FEASIBILITY OF GROUNDWATER ABSTRACTION AND TREATMENT FOR URBAN WATER SUPPLY

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ABSTRACT

Water is one of Earth's most valuable resources and one of Earth's most threatened resources. Continuously increasing population growth coupled with changing climate has resulted in the depletion of water sources. As a result, investigations into alternative water sources are being conducted worldwide. One such alternative water source is groundwater abstraction.

Groundwater abstraction involves the abstraction of water from an underground source. The volume of water that can be sustainably abstracted is governed by legislation. Groundwater typically requires treatment before it can be distributed to the general population for use, and thus the implementation of large-scale groundwater abstraction projects involves large capital outlays, as well as monthly operational outlays. The feasibility into the implementation of large-scale groundwater abstraction projects is therefore of interest to stakeholders involved in the water supply industry.

The lifecycle of a recently implemented large-scale groundwater abstraction project was analysed in order to determine its feasibility. The project was implemented by Drakenstein Municipality in the Western Cape in 2017. The project involved identifying groundwater abstraction points that could provide sustainable volumes of water. The water quality of each groundwater abstraction point was then investigated for any outlying parameters according to SANS 241-1:2015 guidelines for potable water. Groundwater abstraction water treatment plants were then designed in order to treat the combined sustainable flow rates of water at their specific water qualities. The treated water from each groundwater abstraction water treatment plant was then analysed in order to confirm compliance with the SANS 241-1:2015 guidelines, before the booster pumps were commissioned and commenced with their continuous supply of potable water into the network.

The capital expenditure associated with each of the groundwater abstraction water treatment plants was obtained from the Engineer, Aurecon. In addition, the estimated monthly operational expenditure was computed. These expenditures were used to determine the feasibility of the large-scale groundwater abstraction project by computing the payback period and comparing this period to the design life of each of the groundwater abstraction water treatment plants. In addition, the monthly savings applicable to the municipality as a result of the project's implementation was computed. Finally, the feasibility into varying flow rates of groundwater abstraction water treatment plants, and varying water quality of groundwater abstraction points was investigated.

Two sites were identified within the municipal area, each with four groundwater abstraction points capable of delivering a combined 5.18 ML/day and 1.62 ML/day. These sites were identified as Boy Louw Sportsgrounds and Parys Sportsgrounds respectively. Although the sites were only 2.60 kilometres apart, the water quality of the combined flow rates indicated that the groundwater abstraction points were accessing two different water sources. The combined sustainable flow rate at Boy Louw Sportsgrounds required turbidity, iron and manganese removal, as well as disinfection. The combined sustainable flow rate at Parys Sportsgrounds required turbidity removal and disinfection. Groundwater abstraction water treatment plants were then designed to treat the water at Boy Louw Sportsgrounds and Parys Sportsgrounds. Boy Louw Sportsgrounds involved the distribution of equipment across seven shipping containers, whilst Parys Sportsgrounds involved the distribution of equipment across three shipping containers.

It was found that the groundwater abstraction project was feasible with a payback period of three years. This payback period fell well within the 10-year design life of each groundwater abstraction water treatment plant. In addition, it was found that the municipality would be subject to a 72% monthly saving in water costs as a result of utilising the groundwater abstraction water treatment plants, as opposed to purchasing water in bulk from the City of Cape Town.

It was found that the payback periods of Boy Louw Sportsgrounds and Parys Sportsgrounds were two and five years respectively. Although Boy Louw Sportsgrounds delivered almost three times the potable water flow rate than that of Parys Sportsgrounds, its payback period was three years sooner. In addition, it was found that the municipal savings as a result of Boy Louw Sportsgrounds was 8% more than that of Parys Sportsgrounds. It was therefore concluded that the larger the flow rate of water to be treated, the more financially feasible the project. In addition, it was determined that the more water quality parameters lying above the upper limits of SANS 241-1:2015 guidelines for potable water, the more treatment processes would need to be implemented resulting in additional capital and operational expenditure. It was therefore concluded that the more water quality parameters requiring treatment, the less financially feasible the project.

Finally, it was determined that the feasibility of the large-scale groundwater abstraction project is limited by the rate at which the municipality purchases water in bulk from the City of Cape Town. As long as the bulk water purchase tariff remains above R 2.85/m^3, the project will remain feasible. Should the bulk water purchase tariff fall below this value, the project no longer remains feasible as the payback period of the project exceeds the design life of the groundwater abstraction water treatment plants.

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NOMENCLATURE

Symbol	Description
A	Cross-sectional area
C_i	Cost
D	Diameter
f	Friction factor
g	Acceleration due to gravity
h_i	Height / head loss
H^+	Hydrogen concentration
L	Length
$\dot{m}$	Mass flow rate
ρ	Density
$\dot{q}_i$	Individual volume flow rate
$\dot{Q}$	Total volume flow rate
Re	Reynolds number
t	Time
V	Velocity
x	Individual water parameter concentration
ε	Internal roughness
φ	Flux

ABBREVIATIONS

Abbreviation	**Description**
AFM	Activated Filter Media
CCPP	Calcium Carbonate Precipitation Potential
CFU	Colony Forming Unit
CMA	Catchment Management Agency
DWAF	Department of Water Affairs and Forestry
ECA	Environment Conservation Act
FDS	Functional Design Specification
GA	General Authorisation
HAZOP	Hazard and Operability Study
HDPE	High Density Polyethylene
HMI	Human Machine Interface
ICP-OES	Inductively Coupled Plasma – Optical Emission Spectrometry
IR	Infrared Radiation
LSI	Langelier Saturation Index
MBGL	Meters Below Ground Level
MOC	Material of Construction
ML	Megalitres
NEMA	National Environmental Management Act
NWA	National Water Act
ORP	Oxidation Reduction Potential
PBP	Payback Period
PFD	Process Flow Diagram
PH	Potential Hydrogen
PVC	Polyvinyl Chloride
P&ID	Piping and Instrumentation Diagram
RSI	Ryznar Strength Index
SANAS	South African National Accreditation System
SANS	South African National Standard
SS	Stainless Steel
TMG	Table Mountain Group
TOP	Trial Operation Period
TSS	Total Suspended Solids
UV	Ultra-Violet
WB	Water Board
WHO	World Health Organisation

WRC	Water Research Commission
WSA	Water Services Authority
WSP	Water Services Provider
WULA	Water Use Licence Application

CHAPTER 1 – INTRODUCTION

Increased population growth and climate change have resulted in the depletion of water sources, and increased pressure on governmental bodies to investigate alternative water sources. Groundwater abstraction and treatment is one of these alternative water sources and involves the abstraction of water from an underground source. This water typically requires treatment using a specifically designed water treatment plant, before it can be distributed to the population for use. The implementation of large-scale groundwater abstraction projects involves capital expenditure, and monthly operational expenditure. The feasibility of groundwater abstraction projects is therefore important to determine whether these projects should be implemented on a permanent basis, or whether they should only be implemented during drought conditions. In addition, it is important to determine the feasibility of groundwater abstraction and treatment at varying flow rates and water quality, in order to ensure the maximum amount of treated water supply, at the minimum expenditure outlay.

1.1 Introduction

Water is a complex resource, the study of which gives rise to various fields of Science and Engineering. It is seemingly available in abundance, and consistently capable of supporting life on Earth. It is for this reason that not only is water one of Earth's most precious resources, it is one of Earth's most threatened resources.

Climate change and increasing population growth have resulted in depleted water sources (Zhang, 2015). As a result, alternative water sources are being investigated worldwide to compliment the available surface water volumes, from which mankind has typically relied on. One of these alternative sources is groundwater.

Groundwater abstraction involves the removal of groundwater from an underground source (Godfrey et al., 2019). The abstraction of groundwater needs to be carefully controlled based on the sustainable volume of water that can be abstracted without causing stress on the underground source. Treatment of groundwater is conducted according to water quality parameters that exceed their maximum limits as outlined by governmental legislation.

The implementation of large-scale groundwater abstraction projects is being investigated on a global scale (Margat, 2013). These projects typically involve identifying groundwater abstraction points, the conglomeration of the resulting sustainable flow rates, and the treatment of the combined flow rate using a water treatment plant. The implementation of these large-scale projects involves capital expenditure outlays, as well as monthly operational expenditure. Investigations into the feasibility of these large-scale groundwater abstraction projects is therefore critical to stakeholders within the water supply industry.

The primary aim of this study is to investigate the feasibility of large-scale groundwater abstraction projects and determine whether they should be implemented and utilised on a permanent basis, or only be implemented and utilised during drought conditions. The secondary aim of this study involves investigating the feasibility into large-scale groundwater abstraction water treatment plants for varying flow rates, and varying water quality.

In order to perform this investigation, the overall project life of a recently implemented large-scale groundwater abstraction project is to be analysed. The capital expenditure of the project, as well as the operational expenditure during the trail operation phase of the project is to be computed and utilised to determine the payback period of the project. The monthly operational expenditure applicable to the groundwater abstraction project following its trial operation phase is to be computed and utilised to determine whether monthly savings will be applicable as a result of implementing the project as opposed to relying on municipal supply. Finally, the feasibility of individual groundwater abstraction water treatment plants at varying flow rates and water quality is to be determined by computing the costs associated with each scenario, computing the payback periods and determining the applicable monthly savings.

This study is presented through various chapters. Chapter 2 provides background information and knowledge on groundwater abstraction, applicable treatment methods and the determination of the feasibility of groundwater abstraction projects and plants. This section also provides an overview into the design of groundwater abstraction water treatment plants. Chapter 3 presents the methodology applicable to perform this study. Chapter 4 presents the results associated with each aim and discussions thereof. Chapter 5 presents the final conclusions of this study and recommendations for future work.

1.2 Research Aims and Objectives

Water is a fundamental resource for the survival of life on Earth. Unfortunately, water is one of the most exploited resources and has thus become threatened. Through a variety of factors such as increased population, urbanisation and climate change, access to water has become more limited than ever before. As a result, alternative methods for accessing water which can be used for human consumption are under investigation worldwide. One such method is the abstraction of groundwater and its subsequent treatment.

The abstraction of groundwater involves investigating various possible abstraction points and the water quality of each abstraction point. The sustainable yield at which groundwater can be abstracted should be determined, followed by comprehensive designs into water treatment plants that can ensure the treated water quality meets regulatory guidelines. The erection of groundwater abstraction and treatment plants not only requires large capital outlays followed by monthly operational outlays but may have long-term effects on the naturally occurring aquifers from which the water is being abstracted. The feasibility into these abstraction projects should therefore be thoroughly investigated before implementation. This case study provides insight into the process followed during the implementation of a large-scale groundwater abstraction project. The investigation into the sustainable yields of abstraction and subsequent treatment required is discussed. In addition, detail is provided into the design considerations of groundwater abstraction water treatment plants based on the volume of water that can be abstracted, as well as the quality of water abstracted.

The primary aim of this dissertation was to investigate the feasibility of large-scale groundwater abstraction projects for supplying potable water to communities as opposed to continued reliance on existing municipal infrastructure and supply. The objectives of this dissertation were to:

1. Investigate potential groundwater abstraction points;
2. Investigate the sustainable yield of the abstraction points and their subsequent water quality;
3. Design groundwater abstraction water treatment plants that can treat the abstracted groundwater to potable water that complies with regulation;
4. Provide a financial overview of the capital and operational expenditure required to complete the groundwater abstraction project;
5. Investigate the payback period of the groundwater abstraction project as well as the percentage monthly savings as a result of the project thus determining its feasibility.

This feasibility analysis provided insight into whether large-scale groundwater abstraction projects should be investigated on a more permanent basis for potable water supply, or whether they should be used only during drought conditions.

The secondary aim of this dissertation was to investigate the feasibility of groundwater abstraction water treatment plants based on varying flow rates as well as varying water quality, using the following process:

- Following the same overall procedure as described above, compare the feasibility of two groundwater abstraction water treatment plants at two different sustainable flow rates, at the same water quality.
- Following the same overall procedure as described above, compare the feasibility of two groundwater abstraction water treatment plants at varying groundwater source quality, at the same flow rates.

These analyses provided more insight into the effects of varying flow rates and water quality on the feasibility of large-scale groundwater abstraction water treatment plants. This assisted by allowing more accurate assumptions to be made during the planning and budgeting phase of large-scale groundwater abstraction projects.

CHAPTER 2 – LITERATURE REVIEW

Groundwater abstraction involves the removal of water from an underground source. The amount of groundwater abstracted must be sustainable, the determination procedures of which are outlined in various governmental legislation. Groundwater typically requires further treatment to ensure its water quality complies with potable water requirements. Typical treatment applied to groundwater includes pH correction, iron, manganese and turbidity removal and disinfection. These treatment regimens are performed consecutively within an appropriate groundwater abstraction water treatment plant. These plants involve process units sized according to the sustainable flow rate of the groundwater they are tasked with treating, as well as the quality of the groundwater. Large-scale groundwater abstraction and treatment should only be implemented should an overall feasibility study of its implementation prove the project to be feasible. In addition, large-scale groundwater abstraction and treatment should be applied to a sustainable flow rate of water, at a certain water quality that is the most feasible. This is determined by performing feasibility studies on groundwater sources of varying flow rates, and varying water qualities.

The study of water is both complex and fascinating. The physical make-up of water and the constituents which may exist within it at any point in time gives rise to various fields of Science and Engineering. In addition to its complex physical characteristics, water as a resource can also influence the socio-economic circumstances of a community. Regardless of whether water is considered from a scientific or socio-economic point of view, it is ultimately clear that water is essential for survival, and it has never been more threatened.

Earth has an abundance of water however most of the water on Earth is unavailable for human use (Earthwatch Institute, 2020). With 71% of the Earth's surface covered in water, only 0.30% can be utilised safely by humans. Unfortunately, not all water within this 0.30% is obtainable. Humans obtain most of their fresh water from surface waters such as rivers and lakes, and groundwater such as aquifers. These aquifers typically feed rivers and thus this cycle can flow continuously without precipitation (Mullen, 2020). It is for this reason that groundwater abstraction is widely investigated in the face of drought conditions.

As a finite resource, it is critical that the amount of water abstracted by humans, is equivalent to the recharging of water resources within the environment. This recharge happens through processes such as precipitation and run-off. Unfortunately, studies have shown that due to increased population, and changing climate, water resources are being depleted in various areas faster than they can be recharged. It is predicted that in less than 30 years, 40 percent of the projected global population will be subject to serious water shortages (Hinrichsen and Tacio, 2020). This prediction is already evident in the increased number and lengths of droughts worldwide. The City of Cape Town has been no exception to this, when in 2018, it suffered one of the worst droughts in its history.

January 2018 ushered in a state of panic as officials announced that the City of Cape Town would run out of water in three short months. This day became known as “Day Zero” and was a direct result of three consecutive years of record-low rainfall (Alexander, 2019). It was during this time that the City of Cape Town and surrounding municipalities, businesses and private homes began to investigate alternative sources of fresh water to prepare for the failure of the potable water infrastructure. Fortunately, the Western Cape is home to three major aquifers, namely the Table Mountain Group (TMG) aquifer, the Cape Flats aquifer and the Atlantis aquifer (Nel, 2018). The presence of these aquifers resulted in groundwater abstraction being investigated and implemented in and around the City of Cape Town.

2.1 Groundwater Abstraction

Groundwater abstraction involves the use of water available in a natural underground source such as an aquifer (European Environment Agency, 2020). This can be done mechanically through the insertion of mechanical and electrical equipment which allows for the abstraction of the water from the aquifer to the surface (Bartak, and Grischek, 2018). Alternatively, groundwater abstraction can occur via artesian wells. An artesian well involves groundwater which is confined under pressure. By creating an opening between the surface and the artesian well, groundwater will naturally flow to the surface at a force equivalent to the confined pressure it is subject to below ground (Drilcorp, 2018).

The sustainability surrounding groundwater abstraction is a widely researched, discussed and debated topic. Aquifers range from sedimentary deposits, fractured rock and cave systems (Gejl et al., 2019), all of which respond differently to abstraction. In addition to this, insufficient long-term data is available to accurately predict the long-term effects of groundwater abstraction. In order to attempt to mitigate detrimental long-term effects of groundwater abstraction, various testing methodologies and licencing systems exist depending on the region from which the groundwater will be abstracted, the volume of groundwater to be abstracted and the intended use of the water.

In South Africa, the abstraction and use of groundwater is legislated under three acts namely, the National Water Act (NWA) (Act 36 of 1998), the Environment Conservation Act (ECA) (Act 73 of 1989) and the National Environmental Management Act (NEMA) (Act 107 of 1998) (Parsons et al., 2008). The NWA defines groundwater abstraction and use by three different categories. As per the Water Affairs and Forestry guideline document published in 2007, these categories are Schedule 1 water use, water use requiring a General Authorisation (GA) and water use requiring a Water Use Licence Application (WULA). Schedule 1 water use pertains to minimal domestic use such as gardening (excluding any feedlots). Groundwater abstraction and use exceeding Schedule 1 will need to be registered as a GA or licenced under a WULA as per Section 21 of the NWA.

In order to register and/or licence groundwater abstraction and use, the sustainable yield of abstraction from the aquifer needs to be determined, and the water quality needs to be analysed. The sustainable yield of abstraction from the aquifer (specifically boreholes) can be tested in accordance with the South

African National Standards (SANS) 10299-4:2003 guidelines. These test methods include the step-drawdown test, the constant discharge test, the recovery test and the extended step-drawdown test (South African National Standard, 2003). The results of these tests can then be analysed using methods such as the FC, Cooper-Jacob and Barker Fracture Flow methods in order to confirm the sustainable yield of the groundwater abstraction (Murray, 2018).

The test method to be utilised in order to determine the sustainable yield of groundwater abstraction depends on the volume of water intended to be abstracted and the intended use of the water. Once the appropriate test method is established, an appropriate contractor can be appointed to perform the testing and provide a detailed report of the findings clearly outlining the sustainable yield of the water abstraction and the required rest periods (if any). A sample of the water is to be submitted in order to determine the quality of the water and if any further water treatment is required before intended use.

2.2 Groundwater Quality

The quality of any sample of water varies depending on its source. The same can be said for groundwater. Aquifers may be relatively close to one another however it cannot be assumed that they share the same quality of water. The quality of water can be classified according to various classes as per the Water Research Commission (WRC) Domestic Use Standard. These classes range from Class 0 to Class 4 with Class 0 being the most suitable water for indefinite human consumption, and Class 4 being unacceptable for human consumption even if consumed for a short period of time (Water Research Commission, 1999).

Groundwater can be abstracted for a variety of uses from non-potable uses such as irrigation and flushing of toilets, to potable use. The quality of groundwater abstracted for potable use must comply with the SANS 241-1:2015 guideline. This guideline provides the microbiological, physical, aesthetic, operational and chemical determinants to be analysed and their subsequent limits. The SANS 241-1:2015 guideline also provides reference to other SANS guidelines pertaining to the test methods of each determinant. The determinants within water to be analysed and their limits are listed in Table A-1 in Appendix A (adapted from South African National Standard, 2015).

When a sample of water is analysed in accordance with SANS 241-1:2015 at a South African National Accreditation System (SANAS) laboratory, a water quality report is generated. This report indicates the presence of the determinants as listed in Table A-1 and their concentration. This report can then be used to determine whether further treatment of the water is necessary as well as what types of treatment may be necessary. The various types of water treatment methods that can be applied are exhaustive and depend entirely on the quality of the specific water being analysed.

2.3 Groundwater Treatment Methods

Common examples of water treatment methods applicable to groundwater include flocculation and coagulation, sedimentation, stabilization, filtration, disinfection, and pH correction. Membrane technology such as reverse osmosis is typically employed for groundwaters with a higher salt content. The appropriate water treatment regime applicable to a certain water source may range from a simple treatment step to a complex combination of water treatment methods. Common water treatment methods required to treat natural groundwaters in and around the Cape Town area include pH correction, iron and manganese removal, turbidity removal, and disinfection.

2.3.1 pH Correction

The pH of a liquid substance defines the substances acidity or basicity and is measured on a scale from 0 to 14. Liquid substances that have a pH below 7 at a temperature of 25°C are defined as acidic whilst liquid substances that have a pH above 7 at a temperature of 25°C are more basic. Liquid substances with a pH of 7 at a temperature of 25°C are considered neutral. The equation utilised for determining pH was developed by a Danish biochemist Søren Peter Lauritz Sørensen in 1909 (Helmenstine, 2019), and is given by Equation 2.1 below.

$$pH = -\log\,[H^{+}] \tag{2.1}$$

where, log is the base-10 logarithm and the term H^{+} represents the concentration of the hydrogen ion within the liquid substance.

When investigating groundwater abstraction and its use, it is critical to know the pH of the groundwater as this may affect the water infrastructure charged with carrying the groundwater over a period of time, the effectiveness of other treatment units, as well as may require correction for its intended purpose i.e. potable water.

Water infrastructure, such as reticulation pipes and storage vessels are likely to show signs of corrosion and/or damage when exposed to water with a lower pH over time. Water with a lower pH typically has lower hardness levels which refers to the dissolved minerals within the water. As a result, oxidation-reduction reactions occur between the infrastructure and the water. The water then begins to leach metal ions such as iron, zinc, manganese, lead and copper from the infrastructure over time (Oram, 2014).

Conversely, scale, deposits of minerals that have precipitated out of the water (Devs, 2014), may form on the inner lining of water infrastructure as a result of water with a higher pH. Water with a higher pH typically has higher hardness levels. Once the dissolved mineral content within the water reaches saturation, the water will attempt to reach an equilibrium concentration by precipitating these minerals out of solution. These minerals are then deposited on the inner linings of the water infrastructure.

The effect that the pH of the water will have on water infrastructure, such as reticulation pipes and storage vessels, can be investigated using various indices such as Calcium Carbonate Precipitation Potential (CCPP), Langelier Saturation Index (LSI) and the Ryznar Strength Index (RSI). The CCPP is considered the most reliable water stability index and provides the quantity of calcium carbonate deficit or excess within the water. Should the water have a calcium carbonate deficit, it will leach minerals from the water infrastructure, thus causing corrosion. Should the water have an excess of calcium carbonate, the water will precipitate minerals onto the surface of the water infrastructure which will build up over time. Both the LSI and RSI indices provide a value which can then be compared to the limits of the indices. This then allows the water to be characterised as corrosive or scale-forming (Gebbie, 2000). Neither the LSI nor the RSI are able to quantify the degree of corrosion or scale as is the case with the CCPP, thus making the CCPP the more reliable index.

Investigating the pH of the groundwater will assist in determining if pH correction steps will be necessary to ensure the water complies with SANS 241-1:2015 standards as well as ensures the longevity of the downstream water infrastructure.

Various pH correction methods exist in industry. Common examples for increasing the pH of water include neutralizing filters such as calcium carbonate (limestone) filters for pH correction of water with a pH above 6, or synthetic magnesium oxide filters for pH correction of water with a pH below 6. Direct injection of chemicals in-line such as soda ash or sodium hydroxide can assist with raising the pH of water with a pH as low as 4 (Drinking-Water, 2019).

2.3.2 Iron and Manganese Removal

Iron and manganese are two of the most abundant metals in the Earth's crust, with iron being the second most abundant accounting for 5% (WHO, 1996). Manganese typically occurs with iron however it is not found naturally in its elemental form. It occurs as a component within a variety of minerals (WHO, 2011). Both iron and manganese are essential to humans and animals with manganese contributing to the functioning of cellular enzymes (WHO, 2011), and iron contributing to the circulation of haemoglobin, myoglobin, and other enzymes (Cook et al., 1975).

Iron

There are four typical forms in which iron is present in water namely, bacterial iron, ferric iron, ferrous iron and chelated iron. Bacterial iron is responsible for the promotion of bacterial growth within a water distribution network. This is typically seen as a slime coating on the inner surface of the distribution network (WHO, 1996).

Ferric iron (Fe^{3+}) is commonly known as "red water iron" and is the result of iron molecules that have been exposed to air and have thus oxidised out of the water, giving the water a red colour. Ferrous iron (Fe^{2+}) is typically found in groundwater sources and is attributed to water at anaerobic conditions (no oxygen) (Charette, 2002).

Chelated iron refers to iron that is combined with organic matter within the water. This form of iron may be the result of natural or man-made organic compounds and are typically heavily coloured compounds that can cause staining. Chelated iron is a stable compound that prevents the iron from reacting as it normally would in other forms. This makes chelated iron particularly difficult to treat (Hill, 2019).

When investigating groundwater abstraction and its use, it is important to analyse the iron levels and forms of iron within the groundwater in order to determine whether further treatment is necessary. Should iron be present within the groundwater, it is important to oxidise and precipitate the iron out of the water. Dissolved iron can be oxidised using gasses such as air or ozone, as well as chemicals such as hydrogen peroxide. By increasing the pH of the groundwater, the iron can be precipitated out of solution. These precipitates can then be removed through media filtration.

Manganese

Manganese is typically present in groundwaters however its concentration can vary significantly from source to source. Both under and over exposure of manganese can have detrimental effects on humans. Under exposure of manganese is extremely rare as most foods are enriched with manganese. Over exposure is more common as a result of consuming contaminated and/or untreated water with high manganese contents (WHO, 2011).

Manganese can be removed physically, chemically and biologically. Typical methods for manganese removal include ion exchange, oxidation and filtration as well as clarification and flocculation in the event of particulate and/or colloidal manganese (Sengupta, 2016). When employing oxidation and filtration of manganese, it is essential to raise the pH of the water. Water with a higher pH will promote the precipitation of manganese from the water. These precipitates can then be removed via media filtration. In addition, filtration media specifically designed for the removal of dissolved manganese from water show increased performance at higher pH values (typically around a pH of 8).

2.3.3 Turbidity Removal

Turbidity is a measurement used to describe the transparency of water as a result of suspended particles within the water (Lenntech, 2020). Typical material that causes turbidity include clay, silt, organic and inorganic matter and other microscopic organisms (Minnesota Pollution Control Agency, 2008). Turbidity in the water indicates that contaminants are present that cannot be removed through conventional filtration methods. Turbidity also renders certain disinfection methods such as UV light and ozone ineffective as a result of the shielding effect that these suspended particles have for pathogens.

A variety of methods exist for the removal of turbidity including coagulation, flocculation and filtration. Coagulation destabilises any colloids within the water through the addition of a coagulant (typically aluminium or iron based), and rapid mixing. The flocculation process follows the coagulation process and is the process in which slow mixing promotes the destabilised colloids to agglomerate forming larger particles referred to as “flocs”. These flocs can either be lifted to the water surface through the addition of air, and removed via a mechanical scraping system, or removed through conventional media filtration (Berhe, 2015).

