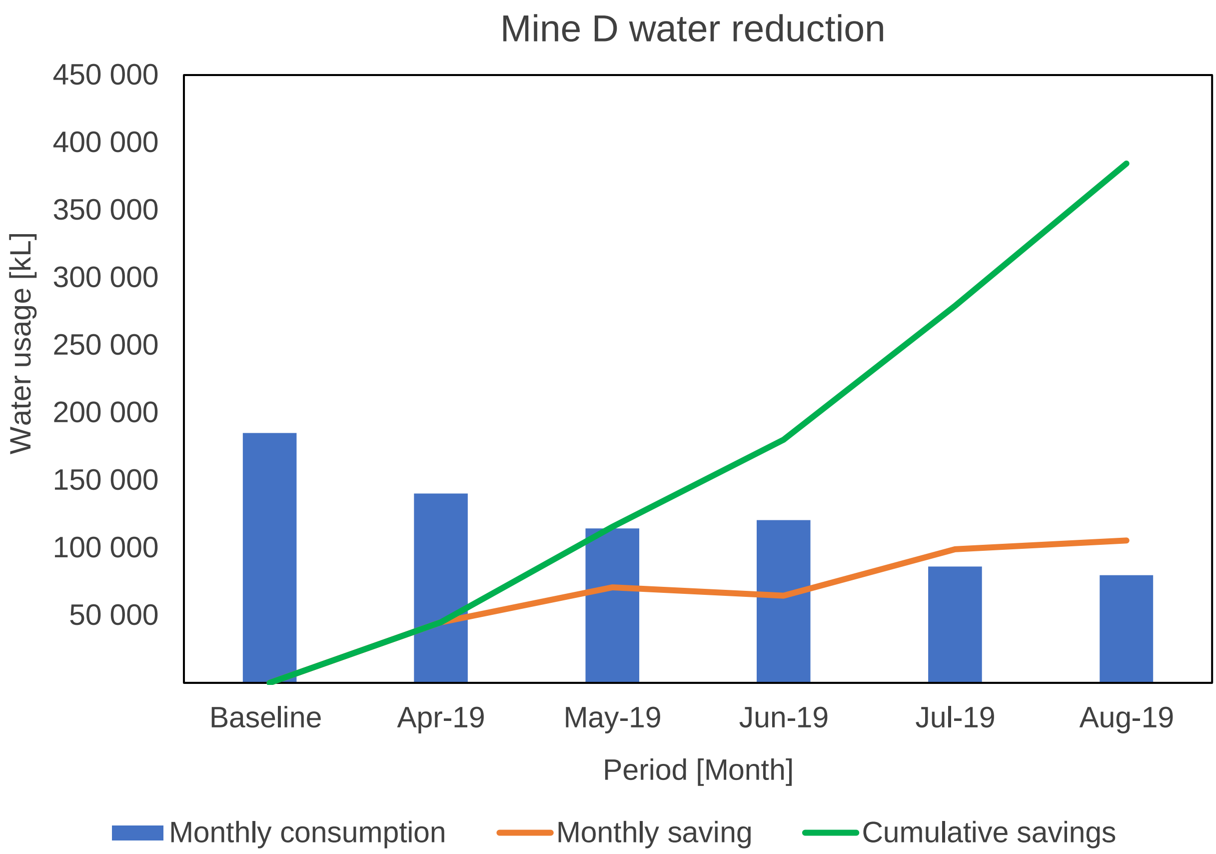


Figure 3.16: Savings achieved at Mine D in kL.

Figure 3.16 clearly shows that water consumed by Mine D continuously decreases, this means that water is being saved monthly. A total of 384 480 kL was saved up to August 2019. The water tariff for this facility is R6 per kL, the total cost saving achieved is therefore R2.3 million and an estimated R5.5 million per annum can be expected.

To validate that the method indeed worked, the previously calculated intensity of Mine D provided in Table 3.4 was compared with the intensity after strategy implementation (April 2019 to August 2019). Figure 3.17 shows a significant decrease of water-use intensity at the shaft after implementation. The graph shows that the strategy is efficient in selecting key failing facilities.

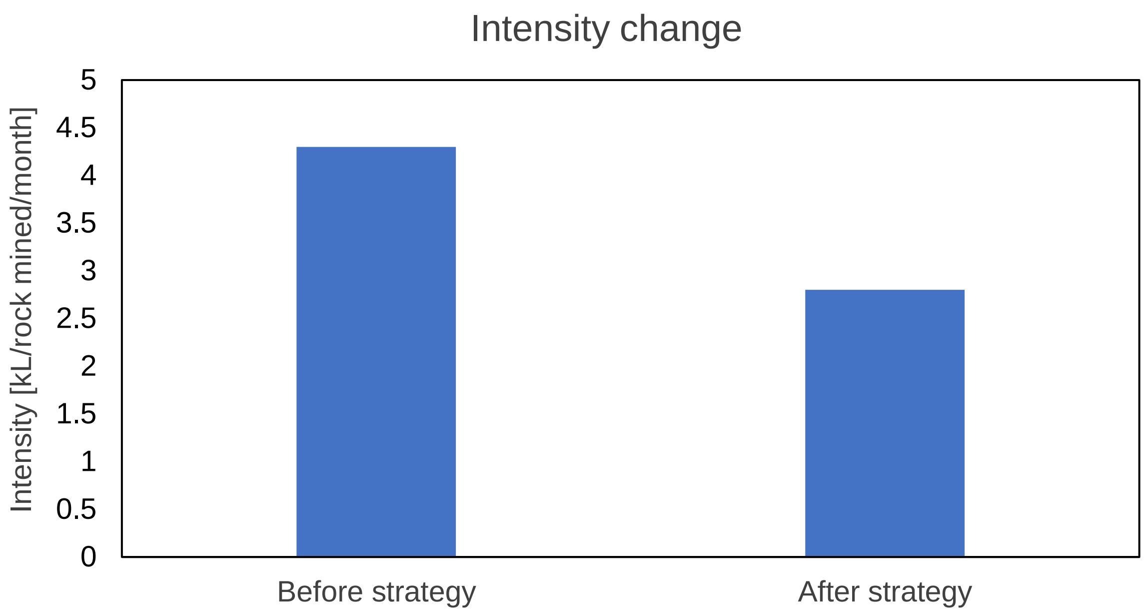


Figure 3.17: Results before and after strategy implementation.

The intensity was calculated to be 2.8 kL/rock mined. This figure is still above the calculated benchmark; however, further investigations will still be made to identify where other water losses are.

3.4.3 CASE STUDY 2

Mine H is located near the Gauteng and Northwest border, according to Figure 1.3, this region is a high-water scarce area. The mine comprises twin vertical and twin sub-vertical shaft systems, this factor is an indication of how deep this mine is. The mine uses conventional mining methods and has a depth of 3 388 metres. Ore mined is treated at the same operation and is referred to as P5 in this study.

The benchmarking method showed that water conservation measures must be implemented in two sections of Mine H: the hostel area and the processing plant. No layout was available prior to the investigation and mine individuals only had limited knowledge of the water reticulation system. Water layouts, therefore, had to be generated as part of this investigation.

During the layout investigation, it was found that the Mine H receives water from two reservoirs: one is named the East reservoir and the second is named the West reservoir. These reservoirs supply water to different sections of the operation. The layout for the East reservoir's water distribution was generated for Case study 2 and is shown on Figure 3.18. Only the East reservoir is considered for Case study 2 because it supplies water to the hostel. From Figure 3.18 it is seen that water from the East reservoir is mainly supplied to the residential areas and the operation's external third parties.