2.3.4 Disinfection

When investigating the abstraction and use of groundwater, it is important to determine whether the water is contaminated with microorganisms that may pose a health risk to the end user. Some of the more common bacteria and pathogens in water are Vibrio Cholerae, Salmonella and Escherichia Coli. These bacteria and pathogens are responsible for cholera, gastroenteritis and acute diarrhoea respectively (Cabral, 2010). There are an array of other bacteria and pathogens that may be present in groundwater and thus it is critical to ensure the effective disinfection of the groundwater before use.

There are a variety of methods employed for groundwater disinfection, the selection of which depends on the treatment regime, budget, operational practicality required etc. These methods include ozone, UV and chlorination. Disinfection via chlorine may be accomplished through gas chlorination or liquid chlorination. Gas chlorination is one of the more popular forms of disinfection especially in larger water treatment plants. Gas chlorination is higher in capital cost than that of a liquid chlorination system however its operational cost is half that of a liquid chlorination system (Plumley, 2018). Liquid chlorination systems utilise substances such as sodium hypochlorite which can be purchased as a bulk liquid. Alternatively, chlorination solutions can be made up by using chlorinated tablets or chips such as calcium hypochlorite.

2.4 Theoretical Design of Groundwater Treatment Plants

Water treatment is an extensive and diverse field of Science. No two water sources are the same and thus it is important to ensure the source water is thoroughly analysed in order to determine the constituents present and their concentration. Water treatment designs can vary largely in complexity based specifically on the constituents in the source water to be treated. For the sake of this research, water treatment requirements under investigation are limited to that of pH correction, iron and manganese removal, turbidity removal and disinfection.

2.4.1 Source Water

It is common in large-scale groundwater abstraction projects, that multiple water sources, such as boreholes, are combined to form a larger raw water stream. This raw water stream is then treated to produce potable water which can then be delivered to the point of use, either through existing municipal infrastructure, or through privately implemented infrastructure.

In order to determine the feasibility of large-scale groundwater abstraction projects, it is critical to obtain an estimate into the sustainable yield of groundwater that can be abstracted, its water quality and thus the treatment required. The resulting costs associated with the erection of such a treatment plant and the operational requirements can then be determined. The intention during the investigation into these large-scale groundwater abstraction projects, is to minimize the financing required to perform investigative functions, whilst maximising the information required to compile an accurate budget and project plan.

The sustainable yield of the groundwater abstraction can be determined on the appointment of a contractor who specialises in locating groundwater abstraction points and performing the required SANS 10299-4:2003 tests to determine each points' sustainable yield. A sample of each of the identified abstraction points can be taken and tested according to SANS 241-1:2015 guidelines at any accredited laboratory. The subsequent water results of each abstraction point can then be arithmetically investigated in order to create a prediction of the combined raw water quality, the procedure for which is described further below.

Predicting the combined raw water quality is done by first determining what the raw water stream flow rate will be based on the combined sustainable yields of the abstraction points as per Equation 2.2 in the equation block at the end of this section. The concentration results of each water parameter for each groundwater abstraction point are then weighted against each abstraction point's sustainable yield, and the combined raw water flow rate as described by Equation 2.3.

Once the combined raw water stream is characterised in terms of its final flow rate and estimated water quality, an investigation can be conducted into the parameters lying outside of their allowable limits (according to SANS 241-1:2015). This will determine what water treatment method should be employed which will dictate what process units are required. The size of the raw water stream will govern the sizing of the process units and subsequent sizing of pipework etc.

Source Water Equations

- Total raw water stream flow rate

$$\dot{Q} = \sum \dot{q}_i \tag{2.2}$$

where $\dot{Q}$ represents the combined raw water flow rate, and $\dot{q}_i$ represents the sustainable yield of each abstraction point.

- Weighted water quality concentrations

$$x_{final} = \frac{x_i \dot{q}_i}{\dot{Q}_i} \tag{2.3}$$

where, x_i represents the concentration of the water parameter under investigation specific to the individual groundwater abstraction point.

2.4.2 Chemical Condition

Most groundwater abstraction water treatment plants involve chemical dosing systems regardless of the plant size. Chemical dosing systems are employed to compliment a variety of water treatment methods such as pH correction, coagulation and flocculation, oxidation and disinfection etc. (Schutte, 2006). When employing chemical dosing systems, it is essential to ensure the correct sizing of dosing pumps based on the flow rate of chemicals to be delivered to the water and at what pressure this should be achieved.

Coagulation and Flocculation

Coagulation and flocculation are water treatment processes typically found in conventional water treatment plants (Muyibi, 2012). Coagulation involves the addition of a coagulant such as polyaluminium chloride or ferric chloride to destabilise colloids within the water. The addition of the coagulant is typically followed by rapid mixing after which a flocculant is added. The flocculant promotes the formation of floccules within the water with slow mixing. These floccules can then be removed from the water through additional downstream processing such as the addition of air and the scraping of the floccules from the surface of the water (Vito, 2020).

Oxidation

Oxidation involves the addition of an oxidant to water to oxidise dissolved ionic species into insoluble compounds. These compounds can then be removed through additional downstream processing such as filtration. Oxidants can be introduced into the water either through liquid oxidants such as potassium permanganate and chlorine, or gaseous oxidants, such as ozone and chlorine dioxide (Atkinson and Palin, 1973).

Disinfection

Disinfection involves the addition of a disinfecting agent to water to destroy micro-organisms within the water that may otherwise pose as a health risk to the end user. As is the case with oxidation, disinfecting agents are available in both liquid and gaseous forms. Liquid disinfectants are typically calcium or sodium hypochlorite, whilst gaseous disinfectants are typically chlorine dioxide (Larsen and Maurer, 2011).

Chemical Dosing Sizing

In order to accurately size the chemical dosing system, the amount of chemical required to achieve the objective has to be known. This value can either be determined arithmetically based on the required change in water parameter from its measured value to its desired value, can be provided by the manufacturer and/or supplier of the chemical or can be a targeted value. An example of this is the required free chlorine value to be achieved for treated water before entering municipal infrastructure.

Once the amount of a specific chemical to be dosed is known, the dosing pump flow rate can be determined using Equation 2.4 in the equation block at the end of this section.

Once the required flow rate of the chemical to be dosed is determined, the pressure at which the dosing pump must deliver the flow rate can be determined. This is determined based on the distance over which the dosing chemical must travel to reach the dosing point, the friction within the pipework it must overcome and any pressure drops that may be inflicted as a result of valves, pressure gauges and other associated equipment situated in the dosing line. Additional detail into friction losses through pipework is provided in Section 2.4.4. below.

Chemical Dosing Equation

- Dosing pump flow rate

$$\dot{Q}_{dosing\ pump} = \frac{\dot{m}_{chemical} \times \dot{Q}_{water}}{x_{chemical}} \tag{2.4}$$

where, $\dot{Q}_{dosing\ pump}$ represents the required flow rate of the dosing pump, $\dot{m}_{chemical}$ represents the amount of chemical required to achieve the objective, $\dot{Q}_{water}$ represents the flow rate of the water stream into which the chemical is being dosed, and $x_{chemical}$ represents the source concentration of the chemical being dosed.

2.4.3 Filtration

Filtration refers to the process whereby particles are removed from suspension in water (Taulbee, 2005). This process can be achieved via strainers or filters. Strainers consist of a thin barrier typically metal or plastic which are designed to remove larger particles from the water. Filters typically make use of a filter media whose selection depends entirely on the constituent and/or particles to be removed. Filters themselves can be designed such that they filter at slow conditions, rapid gravity conditions or under pressurised conditions.

Although designs of filters can range drastically depending on the application, they all share similar characteristics such as backwashing. Backwashing of filter media is critical to ensure the continued effectiveness of filtration as well as the media's longevity. Backwashing is conducted in the opposite flow direction to the normal filtration flow direction, and typically requires much higher velocities than those required for normal filtration. This is to ensure the filter bed is fluidised during backwashing.

Before the design of a filter can be performed, it is critical to determine what filter media is required. Typical filter medias utilised in water treatment include quartz sand, activated carbon, manganese dioxide, activated glass and limestone (Suez, 2020). Each filter media has its own design criteria including the velocity at which normal filtration should occur (filtration flux), the velocity at which backwashing should occur (backwash flux), the height of the filter bed, the time for which the filter bed and the water should be in contact, and the height between the top of the filter media and the top of the filter (freeboard).

Activated Glass

Activated glass is a filter media whose performance surpasses that of quartz sand. Its use in the water treatment industry is thus slowly increasing. One of the more popular activated glass medias is Activated Filter Media (AFM) produced by Dryden Aqua Technology. The filter media itself is manufactured from green glass, is bio-resistant, self-sterilising and provides an increase of 30% in filtering organics (Dryden Aqua, 2015). Although most activated glass filter media results in higher capital expenditure than quartz sand, many producers such as Dryden Aqua boast a service life of over 10 years for the activated glass media, thus the operational expenditure is reduced (Dryden Aqua, 2018).

Activated glass not only performs the same basic function as quartz sand through the removal of suspended particles but is also able to remove turbidity from water. It is for this reason that this filter media is selected when Total Suspended Solids (TSS) is of concern along with turbidity within the water. In order to achieve optimal filtration performance using activated glass filter media, a filtration flux between 1 and 30 $m^3/ h/ m^2$ is to be achieved (Dryden Aqua, 2018). In large-scale groundwater abstraction projects, multiple filters are typically required in order to achieve this flux. The filtration flux is described by Equation 2.5 in the equation block at the end of this section.

Should the designer only have access to a filter with a standard cross-sectional area, this area should be entered into Equation 2.5, and then the flow rate divided by the number of filters until the filtration flux is within the required range. Should the designer have the ability to design the filter and thus the cross-sectional area, the designer can change both the cross-sectional area, and flow rate (based on the number of filters) in order to determine the best filtration option suited to the application and space requirements (if any).

Once the cross-sectional area and number of filters is determined, the height of the filter is determined. This is done according to Equation 2.6. It must be noted that in some cases, filter media suppliers recommend the assistance of air in the backwashing cycle. Should this be the case, the filter height will also be increased by the nozzle plate required to be installed at the bottom of the filter. Should the designer only have access to particular filters, they are to choose the filter whose height is closest to that determined as a result of Equation 2.6. Should the designer be in a position to design the filter, they should design it to the height determined by Equation 2.6, accounting for any nozzle plates if required.

The height of the filter bed ($h_{filter\ bed}$ in Equation 2.6) is either provided by the filter media supplier, or calculated based on the recommended contact time between the filter media and the water. In this case, the filter media is determined as per Equation 2.7. In the case of AFM, the recommended filter bed height is between 1 200 mm and 1 400 mm, however it is acceptable to use a filter bed height of 1 000 mm.

The height of the freeboard required ($h_{freeboard}$ in Equation 2.6), is provided by the filter media supplier. In the case of AFM, the freeboard required is 500 mm.

Effective backwashing of AFM filter media is critical in ensuring its continuous filtration performance. The recommended backwash flux given by Dryden Aqua is between 40 and 45 m^3/ h/ m^2. It is important to note that the filter's design is based on the filtration flux. This will set the number of filters and the cross-sectional area of the filter. Knowing the cross-sectional area of the filter as well as the required backwash flux, allows for the appropriate backwash pump selection based on the resulting flow rate as described by Equation 2.8.

In addition to backwashing with water, backwashing with air is also widely used in the water treatment industry. This is especially common with large slow sand filters and rapid gravity sand filters. Typically, an initial air sparging is conducted to fluidize the bed. After a certain period of time, water is introduced at a slower flow rate than that required to achieve the required backwash flux. This water backwashes the filter along with the air for a set period. The last cycle of the backwash involves switching the air off and increasing the backwash pump speed to the speed required to achieve the backwash flux. Water then backwashes at this rate for a set period.

In the case of AFM, isolated air sparging is not recommended and thus the backwash cycle typically skips the first step of the above described three step process.

Manganese Dioxide

Manganese dioxide is an inorganic compound that is used to remove iron, manganese, arsenic, radium and hydrogen sulphide from water (Wirth, 2013). Manganese dioxide serves as a catalyst in the oxidation-reduction reactions governing the removal of these compounds, resulting in their precipitation from the water and adsorption onto the surface of the manganese dioxide substance. Most filter medias in industry have been designed with a manganese dioxide coating that can facilitate the removal of iron and manganese and can be regenerated.

Maddox is an ion exchange catalyst made up of manganese dioxide and granulated green sand (African Pegmatite, 2019). It is utilised in the removal of iron and manganese from water. It should be noted that there are a variety of filter medias that can be utilised for the removal of iron and manganese such as Birm and normal greensand, however Maddox is one of the more superior filter medias in this regard. This is attributable to its ability to work effectively over a large pH range, as well as its ability to remove hydrogen sulphide, aluminium salts, tannins and chlorides from the water in addition to iron and manganese.

The design of Maddox filters is performed in the same way to that of activated glass filters as described by Equations 2.5 to 2.8. The required filtration flux for Maddox filter media is between 12 and 15 $m^3/h/m^2$. The required backwash flux for Maddox filter media is between 30 and 50 $m^3/h/m^2$. The required bed height for Maddox filter media is less than that of activated glass and is recommended to be between 300 mm to 800 mm with optimum performance at 800 mm. The recommended freeboard for Maddox is between 300 and 500 mm. In the case of Maddox, all three backwashing steps involving both air and water are implemented.

Filtration Equations

- Filtration flux

$$\varphi = \frac{\dot{Q}}{A} \tag{2.5}$$

where, φ represents the filtration flux, $\dot{Q}$ represents the flow rate through the filter, and A represents the cross-sectional area of the filter.

- Height of the filter

$$h_{filter} = h_{filter\ bed} + h_{freeboard} \tag{2.6}$$

were, h_{filter} represents the overall height of the filter, $h_{filter\ bed}$ represents the height of the filter media bed and $h_{freeboard}$ represents the height of freeboard required.

- Filter bed height

$$h_{filter\ bed} = \frac{\dot{Q} \times t}{A} \tag{2.7}$$

where, $\dot{Q}$ represents the flow rate through the filter, A represents the cross-sectional area of the filter and t represents the contact time required between the filter media and the water.

- Backwash flux

$$\dot{Q}_{backwash} = \varphi_{backwash} \times A \tag{2.8}$$

where, $\dot{Q}_{backwash}$ represents the backwash flow rate, $\varphi_{backwash}$ represents the backwash flux, and A represents the cross-sectional area.

2.4.4 Pumps and Pipework

When designing a water treatment plant, it is critical to ensure process units are sized correctly. Under-sizing process units will result in ineffective water treatment and will thus put end users at risk. Over-sizing process units is financially wasteful. The sizing of process units also directly impacts the capital and operational expenditures associated with a water treatment plant, and thus the payback period. Pumps are important process units to size correctly as not only do they impact the capital expenditure, but their maintenance and energy requirements have a significant impact on the operational expenditure of the plant.

There are two characteristics to consider when designing and selecting a pump namely, the flow rate it should achieve, and the pressure to be achieved at that flow rate. These two characteristics are grouped together and are referred to as the pump's duty point. The relationship between the flow rate a pump can deliver and the pressure at which it can deliver that flow rate can be visually determined from its pump curve.

Selecting a pump to achieve a certain flow rate is critical when transferring water through filter vessels. In the case of pressurised filters, it is critical to ensure that the flow rate can be achieved at a pressure sufficient to pass the water through the filter, but not so high as to inflict structural damage to the filter. The required flow rate to be achieved is determined during filter design (refer to Equations 2.5 and 2.8), however the determination of the pressure at which the pump should deliver the flow rate is more complicated.

As water is passed from one point to another, it is subject to pressure losses through pressure drops across process units and friction within pipework. It is therefore imperative to ensure the pump is sized such that it can achieve the required pressure whilst still overcoming any pressure losses. Pressure drops across process units can be determined by measuring the pressure of water entering the process unit as well as the pressure leaving the process unit. The difference between these values indicates the pressure drop. If the pressure drop cannot be determined in this manner, the manufacturer and/or supplier of the process unit can be consulted. The computation of friction losses through the pipework associated with a water treatment plant involves further computational steps.

When investigating the pressure losses through water infrastructure it is important to note that 1 bar of pressure is equivalent to 10 meters of physical height. The pressure loss through infrastructure is therefore computed as head loss and is expressed in units of distance such as meters or feet. The head loss in a pipe is calculated using the Darcy-Weisbach equation (Pipe Flow, 2019) and is described by Equation 2.9 in the equation block at the end of this section.

The friction factor (f in Equation 2.9) can be determined using the Moody Chart. The Moody Chart plots the Reynold's number versus the relative roughness for laminar or turbulent flow. The friction factor can then be determined visually. The Reynold's number is calculated using Equation 2.10.

Laminar flows are typically described by Reynolds numbers below 2 000. Turbulent flows are typically described by Reynolds numbers above 4 000. The relative roughness can be determined using Equation 2.11.

In addition to understanding the friction losses associated with the pipework in a water treatment plant, it is critical to ensure all pipework is sized correctly. As water flows through infrastructure, it speeds up and slows down depending on the inner diameter of the infrastructure, as described by Equation 2.12.

When designing water infrastructure, it is important to note that water velocities should be kept below 1 m/s on the suction side of the pump, and between 2 and 2.50 m/s on the discharge side of the pump.

Pumps and Pipework Sizing Equations

- Darcy-Weisbach equation

$$h_f = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right) \quad (2.9)$$

where, h_f represents the head loss in the pipe, f represents the friction factor, L represents the length of the pipe section in question, D represents the inner diameter of the pipe in question, V represents the velocity of the fluid and g represents the acceleration due to gravity. This is a constant and is measured as 9.81 m/s^2.

- Reynolds number

$$Re = \frac{\rho V D}{\mu} \quad (2.10)$$

where, ρ represents the density of the liquid, V represents the flow velocity, D represents the inner diameter of the pipe in which the liquid is being transferred and μ represents the dynamic viscosity.

- Relative roughness

$$Relative\ Roughness = \frac{\varepsilon}{D} \quad (2.11)$$

The ε in Equation 2-11 above represents the internal roughness whose value depends on the material of the pipe. These can be found in literature and remain constant.

- Pipe diameter as a function of velocity

$$D = \sqrt{\frac{4\dot{Q}}{V\pi}} \quad (2.12)$$

where, D represents the diameter of the pipe, $\dot{Q}$ represents the flow rate of the water and V represents the velocity of the water.

2.5 Feasibility of Groundwater Abstraction and Treatment

When investigating the feasibility of groundwater abstraction and use for potable purposes, it is important to consider the financial implications associated with the abstraction, alongside the water security the abstraction will provide and the impact on the environment. Large-scale groundwater abstraction projects typically involve a variety of abstraction points which, based on their locations, may be grouped together to supply water to individual water treatment plants.

2.5.1 Overall Feasibility of Groundwater Abstraction Projects

The total capital expenditure associated with large-scale groundwater abstraction projects is allocated to all parties who contribute to the completion of the project. For municipal groundwater abstraction projects, these would typically include surveyors, drilling specialists, mechanical and electrical contractors, civil contractors, and consultants. The monthly operation and maintenance costs associated with the groundwater abstraction projects include the consumables and chemicals required for groundwater abstraction and treatment to potable standards, salaries of any personnel required, as well as the electricity consumption.

Once the total capital expenditure along with the monthly operation and maintenance expenditure for a large-scale groundwater abstraction project is known, the payback period can be determined as well as the monthly savings applicable once the payback period is complete. The payback period can therefore be calculated as per Equation 2.13 at the end of this section. Should the payback period fall within the life span of the groundwater abstraction water treatment plant(s), the project is feasible. Should the payback period prove that the groundwater abstraction project is feasible, the percentage of monthly savings can be investigated as per Equation 2.14 in the equation block at the end of this section.

2.5.2 Feasibility of Groundwater Abstraction and Treatment for Varying Flow Rates

During the investigation stage of large-scale groundwater abstraction projects, it is common to identify a number of abstraction points. Abstraction points near to one another can be combined to form one larger raw water stream for treatment. The flow rate of the raw water stream can however vary from site to site depending on the sustainable yields of abstraction. The feasibility of the groundwater abstraction and treatment thereof should therefore be investigated based on the different flow rates that can be achieved. This will ensure that the maximum amount of potable water can be achieved through abstraction at the minimum cost.

In order to investigate the feasibility of groundwater abstraction and treatment to potable standards between sites of varying flow rates, complete designs of the required treatment plants must be compiled based on the varying flow rates. It is important to note that in this case, it is assumed that the water quality will not vary, thus one water source is being utilised. This ensures that the feasibility of groundwater abstraction and treatment to potable standards is only being investigated based on varying flow rates. The completion of the design will allow for the total expenditure of each treatment plant to be compiled. This will allow for the payback periods and percentage monthly savings to be computed as per Equations 2.13 and 2.14 in the equation block at the end of this section. The resulting figures will then provide direction into which of the flow rates will be more feasible for abstraction and treatment.

2.5.3 Feasibility of Groundwater Abstraction and Treatment for Varying Water Quality

The investigation stage of large-scale groundwater abstraction projects may result in various abstraction points that exhibit varying water quality. The feasibility into the groundwater abstraction and treatment thereof from each of these abstraction points therefore needs to be conducted in order to identify the most feasible abstraction point based on the water quality. It is important to note that when performing this feasibility study, it is assumed that the same flow rates can sustainably be abstracted from each abstraction point.

As per the investigation into abstraction points with varying flow rates, when determining the feasibility of varying water quality, complete designs of the required water treatment plants are to be compiled. These will assist in computing the total expenditure associated with each water treatment plant based on the combined abstraction point's water quality. The payback periods and percentage monthly savings can then be computed using Equations 2.13 and 2.14 in the equation block at the end of this section. This will identify which of the abstraction points are the most feasible to utilise based on their water quality.

2.5.4 Price of Water

In South Africa, there are five institutions that govern the price of water that end users are subject to. These are the Department of Water Affairs and Forestry (DWAF), Catchment Management Agencies (CMA), Water Services Authorities (WSA), Water Services Providers (WSP) and Water Boards (WB). Three types of water prices exist namely, water resource prices, bulk water tariffs, and water service tariffs. When investigating the feasibility of large-scale groundwater abstraction projects and treatment to potable use, it is important to use the bulk water tariff that the municipality in which the project is found, would ordinarily be subject to. The prices for bulk water tariffs are determined by WBs and are subject to the relevant ministerial approval (Eberhard, 2020).

Feasibility Equations

- Payback period

$$PBP = \frac{\left(\frac{C_{project}}{\dot{Q}_{net\ potable\ water}} + \frac{C_{operate\ and\ maintain}}{\dot{Q}_{net\ operate\ and\ maintain}}\right)}{C_{municipal\ water}} \quad (2.13)$$

where, PBP represents the payback period, $C_{project}$ represents the capital expenditure of the project, $\dot{Q}_{net\ potable\ water}$ represents the total flow rate of potable water, $C_{municipal\ water}$ represents the cost of water the client would have paid if the project did not go ahead, $C_{operate\ and\ maintain}$ represents the operation expenditure of the plant, and $\dot{Q}_{net\ operate\ and\ maintain}$ represents the flow rate of potable water being supplied during the trial operation phase of the project.

- Monthly percentage savings

$$Monthly\ Saving\ \% = \frac{C_{municipal\ water} - C_{operate\ and\ maintain}}{C_{municipal\ water}} \times 100 \quad (2.14)$$

where, $C_{municipal\ water}$ and $C_{operate\ and\ maintain}$ represent the costs that the client would have paid for water in that month, and the operational expenditure respectively.

CHAPTER 3 – METHODOLOGY

In order to investigate the feasibility of a large-scale groundwater abstraction project, the capital and operational expenditure associated with a recently implemented large-scale groundwater abstraction project were obtained. In addition, the rate at which bulk water would have ordinarily been purchased at if not for the large-scale groundwater abstraction project, was determined. The payback periods, monthly savings and thus the feasibility was then determined. The capital and operational expenditure utilised in this investigation was obtained from the Engineer of the large-scale groundwater abstraction project. In addition, the rates at which bulk water would have ordinarily been purchased at if not for the large-scale groundwater abstraction project, were obtained from literature, and was verified by the Engineer.

In order to achieve the primary and secondary aims of this dissertation, the lifecycle of a large-scale groundwater abstraction project was investigated. In 2017, one of the Western Cape's local municipalities, Drakenstein Municipality set aside funding dedicated to a large-scale groundwater abstraction project. The project scope involved identifying possible abstraction points in and around the municipal area, determining the sustainable yields of the abstraction points, confirming the water quality, and erecting groundwater abstraction water treatment plants. The water treatment plants were to be fully containerised allowing them to be removed if need be. In addition, they were to house booster pumps of sufficient size to deliver potable water directly into the municipal infrastructure.

Drakenstein Municipality appointed an Engineer, Aurecon, to manage the identification of groundwater abstraction points and positions for the water treatment plants. Once the abstraction points were identified and drilled, and the areas required for the water treatment plants were identified, the Engineer published a tender for the design and build of the required water treatment plants. Alveo Water was appointed as the mechanical and electrical contractor and commenced with the design and build of the water treatment plants, followed by the continued operation and maintenance of the plants. The project continued over a period of two years with the project's completion estimated to be at the end of March 2020. The feasibility investigation into the groundwater abstraction project commenced in February 2020.

3.1 Sustainable Groundwater Abstraction Points

During the initial stages of the large-scale groundwater abstraction project, a team of geohydrologists, GEOSS, were appointed by the Engineer to identify potential groundwater abstraction points in and around the municipality. Five main sites were investigated with varying numbers of exploratory abstraction points at each site. Of these exploratory abstraction points, two sites were chosen, Boy Louw Sportsgrounds and Parys Sportsgrounds for further investigation, with four abstraction points per site.

Boy Louw Sportsgrounds and Parys Sportsgrounds along with their four abstraction points are illustrated in Figures 3-1 and 3-2 below.

Figure 3-1: Boy Louw Sportsgrounds and its four abstraction points

Figure 3-2: Parys Sportsgrounds and its four abstraction points

Each of the eight abstraction points were tested using step tests, constant discharge tests and recovery tests in order to determine their individual sustainable yields. These tests were conducted by the geohydrologist. The results of these tests were then analysed using the FC, Cooper-Jacob and Barker Fracture flow methods. Once the sustainable yields of abstraction for each abstraction point were determined, the combined sustainable raw water flow rate from each site was determined.