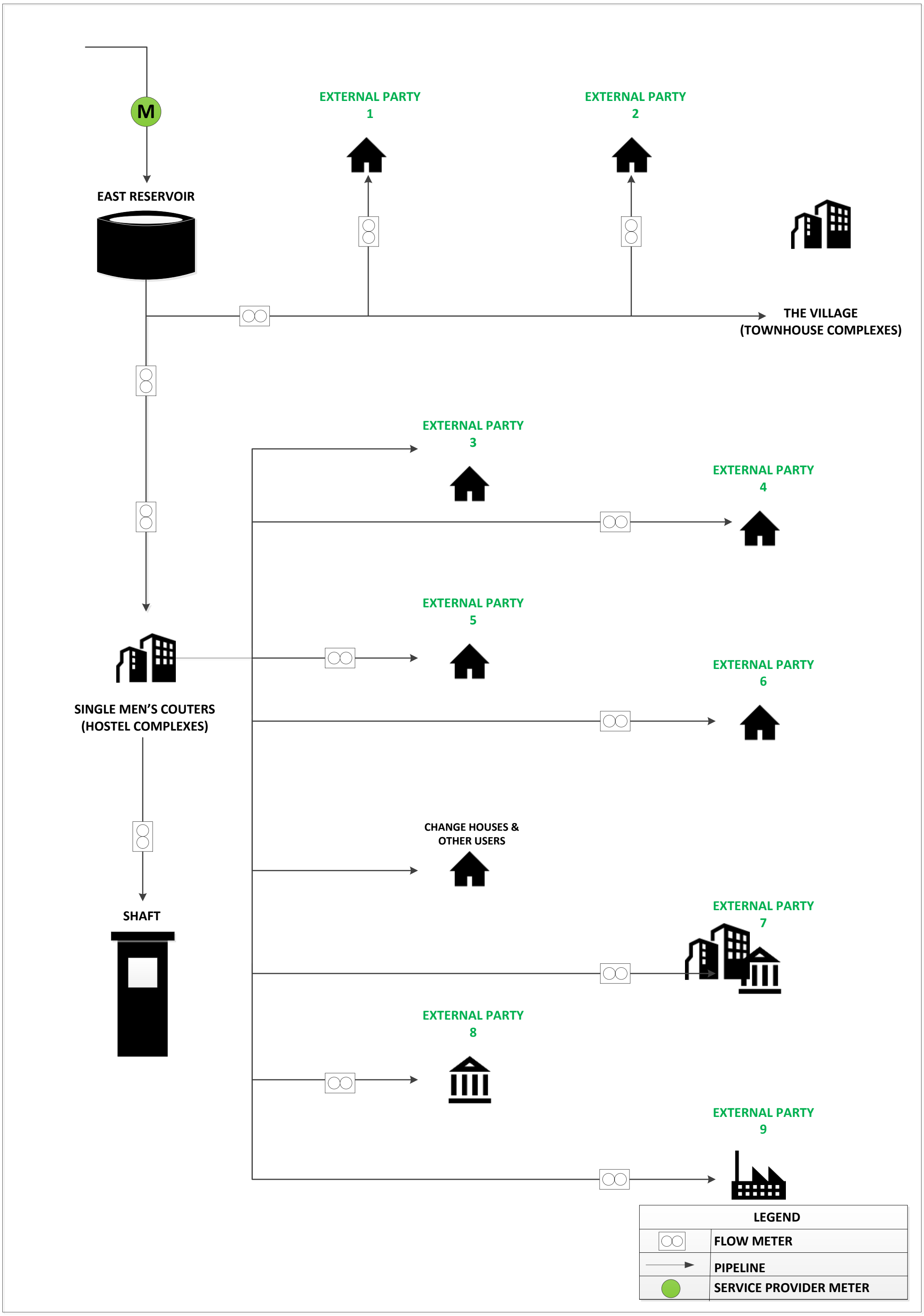


Figure 3.18: Mine H East reservoir water layout.

Since the outcome of the benchmarking methodology in Figure 3.5 revealed that the hostel at Mine H had a significantly higher consumption in comparison to other hostels in this study, a detailed investigation was conducted. The investigation process included walking through all the pipelines to identify leaks, searching for bypass pipelines and monitoring the functionality of meters by installing ultrasonic flowmeters.

The results of the water audit are shown in Figure 3.19. Measurements were taken at various points using an ultrasonic meter. The purpose of this was to determine the average flow per second in the pipelines, a water balance calculation was also completed. The meter readings taken at the different points are also shown in the Figure 3.19. The measurements were done in January 2019. From Figure 3.19 the meter to the hostels reads 40 L/s which is a relatively high amount of water for hostel consumption per second.

Further water audits were conducted, and two pipelines receiving water from the main pipeline were discovered: the one pipeline was found to be going to the operation's workshops while the other pipeline was unknown. An ultrasonic flow meter was installed at the hostel inlet, after the two pipelines to determine the actual consumption of the hostel. It was found that the consumption was 23 L/s, the meter readings are provided in Figure 1 of APPENDIX C. The measurements were taken separately, and a mass balance was used to validate the resulting values, that is, since water to the hostel was measured to be 40 L/s, it was expected that water flowing to the three different streams added up to 40 L/s by mass balance.

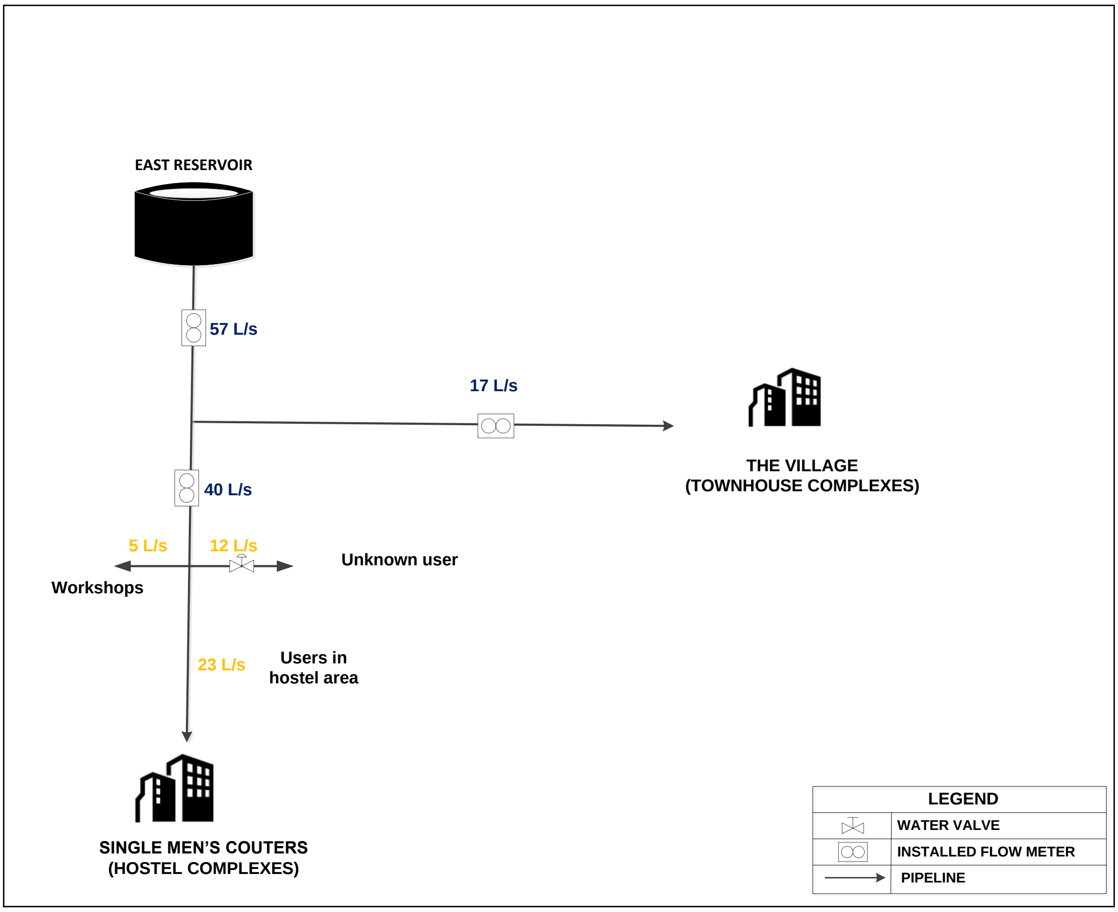


Figure 3.19: Mine H hostel focal point.

The results obtained were communicated to the mine engineer before any decision could be made. The engineer was also unaware of the unknown pipeline. Permission was then granted by the engineer in January 2019 to close the valve of the pipeline going to the unknown user. Figure 3.20 shows how the hostel water consumption changed from January 2019.

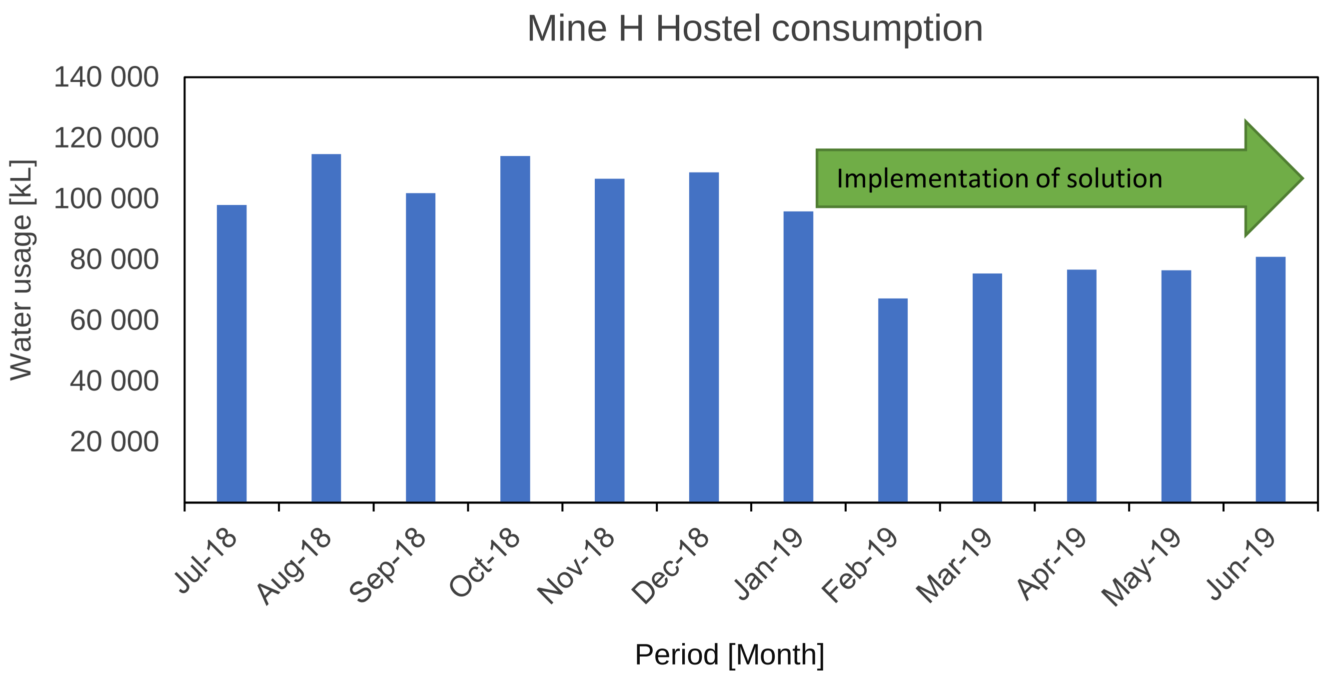


Figure 3.20: Water consumption reduction at the hostel.