A preliminary water sample for each groundwater abstraction point at each Site was taken in March 2018 by the geohydrologist. These were then submitted to Integral Laboratories, a SANAS accredited laboratory for testing of the water quality according to SANS 241-1:2015 standards. The parameters that were tested are illustrated in Table 3-1 below.

Table 3-1: Water parameters tested at a SANAS accredited laboratory

Parameter	Unit	Limit	Technique Used
pH	pH units	5 - 9.7	Electrode
Conductivity	mS/m	<170	Electrode
Turbidity	NTU	<1	Nephelometer
Total Dissolved Solids	mg/L	<1200	Gravimetric
Sodium (as Na)	mg/L	<200	ICP-OES
Potassium (as K)	mg/L	-	ICP-OES
Magnesium (as Mg)	mg/L	-	ICP-OES
Calcium (as Ca)	mg/L	-	ICP-OES
Chloride (as Cl)	mg/L	<300	Spectrophotometric
Sulphate (as SO_4)	mg/L	<250	Ion Chromatography
Fluoride (as F)	mg/L	<1.50	Ion Chromatography
Manganese (as Mn)	mg/L	<0.40	ICP-OES
Iron (as Fe)	mg/L	<2	ICP-OES
Copper (as Cu)	mg/L	<2	ICP-OES
Zinc (as Zn)	mg/L	<5	ICP-OES
Arsenic (as As)	mg/L	<0.01	Ion Chromatography
Cadmium (as Cd)	mg/L	<0.005	ICP-OES
Faecal Coliforms	counts/100 mL	0	Membrane Filtration
Total Coliforms	counts/100 mL	<10	Membrane Filtration

The parameters are illustrated in Table 3-1 above are the standard water quality parameters that the appointed geohydrologist, includes in their water testing report. These parameters serve as an indication of the quality of the raw water only. Full SANS 241-1:2015 water samples were taken later by the Engineer to confirm the exact raw water quality.

The testing techniques used for each parameter are indicated in Table 3-1 above and are in line with the procedures outlined in the SANS 241-1:2015 guidelines. Each abstraction point was then sampled a second time in April 2018 by the Engineer to confirm preliminary water analyses.. It should be noted that the design of a water treatment plant is limited to the confirmed water quality of the raw water and thus is limited by the number of samples taken. Civil, mechanical and electrical contractors were then appointed to carry out the groundwater abstraction project from design phase to commissioning, based on tender documents published by the Engineer

The response of the aquifer to the continued groundwater abstraction was to be monitored through instrumentation, SCADA and telemetry. Instrumentation for this monitoring was therefore incorporated into the designs of the groundwater abstraction water treatment plants by the mechanical and electrical contractor. The subsequent data will continue to be analysed by the team of geohydrologists on a monthly basis.

3.2 Groundwater Abstraction Water Treatment Plants

On completion of the sustainable yield testing and water quality testing of the eight abstraction points, the design of the groundwater abstraction water treatment plants at Boy Louw Sportsgrounds and Parys Sportsgrounds commenced. The mechanical and electrical contractors assigned to the project worked with the Engineer to finalise the water treatment processes required for the resulting potable water to adhere to SANS 241-1:2015 guidelines.

The design process for each of the water treatment plants involved the following aspects:

- Compilation of a Piping and Instrumentation Diagram (P&ID), a Process Flow Diagram (PFD), and a control philosophy
- Hazard and Operability Study (HAZOP)
- Sizing of all process units such as pumps, filters, chemical dosing systems and pipework (as per Section 2.4)
- Sizing of electrical panels and equipment
- Conceptual distribution of equipment amongst shipping containers
- Civil design of site with respect to shipping containers and water storage tanks
- Compilation of final civil, mechanical and electrical drawings illustrating all equipment associated with the water treatment plants
- Compilation of a Functional Design Specification (FDS), outlining the exact control philosophy applicable to the plant including SCADA and telemetry

On completion of the design phase for each groundwater abstraction water treatment plant, the Engineer pursued all required licencing, civil works commenced, and mechanical and electrical manufacturing commenced. The civil, mechanical and electrical contractors worked in conjunction until the erection of the two water treatment plants was complete. The two water treatment plants were then commissioned with the treated water quality of each plant being verified through a water sample taken in February 2019 for Boy Louw Sportsgrounds and July 2019 for Parys Sportsgrounds. The sites were then handed over to the municipality. Each groundwater abstraction water treatment plant was designed to ensure a life span of 10 years.

3.3 Feasibility of the Groundwater Abstraction Project

The large-scale groundwater abstraction project involved co-dependency between various stakeholders responsible for a multitude of different operations and functions. These businesses therefore served as various project units as follows,

- Environmental and safety consultants
- Geohydrologists and drilling contractors
- Civil, mechanical and electrical contractors
- SCADA and telemetry contractor

Each of the above project units contributed to the total capital expenditure of the large-scale groundwater abstraction project, with some of the above units also contributing to the monthly operational expenditure of the project. Once the large-scale groundwater abstraction project had been completed from the design phase to the commissioning phase, the complete capital expenditure associated with each of the project units involved were compiled. This includes the capital expenditure applicable to Boy Louw Sportsgrounds and Parys Sportsgrounds. This data was obtained directly from the Engineer. It is important to note that the feasibility of the large-scale groundwater abstraction project was investigated for the project as a whole. Boy Louw Sportsgrounds and Parys Sportsgrounds were not treated as separate entities.

The operational expenditure applicable to the large-scale groundwater abstraction project was then computed based on the estimated monthly electricity, chemical, labour and maintenance costs associated with each of the groundwater abstraction water treatment plants at Boy Louw Sportsgrounds and Parys Sportsgrounds. In addition, rates at which the municipality normally purchased water at from the City of Cape Town were obtained from literature. These costs and rates were then used to investigate the overall feasibility of the groundwater abstraction project as described in Section 2.5, as well as the monthly savings applicable to the municipality once the payback period was complete.

The effect of varying flow rates on the feasibility of groundwater abstraction was then investigated utilising the data available from the groundwater abstraction water treatment plants at Boy Louw Sportsgrounds and Parys Sportsgrounds. Although both sites made use of activated glass filters, Boy Louw Sportsgrounds involved the addition of Maddox filters, and subsequently air blowers, backwash water settling ponds and backwash water recovery pumps. The mechanical, electrical and civil contractors were consulted in order to determine the costs associated with these sections. These costs were then removed from the capital expenditure associated with Boy Louw Sportsgrounds in order to ensure the capital and operational expenditures for Boy Louw Sportsgrounds and Parys Sportsgrounds could be fairly compared based on similar water quality.

The effect of varying water quality on the feasibility of groundwater abstraction water treatment plants at the same flow rates was then investigated. Boy Louw Sportsgrounds required the use of Maddox filter media to remove iron and manganese from the water, whilst Parys Sportsgrounds did not as no elevated concentrations of iron and manganese were present in the raw water. The effect of the varying water quality on the feasibility was therefore determined by scaling the costs associated with the two water treatment plants such that they were designed to treat the same flow rate with varying water quality. The feasibility results were then determined as described in Section 2.5.

Finally, the limit of feasibility of the large-scale groundwater abstraction project was investigated by determining what bulk water purchase tariff from the City of Cape Town results in the project no longer being financially feasible. Bulk water purchase tariffs change over time and are subject to review during drought conditions. It is therefore important to determine at what bulk water purchase tariff the project is no longer financially feasible at. This will determine whether the implementation of groundwater abstraction and treatment projects to potable use is feasible depending on the time period and environmental conditions such as drought.

The bulk water purchase tariff at which the project was no longer financial feasible was therefore determined by computing the constant capital expenditure associated with the project as well as the constant estimated monthly operational expenditure of the project. These values were then used along with varying bulk water purchase tariffs to establish which tariff results in a payback period equal to or longer than the estimated lifespans of the groundwater abstraction water treatment plants. The large-scale groundwater abstraction project is no longer financially feasible at this municipal rate and below.

CHAPTER 4 – RESULTS AND DISCUSSION

The feasibility of the large-scale groundwater abstraction project is investigated through determining sustainable groundwater abstraction points, their sustainable yields and water quality. The groundwater abstraction points are grouped into two main sites each capable of delivering an overall sustainable raw water flow rate. Two groundwater abstraction water treatment plants are then designed according to the sustainable raw water flow rate to be treated, and the water quality of each flow rate. The capital expenditure associated with each groundwater abstraction water treatment plant is obtained along with the operational expenditure applicable to each plant during its trial operation phase. The monthly operational expenditure of each groundwater abstraction treatment plant is then determined. These three expenditures are then investigated as a function of each groundwater abstraction water treatment plant's volume of treated water in order to determine the payback periods, monthly savings and thus feasibility. The feasibility of groundwater abstraction and treatment at varying flow rates and water quality is then investigated by comparing the expenditure associated with each groundwater abstraction water treatment plant at the same water quality and different flow rate, and same flow rate and different water quality respectively.

4.1 Sustainable Groundwater Abstraction Points

The appointed team of geohydrologists investigated possible groundwater abstraction points in and around the municipality across two towns. Five of these groundwater abstraction sites were found to be sustainable with varying numbers of abstraction points at each site. The resulting sustainable abstraction points and their sustainable yields are summarised in Table 4-1 below.

Table 4-1: Sustainable groundwater abstraction points data (sites with highest flow rates illustrated in green)

Site	Abstraction Point	Pump Depth (mbgl)	Pump Rate (L/s)	Max Water Level (mbgl)
One	A	75	1.00	70
	B	80	1.60	70
Two	A	50	9.80	40
Three	A	80	17.00	70
	B	74	14.00	65
	C	80	14.00	65
	D	70	15.00	65
Four	A	70	4.50	46
	B	60	1.80	33
	C	70	5.20	45
	D	70	7.20	45
Five	A	70	3.30	60
	B	65	3.30	55

As can be seen in Table 4-1 above, Boy Louw Sportsgrounds and Parys Sportsgrounds resulted in the largest possible water abstraction with Boy Louw Sportsgrounds having a combined sustainable abstraction yield of 60 L/s and Parys Sportsgrounds having a combined sustainable abstraction yield of

18.70 L/s. This equates to 5.18 ML/day and 1.62 ML/day for Boy Louw Sportsgrounds and Parys Sportsgrounds respectively (as determined using Equation 2.2). Boy Louw Sportsgrounds and Parys Sportsgrounds were therefore selected for further investigation into the quality of their groundwater, and thus the use of these sites in the large-scale groundwater abstraction project. The remaining sites were not investigated further.

4.2 Groundwater Quality

The water quality of each abstraction point across the two sites was then analysed in March and April 2018. This data was then used to predict the overall water quality resulting from each site based on the combined sustainable flow rate of each site, and the individual flow rates of each abstraction point. Table 4-2 below illustrates the water quality parameters with concentrations above SANS 241-1:2015 upper limits, as determined in April 2018.

Table 4-2: Water quality parameters above SANS 241-1:2015 upper limits (red indicates non-compliant parameters)

Boy Louw Sportsgrounds				
Water Source	**Parameter**	**Unit**	**Result**	**Limit**
Raw Water	Turbidity	NTU	12.38	<1
	Iron as Fe	µg/L	2327	<300
	Manganese as Mn	µg/L	317	<100
	Total Coliforms	cfu's/100 ml	182	<10
	Faecal Coliforms	cfu's/100 ml	7.50	0
Parys Sportsgrounds				
Water Source	**Parameter**	**Unit**	**Result**	**Limit**
Raw Water	Turbidity	NTU	3.13	<1
	Total Coliforms	cfu's/100 ml	130	<10
	Faecal Coliforms	cfu's/100 ml	0.70	0

As can be seen in Table 4-2 above, both Boy Louw Sportsgrounds and Parys Sportsgrounds produced water with high turbidity concentrations and water that required disinfection based on the total coliform and faecal coliform counts. It was however noted that the turbidity concentrations as well as the total coliform and faecal coliform counts differed significantly between the sites. Parys Sportsgrounds produced water with a turbidity of 75% less than that of Boy Louw Sportsgrounds. In addition, the total coliform and faecal coliform counts at Parys Sportsgrounds were found to be 28% and 90% less than those at Boy Louw Sportsgrounds.

It was also observed that Boy Louw Sportsgrounds produced water with an iron concentration of approximately 327 µg/L above the SANS 241-1:2015 upper limit, and a manganese concentration of approximately 217 µg/L above the SANS 241-1:2015 upper limit. The iron and manganese concentrations at Parys Sportsgrounds were both found to be below the SANS 241-1:2015 upper limits. The varying water quality between Boy Louw Sportsgrounds and Parys Sportsgrounds, along with the groundwater source at Parys Sportsgrounds being shallower than that of Boy Louw Sportsgrounds (refer to Table 4-1), led to the conclusion that although the sites were only 2.60 kilometres apart, they were accessing different water sources.

It was therefore concluded that when investigating the implementation of large-scale groundwater abstraction projects, it is critical to analyse the groundwater source in order to confirm which water quality parameters will require additional treatment, as opposed to estimating the water quality based on the location of the groundwater abstraction points, and their subsequent geology. Estimating the water quality based on the location of the groundwater abstraction points and their subsequent geology as opposed to confirming the water quality will have determinantal effects on capital and monthly expenditure budgets. For the complete raw water analyses of each groundwater abstraction point at Boy Louw Sportsgrounds and Parys Sportsgrounds as analysed in April 2018 used in this study, refer to Tables B-1 and B-2 in Appendix B1.

4.3 Groundwater Abstraction Water Treatment Plant Designs

The water treatment process steps required were compiled based on the water quality parameters that were not within SANS 241-1:2015 guidelines for each of the two sites. Once the water treatment process steps were identified, a complete process design was compiled for each site. This included the compilation of P&IDs, PFDs and the performance of HAZOPs for each site. In addition, all mechanical and electrical equipment was sized and selected for each site, with detailed mechanical and electrical drawings being compiled.

4.3.1 Boy Louw Sportsgrounds – 5.18 ML/day

Boy Louw Sportsgrounds differed from Parys Sportsgrounds in that it exhibited a need for the removal of iron and manganese. It was decided that a three-step iron and manganese removal process would be employed. Firstly, chlorine was introduced into the combined raw water stream for pre-oxidation. Caustic was then introduced into the raw water to raise the pH from its estimated 6.78 to between 8 and 8.50. This is the optimum pH range for the operation of the Maddox filter media for the removal of dissolved iron and manganese from the water. The raw water was then passed through surface aerators which would promote additional oxidation through contact of water with oxygen from air. Finally, the water was treated using Maddox filter media in order to remove any remaining dissolved iron and manganese from the water.

The above three-step iron and manganese removal process would result in precipitants forming in the water. This observation along with the turbidity present in the water led to the decision to use activated glass filters after the Maddox filters. On completion of filtration, additional chlorine was introduced into the treated water for final disinfection before entering the municipal network. Figure 4-1 below illustrates the treatment process implemented at Boy Louw Sportsgrounds.

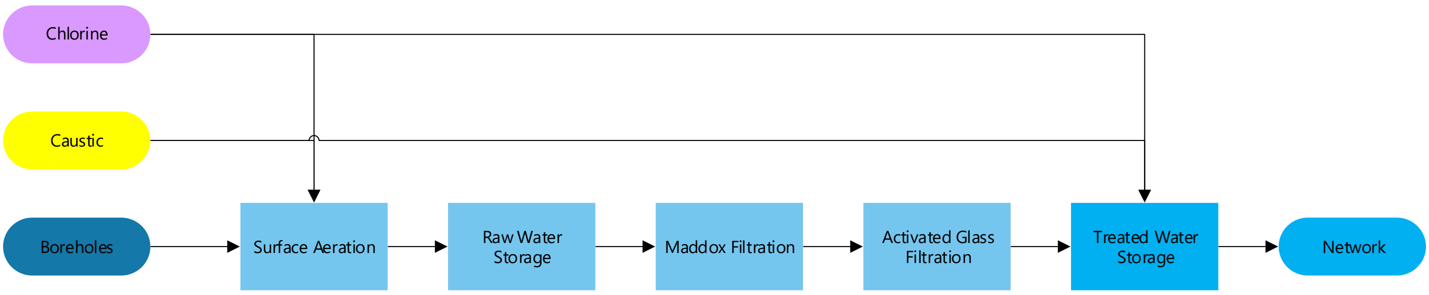

Figure 4-1: Treatment process of the groundwater abstraction water treatment plant at Boy Louw Sportsgrounds

Chemical Dosing Systems

Two dosing systems were required in order to achieve the water treatment requirements of Boy Louw Sportsgrounds. The first dosing system was dedicated to chlorine dosing. For ease of operation and system robustness, an off-the-shelf chlorine manufacturing apparatus was purchased. This apparatus known as a “Klorman Unit” utilises dry calcium hypochlorite tablets or “chips”. The dry calcium hypochlorite is placed into cartridges within the unit’s lid. Water is then passed through this dry calcium hypochlorite at a constant flow rate, dissolving the calcium hypochlorite and thus creating a chlorinated solution. The chlorine concentration of the make-up solution can be increased and decreased depending on the flow of water passing over the calcium hypochlorite and is therefore set using a globe valve and flow rotameter.

The manufacturer and supplier of the “Klorman Unit” was consulted with regards to how many units would be required to treat the combined 5.18 ML/day of groundwater. It was decided that three units would be employed such that the saturated chlorine concentration of the chlorine solution to be dosed into the water would be 500 mg/L. This chlorinated solution would need to be dosed into two points within the plant namely, the combined raw water stream for pre-oxidation of iron and manganese, and the treated water stream for final disinfection.

In order to determine the dosing setpoint of the pumps dedicated to deliver chlorinated solution to the raw water line, it was assumed that approximately 60% of iron in the water and approximately 80% of manganese in the water could be oxidised using chemical chlorine. It should also be noted that 0.64 mg of chlorine is required for oxidation per milligram of iron, and 0.94 mg of chlorine is required for oxidation per milligram of manganese. This therefore resulted in a total of 1.24 mg/L of chlorinated solution to be dosed into the combined raw water line, based on the total iron and total manganese readings as illustrated in Table B-1 in Appendix B1. A standard chlorine setpoint of 3 mg/L was targeted for the treated water in order to ensure it was adequately disinfected within the treated water storage tank and throughout the municipal network.

Equation 2.4 was then employed to determine the required flow rates of the two chlorine dosing sets. The required flow rate of the dosing set responsible for delivering chlorinated solution to the combined raw water line for iron and manganese oxidation was found to be approximately 537 L/hr. The required flow rate of the dosing set responsible for delivering chlorinated solution to the treated water line was found to be 1 270 L/hr.

A local dosing skid manufacturer and supplier was then consulted in order to assist in determining the required pressure required for each dosing pump to supply the chlorinated water based on the estimated distances of the dosing skids from their dosing points. This local manufacturer and supplier provided the required dosing pumps and skids to ensure effective dosing. It should be noted that although the dosing systems were sized to supply the above-mentioned flow rates, the dosing pumps were controlled based on the Oxidation Reduction Potential (ORP) of the water. The amount of chlorine supplied at any point in time therefore fluctuated based on what the raw and treated water stream ORP requirements were.

The caustic (sodium hydroxide) dosing flow rate required for Boy Louw Sportsgrounds was determined based on what the concentration of the bulk caustic would be when supplied by a local chemical supplier, and the amount of caustic to be dosed. The bulk caustic concentration from the local chemical supplier was determined to be 46%. The amount of caustic to be dosed in order to bring the pH to between 8 and 8.50 was determined to be 10.50 mg/L. The effective dosing volume was therefore found to be 22.83 ml/L. When applied to the 5.18 ML/day flow rate, the required caustic dosing rate was found to be 4.93 L/hr. Once again, the local dosing skid manufacturer was consulted in order to determine at what pressure the caustic dosing skid should deliver based on the distance from the dosing skid to the dosing point, as well as the high viscosity of the caustic liquid.

Filters

Boy Louw Sportsgrounds involved a much larger combined sustainable groundwater abstraction flow rate than Parys Sportsgrounds. In addition, the combined flow rate at Boy Louw Sportsgrounds required additional treatment as a result of the iron and manganese present in the water. It was therefore identified that Boy Louw Sportsgrounds would have more filters than Parys Sportsgrounds, with the filters requiring a significant amount of the available space on site. The design of the filters was therefore critical in determining the number of shipping containers required to house the groundwater abstraction water treatment plant for Boy Louw Sportsgrounds.

The filter design commenced with determining how many filters could be adequately spaced within a twelve-meter container, and the most feasible filter diameter to be utilised. It was determined that a local filter manufacturer and supplier was able to assist with the design, manufacturing and supply of large filters with a diameter of up to 1.50 meters. This option was found to be favourable in that although larger valves and actuators were required, they were required in fewer numbers ensuring less mechanical and electrical items that could breakdown. In addition, although much larger pipes were required, less pipework would be applicable, decreasing the possibility of leaks throughout the plant.

The filters to be filled with Maddox filter media and activated glass filter media were designed to be pressurised filters as they would be situated in retrofitted shipping containers. Pumps would therefore be required to transfer water from the raw water storage tank through the various pipework and filters before being transferred to the treated water storage tank. The pressurised filters would require actuated butterfly valves that would allow for automated filtration, backwashing and air scouring of the filters. This meant that each filter would require five actuated valves, the size of which would be determined through pipework design and sizing.

The number of pressurised Maddox filters was investigated first. This was done by determining how many filters with a diameter of 1.50 meters could be placed within a twelve-meter shipping container such that sufficient space was available between them for pipework with actuated butterfly valves and movement during servicing. It was determined that if six filters were inserted into one twelve-meter shipping container, there would be 400 mm of space available between each filter. In addition to this, if the filters were positioned such that the inlet and outlet pipework was placed at 45° angles, there would be sufficient space for actuated butterfly valves and movement.

A filter diameter of 1.50 meters was therefore set and used to determine the number of Maddox filters required. A filter diameter of 1.50 meters results in a filter area of 1.76 m^2. The sustainable abstraction flow rate for Boy Louw Sportsgrounds was determined to be 5.18 ML/day which equates to 216 m^3/hr. Applying Equation 2.5 resulted in a filtration flux of 122 m^3/ h/ m^2. This falls outside of the required filtration flux range of Maddox. The flow rate was then divided by an increasing number of filters until the filtration flux reached approximately 15 m^3/ h/ m^2. It was therefore found that eight Maddox filters would be required.

The height of the Maddox filters was then determined by considering the space required at the bottom of the filter, the height of the filter media, the required freeboard, and the height of the top dome. The space required at the bottom of the filter was determined by considering the feet, the bottom outlet hatch, the required inlet and outlet flanges as well as the air distribution nozzle plate. The height of the Maddox filter media was then selected as 900 mm in order to comply with manufacturer recommendations as well as allow for slightly more contact time for the removal of iron and manganese. The required space for the dome at the top of each filter with the required spreader pipe and backwashing flanges was then allowed for. This resulted in a total filter height of 1 935 mm. This filter height allowed air release valves to be placed on top of the filters with the filters fitting comfortably within the twelve-meter, high cube container.

The number of activated glass filters required was determined in the same way as the number of Maddox filters as described above. Although the number of Maddox filters was selected based on the upper limit of the recommended filtration flux range, the filtration flux targeted for the activated glass filters was slightly lower than its upper limit. This was due to the high level of turbidity in the combined raw water stream, as well as the addition of particulates within the water that the activated glass filters would have to remove. A filtration flux closer to 10 m³/ h/ m² was therefore targeted resulting in twelve activated glass filters being selected.

The total height of the activated glass filters was determined in the same way as the total height of the Maddox filters. The heights required for the feet, nozzle plate, inlet and outlet flanges were added to the height required for the top dome and inlet spreader pipe. These heights were then added to the total height required for the activated glass media bed of 1 000 mm. The final height of the activated glass filters was therefore found to be 2 135 mm. As was the case with the Maddox filters, it was found that an air release valve could still be added to the top of the activated glass filters without exceeding the total internal height of the twelve-meter, high cube container.

Pumps and Pipework

Five pump sets were required for the operation of the groundwater abstraction water treatment plant at Boy Louw Sportsgrounds. These sets are summarised as follows,

1. Borehole pumps to allow groundwater abstraction from each of the four groundwater abstraction points
2. Raw water pumps to transfer water from the raw water storage tank, through the two banks of filters (Maddox and activated glass), to the treated water storage tank
3. Treated water pumps to transfer water from the treated water storage tank to the municipal network
4. Backwash pumps to transfer water from the treated water storage tank, through the filters and to the backwash water settling ponds
5. Backwash water recovery pumps for transferring water from the backwash water settling ponds overflow point, back to the raw water tank

The borehole pumps were sized as per the geohydrologist-determined sustainable yields as indicated in Table 5-1 above. The raw water pumps were designed to supply the combined raw water flow rate of 60 L/s at a pressure of 2 bar. This pressure ensured that any estimated friction losses within the pipework were overcome, as well as the pressure drops as a result of the two filter banks.

The treated water pumps were sized to achieve 75 L/s at 9 bar. This would allow for slightly more treated water to be delivered to the network from the treated water storage tank for a short period of time if required. The pressure was selected based on the pressure the pumps had to overcome in order to deliver water into the municipal network.

The backwash pumps were selected based on the required backwash flux of Maddox and activated glass media to be achieved. The design only allows for one filter to be backwashed at any time in order to avoid excessively large backwash pumps. The backwash pump set was therefore designed to achieve 15 L/s at 0.20 bar. It is important to note that the backwash line was open to air through the backwash water settling ponds and thus little pressure was required to achieve sufficient backwash.

The backwash water recovery pumps were selected based on the estimated overflow of clarified water from the backwash water settling ponds, along with the distance from the pump suction point, to the raw water tank in which the clarified water was being transferred. In addition, the self-priming nature of these pumps was considered. The backwash water recovery pumps were therefore sized to achieve 23.61 L/s at 0.70 bar.

The pipework required for the groundwater abstraction water treatment plant at Boy Louw Sportsgrounds was sized according to the flow rates of the water that they were charged with transporting.

Process Design

Once the required chemical dosing systems were identified, the number of filters was determined and the pumps were selected, the overall process design was finalised. This was done by generating preliminary P&IDs and a preliminary PFD. These documents were then submitted to an external consulting company for analysis.