The strategy was only implemented in January 2019. The baseline is the average prior to implementation and in this case, the baseline was calculated to be the average water consumed from July 2018 to January 2019. The baseline is calculated for these months because the consumption was consistently high. It is assumed that the consumption would follow the same trend if the strategy was not implemented. The baseline gives a good representation of the hostel performance prior to implementation. Table 3.10 shows the months used to calculate the baseline as well as water consumption in those months.

Table 3.10: Mine H hostel baseline determination.

Month	**Water consumed [kL]**
Jul-18	97 912
Aug-18	114 712
Sep-18	101 822
Oct-18	114 084
Nov-18	106 601
Dec-18	108 689
Jan-19	95 893
Average	105 673

The baseline as well as the monthly consumption of the hostel are shown in Figure 3.21 below.

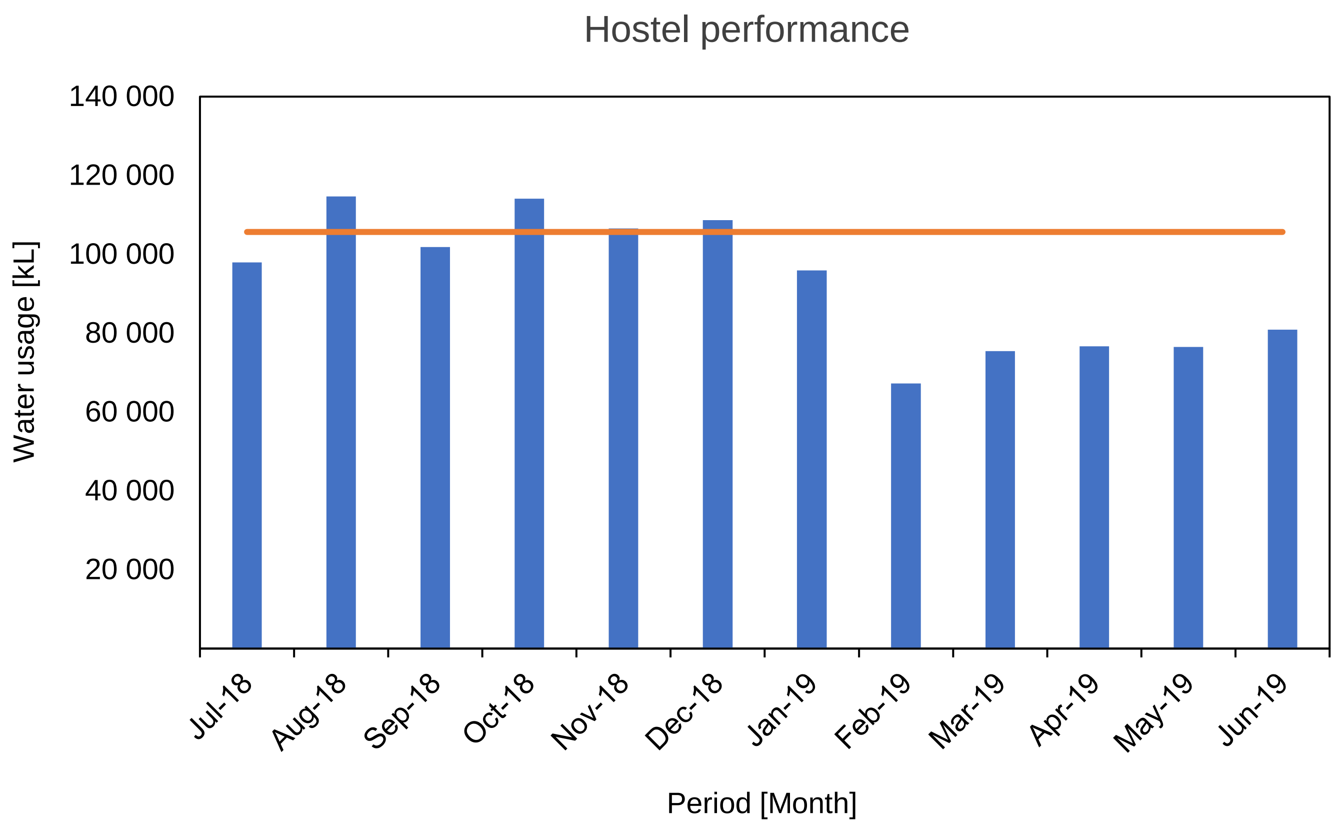


Figure 3.21: Hostel performance against the baseline.

From Figure 3.21, it can clearly be seen that water consumed after strategy implementation is lower than the baseline and the monthly consumption prior to implementation. With the baseline clearly defined, savings can be quantified. Monthly savings and cumulative savings are determined relative to the baseline. Figure 3.22 gives a graphical representation of the savings achieved.

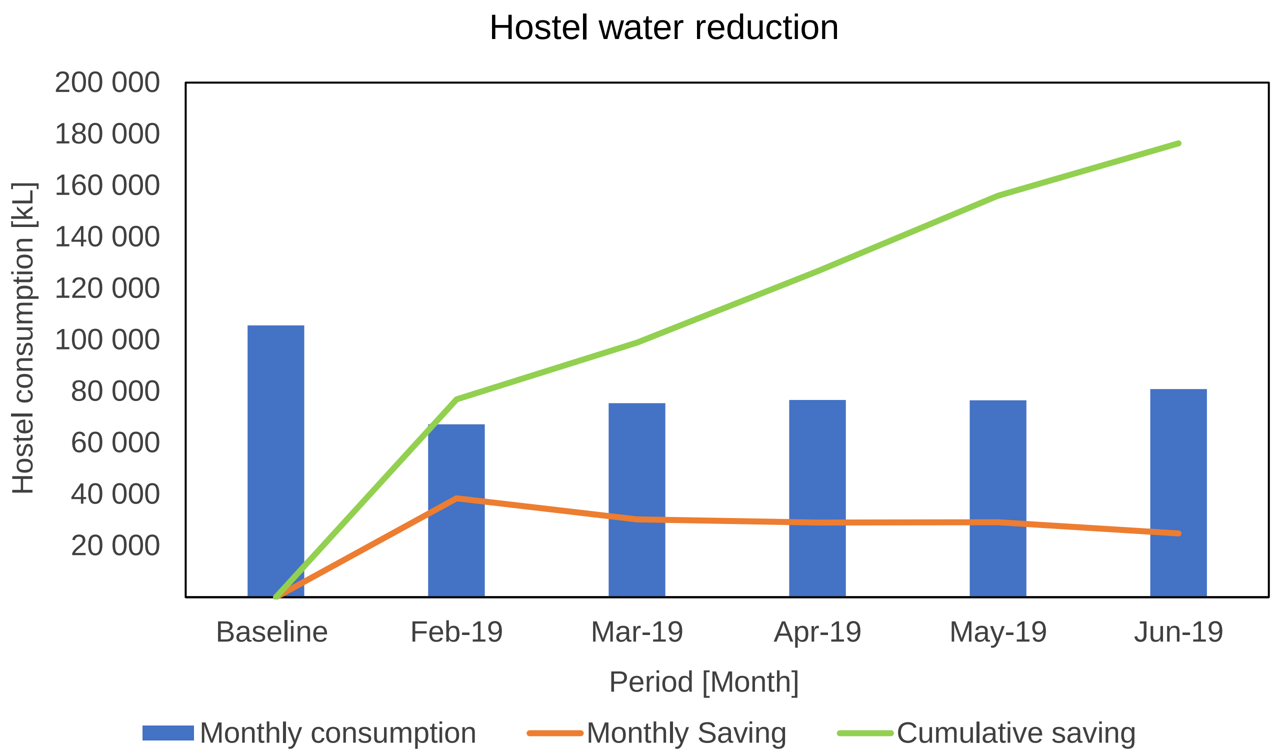


Figure 3.22: Savings achieved at the hostel in kL.

The cumulative savings curve gives a total water saving of 151 609 kL in June 2019. The water tariff at the hostel area is R18.9/kL, which gives a total financial saving of R2.9 million and an estimated annual saving of R6.9 million if the valve remains closed. No impacts were identified after closing the valve, however there is an ongoing investigation to ensure that the valve closure does not impact the process negatively.

The benchmarking methodology revealed that the hostel at Mine H was inefficient relative to other hostels. Table 3.11 gives the hostel water intensity reported in Table 3.7 and the final intensity calculated from February 2019 to June 2019. The decline in intensity proves that the correct facility was selected.

Table 3.11: Results summary.

	Intensity
Before strategy	3 191 L/person/day
After strategy	2 233 L/person/day

From Table 3.11, the intensity decreased by 43%. Although the strategy resulted in a big saving financially, the consumption at the hostel is still higher than the calculated benchmark of 611.49 L/person/day. Further investigations should be made to identify water leakages along the pipelines and to investigate the water culture of the occupants at the hostels. It is highly possible that water is being wasted and taps are left open. Ongoing consultations and education of the importance of conserving water is being implemented at the hostel.

3.4.4 CASE STUDY 3

Case study 3 is in the same mine as Case study 2. The benchmarking methodology revealed that P5, which receives ore from Mine H exceeds the benchmark and should be monitored. Water to the plant comes from the West reservoir of mine H and not the East, but since the plant is another area of focus, the layout of water distribution in the West reservoir was also generated. As seen in

Figure 3.23, the outlet of the West reservoir immediately splits into two pipelines A and B. The pipeline A supplies water to the gold processing plant, the waste washing plant and the condenser make-up water. It is also used to top-up the flow to underground from the water treatment plant (WTP). The flow of potable water to underground is controlled through a manual valve that is referred to as the Water Board (WB) valve.