The external consulting company facilitated a HAZOP study on the groundwater abstraction water treatment plant with the Engineer, mechanical and electrical contractors present. During this HAZOP study, any potential risks and hazards associated with the preliminary design were identified. These were then incorporated into the design and the final P&IDs and PFD for the groundwater abstraction water treatment plant for Boy Louw Sportsgrounds were generated.

The final P&IDs for the groundwater abstraction water treatment plant for Boy Louw Sportsgrounds can be found in Figures B1 to B-20 in Appendix B2. The final PFD for the groundwater abstraction water treatment plant for Boy Louw Sportsgrounds can be found in Figure B-21 in Appendix B2.

Site Layout

Once the process design was finalised, and the major equipment items selected, the required equipment was distributed amongst shipping containers. It was found that a total of seven shipping containers would be required to fit all of the equipment required for the groundwater abstraction water treatment plant at Boy Louw Sportsgrounds. Preliminary mechanical and electrical layout drawings were compiled in order to ascertain the layout of the site. These drawings were reviewed by the Engineer in conjunction with the mechanical, electrical and civil contractors. Final mechanical and electrical layout drawings were then compiled based on the review.

The final layout of the groundwater abstraction water treatment plant at Boy Louw Sportsgrounds can be found in Figure B-35 in Appendix B3. Figure 4-2 below illustrates the final groundwater abstraction water treatment plant at Boy Louw Sportsgrounds taken during commissioning of the plant.

Figure 4-2: Final groundwater abstraction water treatment plant at Boy Louw Sportsgrounds

On commissioning of Boy Louw Sportsgrounds, it was determined that the addition of caustic and chlorine to the raw water as described in Section 4.3.1 made achieving steady state within the plant difficult. Future designs should involve the addition of caustic for pH correction, followed by aeration to reduce the chemical demand for iron oxidation, followed by chlorine addition.

4.3.2 Parys Sportsgrounds – 1.62 ML/day

The combined sustainable flow rate provided by the groundwater abstraction points at Parys Sportsgrounds, did not require as extensive treatment as that of Boy Louw Sportsgrounds. This was due to the negligible iron and manganese contents of the combined sustainable flow rate. It was found that the combined sustainable flow rate exhibited a high turbidity concentration as well as high total and faecal coliform counts. It was therefore determined that activated glass filters would be required to remove the turbidity, and chlorine disinfection would be applied in order to remove the total and faecal coliform counts. The addition of chlorine would therefore ensure the water's adequate disinfection before entry into the municipal network. Lastly, allowance would be made for pH buffering should it be required. Figure 4-3 below illustrates the treatment process implemented at Parys Sportsgrounds.

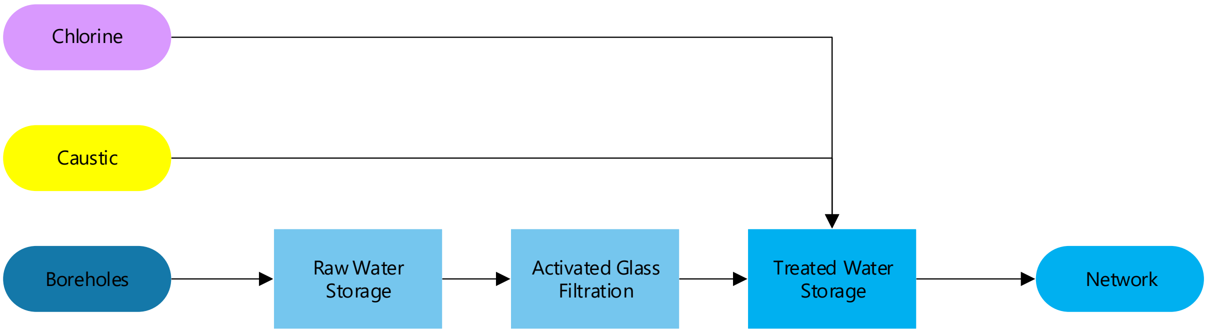

Figure 4-3: Treatment process of the groundwater abstraction plant at Parys Sportsgrounds

As can be seen in Figure 4-3 above, caustic and chlorine are dosed only into the treated water at Parys Sportsgrounds. This differs from the treatment process at Boy Louw Sportsgrounds (as illustrated in Figure 4-1) as Boy Louw Sportsgrounds had caustic and chlorine dosed into both the raw and treated water. In addition, Figure 4-3 differs from Figure 4-1 in that it does not have surface aeration or Maddox filtration. The differences between Figures 4-1 and 4-3 are attributed directly to the difference in iron and manganese concentrations between the sustainable raw water flow rates at Boy Louw Sportsgrounds and Parys Sportsgrounds respectively.

Chemical Dosing Systems

Two dosing systems were required at Parys Sportsgrounds namely chlorine dosing and caustic dosing. Chlorine dosing was applied into a static mixer before the treated water tank. This ensured adequate disinfection of the water within the treated water tank before entry into the municipal network. Caustic was dosed into the suction of the treated water pumps. This allowed for sufficient mixing of the caustic with the treated water via the impellers of the pumps and would allow for pH buffering of the water entering into the municipal network, should it be required.

As was the case with Boy Louw Sportsgrounds, a "Klorman Unit" was employed to make-up a chlorinated solution of consistent chlorine concentration. The manufacturer and supplier of the unit was consulted with regards to the number and type of units required to adequately treat the 1.62 ML/day flow rate. It was determined that two units would be required, resulting in a saturated chlorine concentration of 500 mg/L.

The combined sustainable flow rate at Parys Sportsgrounds did not contain iron and manganese and thus considerations into the amount of chlorine required to remove these components was not required. In addition, chlorine would only be dosed at one point within the plant, namely before the treated water tank. It was therefore decided that the same chlorine dosing flow rate as was used for the pre-chlorination at Boy Louw Sportsgrounds would be utilised at Parys Sportsgrounds. This would provide a sufficient ORP range to disinfect the treated water tank as well as the water in the remaining pipeline before entry into the municipal network. Similarly, the same caustic dosing flow rate utilised for Boy Louw Sportsgrounds was used for Parys Sportsgrounds. This would allow for a sufficient range in buffering the pH as and when required.

The local dosing skid manufacturer and supplier utilised for Boy Louw Sportsgrounds was consulted in order to confirm that the selected chlorine and caustic dosing pumps would be able to provide the required flow rates, based on their distances from their respective dosing points. The supplier confirmed that the same chlorine pumps could be utilised for Parys Sportsgrounds as those utilised for the pre-chlorination at Boy Louw Sportsgrounds. In addition, the supplier confirmed that the same caustic dosing pumps utilised for Boy Louw Sportsgrounds could be utilised for Parys Sportsgrounds.

Filters

The combined sustainable flow rate at Parys Sportsgrounds did not require treatment through Maddox filters as a result of the negligible iron and manganese contents in the water. An investigation into the filters required was therefore only applied to activated glass filters which would be responsible for the removal of the turbidity from the water, as well as any particulates in the water. The filtration through the activated glass filters at Boy Louw Sportsgrounds at a filtration flux of 10 $m^3/h/m^2$ proved to be highly effective and thus it was decided that a filtration flux of 10 $m^3/h/m^2$ at Parys Sportsgrounds would also be targeted. It was also known that a total of six filters at a diameter of 1.50 meters could be placed within a twelve-meter high cube container.

The filtration flux as a result of passing 1.62 ML/day of water through six filters with diameters of 1.50 meters each was found to be 6.36 $m^3/h/m^2$. The filtration flux was then determined again by changing the diameter from 1.50 meters to 1.20 meters. This resulted in a filtration flux of 9.94 $m^3/h/m^2$. It was therefore decided that six activated glass filters would be employed at diameters of 1.20 meters each. It should be noted that four filters with a diameter of 1.50 meters could be utilised to achieve the same flux, however this was decided against as the removal of one of these filters from service, would result in more stress on the system than the removal of a filter with a 1.20 meter diameter from service.

The heights of the activated glass filters were determined in much the same way as for Boy Louw Sportsgrounds, with the heights required for the feet, nozzle plate, inlet and outlet flanges being added to that of the inlet spreader pipe and top dome. The height of the filter media bed (1 000 mm) was then added to these heights. Unlike Boy Louw Sportsgrounds, Parys Sportsgrounds saw the addition of an additional drain point at the bottom of the filter to allow for easier draining of the filter. This resulted in the filter feet being raised 150 mm for Parys Sportsgrounds. The total height of the activated glass filters for Parys Sportsgrounds was therefore found to be 2 285 mm.

Pumps and Pipework

Four pump sets were required for the groundwater abstraction water treatment plant at Parys Sportsgrounds. These sets are summarised as follows,

1. Borehole pumps responsible for groundwater abstraction from each of the four groundwater abstraction points

2. Raw water pumps responsible for the transfer of water from the raw water storage tank, through the bank of activated glass filters, into the treated water storage tank
3. Backwash pumps responsible for the transfer of treated water from the treated water storage tank, through the bank of activated glass filters and to storm water
4. Treated water pumps responsible for the transfer of treated water from the treated water storage tank to the municipal network

As was the case with Boy Louw Sportsgrounds, the borehole pumps at Parys Sportsgrounds were sized according to the geohydrologist determined yields as indicated in Table 4-1 above. The raw water pumps were designed to supply a combined raw water flow rate of 18.85 L/s at a total pressure of 3 bar. The selected flow rate was based on the combined sustainable yield, and the selected pressure was based on the friction losses and pressure drops to be overcome by the raw water pumps.

As was the case for Boy Louw Sportsgrounds, it was determined that only one filter at a time would be backwashed at Parys Sportsgrounds. This would prevent the need for oversized backwash pumps and would allow for continued filtration at minimal stress through the remaining filters whilst backwashing occurs. The backwash pumps were selected based on the required backwash flux to be achieved through each filter at a diameter of 1.20 meters. The backwash pumps were therefore selected to deliver 12.57 L/s of water at a pressure of 1.80 bar. This pressure would ensure any friction losses and pressure drops would be overcome by the backwash pumps. It should also be noted that backwash settling ponds were not required at Parys Sportsgrounds as was the case with Boy Louw Sportsgrounds due to the improved water quality at Parys Sportsgrounds. The backwash water at Parys Sportsgrounds therefore discharges directly to stormwater.

The treated water pumps were selected to supply 18.85 L/s of treated water at a pressure of 9 bar. This flow rate was selected based on the combined sustainable flow rate available at Parys Sportsgrounds. The pressure was selected based on the municipal pressure to be overcome by the treated water pumps, in order to deliver treated water into the network. The pipework required for the groundwater abstraction water treatment plant at Parys Sportsgrounds was sized according to the flow rates of the water that they were charged with transporting.

Process Design

Once the number of filters was determined, the chemical dosing systems identified and the pumps required were selected, the overall process design was illustrated through the compilation of preliminary P&IDs and a preliminary PFD. As was the case with Boy Louw Sportsgrounds, these documents were submitted to an external consultant. The external consultant facilitated a HAZOP of the groundwater abstraction water treatment plant at Parys Sportsgrounds with the Engineer, mechanical and electrical contractors present.

All comments and considerations arising from the HAZOP were incorporated into the design of the groundwater abstraction water treatment plant at Parys Sportsgrounds, and the finalised P&IDs and

PFD were compiled. The final P&IDs and PFD for the groundwater abstraction water treatment plant at Parys Sportsgrounds can be found in Figures B-22 to B-33, and Figure B-34 in Appendix B2 respectively.

Site Layout

On completion of the design phase of the groundwater abstraction water treatment plant at Parys Sportsgrounds, it was determined that three twelve-meter high cube shipping containers would be required to house the mechanical and electrical equipment. Preliminary mechanical and electrical drawings were compiled and submitted to the Engineer illustrating the envisioned layout of the site and distribution of the equipment amongst the three containers.

Based on comments and reviews by the Engineer, final mechanical and electrical drawings were compiled. The final site layout of the groundwater abstraction water treatment plant at Parys Sportsgrounds can be found in Figure B-36 in Appendix B3. Figure 4-4 below illustrates the final groundwater abstraction water treatment plant at Parys Sportsgrounds taken during commissioning of the plant.

Figure 4-4: Final groundwater abstraction water treatment plant at Parys Sportsgrounds

4.4 Treated Water Quality

During the commissioning phase of the groundwater abstraction water treatment plants at Boy Louw Sportsgrounds and Parys Sportsgrounds, a water sample of the treated water from each of the groundwater abstraction water treatment plants was taken and submitted to Integral Laboratories for testing. This was done in order to confirm that all water quality parameters were within SANS 241-1:2015 upper limits before the booster pumps could be commissioned and commence with the continuous supply of treated water into the municipal network. Once the booster pumps were commissioned and commenced with their continuous supply into the municipal water network, online pH, ORP and turbidity controllers commenced with logging the pH, ORP and turbidity of the water, ensuring they remain within SANS 241-1:2015 upper limits at all times. In addition, dedicated plant operators performed daily tests on the treated water at Boy Louw Sportsgrounds to confirm that the iron and manganese contents of the water remained within the SANS 241-1:2015 upper limits.

Table 4-3 below illustrates the comparison between the raw water quality parameters identified as requiring further treatment in April 2018, and the concentrations of these parameters within the treated water for Boy Louw Sportsgrounds and Parys Sportsgrounds as analysed in February 2019 and July 219 respectively.

Table 4-3: Water quality results before and after treatment at sites Three and Four (red indicates non-compliant parameters and green indicates compliant parameters)

Boy Louw Sportsgrounds				
Water Source	**Parameter**	**Unit**	**Result**	**Limit**
Raw Water	Turbidity	NTU	12.38	<1
	Iron as Fe	µg/L	2327	<300
	Manganese as Mn	µg/L	317	<100
	Total Coliforms	cfu's/100 ml	182	<10
	Faecal Coliforms	cfu's/100 ml	7.50	0
Treated Water	Turbidity	NTU	0.16	<1
	Iron as Fe	µg/L	<50	<300
	Manganese as Mn	µg/L	<10	<100
	Total Coliforms	cfu's/100 ml	Not Detected	<10
	Faecal Coliforms	cfu's/100 ml	Not Detected	0
Parys Sportsgrounds				
Water Source	**Parameter**	**Unit**	**Result**	**Limit**
Raw Water	Turbidity	NTU	3.13	<1
	Total Coliforms	cfu's/100 ml	130	<10
	Faecal Coliforms	cfu's/100 ml	0.70	0
Treated Water	Turbidity	NTU	0.39	<1
	Total Coliforms	cfu's/100 ml	Not Detected	<10
	Faecal Coliforms	cfu's/100 ml	Not Detected	0

As can be seen in Table 4-3 above, the groundwater abstraction water treatment plants at Boy Louw Sportsgrounds and Parys Sportsgrounds, provided adequate treatment of the raw water quality parameters above SANS 241-1:2015 upper limits. The groundwater abstraction water treatment plant at Boy Louw Sportsgrounds reduced the turbidity by 98%, whist the plant at Parys Sportsgrounds reduced the turbidity by approximately 88%. It is estimated that the additional 10% of turbidity removal at Boy Louw Sportsgrounds was a result of the additional chlorine and caustic introduced into the raw water at Boy Louw Sportsgrounds, resulting in the oxidation of organic matter that may have contributed to the turbidity concentration.

The iron and manganese concentrations at Boy Louw Sportsgrounds were reduced by 2 277 µg/L and 307 µg/L respectively, bringing both water quality parameters to well within the SANS 241-1:2015 limits. The total coliform and faecal coliform counts at both Boy Louw Sportsgrounds and Parys Sportsgrounds were reduced to "Not Detected". It was therefore confirmed and concluded that both groundwater abstraction water treatment plants at Boy Louw Sportsgrounds and Parys Sportsgrounds performed adequate treatment of the water quality parameters above SANS 241-1:2015 upper limits. The booster pumps at Boy Louw Sportsgrounds and Parys Sportsgrounds were then commissioned and proceeded with their continuous supply of 5.18 ML/day and 1.62 ML/day of potable water into the municipal network respectively. For the complete water analyses of the treated water at Boy Louw Sportsgrounds and Parys Sportsgrounds, refer to Tables B-3 and B-4 in Appendix B4.

4.5 Groundwater Abstraction Project Feasibility

The capital expenditure associated with the large-scale groundwater abstraction project was considered to be all project costs associated with Boy Louw Sportsgrounds and Parys Sportsgrounds, from the groundwater sustainable yield investigation phase, through to the end of the 84-day Trial Operation Period (TOP). The TOP period for each groundwater abstraction water treatment plant commenced from the date of commissioning completion. The end of the TOP period signifies the handover of the groundwater abstraction water treatment plant in question. All monthly expenditure as a result of the groundwater abstraction water treatment plants at Boy Louw Sportsgrounds and Parys Sportsgrounds following the TOP period, was considered operational expenditure.

4.5.1 Capital Expenditure

The total capital expenditure of the large-scale groundwater abstraction project was determined as the sum of the capital expenditures associated with the groundwater abstraction water treatment plants at Boy Louw Sportsgrounds and Parys Sportsgrounds.

The capital expenditure associated with the groundwater abstraction water treatment plants at Boy Louw Sportsgrounds and Parys Sportsgrounds was obtained directly from the Engineer and is given in Table 4-4 below.

Table 4-4: Capital expenditure associated with the large-scale groundwater abstraction project

Site	Project Unit	Total (excl. VAT)
Three	Mechanical and electrical works	R26 555 000
	Civil works	R11 400 000
	Electrical supply	R996 000
	Other fees and contractors	R5 500 000
Total for Boy Louw Sportsgrounds		**R44 451 000**
Four	Mechanical and electrical works	R12 371 000
	Civil works	R8 542 000
	Electrical supply	R728 000
	Other fees and contractors	R3 400 000
Total for Parys Sportsgrounds		**R25 041 000**
Total for Groundwater Abstraction Project		**R69 492 000**

It was found that 64% of the total capital expenditure associated with the large-scale groundwater abstraction project was attributed to the plant at Boy Louw Sportsgrounds, whilst the remaining 36% was attributed to the plant at Parys Sportsgrounds. The difference in the capital expenditure between the groundwater abstraction water treatment plants is the result of different sustainable flow rates that each plant had to treat, as well as the varying water quality between the two plants.

4.5.2 Monthly Operational Expenditure

The operational expenditure associated with the large-scale groundwater abstraction project was determined by considering the estimated electricity consumption, chemical consumption, labour requirements and maintenance requirements of each groundwater abstraction water treatment plant. It was also assumed that each groundwater abstraction water treatment plant would run for 24 hours per day, each day of the week, with the pumps operating at 80% of their maximum capacity.

Monthly Electricity Consumption

The estimated monthly electricity consumption was computed using the energy charge per kWh applicable to bulk users between 40 kVA and 100 kVA in the municipal area. This rate was published as R 1.19 / kWh for the 2019/2020 period. The estimated monthly electricity consumption for each groundwater abstraction water treatment plant was then computed as per Table 4-5 below.

Table 4-5: Estimated monthly electricity expenditure

Description of Use	Max Power Rating (kW)	Actual Power Rating (kW)	Operational Time (hrs/day)	Energy Consumption (kWh)	Rate (excl. VAT) (R/day)
Boy Louw Sportsgrounds					
Borehole pumps					
A	22	17.6	24	422	R505.70
B	15	12	24	288	R344.80
C	22	17.6	24	422	R505.70
D	18.5	14.8	24	355	R425.25
Raw water pumps	30	24	24	576	R689.59
Backwash pumps	8	6.4	2	11	R13.03
Backwash recovery pumps	8	6.4	1	6	R7.66
Treated water pumps	120	96	24	2304	R2 758
Blowers	8	6.4	2	11	R13.03
Other small power and lighting	5	4	24	96	R114.93
Total per day					**R5 378**
Total per month					**R161 340**
Parys Sportsgrounds					
Description of Use	**Max Power Rating (kW)**	**Actual Power Rating (kW)**	**Operational Time (hrs/day)**	**Energy Consumption (kWh)**	**Rate (excl. VAT) (R/day)**
Borehole pumps					
A	5.5	4.4	24	105.6	R126.42
B	2.2	1.76	24	42.24	R50.57
C	5.5	4.4	24	105.6	R126.42
D	7.5	6	24	144	R172.40
Raw water pumps	11	8.8	24	211.2	R252.85
Backwash pumps	4.4	3.52	1	3.52	R4.21
Treated water pumps	30	24	24	576	R689.59
Other small power and lighting	5	4	24	96	R114.93
Total per day					**R1 537**
Total per month					**R46 121**

As can be seen in Table 4-5 above, the monthly electricity expenditure associated with Boy Louw Sportsgrounds is 78% of the total electricity expenditure of the large-scale groundwater abstraction project, whilst the electricity expenditure for Parys Sportsgrounds is 22%. This is due to larger equipment being utilised at Boy Louw Sportsgrounds to treat the larger flow rate, as well as the additional backwash water recovery pumps and the blowers. The additional backwash water recovery pumps and blowers were incorporated into the design of Boy Louw Sportsgrounds as a result of the additional iron and manganese to be removed from the water.

The operational hours of the backwash pumps and blowers for Boy Louw Sportsgrounds as illustrated in Table 4-5 above were determined by considering the control philosophy of the backwash. The backwash cycle for the Maddox and activated glass filters at Boy Louw Sportsgrounds consists of an initial two-minute air scour, followed by a three-minute dual air and water backwash. Finally, a five-minute rinse cycle occurs. This equates to a total backwash time of 10 minutes per filter. Due to the capacity of the backwash water settling ponds, only two filters can be backwashed at a time, followed by a 30-minute rest period. The total backwash time per day is therefore 200 minutes, of which 100 minutes are performed by the backwash pumps and the remaining 100 minutes are performed by the backwash blowers.

The backwash water recovery pumps are responsible for transferring water from the backwash water supernatant sump to the raw water tank. The backwash water supernatant sump is filled with overflowing clarified backwash water from the backwash water settling ponds. The backwash pumps result in a total of 90 m^3/day of backwash water being transferred to the backwash settling ponds. On the assumption that the ponds are balanced, the backwash water recovery pumps must transfer 90 m^3/day of overflowing clarified backwash water to the raw water tank. The backwash water recovery pumps therefore run for approximately one hour every day.

The operational time of the backwash pumps for Parys Sportsgrounds was determined based on the time required for each activated glass filter to backwash. Each activated glass filter backwashes for approximately 10 minutes. Unlike Boy Louw Sportsgrounds, the backwash water at Parys Sportsgrounds is transferred directly to stormwater and thus no rest period between backwashing is required. The backwash pumps run for a total of one hour per day.

Monthly Chemical Consumption

The estimated monthly chemical expenditure was determined as per Table 4-6 below.

Table 4-6: Estimated monthly chemical expenditure

Boy Louw Sportsgrounds					
Chemical	**Concentration (%)**	**Dose Rate (mg/L)**	**Consumption (kg/day)**	**Cost of Chemical (R/kg)**	**Rate (excl. VAT) (R/day)**
Calcium hypochlorite	65	4.27	34	47	R1 599
Caustic	46	10.5	118	7	R827.67
Total per day					**R2 427**
Total per month					**R72 810**
Parys Sportsgrounds					
Chemical	**Concentration (%)**	**Dose Rate (mg/L)**	**Consumption (kg/day)**	**Cost of Chemical (R/kg)**	**Rate (excl. VAT) (R/day)**
Calcium hypochlorite	65	3	7	47	R351.42
Caustic	46	10.5	37	7	R258.85
Total per day					**R610.26**
Total per month					**R18 307**

As can be seen in Table 4-6 above, the monthly chemical consumption of Boy Louw Sportsgrounds and Four is 80% and 20% of the total chemical consumption of the large-scale groundwater abstraction project, respectively. The dose rates of calcium hypochlorite and caustic for Boy Louw Sportsgrounds and Parys Sportsgrounds were determined as described in Sections 4.3.1 and 4.3.2 respectively. The consumption of each chemical for Boy Louw Sportsgrounds and Parys Sportsgrounds was determined by considering the dose rate and overall flow rate for each groundwater abstraction water treatment plant, as well as the concentration of the pure chemicals.

Monthly Labour

The groundwater abstraction water treatment plants at Boy Louw Sportsgrounds and Parys Sportsgrounds were designed to be automated with very little operator input. There is however a requirement for an operator to perform daily operation and maintenance checks at each of the plants in order to ensure their efficiency and longevity. It is envisioned that two process controllers can be employed to rotate operational duties between the groundwater abstraction water treatment plants, each day of the week. An average process controller salary of R 15 000 per month was considered, resulting in a total monthly labour expenditure of R 30 000.

Monthly Maintenance

The estimated monthly maintenance expenditure was determined as per Table 4-7 below.

Table 4-7: Estimated monthly maintenance expenditure

Boy Louw Sportsgrounds		
Maintenance Area	**Percentage of CAPEX (%/annum)**	**Cost per Month (R/month)**
Mechanical and electrical equipment	6	R92 943
Civil works	4	R26 600
Total per month		**R119 543**
Parys Sportsgrounds		
Maintenance Area	**Percentage of CAPEX (%/annum)**	**Cost per Month (R/month)**
Mechanical and electrical equipment	6	R43 299
Civil works	4	R19 931
Total per month		**R63 230**

As can be seen in Table 4-7 above, the estimated monthly maintenance expenditure for Boy Louw Sportsgrounds and Parys Sportsgrounds were 65% and 35% of the total monthly maintenance expenditure of the large-scale groundwater abstraction project respectively. The estimated maintenance expenditure percentage for each of the groundwater abstraction water treatment plants was obtained from the Engineer. This was estimated to be 10% of each groundwater abstraction water treatment plant’s capital expenditure. A total of 6% per annum was attributed to mechanical and electrical works, and the remaining 4% per annum was attributed to the civil works.

Total Monthly Operational Expenditure

Table 4-8 below summarises the total estimated monthly operational expenditure for the combined large-scale groundwater abstraction project involving both Boy Louw Sportsgrounds and Parys Sportsgrounds.

Table 4-8: Estimated monthly operational expenditure

Boy Louw Sportsgrounds		
Description of Expenditure	**Total Expenditure (R/month)**	**Total Expenditure (R/m³)**
Electricity	R161 340	1.04
Chemicals	R72 811	0.47
Labour	R15 000	0.10
Maintenance	R119 543	0.77
Total per month	**R368 693**	**2.37**
Parys Sportsgrounds		
Description of Expenditure	**Total Expenditure (R/month)**	**Total Expenditure (R/m³)**
Electricity	R46 122	0.95
Chemicals	R18 308	0.38
Labour	R15 000	0.31
Maintenance	R63 230	1.30
Total per month	**R142 660**	**2.94**

As can be seen in Table 4-8 above, the estimated monthly operational expenditure for Boy Louw Sportsgrounds and Parys Sportsgrounds were found to be 72% and 28% of the total monthly operational expenditure of the project respectively. In addition, it can be seen in Table 4-8 above that the total monthly operational expenditure for the project is R 511 353. When considering this along with the 204 000 m³ of potable water entering the municipal network each month, the total operational expenditure per month equates to R 2.51/m³. This operational rate was found to be lower than the operational rates associated with conventional municipal water treatment. The City of Cape Town's operational expenditure rates for water treatment and supply range from R 3/m³ to R 8/m³ depending on the water source (Department of Water and Sanitation, 2018).