Pipeline B supplies office buildings near the storerooms, before it flows to main security gate. From there, lines tie off to the office buildings, the change houses, to underground, sub-shaft engineering and to the compressors for cooling compressed air.

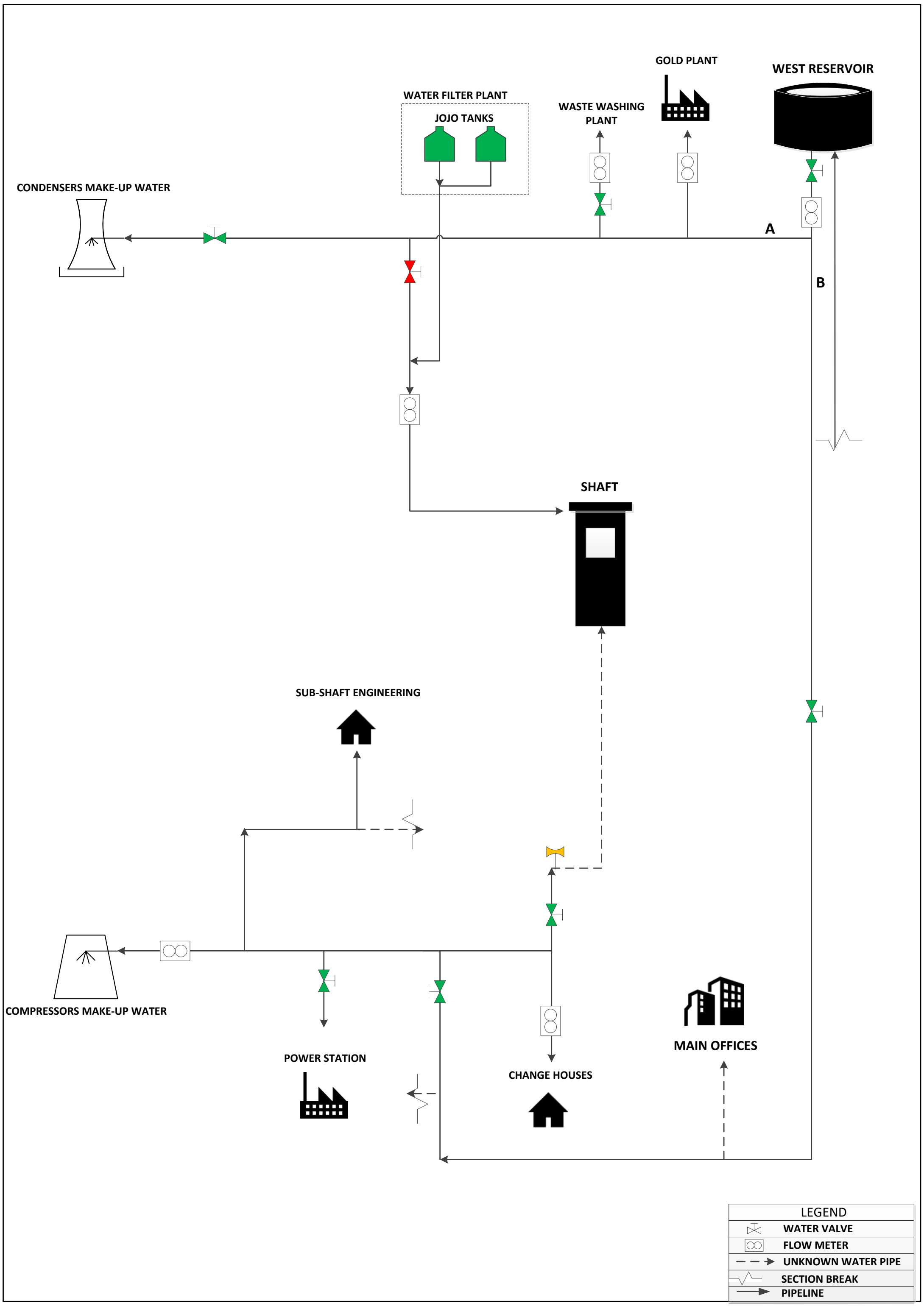


Figure 3.23: Mine H west reservoir water layout

A water audit was carried out to understand why this plant utilises such large amounts of potable water compared to other plants as indicated in Figure 3.8. Ultrasonic meters were used to verify flow readings. One meter was placed at the plant inlet, the other was placed at the split to the plant and the meters are labelled M1 and M2 as shown in Figure 3.24. No leaks were found in any of the lines going into the plant. This was because the flows were the same at both measurement points. Meter readings of M1 and M2 are shown in Figure 1 of APPENDIX D.

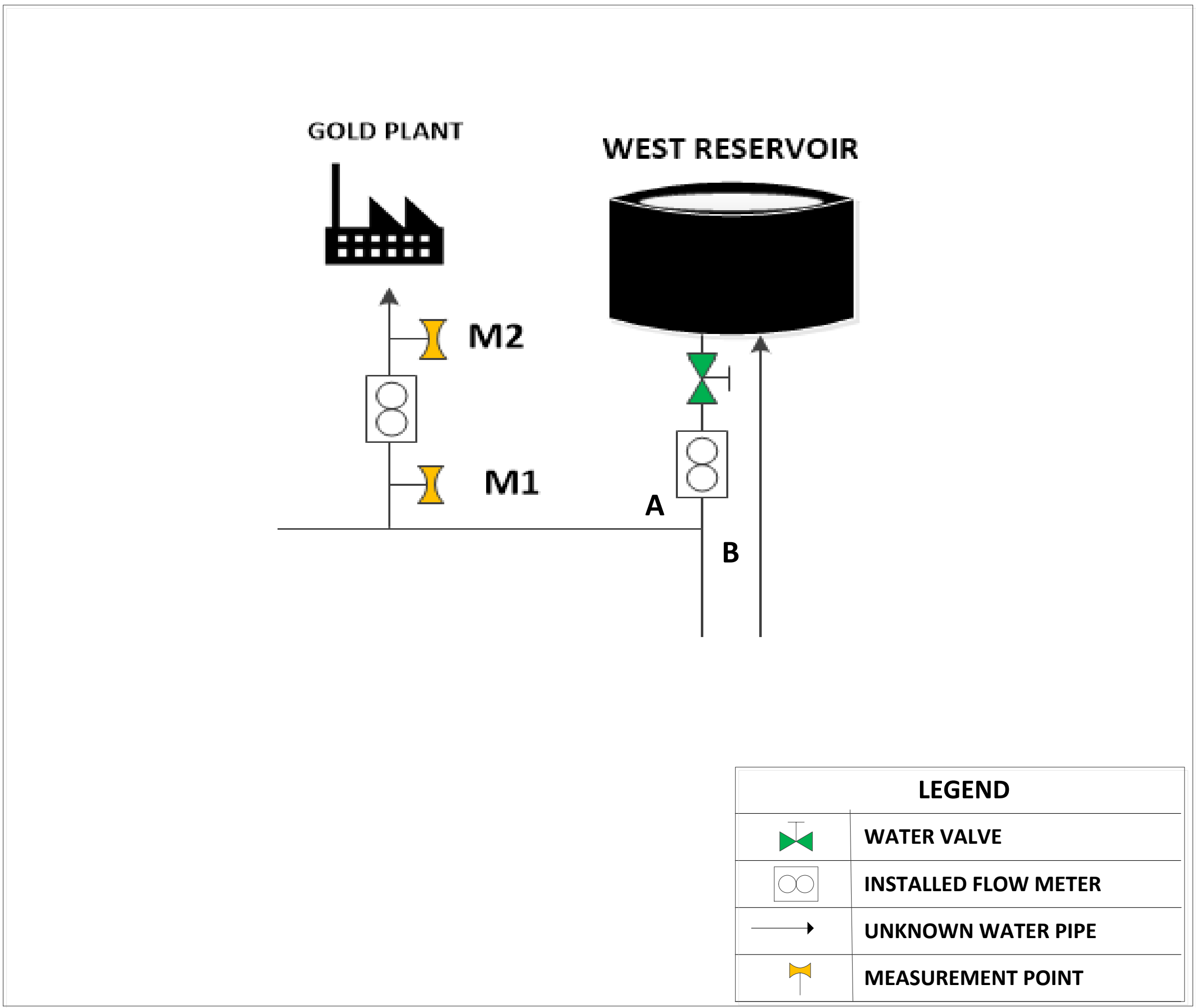


Figure 3.24: Gold plant measurement points.

The actual process at the plant therefore had to be evaluated. The senior metallurgist at the plant was informed about the situation. There were no mechanical problems in the system, so the actual production processes needed to be evaluated. This was beyond the scope of this study, but the plant metallurgist continued to investigate the matter. The plant metallurgist discovered that there were high volumes of water exiting the thickeners to the tailings facilities, this resulted in great amounts of water loss because water was being lost due to evaporation and less water was being recycled from the tailings dams.

The plant consists of three thickeners which are used before the leaching process. Since too much water was going to the tailing's facility, one of the thickeners was converted to a tailing's thickener. This reduced the amount of water in tailings and increased water recycled in process. Less potable water was required for the process. A simplified diagram of the process plant is provided in Figure 3. 25 to indicate where water is needed in gold processing. Blue lines indicate potable water while brown lines indicate non-potable water and process water.