The total estimated monthly operational expenditure distribution for Boy Louw Sportsgrounds is illustrated in Figure 4-5 below.

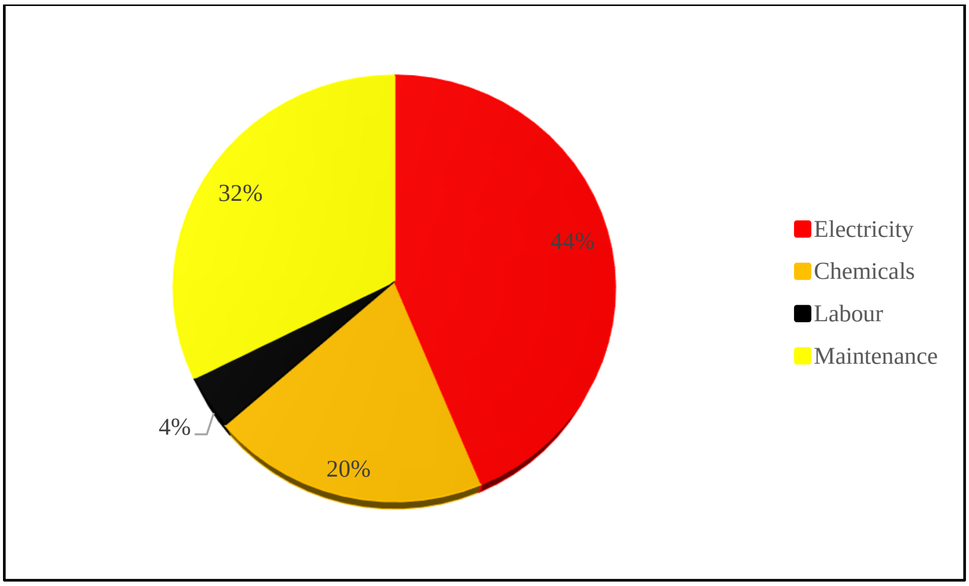

Figure 4-5: Monthly operational expenditure distribution for Boy Louw Sportsgrounds

The total estimated monthly operational expenditure distribution for Parys Sportsgrounds is illustrated in Figure 4-6 below.

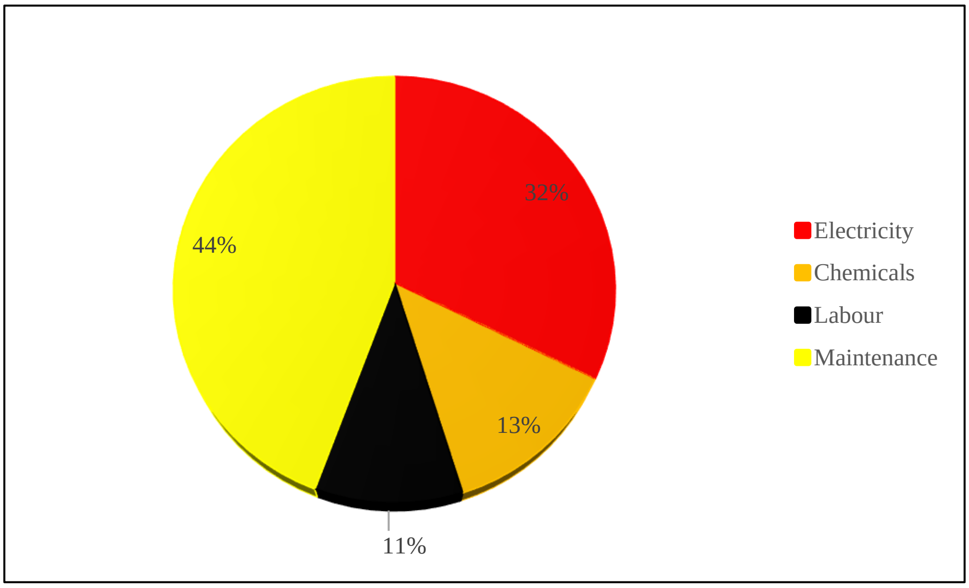

Figure 4-6: Monthly operational expenditure distribution for Parys Sportsgrounds

4.5.3 Overall Project Feasibility

The total capital expenditure for the large-scale groundwater abstraction project was determined to be R 69 492 000 excl. VAT. The total sustainable volume of potable water to be introduced into the municipal network as a result of this project equates to 6.8 ML/day. The total capital expenditure as a function of this volume was therefore found to be R 10 219/m³. This rate is significantly lower than that associated with large-scale conventional municipal water treatment and supply.

The City of Cape Town estimates that the capital expenditure associated with the provision of 300 ML/day equates to R 5.4 billion. This equates to a capital expenditure rate of R 18 000/m³ (Department of Water and Sanitation, 2018).

The total sustainable volume of potable water to be added to the municipal network as a result of this project equates to 204 000 m³ per month. Considering this volume, with a capital expenditure of R 69 492 000 (excl. VAT), the capital expenditure as a function of volume per month is R 340.65/m³.

The groundwater abstraction water treatment plants at Boy Louw Sportsgrounds and Parys Sportsgrounds were operated for a TOP of 84 days. The total volume of potable water that entered the network during TOP equated to 571 200 m³. The total estimated monthly operational expenditure of the large-scale groundwater abstraction project was found to be R 511 353 per month. The estimated monthly operational expenditure as a function of the volume of water that entered the municipal network during TOP therefore equated to R 0.90/m³.

In order to determine the payback period of the large-scale groundwater abstraction project, the rates at which the municipality purchases water from the City of Cape Town for distribution were required. The municipal water tariffs for the 2019/2020 period were consulted, and the municipal flat rate of R 8.94/m³ was utilised. The use of this flat rate for an adequate determination of the payback period was confirmed by a bulk water study compiled by the Engineer in 2018. This bulk water study suggested that the bulk water tariff for the 2018/2019 period of R 8.13/m³ would increase at 1% above the inflation rate resulting in an estimated 2019/2020 bulk water tariff of R 9.39/m³. The bulk water tariff did not increase to R 9.39/m³ as predicted and was therefore published at R 8.94/m³.

The payback period for the large-scale groundwater abstraction project was then determined using this rate along with the above capital expenditure as a function of each plant's potable water supply rate, and operational expenditure as a function of potable water supplied during TOP (see Equation 2.13).

The payback period of the large-scale groundwater abstraction project was therefore determined to be 38.20 months which equates to approximately three years. This observation along with the 10-year design life applicable to the groundwater abstraction water treatment plants at Boy Louw Sportsgrounds and Parys Sportsgrounds, confirms that the implementation of this project was feasible.

The total monthly operational expenditure applicable to this project following handover to the municipality was determined to be R 2.51/m³. This rate, along with the rate that the municipality would have purchased water at from the City of Cape Town were considered in order to compute the percentage monthly savings (see Equation 2.14). It was found that after the payback period, the municipality will be subject to a 72% monthly savings by utilising the groundwater abstraction water treatment plants at Boy Louw Sportsgrounds and Parys Sportsgrounds, as opposed to purchasing water from the City of Cape Town.

Although it has been determined that the implementation of the large-scale groundwater abstraction project was financially feasible, it is important to investigate the long-term impacts of this alternative potable water supply. The results of such an investigation will determine whether this alternative potable water supply should be employed on a more permanent basis, or whether it should only be utilised during drought conditions.

4.5.4 Feasibility of Groundwater Abstraction and Treatment at Varying Flow Rates

When investigating sustainable groundwater abstraction, it is common to find more than one site from which groundwater can be sustainably abstracted. The flow rates at which groundwater can be sustainably abstracted may differ amongst these sites depending on the number of sustainable groundwater abstraction points. It is therefore important to perform a feasibility analysis when sustainable groundwater abstraction is possible from more than one site, however only one site is applicable for investment.

In order to perform this analysis using Boy Louw Sportsgrounds and Parys Sportsgrounds, the capital and operational expenditure for the two plants was normalised such that the feasibility of the sites could be compared at varying flow rates, whilst treating the same quality of raw water to potable standards.

Boy Louw Sportsgrounds and Parys Sportsgrounds differed in that Boy Louw Sportsgrounds required iron and manganese removal. This required the need for Maddox filters which in turn triggered the need for backwash water settling ponds and backwash water recovery pumps. The mechanical and electrical contractors were consulted in order to determine the mechanical and electrical costs associated with the iron and manganese removal process units. The difference in the civil capital expenditure between Boy Louw Sportsgrounds and Parys Sportsgrounds was considered, with 80% of this difference assumed to be attributed to the backwash water settling ponds. The final estimated capital expenditure associated with the iron and manganese removal process units is summarised in Table 4-9 below.

Table 4-9: Capital expenditure associated with iron and manganese removal process units

Section	Total Rate (excl. VAT)
Maddox filters	R3 000 000
Backwash recovery pumps	R242 880
Backwash settling ponds	R2 286 400
Total (excl. VAT)	**R5 529 280**

The total capital expenditure for Boy Louw Sportsgrounds including the iron and manganese process units was found to be R 44 451 000 excl. VAT. The capital expenditure applicable to Boy Louw Sportsgrounds after the removal of the iron and manganese process units was determined to be R 38 921 720 excl. VAT. The monthly estimated electricity expenditure for Boy Louw Sportsgrounds without the iron and manganese removal process units, is illustrated in Table 4-10 below.

Table 4-10: Monthly electricity expenditure for Boy Louw Sportsgrounds without iron and manganese removal

Boy Louw Sportsgrounds					
Description of Use	**Max Power Rating (kW)**	**Actual Power Rating (kW)**	**Operational Time (hrs/day)**	**Energy Consumption (kWh)**	**Rate (excl. VAT) (R/day)**
Borehole pumps					
A	22	17.6	24	422	R505.70
B	15	12	24	288	R344.79
C	22	17.6	24	422	R505.70
D	18.50	14.8	24	355	R425.25
Raw water pumps	30	24	24	576	R689.59
Backwash pumps	8	6.4	2	11	R13.03
Treated water pumps	120	96	24	2304	R2 758
Blowers	8	6.4	2	11	R13.03
Other small power and lighting	5	4	24	96	R114.93
Total per day					**R5 370**
Total per month					**R161 110**

The estimated monthly operational expenditure associated with the monthly chemical consumption of the groundwater abstraction plant at Boy Louw Sportsgrounds does not change as a result of removing the iron and manganese removal process units from the design. In addition, the removal of these process units does not reduce the estimated monthly operational expenditure associated with labour. The monthly estimated maintenance expenditure for Boy Louw Sportsgrounds without the iron and manganese removal process units, is illustrated in Table 4-11 below.

Table 4-11: Monthly maintenance expenditure for Boy Louw Sportsgrounds without iron and manganese removal

Boy Louw Sportsgrounds		
Maintenance Area	**Percentage of CAPEX (%/annum)**	**Cost per Month (R/month)**
Mechanical and electrical equipment	6	R81 592
Civil works	4	R21 265
Total per month		**R102 857**

Table 4-12 below summarises the total estimated monthly operational expenditure for Boy Louw Sportsgrounds after the removal of the iron and manganese removal process units.

Table 4-12: Monthly operational expenditure of Boy Louw Sportsgrounds without iron and manganese removal

Boy Louw Sportsgrounds		
Description of Expenditure	**Total Expenditure (R/month)**	**Total Expenditure (R/m³)**
Electricity	R161 110	1.04
Chemicals	R72 810	0.47
Labour	R15 000.	0.10
Maintenance	R102 857	0.66
Total per month	**R351 779**	**2.26**

The capital expenditure of Boy Louw Sportsgrounds and Parys Sportsgrounds with process units selected to treat the same water quality at varying flow rates was therefore determined to be R 38 921 720 excl. VAT and R 25 041 000 excl. VAT respectively. Boy Louw Sportsgrounds was capable of providing 5.18 ML/day of potable water into the network whilst Parys Sportsgrounds was capable of providing 1.62 ML/day of potable water into the network. By considering the capital expenditure associated with each of these sites along with the volume of water each site could produce, the resulting capital expenditure rates were found to be R 250.46/m³ for Boy Louw Sportsgrounds and R 515.25/m³ for Parys Sportsgrounds.

The total estimated monthly operational expenditure for Boy Louw Sportsgrounds was determined to be R 351 778 excl. VAT. This value was found to be R 142 659 excl. VAT for Parys Sportsgrounds. Considering these operational expenditure amounts along with the volume of water introduced into the municipal network during TOP, the operational expenditure rates associated with Boy Louw Sportsgrounds and Parys Sportsgrounds were found to be R 0.81/m³ and R 1.05/m³ respectively.

By applying the published municipal flat rate of R 8.94/m³ and the capital expenditure and operational expenditure rates with Equation 2.13, the payback periods of Boy Louw Sportsgrounds and Parys Sportsgrounds were found to be 28.11 and 57.75 months respectively. This equates to approximately two and five years respectively. Both payback periods fall within the design life of each plant, thus reconfirming the overall feasibility of the large-scale groundwater abstraction project. It is also noted that the payback period of the groundwater abstraction water treatment plant at Boy Louw Sportsgrounds is approximately half that of the plant at Parys Sportsgrounds, whilst delivering more than three times the flow rate of the plant at Parys Sportsgrounds. It is therefore determined that the larger the groundwater abstraction water treatment plant is, the more financially feasible the plant is.

The total estimated monthly operational expenditure for Boy Louw Sportsgrounds and Parys Sportsgrounds after TOP and thus handover to the municipality was determined to be R 2.26/m³ and R 2.94/m³ respectively. By applying these rates with the published municipal flat rate of R 8.94/m³, it was found that the monthly savings applicable to the municipality as a result of implementing the groundwater abstraction water treatment plants at Boy Louw Sportsgrounds and Parys Sportsgrounds were approximately 75% and 67% respectively. It was therefore determined that not only does the groundwater abstraction water treatment plant at Boy Louw Sportsgrounds produce three times more potable water than the plant at Parys Sportsgrounds, it also results in approximately 8% more financial savings per month. This observation therefore reconfirmed that for the same water quality, the higher the potable water flow rate that can be supplied to the municipal network, the more financially feasible the groundwater abstraction project.

4.5.5 Feasibility of Groundwater Abstraction and Treatment at Varying Water Quality

When investigating groundwater abstraction and treatment, not only is it common to find various sites capable of producing sustainable groundwater at varying flow rates but can also supply groundwater of various water quality. Figure 4-7 below illustrates how the Electrical Conductivity (EC) of the water varies in Drakenstein Municipality. It should be noted that both Boy Louw Sportsgrounds and Parys Sportsgrounds appear in the darker green and thus have typical EC values between 0 and 70 mS/m whilst other aquifers in the area may have EC values between 70 and 300 mS/m (Murray, 2018).

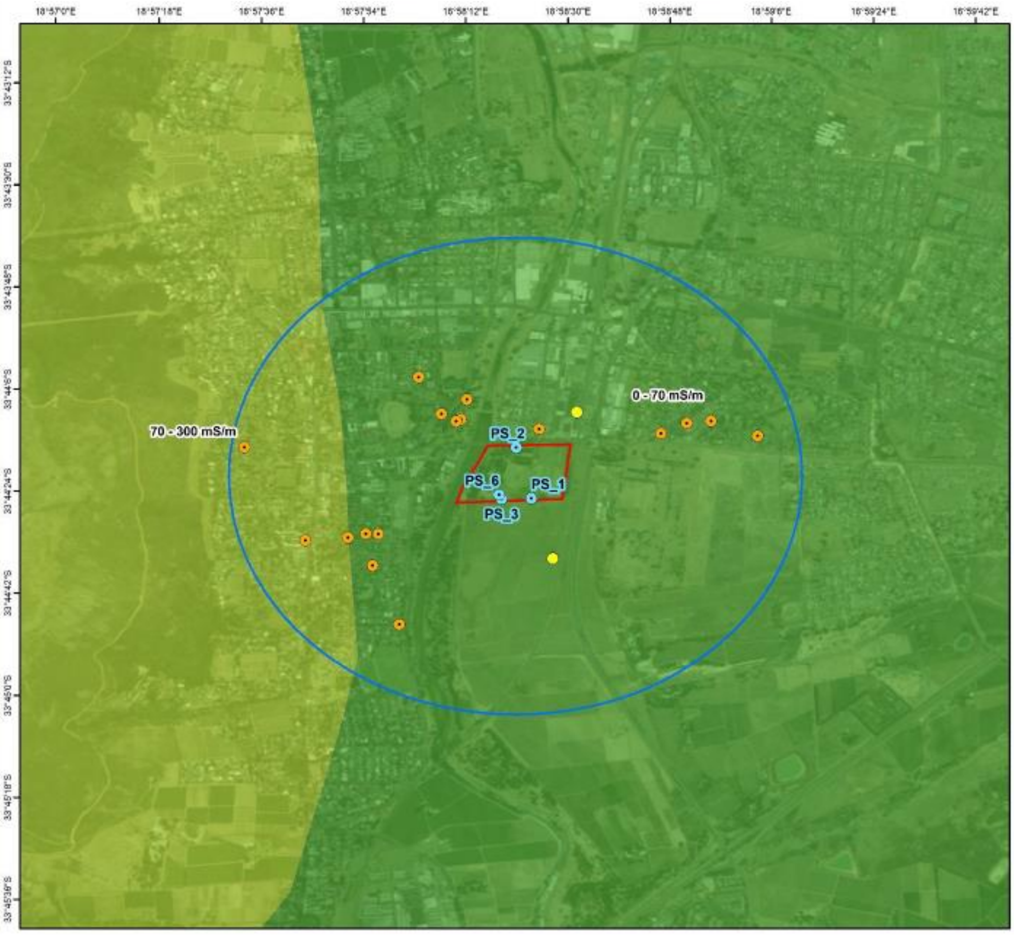

Figure 4-7: Groundwater EC range around Boy Louw Sportsgrounds and Parys Sportsgrounds

It should be noted that the feasibility of groundwater abstraction and treatment varies significantly depending on the intended use of the water. Should the water be intended for non-potable purposes, such as irrigation, treatment may not be required which will have a significant impact on whether the abstraction is feasible or not. Generally, when the abstracted groundwater is to be treated to potable standards, the more water quality parameters above SANS 241-1:2015 upper limits, the more treatment needs to be employed and thus the higher the capital and operational expenditure attributable to the treatment.

This is confirmed by considering the groundwater abstraction water treatment plants at Boy Louw Sportsgrounds and Parys Sportsgrounds, at the same flow rate of 5.18 ML/day at their varying water quality. The groundwater quality at Boy Louw Sportsgrounds requires turbidity, iron and manganese removal as well as disinfection whilst the groundwater quality at Parys Sportsgrounds requires only turbidity removal and disinfection. The capital and operational expenditure associated with groundwater abstraction and treatment for the removal of turbidity and disinfection at 5.18 ML/day as opposed to the capital expenditure associated with the turbidity, iron and manganese removal along with disinfection at 5.18 ML/day are illustrated in Table 4-13 below.

Table 4-13: Capital and operational expenditures of treatment regimens at the same flow rate

Process Unit	**Total (excl. VAT)**
Capital Expenditure	
Turbidity removal and disinfection	R38 921 720
Turbidity, iron and manganese removal and disinfection	R44 451 000
Operational Expenditure	
Turbidity removal and disinfection	R351 779
Turbidity, iron and manganese removal and disinfection	R368 693

The capital expenditure as illustrated in Table 4-13 above, as a function of 5.18 ML/day of potable water that is introduced into the network results in R 250.46/m³ for turbidity removal and disinfection, and R 286.04/m3 for turbidity, iron and manganese removal along with disinfection. Similarly, the operational expenditure as a function of the volume of potable water introduced into the municipal network during TOP equates to R 0.81/m³ for turbidity removal and disinfection, and R 0.85/m³ for turbidity, iron and manganese removal along with disinfection. The resulting payback periods for turbidity removal and disinfection, and turbidity, iron and manganese removal with disinfection, was found to be 28.11 and 32 months which equates to approximately two and three years respectively.

The estimated monthly operational expenditure associated with turbidity removal and disinfection as a function of the 5.18 ML/day of potable water introduced into the network was found to be R 2.26/m³. Similarly, the estimated monthly operational expenditure associated with turbidity, iron and manganese removal along with disinfection at the same potable water supply volume, was found to be R 2.37/m³. The resulting monthly savings applicable to the municipality were therefore found to be 75% for turbidity removal and disinfection, and 73% for turbidity, iron and manganese removal along with disinfection.

The computed payback periods of the two treatment regimens at the same flow rate therefore confirmed that regardless of the flow rate, varying water quality will impact the feasibility of the large-scale groundwater abstraction project. The more groundwater quality parameters that are above SANS 241-1:2015 upper limits, the less financially feasible the project will become.

4.5.6 Groundwater Abstraction Project Feasibility Limit

Thus far it has been determined that the large-scale groundwater abstraction project initiated by the municipality was feasible based on its payback period of three years which is well within each of the groundwater abstraction water treatment plant's 10-year life span. In addition, the implementation of the large-scale groundwater abstraction project will allow the Municipality to save 72% of the costs normally dedicated to bulk water supply from the City of Cape Town.

Furthermore, it has been determined that the larger the volume of potable water that can be supplied to the municipal network, with the fewer number of water quality parameters above SANS 241-1:2015 upper limits, the more financially feasible the large-scale groundwater abstraction project.

Whilst the above determinations prove favourable for the municipality responsible for implementing the large-scale groundwater abstraction project under investigation, it should be noted that this may not always be the case. The feasibility of such a project depends largely on the rate at which the municipality purchases water. The lower this rate, the longer the payback periods will be, with a reduction in the monthly savings applicable. It is therefore important to ascertain at what bulk water purchase rate, the implementation of a groundwater abstraction project of this scale is no longer feasible.

When utilising the municipal flat rate of R 8.94/m³, the payback period of the large-scale groundwater abstraction project equates to 38.20 months or approximately three years. An investigation was then conducted into the municipal flat rate at which this project would no longer be feasible. This was done by considering the constant capital expenditure rate of R 340.65/m³, and the constant estimated monthly operational expenditure rate of R 0.90/m³ with a variable municipal flat rate. Refer to Table C-1 in Appendix C1 for these calculations.

It was therefore determined that this large-scale groundwater abstraction project is feasible as long as the rate at which the municipality purchases water is above R 2.85/m³. All payback periods below this rate were found to be 10 years or more which supersedes the estimated life spans of the groundwater abstraction water treatment plants. The large-scale groundwater abstraction project is therefore no longer financially feasible at this bulk water purchase rate and below.

CHAPTER 5 – CONCLUSION

The results of this study's primary aim namely the feasibility of large-scale groundwater abstraction projects is presented. In addition, the results of this study's secondary aim pertaining to the feasibility of groundwater abstraction water treatment plants at varying flow rates and water quality are presented. Recommendations for future work as identified through the conduction of this study are proposed.

Water is one of Earth's most precious yet threatened resources. As a result, alternative water sources are being investigated worldwide. One such alternative water source is groundwater. Groundwater abstraction and treatment involves the abstraction of water from an underground source, and the treatment of the water such that it can be distributed to the general population for use. The abstraction of groundwater can only be done according to the abstraction point's sustainable yield, the determination of which is governed by governmental legislation. The treatment of the groundwater is based on the water quality parameters of the groundwater that lie outside of legislative guidelines for its required use.

5.1 Conclusions of Aims

The primary aim of this study was to investigate the feasibility of large-scale groundwater abstraction projects. This work provided insights into whether large-scale groundwater abstraction projects specifically for potable water use should be investigated for continued potable water supply, or only during drought conditions. The secondary aim of this study was to investigate the feasibility of groundwater abstraction water treatment plants at varying flow rates and varying water quality.

5.1.1 Primary Aim Conclusion

In order to achieve this primary aim, the project lifecycle of a recently implemented large-scale groundwater abstraction project was analysed. It was found that two sites in Drakenstein Municipality, consisted of groundwater abstraction points capable of delivering 5.18 ML/day and 1.62 ML/day of groundwater continuously without causing undue stress on the underground aquifer. The sites were named Boy Louw Sportsgrounds and Parys Sportsgrounds respectively and each consisted of four groundwater abstraction points.

It was determined that both Boy Louw Sportsgrounds and Parys Sportsgrounds required turbidity removal and disinfection, however it was noted that Boy Louw Sportsgrounds turbidity concentration, total coliform and faecal coliform counts were all significantly higher than those of Parys Sportsgrounds. In addition, it was noted that the maximum water levels of the underground source at Parys Sportsgrounds were higher than that of Boy Louw Sportsgrounds. It was therefore suspected that the groundwater abstraction points at Boy Louw Sportsgrounds and Parys Sportsgrounds were accessing different water sources, even though the sites were only 2.60 kilometres away from one another. This was confirmed when it was determined that Boy Louw Sportsgrounds required iron and manganese removal whereas Parys Sportsgrounds did not. It was therefore concluded that the water quality of an underground water source cannot be reliably predicted based on the area and subsequent geology of the source and should rather be measured for accurate budgeting and planning purposes.

Water treatment plants for Boy Louw Sportsgrounds and Parys Sportsgrounds were then designed taking cognisance of the combined sustainable flow rates to be treated, as well as the water quality parameters to be treated. The design phase of the two groundwater abstraction water treatment plants involved process, mechanical, electrical, and civil design work which was agglomerated into final approved documentation.

The documentation was then utilised as the framework for the manufacturing, installation and commissioning of the mechanical and electrical works associated with each plant, and the civil site work required for each plant. Each plant was commissioned with its treatment method verified through accredited water analyses of the final treated water.

It was found that turbidity was reduced by 98% at Boy Louw Sportsgrounds, and 88% at Parys Sportsgrounds, with the additional 10% of removal at Boy Louw Sportsgrounds attributed to the oxidation of organics as a result of the additional chlorine and caustic introduced into the raw water. The iron and manganese contents at Boy Louw Sportsgrounds were reduced by 2 277 μg/L and 217 μg/L respectively. All water quality parameters requiring disinfection were reported as “Not Detected” in the treated water.