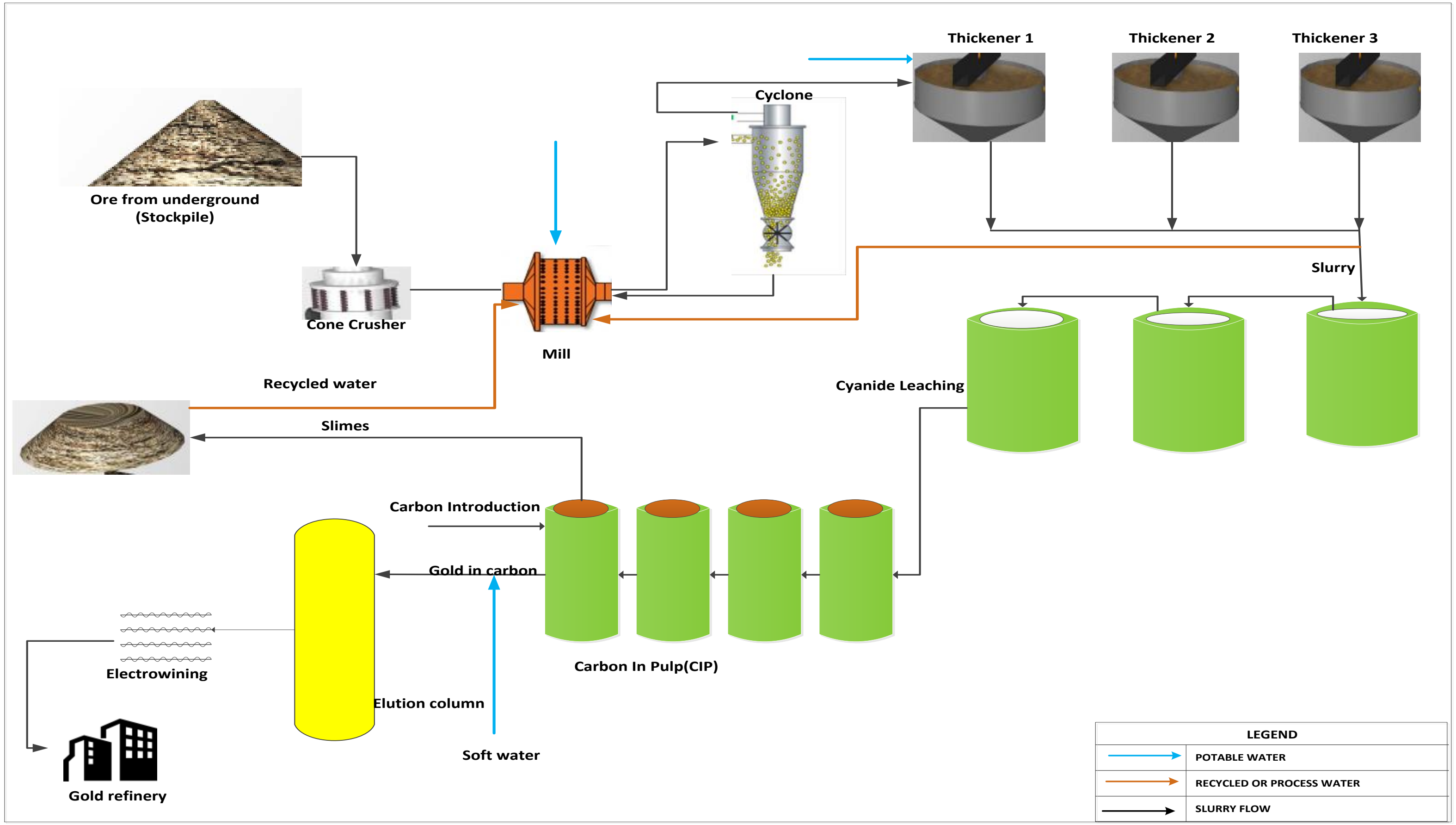


Figure 3. 25: Gold production process layout.

Figure 3.26 shows the reduction of water at the plant after the metallurgist's involvement.

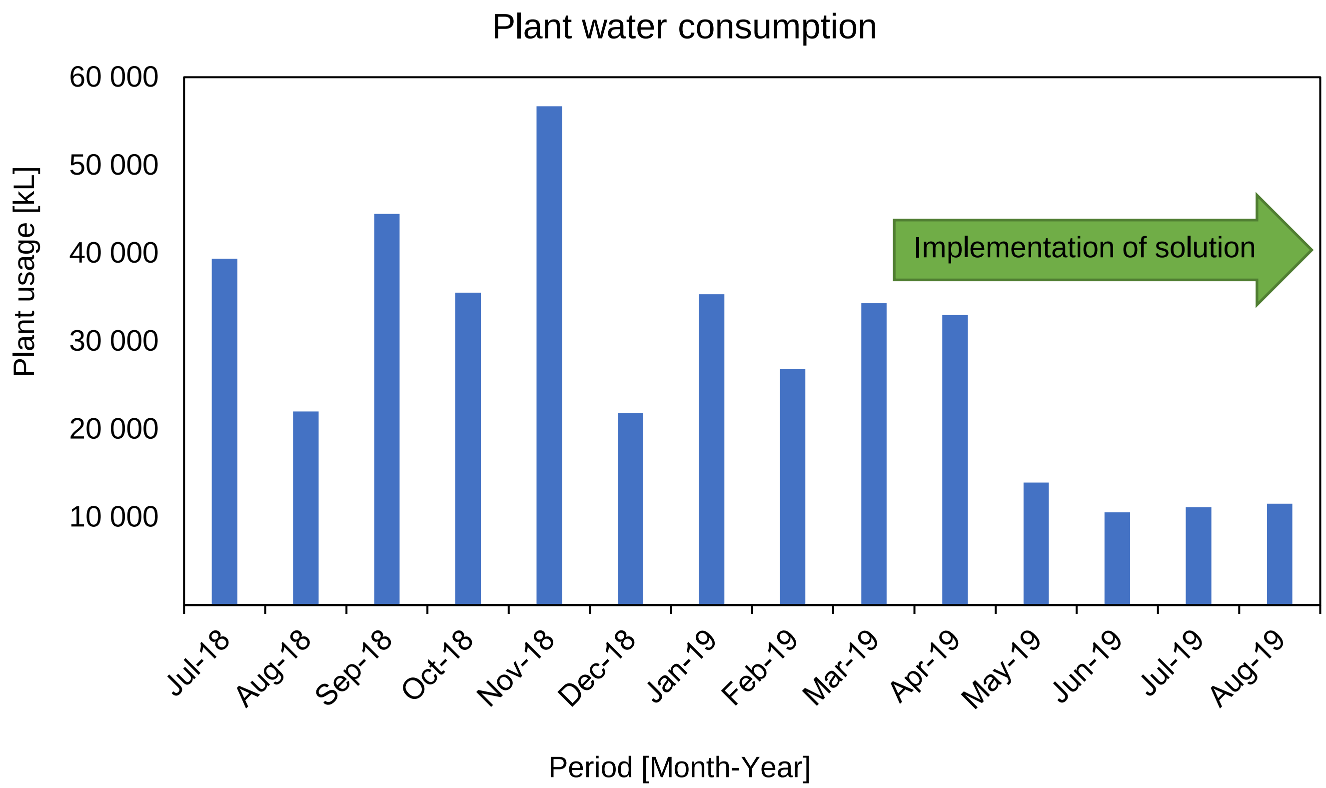


Figure 3.26: Plant 5 water reduction after implementation.

A constant reduction of water at the plant was observed. In order to quantify the savings achieved, a baseline is determined. In this case study, the baseline is calculated as the average water consumed by the plant from July 2018 to April 2019. This is a period before the normal thickener was turned into a tailing's thickener. Table 3.12 shows the months used to calculate the baseline as well as water consumption during those months.

Table 3.12: Baseline determination for P5

Month	Water consumed [kL]
Jul-18	39 388
Aug-18	22 021
Sep-18	44 472
Oct-18	35 500
Nov-18	56 700
Dec-18	21 806
Jan-19	35 328
Feb-19	26 826
Mar-19	34 313
Apr-19	32 980
Average	34 933

The baseline, as well as the monthly consumption of the processing plant, are shown in Figure 3.27. From Figure 3.27 it can be clearly seen that water-use reduced significantly after implementation.

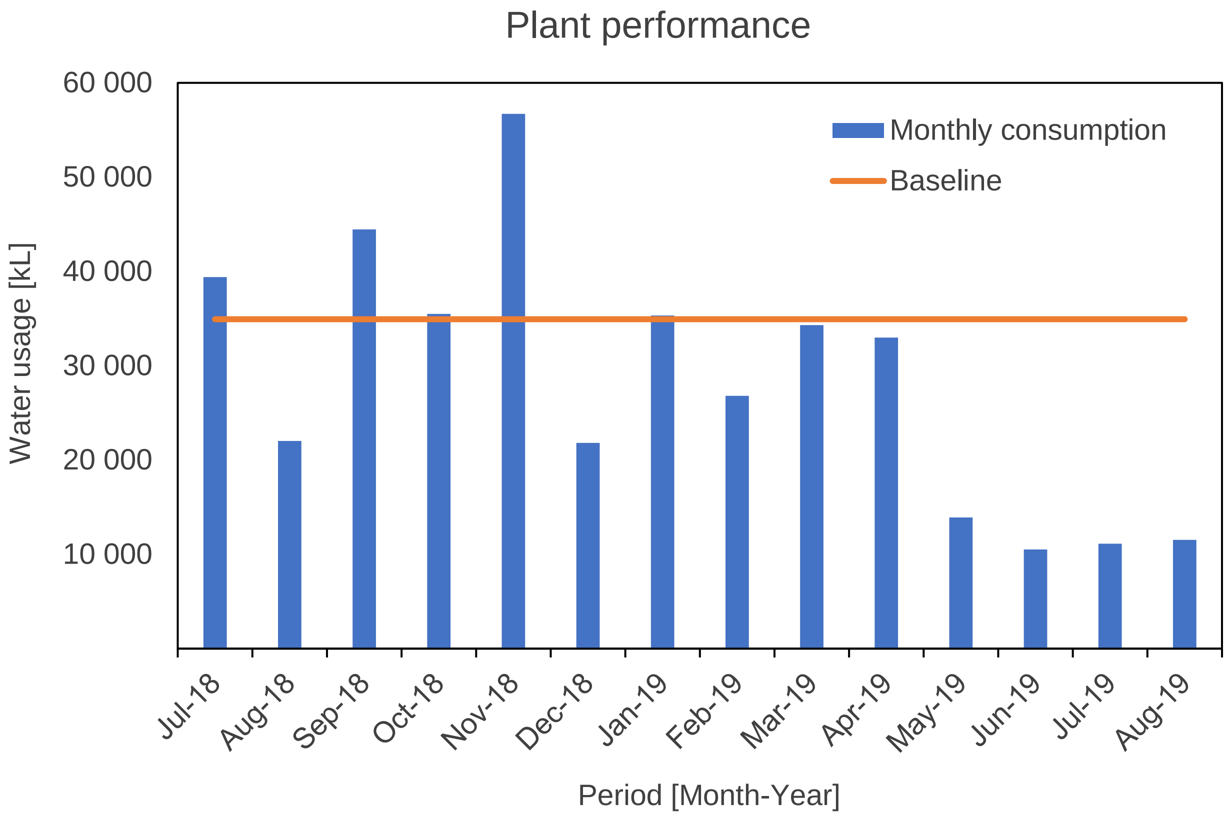


Figure 3.27: Plant performance against the baseline.

The savings are calculated from May 2019, after the strategy was implemented. Figure 3.28 shows the baseline, the monthly water savings and cumulative savings.

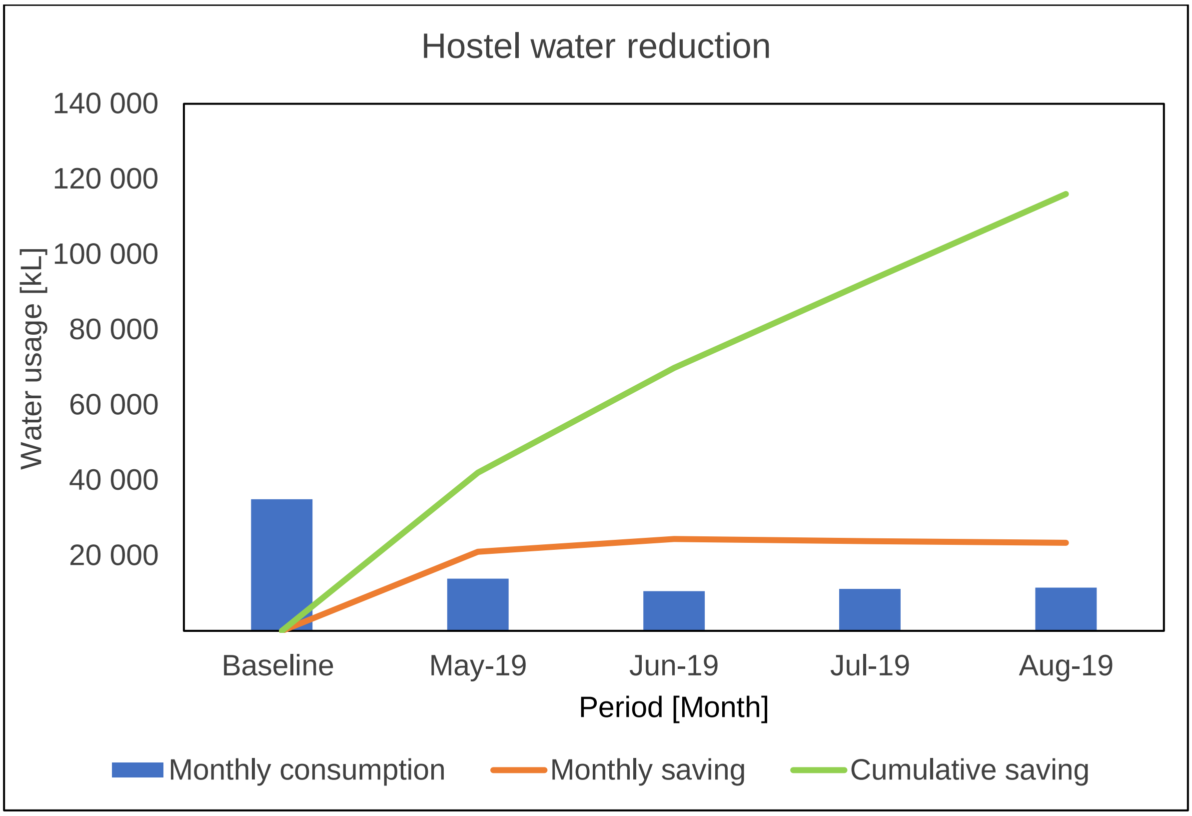


Figure 3.28: Savings achieved at P5 in kL.

With baseline determined and Figure 3.28 shown, the total savings were quantified. A total of 92 632 kL was saved up to August 2019. The water tariff at this operation is R18.9/kL. The total cost saving by August 2019 was R1.8 million and an estimated saving of R5.25 million per annum was expected.

To prove that the benchmarking method identified the key failing facilities. The plant intensity provided in Table 3.7 which was calculated for July 2017 to June 2018 was compared to the intensity calculated from May 2019 to August 2019. Figure 3.29 shows this comparison. There was a significant decrease in intensity which implies that the strategy is indeed effective.

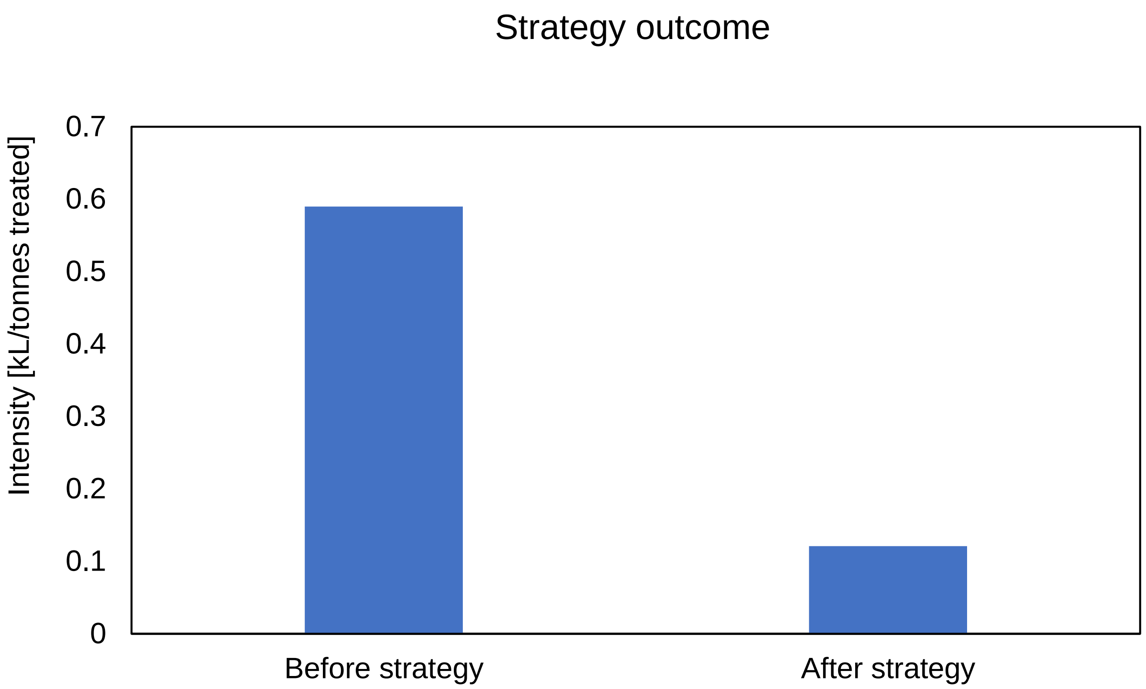


Figure 3.29: Before and after strategy application.

3.5 CONCLUSION

In Case study 1, conservation measures were applied to a typical underground gold mine that is in the middle depth category. Water benchmarking was used to identify that the intensity of this mine was abnormally high. Thereafter, water conservation measures were used to identify the specific critical areas of excessive usage and wastage, followed by the implementation of appropriate methods to reduce inefficient water use at this operation. Leaks were identified using an ultrasonic flow meter, and their repair resulted in an estimated cost saving of R5.5 million. The intensity reduced by half after implementation of this conservation strategy.

In Case study 2 and Case study 3, two different sections of the same mine were investigated. The water intensity benchmarking showed that both sections' water usage was high. After detailed investigations of the water balance, with the use of ultrasonic water meters on pipelines, critical wastages were identified. After the implementation of conservation interventions, water and cost savings were achieved. Case study 2, which represents the hostel area of Mine H, resulted in an estimated cost saving of R 6.9 million per annum and water saving of about 383 ML per annum. Case study 3, at the gold processing plant of Mine H, resulted in an estimated overall saving of R 5.3 million per annum

The main objective of this study was to develop a holistic strategy for conserving potable water in gold mines. The results from the three case studies validate that the strategy is effective and is able to pinpoint areas of focus. It shows that water should be recycled, and that inefficient use and wastage must be identified through a detailed understanding of the water balance and through effective monitoring and reporting.

Although all case studies achieved a degree of water and cost savings, the resultant consumption did not reach the benchmark intensity. More investigations are still underway to ensure that the benchmark is reached. From the case studies, the holistic conservation strategy proves to be a great tool to identify water savings opportunities and is an efficient way of conserving water in the operations without having to look at the entire population of data.