Once the treated water of each groundwater abstraction water treatment plant was confirmed to be suitable for potable use, the booster pumps at each plant commenced with delivering 5.18 ML/day and 1.62 ML/day of potable water into the municipal network.

It was found that the capital expenditure of the overall large-scale groundwater abstraction project was R 69 492 000 excl. VAT. The capital expenditure rate as a function of the volume of treated groundwater produced per month as a result of the project was found to be R 340.65/m³. This rate was significantly lower than the capital expenditure rate associated with conventional large-scale municipal water treatment of R 18 000/m³.

The monthly operational expenditure of the overall large-scale groundwater abstraction project was determined to be R 511 353 excl. VAT. During the TOP phase of the project, 571.20 ML of treated groundwater was supplied to the municipal network. The resulting operational expenditure rate as a function of this volume was found to be R 0.90/m³. These rates along with the bulk water purchase tariff of R 8.94/m³ that the municipality would have ordinarily been subject to, resulted in a payback period of 38.20 months, or approximately three years.

The operational expenditure of R 511 353 excl. VAT. as a function of monthly supply of treated groundwater to the municipal network was found to be R 2.51/m³. This rate was found to be lower than the operational expenditure rates associated with conventional large-scale municipal water treatment which are typically between R 3/m³ and R 8/m³.

When considering the operational rate of R 2.51/m³ as opposed to the bulk water purchase tariff of R 8.94/m³, it was determined that the municipality would be subject to 72% monthly savings in water costs. Considering the monthly savings and the payback period falling within each groundwater abstraction water treatment plant's design life of 10 years, it was found that the large-scale groundwater abstraction project was feasible.

5.1.2 Secondary Aim Conclusion

The design and costs associated with the groundwater abstraction water treatment plant at Boy Louw Sportsgrounds were adjusted by removing the iron and manganese removal process units and related civil works. The feasibility of the groundwater abstraction water treatment plants at both Boy Louw Sportsgrounds and Parys Sportsgrounds were then compared based on the assumption that both plants were treating the same water quality at different flow rates.

The capital expenditure associated with Boy Louw Sportsgrounds without the iron and manganese removal process units was therefore found to be R 38 921 720 excl. VAT. This results in a capital expenditure rate of R 250.46/m³ when considering Boy Louw Sportsgrounds flow rate. In addition, the operational expenditure rate of Boy Louw Sportsgrounds without the iron and manganese removal process units was found to be R 0.81/m³. By utilising these rates, along with the bulk water purchase tariff of R 8.94/m³, it was found that the payback period of Boy Louw Sportsgrounds was 28.11 months, or approximately two years, whilst the payback period of Parys Sportsgrounds was 57.75 months, or approximately five years.

It was also found that the groundwater abstraction water treatment plant at Boy Louw Sportsgrounds resulted in approximately 75% savings on water costs, whereas Parys Sportsgrounds resulted in approximately 67% savings. It was therefore found that the larger the groundwater abstraction flow rate to be treated, the more financially feasible the project.

The design and costs associated with Boy Louw Sportsgrounds with and without iron and manganese removal were then compared in order to determine the feasibility of groundwater abstraction water treatment plants at varying water quality. It was found that a groundwater abstraction water treatment plant involving turbidity, iron and manganese removal along with disinfection had a payback period of 32.74 months or approximately three years. The same plant with only turbidity removal and disinfection had a payback period of 28.72 months or approximately two years. In addition, the first scenario results in approximately 73% savings, whilst the second scenario results in 75% savings. It was therefore concluded that the fewer water quality parameters above SANS 241-1:2015 upper limits, the fewer treatment processes would be required, and thus the more financially feasible the project.

Overall, it was determined that the implementation of large-scale groundwater abstraction projects is feasible resulting in significant financial savings in monthly water costs for municipalities. In addition, the more groundwater that can be sustainably abstracted, with fewer water quality parameters requiring treatment, the more financially feasible the project, and the more monthly savings on water costs can be expected. The implementation of large-scale groundwater abstraction projects should be considered for use during drought conditions and should be considered for permanent utilisation subject to in-depth investigations into the long-term effects of groundwater abstraction being applied.

It should be noted that although this study has determined that the implementation of large-scale groundwater abstraction projects for potable water supply is feasible, further consideration should be made for aquifer recharge requirements and the potential for environmental impacts by the project such as potential future groundwater pollution.

5.2 Recommendations for Future Work

Recommendations for future work were compiled based on this study.

5.2.1 Bulk Water Purchase Tariffs

This investigation was conducted based on the bulk water purchase tariff of water from the City of Cape Town. This investigation is therefore directly applicable to municipalities that purchase water from the City of Cape Town. This study should be performed utilising the bulk water purchase tariffs of various bulk water suppliers in order to establish the feasibility of large-scale groundwater abstraction projects in other municipal areas.

5.2.2 Groundwater Quality

This investigation was performed based on typical groundwater found within the municipal area where the large-scale groundwater abstraction project was implemented. The groundwater quality in this municipal area may vary significantly to that of other municipal areas resulting in different capital and operational expenditures. Future work should be performed using typical groundwater quality of other municipal areas to establish whether large-scale groundwater abstraction projects are always feasible, or whether there are certain water quality parameters that result in the project not being feasible, regardless of the bulk water purchase tariff.

5.2.3 Additional Considerations

The feasibility of large-scale groundwater abstraction projects, specifically for potable water supply, should be investigated further by factoring in groundwater aquifer recharge requirements for aquifer sustainability. In addition, the feasibility should factor in the potential environmental impacts of large-scale groundwater abstraction projects such as potential groundwater pollution, invasion of the natural environment etc. Finally, the feasibility of groundwater abstraction and treatment to potable standards from boreholes, as opposed to conventional surface water resources such as rivers and dams, should be considered. This will provide insight as to whether groundwater abstraction and treatment from boreholes should be relied on for potable water supply as opposed to conventional surface water resources.

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APPENDICES

Appendix A – SANS 241-1:2015 Physical, Aesthetic, Operational and Chemical Determinants

Table A-1: SANS 241-1:2015 water quality determinants and limits

Determinant	Risk	Unit	Standard Limits
Microbiological determinants			
E. coli	Acute health	Count per 100 mL	Not detected
Faecal coliforms	Acute health	Count per 100 mL	Not detected
Protozoan parasites	Acute health	Count per 10 L	Not detected
Total coliforms	Operational	Count per 100 mL	≤ 10
Heterotrophic plate count	Operational	Count per mL	≤ 1000
Somatic coliphages	Operational	Count per 10 mL	Not detected
Physical and aesthetic determinants			
Colour	Aesthetic	mg/L Pt-Co	≤ 15
Conductivity at 25°C	Aesthetic	mS/m	≤ 170
Total dissolved solids	Aesthetic	mg/L	≤ 1200
Turbidity	Operational	NTU	≤ 1
	Aesthetic	NTU	≤ 5
pH at 25°C	Operational	pH units	≥ 5 to ≤ 9.7
Chemical determinants - macro-determinants			
Free chlorine as Cl_2	Chronic health	mg/L	≤ 5
Monochloramine	Chronic health	mg/L	≤ 3
Nitrate as N	Acute health	mg/L	≤ 11
Nitrite as N	Acute health	mg/L	≤ 0.9
Combined nitrate plus nitrite	Acute health	mg/L	≤ 1
Sulfate as SO_4^{2-}	Acute health	mg/L	≤ 500
	Aesthetic	mg/L	≤ 250
Fluoride as F^-	Chronic health	mg/L	≤ 1.5
Ammonia as N	Aesthetic	mg/L	≤ 1.5
Chloride as Cl^-	Aesthetic	mg/L	≤ 300
Sodium as Na	Aesthetic	mg/L	≤ 200
Zinc as Zn	Aesthetic	mg/L	≤ 5
Chemical determinants - micro-determinants			
Antimony as Sb	Chronic health	µg/L	≤ 20
Arsenic as As	Chronic health	µg/L	≤ 10
Barium as Ba	Chronic health	µg/L	≤ 700
Boron as B	Chronic health	µg/L	≤ 2400
Cadmium as Cd	Chronic health	µg/L	≤ 3
Total chromium as Cr	Chronic health	µg/L	≤ 50
Copper as Cu	Chronic health	µg/L	≤ 2000
Cyanide (recoverable) as CN^-	Acute health	µg/L	≤ 200
Iron as Fe	Chronic health	µg/L	≤ 2000
	Aesthetic	µg/L	≤ 300
Lead as Pb	Chronic health	µg/L	≤ 10
Manganese as Mn	Chronic health	µg/L	≤ 400
	Aesthetic	µg/L	≤ 100
Mercury as Hg	Chronic health	µg/L	≤ 6
Nickel as Ni	Chronic health	µg/L	≤ 70
Selenium as Se	Chronic health	µg/L	≤ 40
Uranium as U	Chronic health	µg/L	≤ 30
Aluminium as Al	Operational	µg/L	≤ 300
Chemical determinants - organic determinants			
Total organic carbon as C	Chronic health	mg/L	≤ 10
Trihalomethanes			

Determinant	Risk	Unit	Standard Limits
Chloroform	Chronic health	µg/L	≤ 300
Bromoform	Chronic health	µg/L	≤ 100
Dibromochloromethane	Chronic health	µg/L	≤ 100
Bromodichloromethane	Chronic health	µg/L	≤ 60
Combined trihalomethane	Chronic health		≤ 1
Total microcystin	Chronic health	µg/L	≤ 1
Phenols	Aesthetic	µg/L	≤ 10

Appendix B – Groundwater Abstraction Project Design

Appendix B1 – Groundwater Abstraction Points Water Quality

Table B-1: Water quality of abstraction points at Boy Louw Sportsgrounds

Parameter	Unit	Results				Weighted Concentration	Limit
		A	B	C	D		
Chemistry Parameters							
Acidity as $CaCO_3$	mg/L	6	22.60	14.70	19	15.15	-
Alkalinity - Total as $CaCO_3$	mg/L	43.60	34.70	42.30	45.60	41.72	-
pH @ 25°C	pH units	7.09	6.60	6.59	6.78	6.78	5 - 9.7
Total Dissolved Solids	mg/L	207	247	272	251	242.50	<1200
Physical Parameters							
Carbonate	mg/L	26.20	20.80	25.40	27.40	25.05	-
Colour	Pt-Co-true	<10	<10	15	10	6	<15
Electrical Conductivity @ 25°C	mS/m	29.50	35.30	38.80	35.80	34.60	<170
Turbidity	NTU	2.51	9.20	27	12.90	12.38	<1
Total Suspended Solids	mg/L	<2	<2	<2	44	11	
Cations and Anions Parameters							
Calcium as Ca	mg/L	12.80	8.83	15.90	11.50	12.27	-
Sodium as Na	mg/L	28.70	51.80	34.20	48.50	40.32	<200
Magnesium as Mg	mg/L	6.66	8.18	11.50	10.10	9	-
Potassium as K	mg/L	2.74	4.65	2.62	4.66	3.64	-
Chloride as Cl^-	mg/L	45.70	72.80	80.40	66.70	65.37	<300
Fluoride as F^-	mg/L	0.14	<0.10	0.13	<0.10	0.07	<1.50
Sulphate as SO_4^{2-}	mg/L	16.90	64.90	17.70	64.20	40.11	<250
Ammonia as N	mg/L	<0.16	<0.16	<0.16	<0.16	0	<1.50
Ortho-Phosphate as P	mg/L	<0.50	<0.50	<0.50	<0.50	0	-
Bromine as Br_2	mg/L	0.13	0.40	0.14	1.22	0.47	-
Nitrate / Nitrite	Calc	0.12	<0.03	<0.03	<0.03	0.03	<1
Sulphide as S	mg/L	<0.10	<0.10	<0.10	<0.10	0	-
Elemental Parameters							
Aluminium as Al (Total)	µg/L	<50	273	<50	6040	1574	-
Aluminium as Al	µg/L	<50	<50	<50	<50	0	<300
Antimony as Sb	µg/L	<20	<20	<20	<20	0	<20
Arsenic as As	µg/L	<10	<10	<10	<10	0.00	<10
Barium as Ba	µg/L	50	106	81	147	94.49	<700
Chromium as Cr	µg/L	<10	<10	<10	<10	0	<50
Copper as Cu	µg/L	<10	<10	<10	<10	0	<2000
Iron as Fe (Total)	µg/L	86	1810	<50	7520	2327	<2000
Iron as Fe	µg/L	66.80	<50	<50	<50	18.93	<300
Manganese as Mn	µg/L	216	303	290	470	317	<100
Manganese as Mn (Total)	µg/L	220	331	299	632	367.33	<400
Mercury as Hg	µg/L	<6	<6	<6	<6	0	<6
Nickel as Ni	µg/L	<20	<20	<20	<20	0	<70
Selenium as Se	µg/L	<40	<40	<40	<40	0	<40
Silicon as Si	mg/L	18.90	19.40	19.10	19.20	19.14	-
Strontium as Sr	µg/L	84.90	93.40	144	115	108.20	-

Vanadium as V	µg/L	<10	<10	<10	<10	0	-
Zinc as Zn	mg/L	<0.05	0.06	<0.05	<0.05	0.01	<5
Indexes							
Calcium Hardness	mg/L as CaCO3	32	22.10	39.80	28.80	30.71	-
Magnesium Hardness as $CaCO_3$	mg/L as CaCO3	27.30	33.50	47.20	41.40	36.92	-
Total Hardness as $CaCO_3$	mg/L	59.30	55.60	86.90	70.20	67.60	-
Micro Parameters							
Total Coliforms	cfu's/100 ml	92	>2 000	50	580	182.73	<10
Faecal Coliforms	cfu's/100 ml	1	16	1	13	7.50	0
Heterotrophic Plate Count	cfu's/1 ml	>1000	>1000	>1000	>1000	0	<1000
Organic Parameters							
Cyanide as CN^-	µg/L	<10	<10	<10	<10	0	<200
Dissolved Organic Carbon	mg/L	<2	<2	<2	<2	0	-
Dissolved Oxygen	mg/L	6.12	6.63	5.80	7.96	6.62	-
Chloroform	µg/L	<20	<20	<20	<20	0	<300
Bromodichloromethane	µg/L	<20	<20	<20	<20	0	<60
Dibromochloromethane	µg/L	<20	<20	<20	<20	0	<100
Bromoform	µg/L	<20	<20	<20	<20	0	<100
Trihalomethane as Total THM	µg/L	<20	<80	<80	<80	0	
Total THM ratio	Calc	0.09	0.08	0.07	0.08	0.08	<1

Table B-2: Water quality of abstraction points at Parys Sportsgrounds

Parameter	Unit	Results				Weighted Concentration	Limit
		A	B	C	D		
Chemistry Parameters							
Acidity as $CaCO_3$	mg/L	3.09	2.94	9.80	9.56	6.24	-
Alkalinity - Total as $CaCO_3$	mg/L	61	48.10	53.70	58.20	55.59	-
pH @ 25°C	pH units	7.63	6.96	6.79	6.91	7.10	5 - 9.7
Total Dissolved Solids	mg/L	151	133	174	178	158.92	<1200
Physical Parameters							
Carbonate	mg/L	36.60	28.90	32.20	34.90	33.35	-
Colour	Pt-Co-true	<10	<10	<10	<10	0	<15
Electrical Conductivity @ 25°C	mS/m	21.60	19.10	24.90	25.40	22.74	<170
Turbidity	NTU	0.42	0.62	11.40	0.84	3.13	<1
Total Suspended Solids	mg/L	<2	<2	22.40	<2	5.23	
Cations and Anions Parameters							
Calcium as Ca	mg/L	7.30	4.89	9.37	10.50	8.02	-
Sodium as Na	mg/L	24.50	29.20	32.00	32.30	29.30	<200
Magnesium as Mg	mg/L	5.56	4.80	6.24	7.03	5.91	-
Potassium as K	mg/L	2.16	2.45	1.67	1.81	2.03	-
Chloride as Cl^-	mg/L	23.60	24.50	29.00	30.20	26.72	<300
Fluoride as F^-	mg/L	0.16	0.16	<0.10	<0.10	0.08	<1.50
Sulphate as SO_4^{2-}	mg/L	3.83	36.80	18.20	53.50	27.29	<250
Ammonia as N	mg/L	<0.16	<0.16	<0.16	<0.16	0	<1.50
Ortho-Phosphate as P	mg/L	<0.50	<0.50	<0.50	<0.50	0	-
Bromine as Br_2	mg/L	0.11	<0.10	0.37	0.13	0.15	-
Nitrate / Nitrite	Calc	0.11	0.14	1.52	2.09	0.94	<1
Sulphide as S	mg/L	<0.10	<0.10	<0.10	<0.10	0	-
Elemental Parameters							
Aluminium as Al (Total)	µg/L	<50	<50	74.90	<50	17.48	-
Aluminium as Al	µg/L	<50	<50	<50	<50	0	<300
Antimony as Sb	µg/L	<20	27.50	<20	<20	6.42	<20
Arsenic as As	µg/L	<10	<10	<10	<10	0	<10
Barium as Ba	µg/L	26.40	36.20	39.20	38.70	34.75	<700
Chromium as Cr	µg/L	<10	<10	<10	<10	0	<50
Copper as Cu	µg/L	<10	<10	<10	<10	0	<2000
Iron as Fe (Total)	µg/L	<50	55.50	55.70	<50	25.95	<2000
Iron as Fe	µg/L	<50	52.30	<50	<50	12.20	<300
Manganese as Mn	µg/L	30.10	15.20	35.40	29	27.59	<100
Manganese as Mn (Total)	µg/L	46	19.50	36.50	29	33.35	<400
Mercury as Hg	µg/L	<6	<6	<6	<6	0	<6
Nickel as Ni	µg/L	<20	<20	<20	<20	0	<70
Selenium as Se	µg/L	<40	157	<40	<40	36.63	<40
Silicon as Si	mg/L	14.90	17.20	18.30	15.80	16.46	-
Strontium as Sr	µg/L	66	73.80	110	123	92.34	-
Vanadium as V	µg/L	<10	<10	<10	<10	0	-
Zinc as Zn	mg/L	<0.05	0.10	<0.05	<0.05	0.02	<5
Indexes							
Calcium Hardness	mg/L as CaCO3	18.30	12.20	23.40	26.30	20.07	-

Magnesium Hardness as $CaCO_3$	mg/L as CaCO3	22.80	19.70	25.60	28.80	24.23	-
Total Hardness as $CaCO_3$	mg/L	41	31.90	49	55.10	44.27	-
Micro Parameters							
Total Coliforms	cfu's/100 ml	4	19	500	34	130.73	<10
Faecal Coliforms	cfu's/100 ml	0	0	3	0	0.70	0
Heterotrophic Plate Count	cfu's/1 ml	202	98	>1000	>1000	80.10	<1000
Organic Parameters							
Cyanide as CN^-	µg/L	<10	<10	<10	<10	0	<200
Dissolved Organic Carbon	mg/L	2.95	<2	<2	<2	0.84	-
Dissolved Oxygen	mg/L	6.10	6.37	2.69	4.92	5.07	-
Chloroform	µg/L	<20	<20	<20	<20	0	<300
Bromodichloromethane	µg/L	<20	<20	<20	<20	0	<60
Dibromochloromethane	µg/L	<20	<20	<20	<20	0	<100
Bromoform	µg/L	<20	<20	<20	<20	0	<100
Trihalomethane as Total THM	µg/L	<80	<80	<80	<80	0	
Total THM ratio	Calc	0.13	0.04	0.09	0.07	0.08	<1

Appendix B2 – Groundwater Abstraction Water Treatment Plant Process Design

DESCRIPTION	BOREHOLE PUMP
TAG No.	BH1-PP-1
FLOW (l/s)	17
HEAD (m)	80
DRIVE (kW)	22

DESCRIPTION	BOREHOLE PUMP
TAG No.	BH2-PP-1
FLOW (l/s)	14
HEAD (m)	74
DRIVE (kW)	15

DESCRIPTION	DRAIN PUMP
TAG No.	BH1-PP-2
FLOW (l/s)	2.5
HEAD (m)	7
DRIVE (kW)	0.75

DESCRIPTION	DRAIN PUMP
TAG No.	BH2-PP-2
FLOW (l/s)	2.5
HEAD (m)	7
DRIVE (kW)	0.75

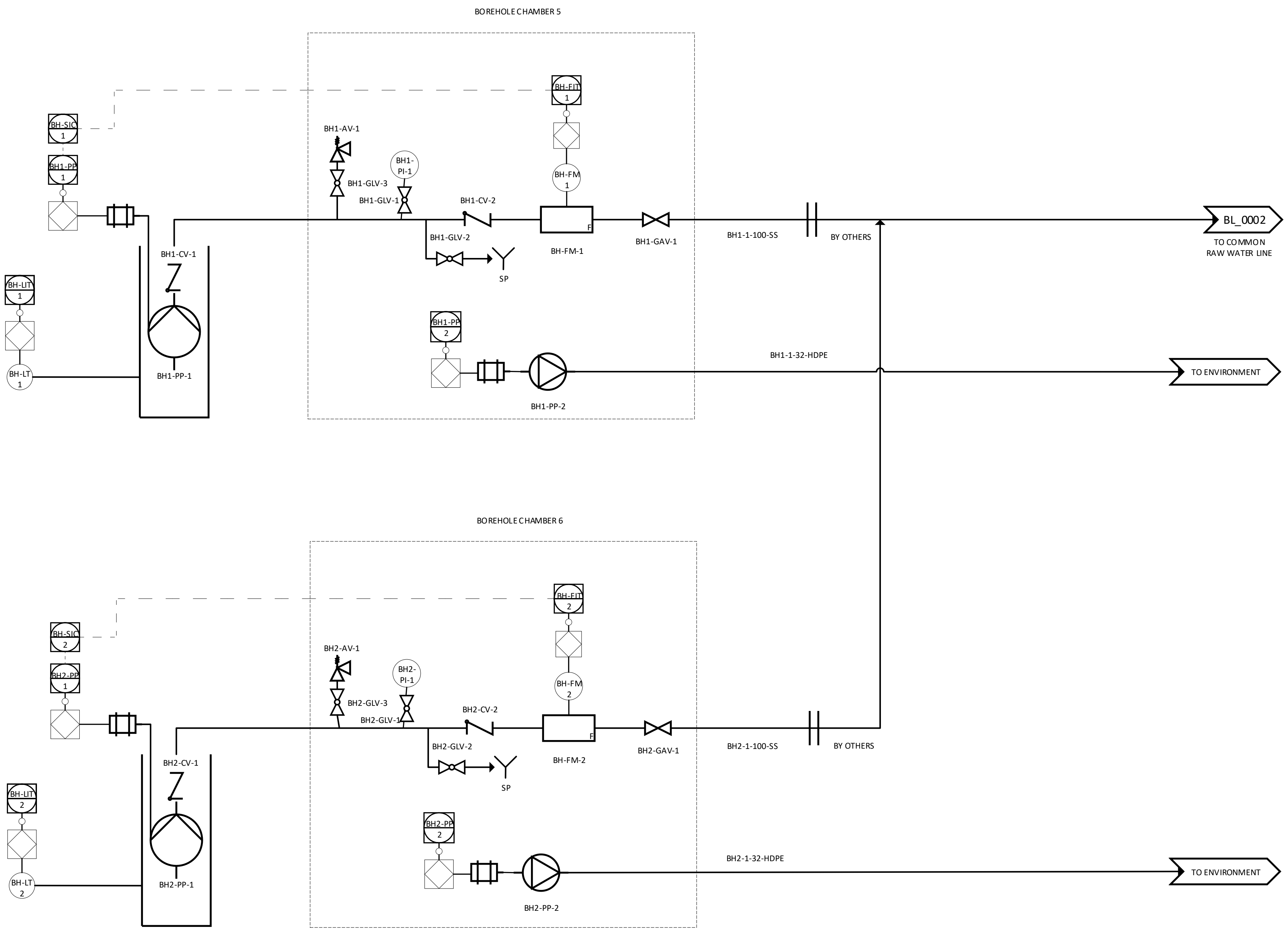


Figure B-1: P&ID of Boy Louw Sportsgrounds: abstraction points A and B of Boy Louw Sportsgrounds

DESCRIPTION	BOREHOLE PUMP
TAG No.	BH3-PP-1
FLOW (l/s)	14
HEAD (m)	80
DRIVE (kW)	18.5

DESCRIPTION	BOREHOLE PUMP
TAG No.	BH4-PP-1
FLOW (l/s)	15
HEAD (m)	70
DRIVE (kW)	22

DESCRIPTION	DRAIN PUMP
TAG No.	BH3-PP-2
FLOW (l/s)	2.5
HEAD (m)	7
DRIVE (kW)	0.75

DESCRIPTION	DRAIN PUMP
TAG No.	BH4-PP-2
FLOW (l/s)	2.5
HEAD (m)	7
DRIVE (kW)	0.75

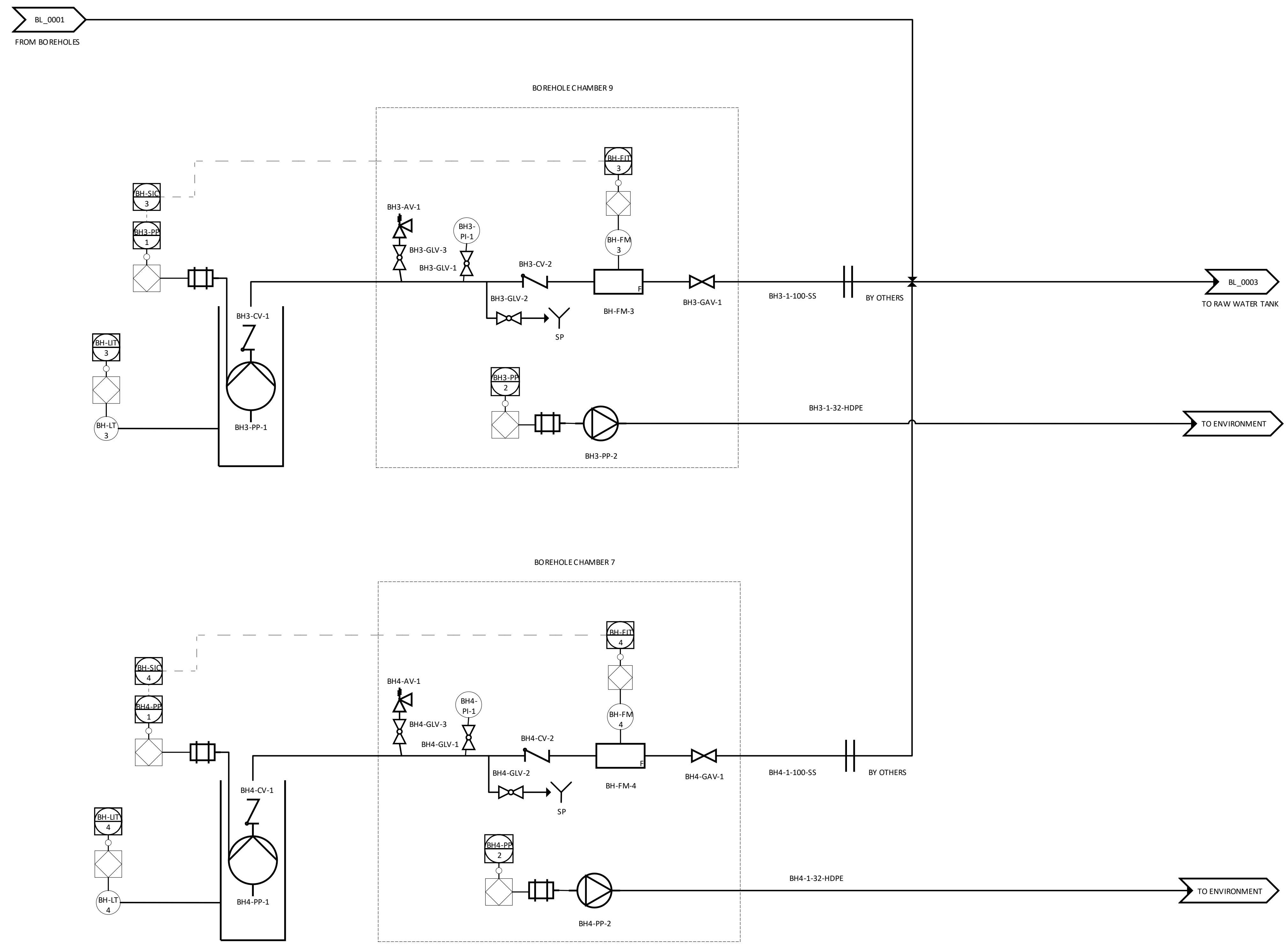


Figure B-2: P&ID of Boy Louw Sportsgrounds: abstraction points C and D of Boy Louw Sportsgrounds

DESCRIPTION	STATIC MIXER
TAG No.	RW-SM-1
SIZE	250 mm

DESCRIPTION	RAW WATER TANK
TAG No.	RW-TK-1
VOLUME (m³)	80
SHAPE	ROUND
MOC	STEEL

DESCRIPTION	TRANSFER PUMPS
TAG No.	RW-PP-1/2/3
FLOW (l/s)	60
HEAD (m)	20
DRIVE (kW)	22

DESCRIPTION	PRESSURE TANK
TAG No.	RW-PV-1
VOLUME (L)	300
PRESSURE (bar)	10

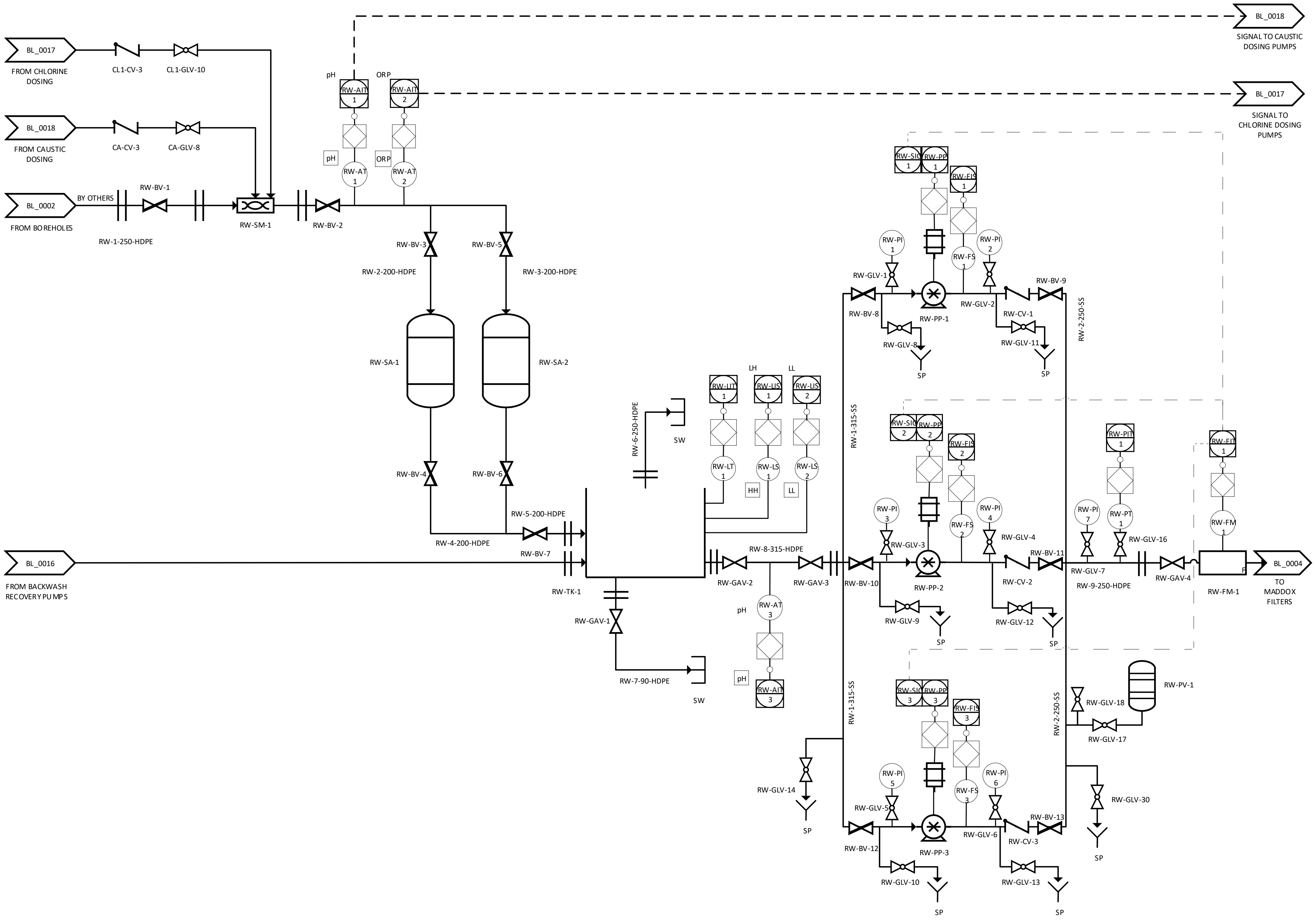


Figure B-3: P&ID of Boy Louw Sportsgrounds: raw water storage tank and pumps of Boy Louw Sportsgrounds

DESCRIPTION	MADDOX FILTERS
TAG No.	MF-VE-1/2
DIAMETER (mm)	1500
HEIGHT (mm)	1935
TYPE	PRESSURISED

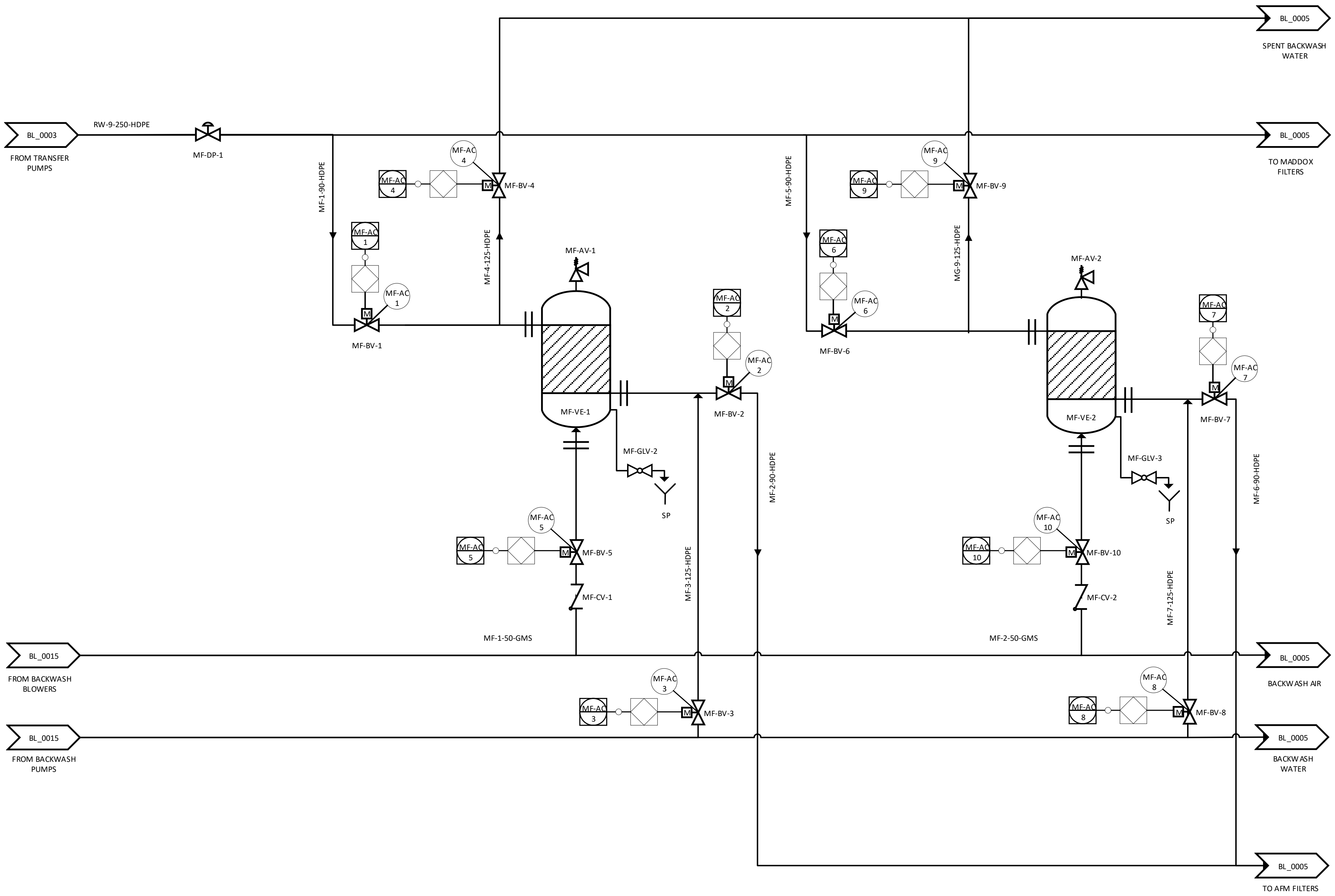


Figure B-4: P&ID of Boy Louw Sportsgrounds: Maddox filters 1 and 2 of Boy Louw Sportsgrounds

DESCRIPTION	MADDOX FILTERS
TAG No.	MF-VE-3/4
DIAMETER (mm)	1500
HEIGHT (mm)	1935
TYPE	PRESSURISED

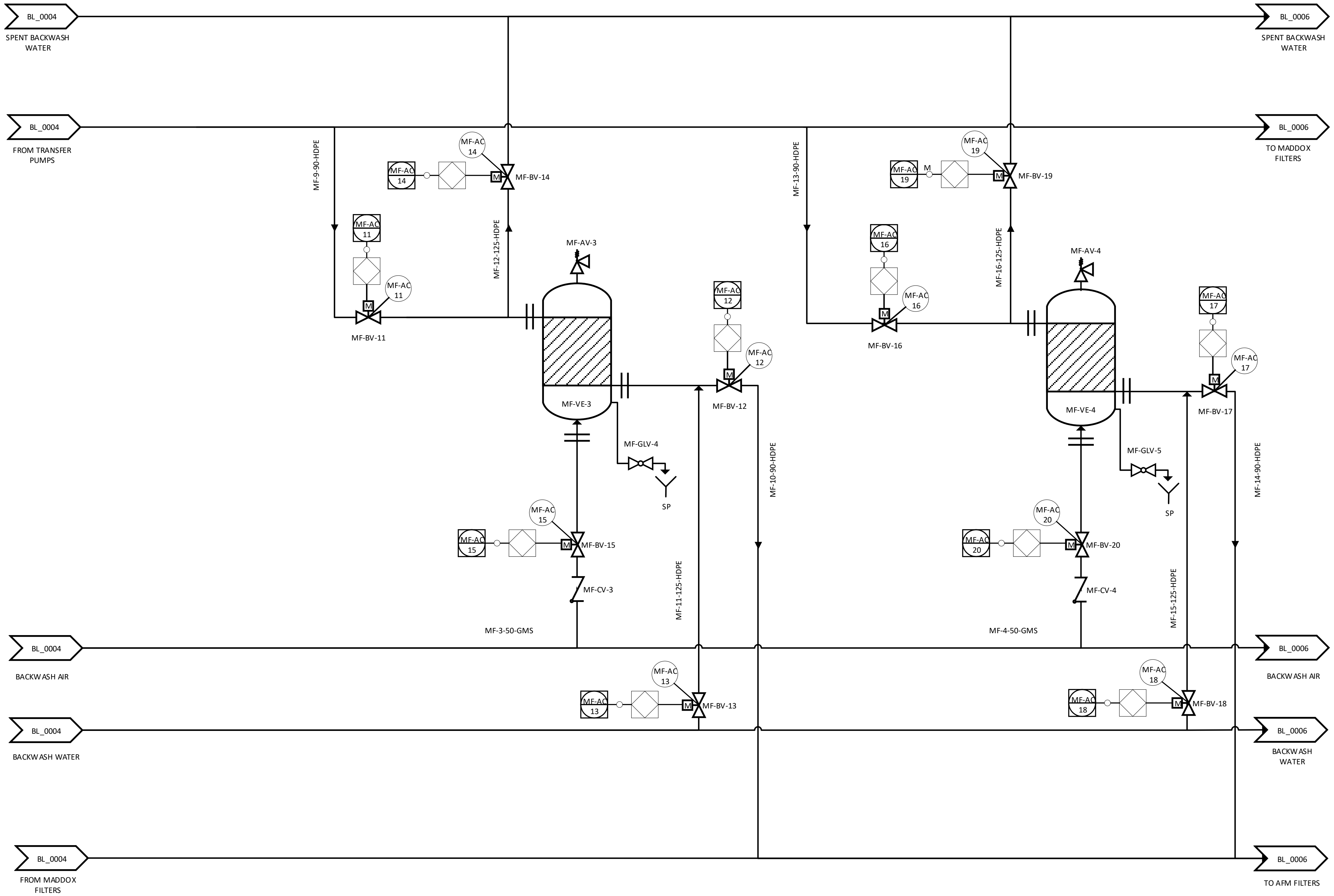


Figure B-5: P&ID of Boy Louw Sportsgrounds: Maddox filters 3 and 4 of Boy Louw Sportsgrounds

DESCRIPTION	MADDOX FILTERS
TAG No.	MF-VE-5/6
DIAMETER (mm)	1500
HEIGHT (mm)	1935
TYPE	PRESSURISED

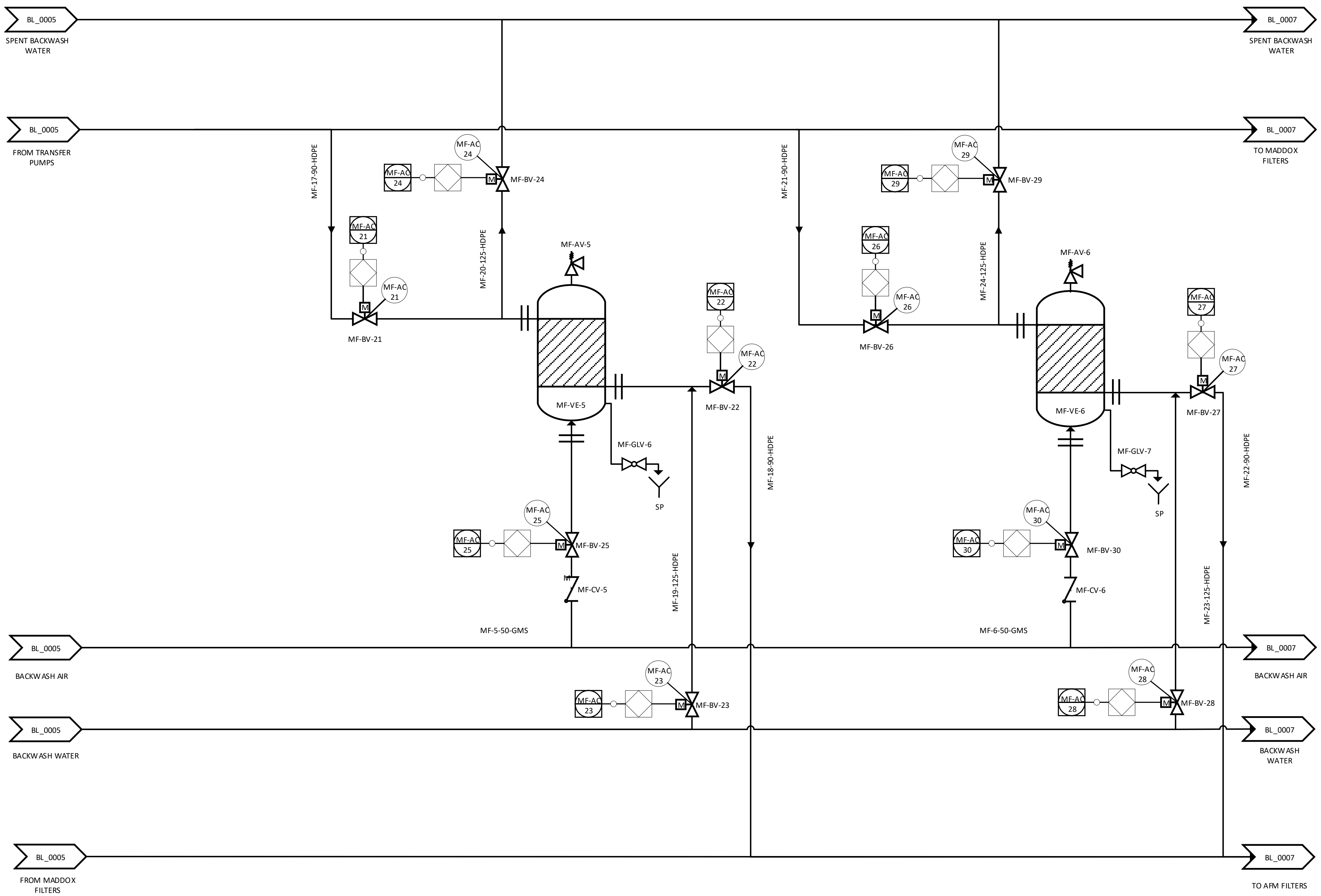


Figure B-6: P&ID of Boy Louw Sportsgrounds: Maddox filters 5 and 6 of Boy Louw Sportsgrounds

DESCRIPTION	MADDOX FILTERS
TAG No.	MF-VE-7/8
DIAMETER (mm)	1500
HEIGHT (mm)	1935
TYPE	PRESSURISED

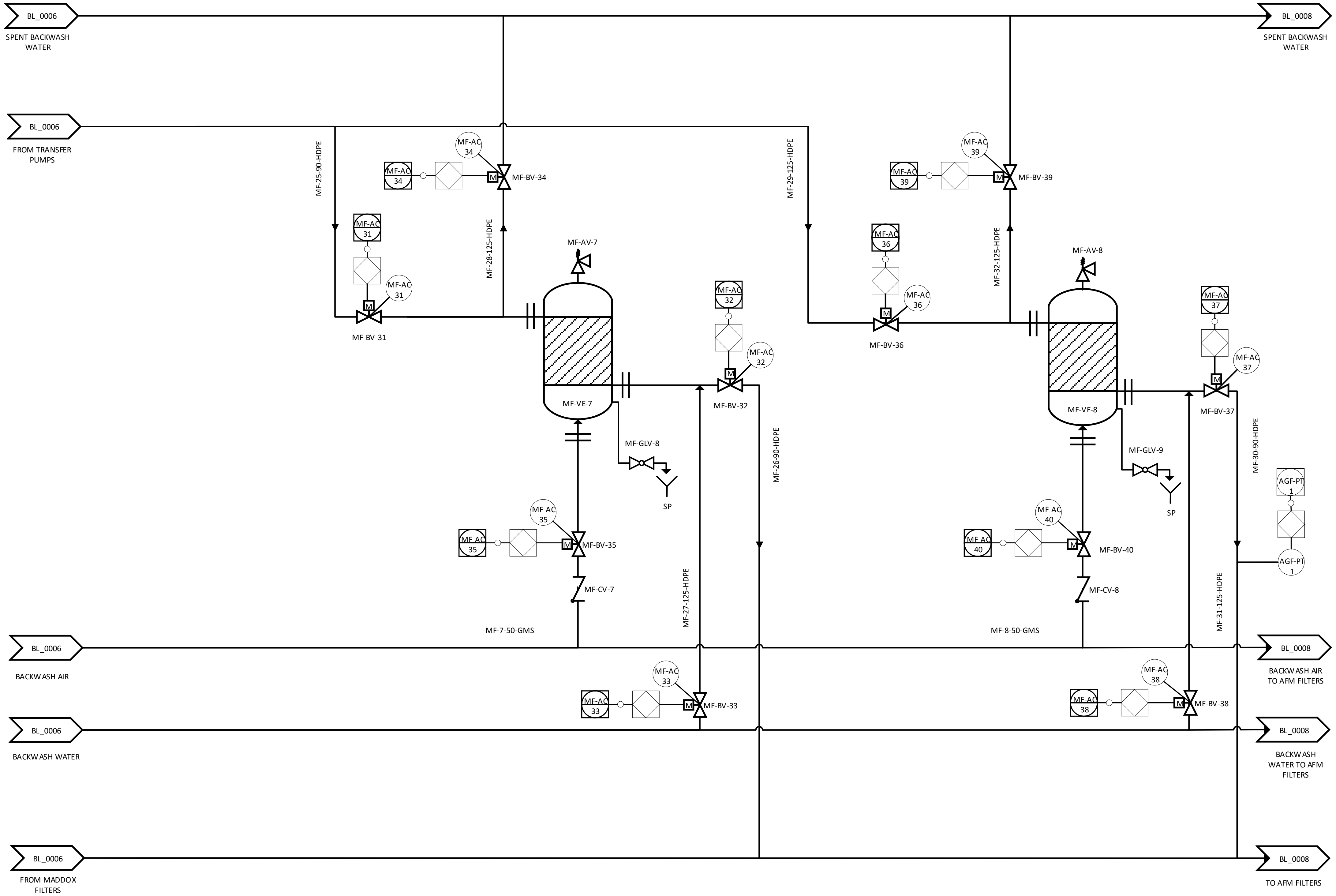


Figure B-7: P&ID of Boy Louw Sportsgrounds: Maddox filters 7 and 8 of Boy Louw Sportsgrounds

DESCRIPTION	AFM FILTERS
TAG No.	AGF-VE-1/2
DIAMETER (mm)	1500
HEIGHT (mm)	2135
TYPE	PRESSURISED

DESCRIPTION	SPOOL PIECE
TAG No.	RW-SP-1
LENGTH (mm)	1500
DIAMETER (mm)	250
MOC	SS316

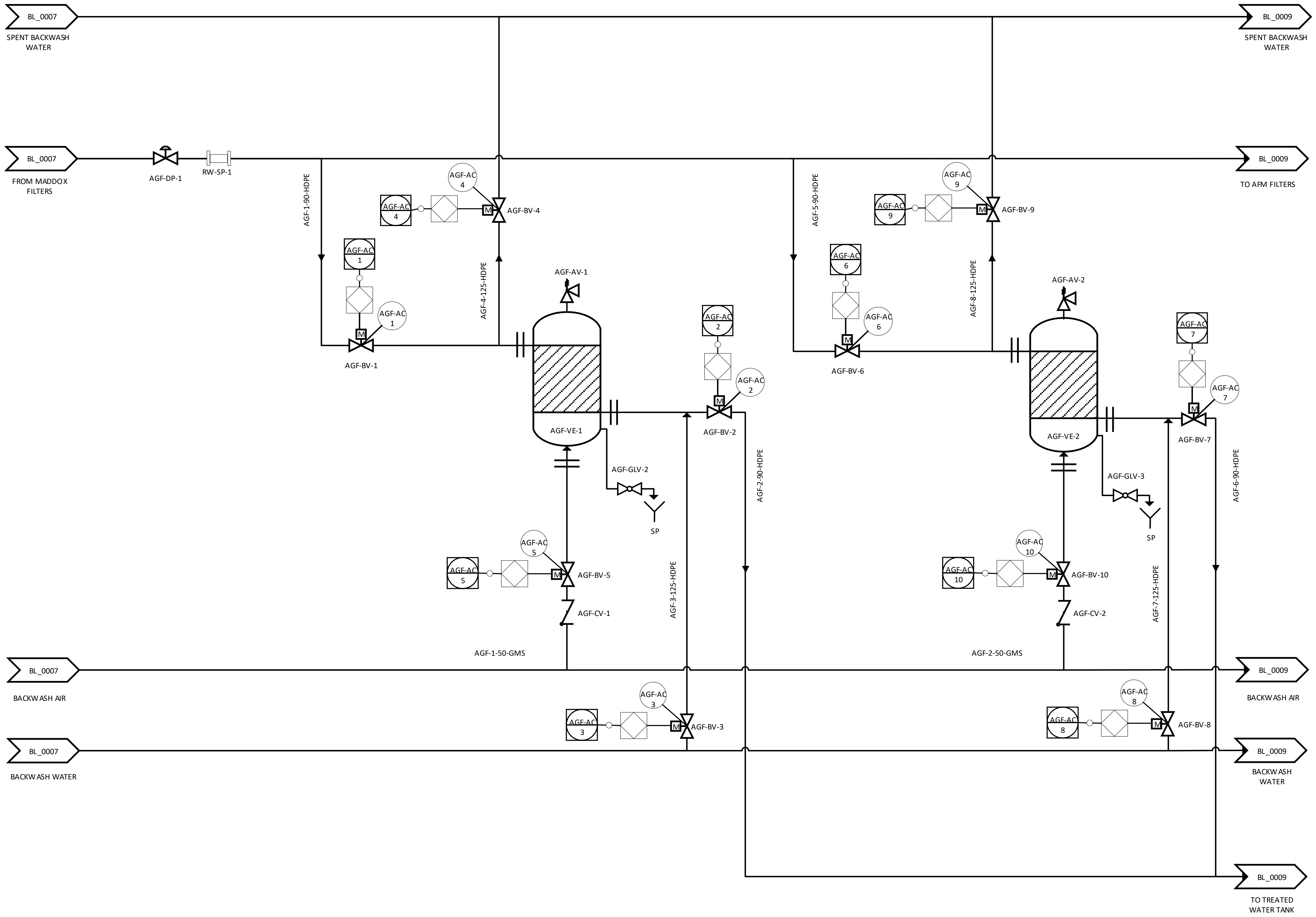


Figure B-8: P&ID of Boy Louw Sportsgrounds: activated glass filters 1 and 2 of Boy Louw Sportsgrounds