4 CONCLUSION AND RECOMMENDATIONS

4.1 CONCLUSION

The mining industry consumes water for a variety of applications. South Africa's water resources are reducing and are expected to reach a water deficit in 2030. Although the mining industry only consumed 5% of South Africa's water, it is important to ensure that water is being conserved and that potable water consumption by mines is efficient.

Mines mainly focus on ZLD because of stringent regulations regarding water quality and environmental impacts. This enables mines to protect water resources and to conserve water by recycling water and reducing the inlet potable water. This method of saving water is expensive and has expensive maintenance due to the increased amount of infrastructure required to do so. Although this method is effective in reducing potable water consumption, other measures should be used to conserve water as well. Therefore, a holistic strategy of saving water was developed to ensure that water is not only conserved through recycling but through equipment maintenance and knowledge of process flow.

The DWS adapted BPGs and integrated water management strategies to enable water consumers to be aware of their consumption and to develop practical solutions for saving water in gold mines. Benchmarking is a tool that can be used to identify poor performing facilities compared to their partner companies. Benchmarking allows the person responsible for water conservation to identify exactly which operations are under-performing and in which system water needs to be saved.

The objectives of this study were met:

- An effective potable water conservation strategy was developed for gold mines.
- Practical ways of achieving water conservation were identified.
- These water conservation methods were implemented and reported.

This strategy therefore investigates normalisation techniques to ensure that water users are compared fairly.

The strategy is efficient in that it allows the user to pinpoint exactly where in the system the problem is. Chapter 3 indicates how the strategy was successful in determining areas that required more focus in terms of water conservation and management. Three facilities were selected using the strategy, investigations were made, and a substantial amount of water was saved as a result.

The development of water conservation plans is now a requirement by the DWS, failure to submit water conservation plans may result in mines being at a risk of losing their water licences or licences to operate. This conservation strategy can serve as a foundation for the development of water conservation plans for mining operations.

In the first two case studies, leak detection and subsequent management proves to be one of the biggest problems at mines. Most water losses are as a result of mismanaged and unmonitored water leaks. It was also identified that an uncomplicated solution like closing leaks can save large amounts of water and thus save money for the company.

Water treatment measures should still be implemented in mines as a way of water resource protection and water reuse or recycling. The implemented strategy resulted in a total annual saving of about R 17.7 million per annum and approximately 1 356 million litres of water being saved across the three case studies at the two mines in this study. With an average South African consuming 235 litres per day, the water saved can sustain approximately 11 000 South Africans per day. The results confirm that the study objectives were met, therefore validating the water conservation strategy described.

4.2 RECOMMENDATIONS FOR FURTHER WORK

The study mainly focused on dividing mining operations into three main sections, namely, mining, residential areas and processing plants. This is because the data obtained could clearly distinguish between the three different sections of the mines. There are, however, other sections of the mines that should be carefully evaluated for benchmarking purposes. Change houses are one of these sections. Large amounts of water are consumed by mine change houses, however, change houses are not only used by mining personnel but also contractors at the mine. It is therefore difficult to determine the number of people that use change houses.

For the mining section of the strategy, water is used for a variety of applications. Most mines receive make-up potable water at times when underground fissure water is not enough. Benchmarking make-up water with respect to the amount of water produced underground is also necessary to indicate days or months when potable water is needed to supplement underground fissure water, an automated system could be implemented to ensure that potable make-up water is only sent when necessary. There are also a variety of machines underground used for cooling systems. Benchmarking each machine may also assist in reducing the amount of water consumed underground. Bulk air coolers are one such machines.

The benchmarking methodology focused on monthly benchmarks, weekly benchmarks may result in more prompt solution implementation and potable water loss prevention. It is strongly recommended that the industry takes meter readings weekly and check the weekly consumption against weekly benchmarks.

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APPENDIX A

SUSTAINABLE DEVELOPMENT STATISTICS CONTINUED

		2018				2017			
		Group	US operations	SA operations		Group	US operations	SA operations	
	Unit		PGM	PGM	Gold		[1]PGM	PGM	Gold
Environment									
Cyanide consumption	000t	**3,450**	**NA**	**NA**	**3,450**	7,552	NA	NA	7,552
Total CO_2e emissions:									
Scope 1 and 2 [11]	000t	**[5]5,666**	**141**	**1,442**	**4,083**	6,598	215	1,616	4,766
Scope 3 [12]	000t	**[5]2,157**	**569**	**995**	**593**	2,539	544	980	1,016
Emissions intensity [13]	tCO_2e/t milled	**0.14**	**0.11**	**0.07**	**0.24**	0.13	0.01	0.06	0.25
SO_2 emissions [14]	tonnes	**660**	**[5]4.4**	**197**	**459**	611	6	200	405
Electricity consumed	TWh	**[5]5.60**	**0.32**	**1.49**	**3.79**	6.01	0.24	1.61	4.16
Diesel	TJ	**[5]1,003**	**314**	**481**	**208**	853	179	460	214
Total water withdrawn	000ML	**[5]126**	**4**	**16**	**106**	126	2	14	109
Water used [15]	000ML	**56**	**1.2**	**16**	**39**	55	1	14	40
Water use intensity	kL/t treated	**1.35**	**[17]0.35**	**0.78**	**2.23**	1.32	[17]0.43	[21]0.69	2.10
Environmental incidents: level 3 and higher	Number	**[5]6**	**1**	**3**	**2**	18	6	3	9
Gross rehabilitation liabilities	R billion	**7.77**	**0.67**	**2.83**	**4.27**	7.46	0.56	2.72	4.18
HDSA representation (South Africa) [22]									
Top management (Board)	%	**[5]46**				45			
Senior management (Executives)	%	**[5]36**				40			
Middle management (E band)	%	**[5]40**	**NA**	**33**	**43**	36	NA	38	35
Junior management (D band)	%	**[5]49**	**NA**	**52**	**48**	50	NA	53	49
Social and procurement spend [22]									
Total socio-economic development	R million	**[5]1,390**	**5.13**	**399**	**986**	1,161	3	367	792
Social and labour plan (SLP) projects [18]	R million	**[5]18**	**NA**	**15**	**3**	24	NA	11	13
Total BEE procurement spend [19]	R million	**[5]10,841**	**NA**	**5,505**	**5,336**	10,605	NA	4,901	5,704
Capital goods [19]	%	**[5]82**	**NA**	**83**	**75**	81	NA	82	81
Services [19]	%	**[5]76**	**NA**	**85**	**81**	77	NA	82	73
Consumables [19]	%	**[5]81**	**NA**	**83**	**70**	78	NA	78	77
% of total procurement [19]	%	**79**	**NA**	**83**	**75**	78	NA	80	76
Other									
Current tax and royalties	R million	**308**				903			
Research and development	R million	**19**				13			

Figure A. 1: Integrated report for company 1

SECTION 2 / DELIVERING ON OUR STRATEGY

REGIONAL REVIEWS CONTINUED

Continental Africa

Key statistics (continued)

	Units	2018	2017	2016
Environment				
Total water consumption	ML	**15,575**	16,651	11,911
Total water use per tonne treated	kL/t	**0.592**	0.614	0.428
Total energy usage	PJ	**9.32**	9.17	8.46
Total energy usage per tonne treated	GJ/t	**0.35**	0.34	0.30
Total GHG emissions	000t CO_2e	**676**	666	682
Total GHG emissions per tonne treated	t CO_2e/t	**0.026**	0.025	0.025
Cyanide used	t	**8,185**	7,274	7,693
No. of reportable environmental incidents		**1**	2	0
Total rehabilitation liabilities:	$m	**378**	431	430
– restoration	$m	**235**	253	262
– decommissioning	$m	**143**	178	168
Community and government				
Community expenditure	$m	**8**	9	8
Total payments to government	$m	**352**	331	260
– Dividends	$m	**9**	10	13
– Taxation	$m	**117**	114	76
– Withholding tax (royalties, etc.)	$m	**135**	98	79
– Other indirect taxes and duties	$m	**24**	47	25
– Employee taxes and other contributions	$m	**56**	51	46
– Property tax	$m	**1**	1	1
– Other (includes skills development)	$m	**10**	10	20

(1) *Excludes stockpile write-offs.*
(2) *Includes attributable share of equity-accounted investments.*

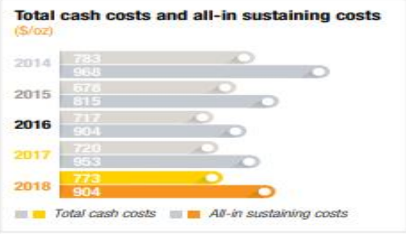

Figure A. 2: Integrated report for Company 2

NON-FINANCIAL DATA

	2018	2017	2016	2015	2014
Safety[1]					
Work-related fatalities	**5**	9	11	6	6
Fatal-injury frequency rate (FIFR)[2]	**0.024**	0.035	0.038	0.018	0.017
Total recordable case frequency rate (TRCFR)[2]	**2.66**	3.17	3.55	4.66	4.02
Lost-time injury frequency rate (LTIFR)[2]	**1.63**	1.68	1.87	2.35	1.76
Occupational health[1]					
New cases of occupational disease (NCOD)[2]	**101**	96	111	159	175
Environment[1]					
Total CO_2 emissions (Mt CO_2e)	**16.0**	18.0	17.9	18.3	17.3
Total energy consumed (million GJ)[2]	**85**	97	106	106	108
Total water withdrawals (million m^3)[2]	**227**	306	296	339	276
Human Resources					
Women in management (%)[4]	**28**	26	25	25	24
Historically Disadvantaged South Africans in management (%)[5]	**65**	66	62	60	60
Resignations (%)[6]	**2.4**	2.3	2.2	1.9	2.0
Redundancies (%)[7]	**0.7**	0.7	7.1	3.5	0.9
Dismissals (%)[8]	**1.2**	1.4	1.8	1.4	1.0
Other reasons for leaving (%)[9]	**5.8**	4.0	3.5	4.2	1.9
Social					
CSI spend (total in US$ million)[10]	**82**	88	84	124	136
CSI spend (% of underlying EBIT)[10]	**2**	2	3	6	3
Businesses supported through enterprise development initiatives[11]	**64,830**	64,291	62,447	62,394	58,257
Jobs created/maintained through enterprise development programmes[11]	**125,095**	120,812	116,298	110,780	96,873

Figure A. 3: Integrated report for company 3

Key measurements – Licence and reputation

	2017	Status	2016	2015	2014	2013
Total value distribution (US$m)	**2,850**	●	2,505	2,425	2,650	2,980
SED spending (US$m)	**17.4**	●	16.2	13.7	17.4	17.2
Workforce from host communities (%)	**40**	●	48[4]	59	57	–
In-country procurement (US$m)	**1,626**	●	1,360	1,270	1,440	1,440
Host community procurement (US$m)	**774**	●	558	514	600	430
Environmental incidents (Level 3 and above)	**2**	●	3	5	4	3
Water recycled/reused (Mℓ)	**43,289**	●	44,274	43,120	42,409	33,453
Water withdrawal (Mℓ)[1]	**32,985**	●	30,321	35,247	30,207	30,302
Electricity purchased (MWh)[1]	**1,366,086**	●	1,400,422	1,322,353	1,338,075	1,382,106
Diesel (TJ)[1]	**6,765**	●	6,608	6,930	6,066	5,509
CO_2 emissions ('000 tonnes)[2, 3]	**1,959**	●	1,964	1,753	1,694	1,731
Mining waste ('000 tonnes)	**212,089**	●	187,036	167,357	138,522	190,007
Gross closure costs provisions (US$m)	**381**	●	381	353	391	355

Figure A. 4: Integrated report for company 4

Water use – measured

		[3]FY17	FY16	FY15	FY14	FY13
Water used for primary activities	000m³	**13 123**	[1]13 689	14 614	16 495	18 556
Potable water from external sources	000m³	**10 953**	12 459	11 993	13 139	15 610
Non-potable water from external sources	000m³	**5 638**	1 230	2 620	3 355	2 946
Surface water used	000m³	**4 863**	716	776	1 037	1 230
Groundwater used	000m³	**775**	[2]513	1 844	1 550	1 716
Water recycled in process	000m³	**41 112**	38 821	38 338	24 531	27 593
Percentage of water recycled	%	**86**	74	72	61	60

Figure A. 5: Integrated report for company 5

APPENDIX B

[redacted]

TAX INVOICE

VAT Reg Nr. 4540105923

Number:	IN0000109614
Page:	1
Date:	2018-10-31

To: [redacted]

Attn: [redacted] VAT Reg Nr. 4960164525 [redacted]

From: [redacted]

Attn: [redacted]

Reference - P.O. #	Customer No.	Salesperson	Ship Via	Terms Code
	16011006			30DAYS

	Description/Comments				Amount
	[redacted] 392400-339890-52510				297,206.60
	[redacted] 2538-2291-247				1,398.02

Due Date	Amount Due	Disc. Date	Disc. Amount
2018-11-30	343,395.31	2018-11-30	0.00

Banking details:

Account Name:
Bank:
Branch Name:
Branch Number:
Acc. Number:
[redacted]

SARS 44,790.69

Subtotal before taxes	298,604.62
Total taxes	44,790.69
Total amount	343,395.31
Payment received	0.00
Discount taken	0.00
Amount due	343,395.31

Please use your Customer ID **16011006** as reference on deposit.

Figure B. 1: Example of a water invoice

Gold Plant										
Jan-17										
06-Nov-19			**Stream**		**Stream**					
SOURCE			Not Used 1	Not Used 2	Cooke 1	Cooke 2	Cooke 3	Cooke 2 LG		TOTAL
Delivered Tons (Wet)		tons	-	-	13 893	-	33 456	692	-	99 630
Moisture Factor		%	-	-	5.29	-	5.53	6.08	-	5.07
Delivered Tons (Dry)		tons	-	-	13 158	-	31 605	650	-	94 579
includes Sludge Tons (Dry)		tons	-	-	-	-	-	-	-	-
Tons Delivered Indicated (Dry)		tons	-	-	13 158	-	31 605	650	-	94 579
GCF		kg	-	-	67.4985	-	110.1064	0.9792	-	404.1792
Delivery Tonnage Adjustment Factor (Calc)			-	-	0.98	-	0.98	0.98	-	0.984
Tons Delivered - Adjusted (Dry)		tons	-	-	12 941	-	31 086	639	-	93 024
Go-Belt Grades		g/t	-	-	5.13	-	3.48	1.51	-	4.273
Gold Delivered		kg	-	-	66.3887	-	108.2961	0.9631	-	397.5338
Leach Recovery		%			95.34	95.34	95.34	95.34	95.34	94.84
Pro Rata Tons for split (Calc)		tons	-	-	12 643	-	30 367	616	31	89 771
Pro Rata Gold for split (Calc)		kg	-	-	54.7873	-	86.6306	0.6733	0.3367	326.1783
Tons Treated		tons	-	-	12 723	-	30 557	620	31	**90 050**
Head Grade (Plant TUF)		g/t	-	-	4.193	-	4.193	4.193	4.193	4.193
Total opening inventory	Open	tons	-	-	169	-	402	-	31	1 740
Total closing inventory	Close	tons	-	-	467	-	1 121	23	-	4 715
Total opening inventory	Open	kg	-	-	8.7870	-	11.4591	-	0.3531	52.4496
Total closing inventory	Close	kg	-	-	17.7124	-	28.8932	0.2570	-	106.0613
Gold ± Inventories		kg	-	-	57.4634	-	90.8620	0.7062	0.3531	343.9221
Total Gold Produced		kg	-	-	63.7072	-	100.7348	0.7829	0.3915	**345.8817**
Recovered Grade		g/t	-	-	5.01	-	3.30	1.26	12.43	3.84
Residue Gold		kg	-	-	3.7329	-	5.9025	0.0459	0.0229	22.2240
Residue Grade		g/t	-	-	0.293	-	0.193	0.074	0.729	0.247
GAF		kg	-	-	67.4401	-	106.6373	0.8288	0.4144	368.1058
Recovery %		%	-	-	94.46	-	94.46	94.46	94.46	93.96
PCF (GAF/GCF)		%	-	-	99.91	-	96.85	84.64	-	91.07
Accountability (GAF/TUF Gold)		%								97.49

Figure B. 2: Example of a metal account

APPENDIX C

Date(YY-MM-DD) Time	Err Code	Flow[L/s] Hostel entrance
2019-01-13 08:57		23.01
2019-01-13 08:58		23.04
2019-01-13 08:58		23.02
2019-01-13 08:59		23.88
2019-01-13 08:59		23.98
2019-01-13 09:00		23.01
2019-01-13 09:00		23.00
2019-01-13 09:01		23.00
2019-01-13 09:01		23.00
2019-01-13 09:01		23.00
2019-01-13 09:01		23.00
2019-01-13 09:03		23.00
2019-01-13 09:03		23.00
2019-01-13 09:04		23.00
2019-01-13 09:04		23.00
2019-01-13 09:05		23.00
2019-01-13 09:05		23.00
2019-01-13 09:06		23.00
2019-01-13 09:06		23.00
2019-01-13 09:07		23.00
2019-01-13 09:07		23.00
2019-01-13 09:08		23.00
2019-01-13 09:08		23.00
2019-01-13 09:09		23.00
2019-01-13 09:09		23.00
2019-01-13 09:10		23.00
2019-01-13 09:10		23.00
2019-01-13 09:11		23.00
2019-01-13 09:11		23.00
2019-01-13 09:12		23.00
2019-01-13 09:12		23.00
2019-01-13 09:13		23.00
2019-01-13 09:13		23.00
2019-01-13 09:14		23.00
2019-01-13 09:14		23.00
2019-01-13 09:15		23.00
2019-01-13 09:15		23.00
2019-01-13 09:16		23.00
2019-01-13 09:16		23.00
2019-01-13 09:17		23.00
2019-01-13 09:07	**Average:**	23.0

Figure C.1: Hostel entrance meter reading.

APPENDIX D

Date(YY-MM-DD) Time	Err Code	M1 Flow[L/s]	M2 Flow[L/s]
2019-01-13 09:47		14.01	14.01
2019-01-13 09:48		14.12	14.12
2019-01-13 09:48		14.08	14.08
2019-01-13 09:49		14.33	14.33
2019-01-13 09:49		14.02	14.02
2019-01-13 09:50		14.01	14.01
2019-01-13 09:50		14.03	14.03
2019-01-13 09:51		14.17	14.17
2019-01-13 09:51		14.2	14.2
2019-01-13 09:52		14.22	14.22
2019-01-13 09:52		14.03	14.03
2019-01-13 09:53		14.14	14.14
2019-01-13 09:53		14.22	14.22
2019-01-13 09:54		14.12	14.12
2019-01-13 09:54		14.13	14.13
2019-01-13 09:55		14.08	14.08
2019-01-13 09:55		14.01	14.01
2019-01-13 09:56		14.33	14.33
2019-01-13 09:56		14.01	14.01
2019-01-13 09:57		14.02	14.02
2019-01-13 09:57		14.03	14.03
2019-01-13 09:58		14.03	14.03
2019-01-13 09:58		14.01	14.01
2019-01-13 09:59		14.11	14.11

Figure D. 1: Flow readings of M1 & M2