DESCRIPTION	AFM FILTERS
TAG No.	AGF-VE-3/4
DIAMETER (mm)	1500
HEIGHT (mm)	2135
TYPE	PRESSURISED

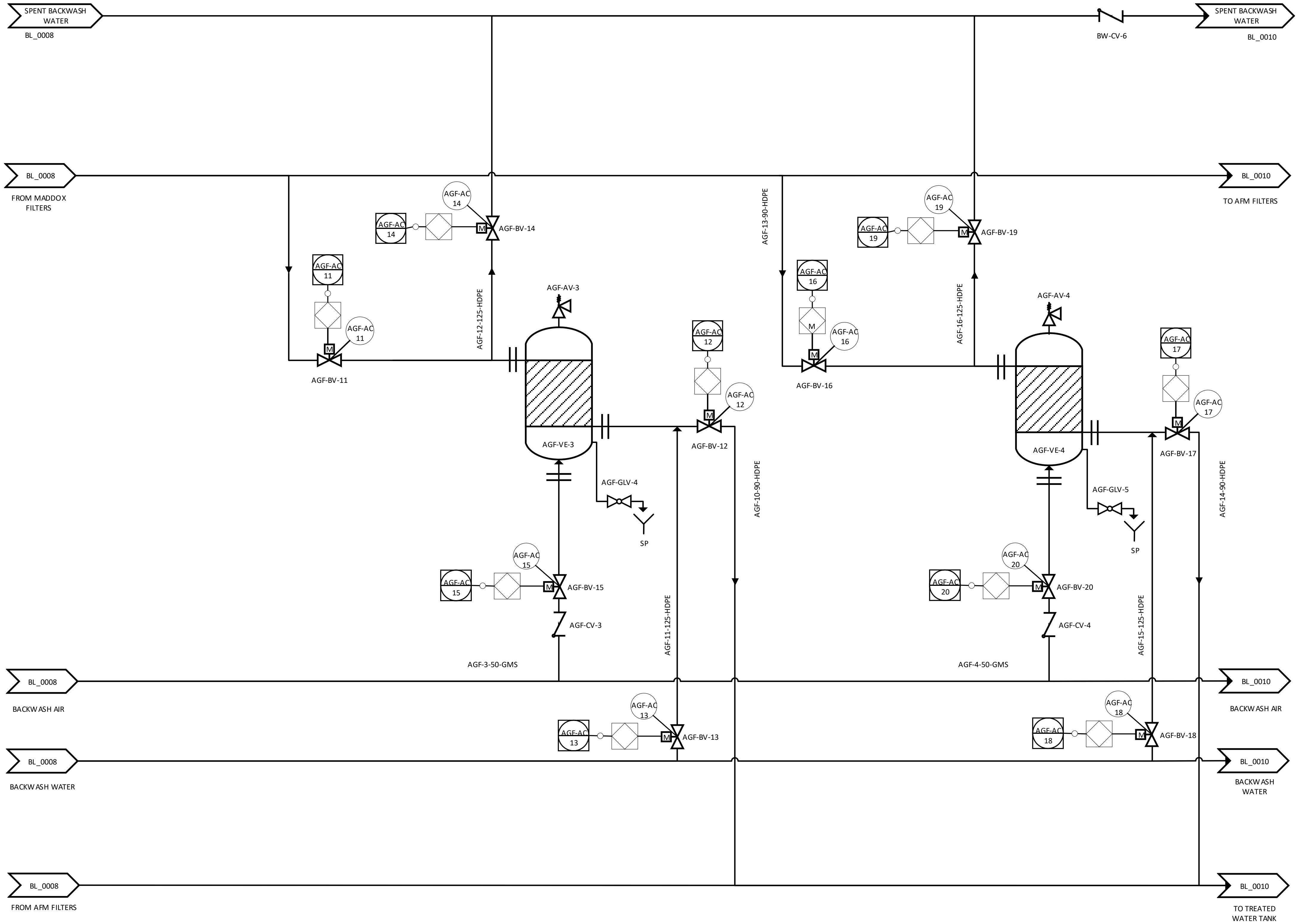


Figure B-9: P&ID of Boy Louw Sportsgrounds: activated glass filters 3 and 4 of Boy Louw Sportsgrounds

DESCRIPTION	AFM FILTERS
TAG No.	AGF-VE-5/6
DIAMETER (mm)	1500
HEIGHT (mm)	2135
TYPE	PRESSURISED

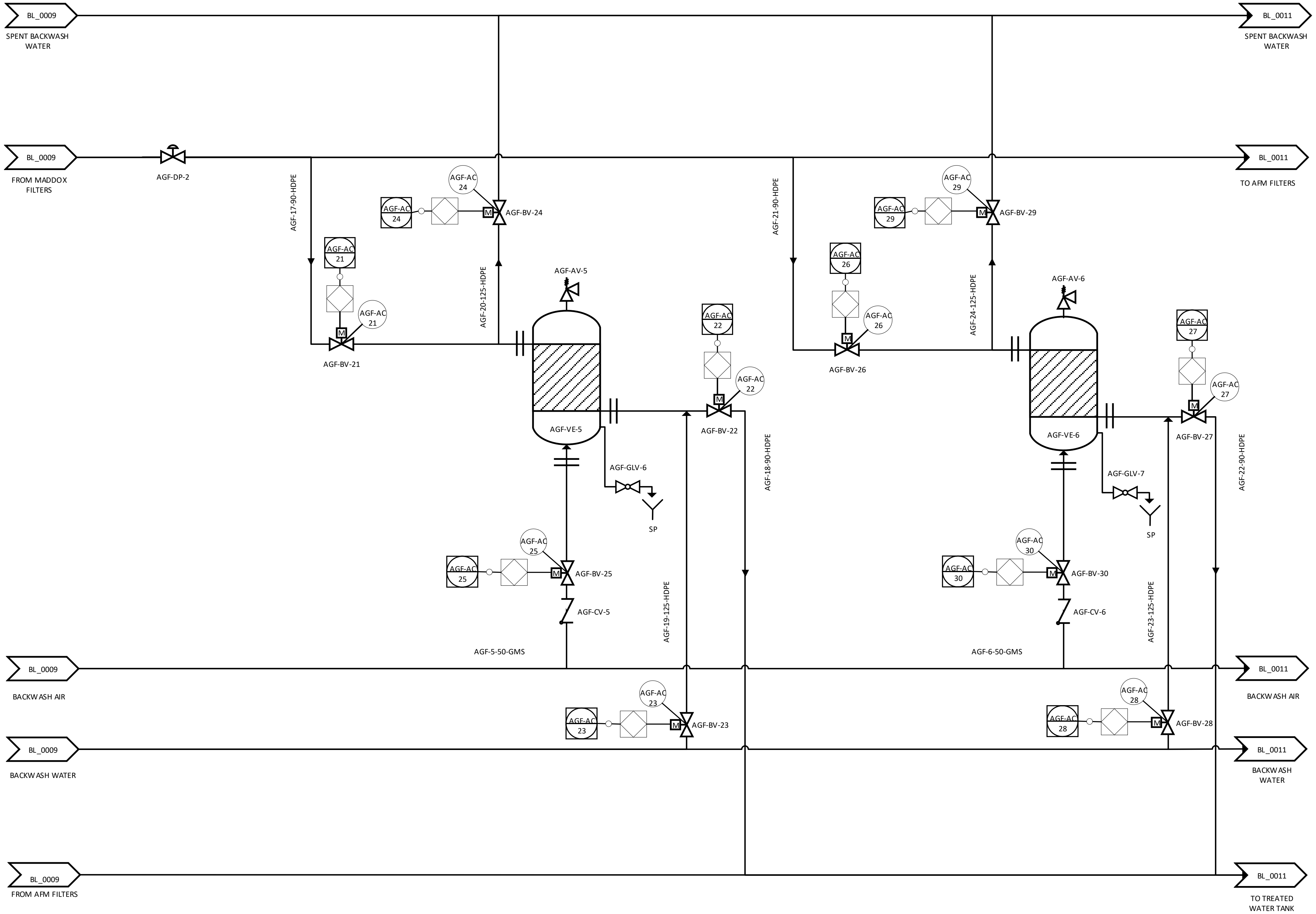


Figure B-10: P&ID of Boy Louw Sportsgrounds: activated glass filters 5 and 6 of Boy Louw Sportsgrounds

DESCRIPTION	AFM FILTERS
TAG No.	AGF-VE-7/8
DIAMETER (mm)	1500
HEIGHT (mm)	2135
TYPE	PRESSURISED

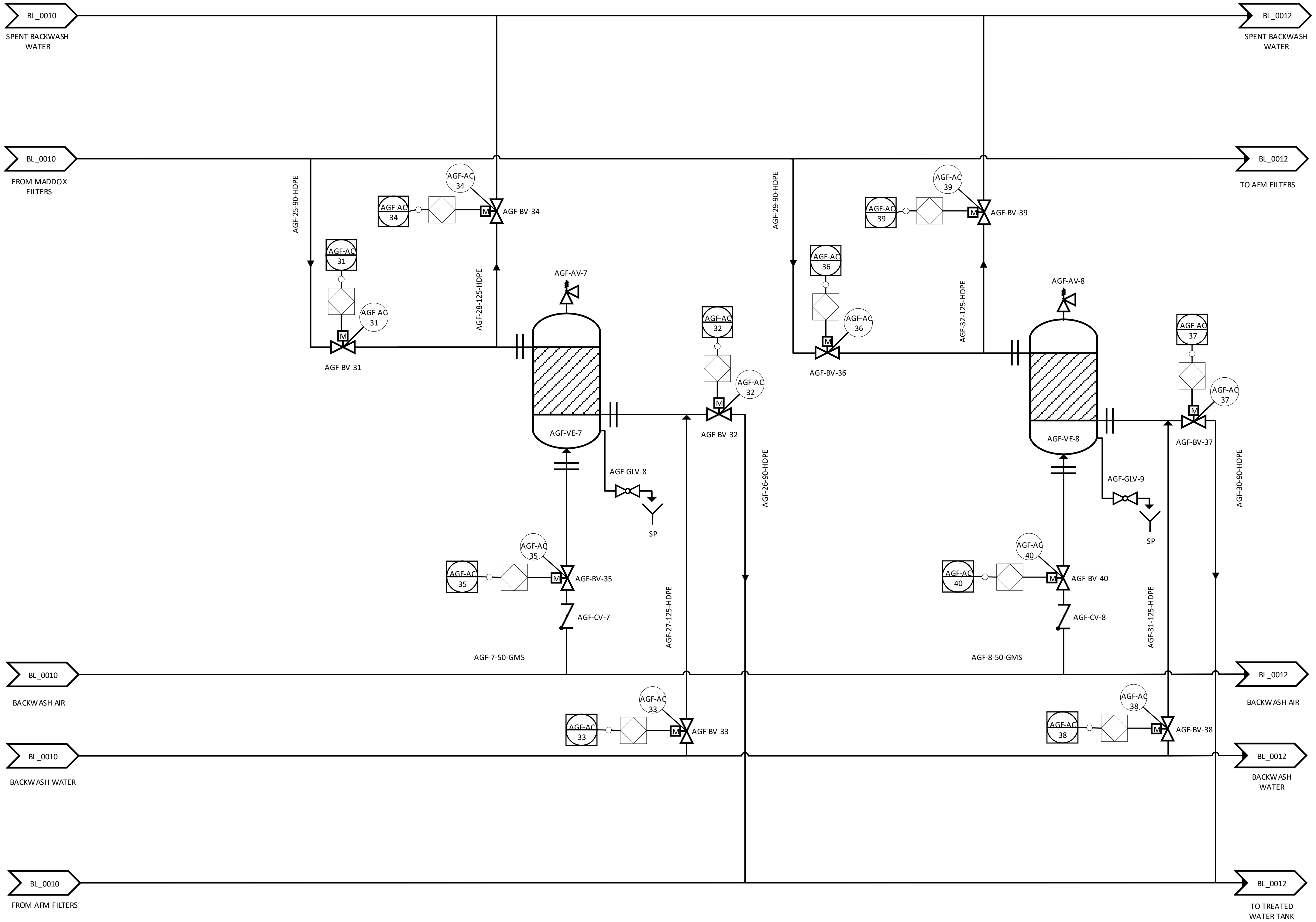


Figure B-11: P&ID of Boy Louw Sportsgrounds: activated glass filters 7 and 8 of Boy Louw Sportsgrounds

DESCRIPTION	AFM FILTERS
TAG No.	AGF-VE-9/10
DIAMETER (mm)	1500
HEIGHT (mm)	2135
TYPE	PRESSURISED

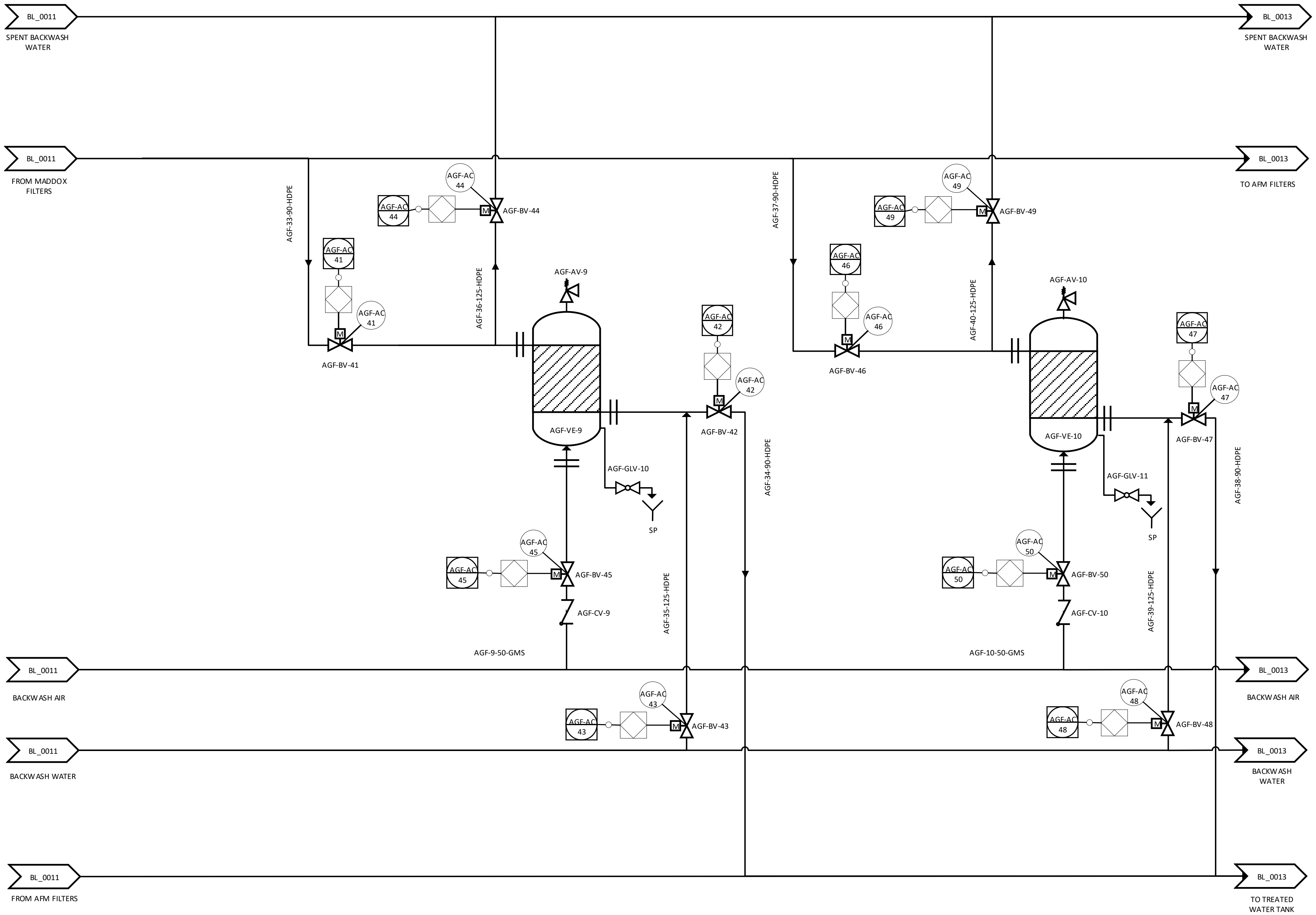


Figure B-12: P&ID of Boy Louw Sportsgrounds: activated glass filters 9 and 10 of Boy Louw Sportsgrounds

DESCRIPTION	AFM FILTERS
TAG No.	AGF-VE-11/12
DIAMETER (mm)	1500
HEIGHT (mm)	2135
TYPE	PRESSURISED

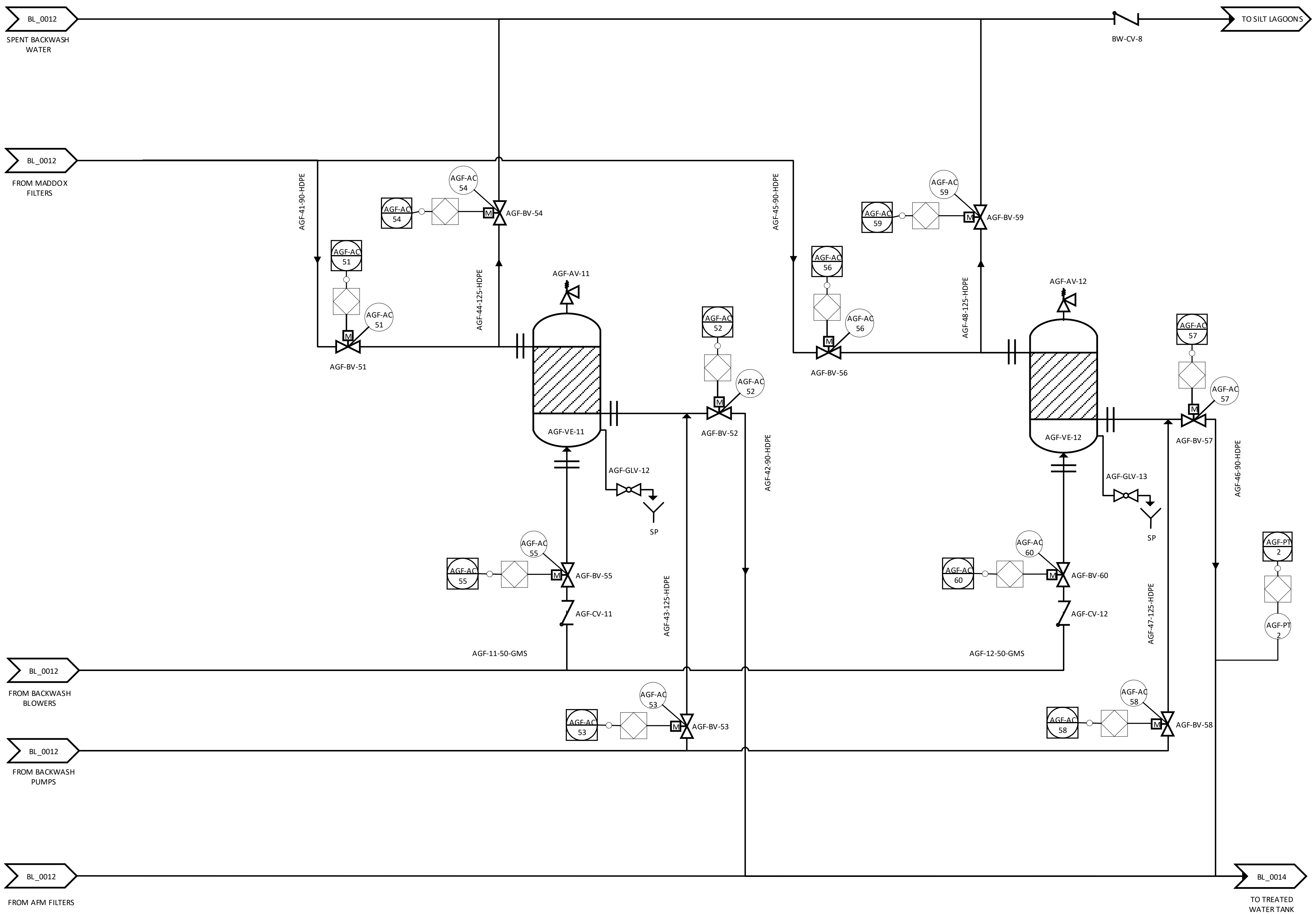


Figure B-13: P&ID of Boy Louw Sportsgrounds: activated glass filters 11 and 12 of Boy Louw Sportsgrounds

DESCRIPTION	STATIC MIXER
TAG No.	TW-SM-1
SIZE	250 mm

DESCRIPTION	TREATED WATER TANK
TAG No.	TW-TK-1
VOLUME (m³)	80
SHAPE	ROUND
MOC	STEEL

DESCRIPTION	TREATED WATER PUMPS
TAG No.	TW-PP-1/2/3/4/5
FLOW (l/s)	75.6
HEAD (m)	90
DRIVE (kW)	30

DESCRIPTION	PRESSURE TANKS
TAG No.	TW-PV-1/2
VOLUME (L)	300
PRESSURE (bar)	16

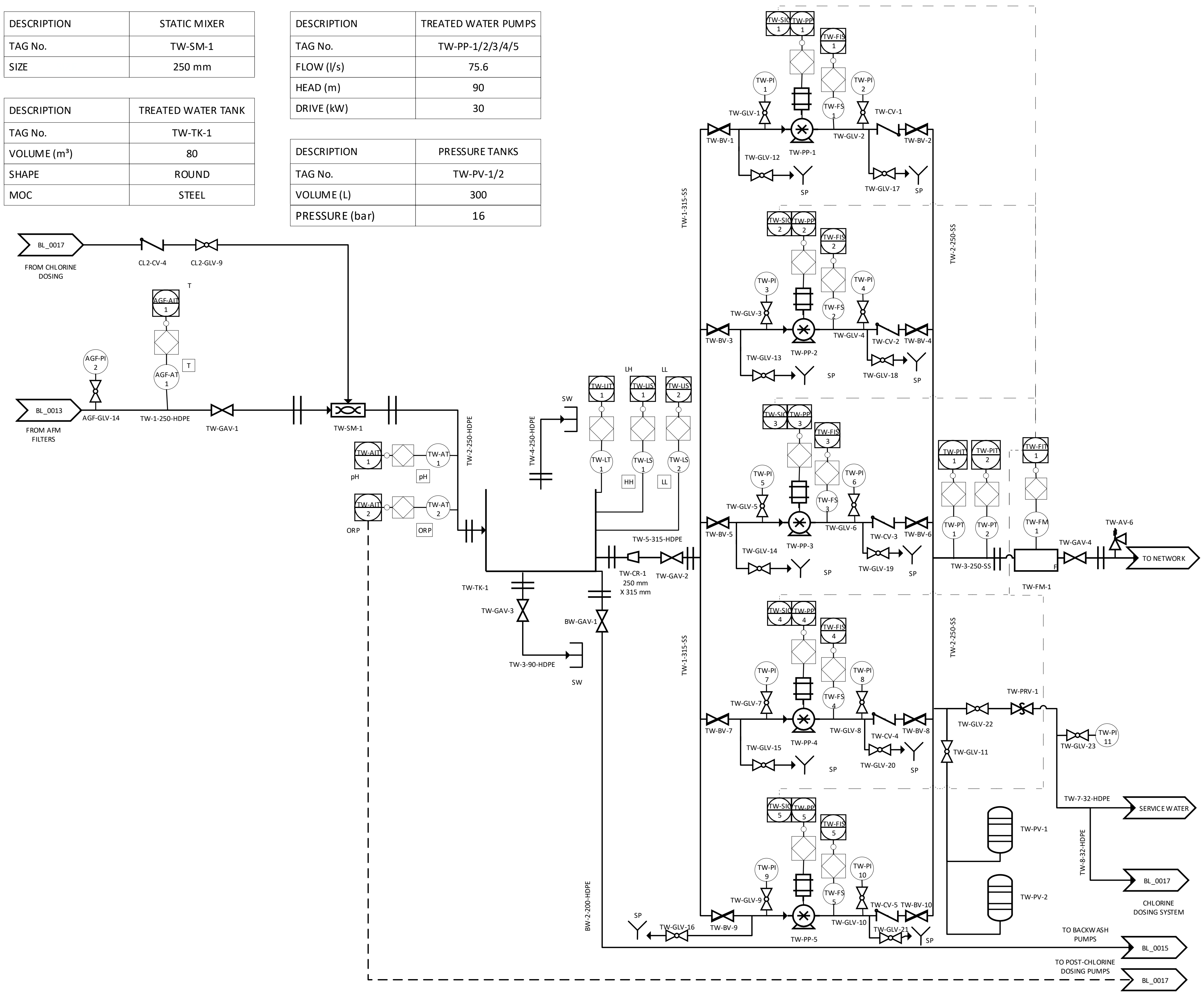


Figure B-14: P&ID of Boy Louw Sportsgrounds: treated water storage tank and treated water pumps of Boy Louw Sportsgrounds

DESCRIPTION	BACKWASH PUMPS
TAG No.	BW-PP-1/2/3
FLOW (l/s)	22
HEAD (m)	12
DRIVE (kW)	4

DESCRIPTION	BACKWASH BLOWERS
TAG No.	BW-BB-1/2
FLOW (m³/hr)	106
HEAD (mbar)	460
DRIVE (kW)	4

DESCRIPTION	PRESSURE TANK
TAG No.	BW-PV-1
VOLUME (L)	300
PRESSURE (bar)	10

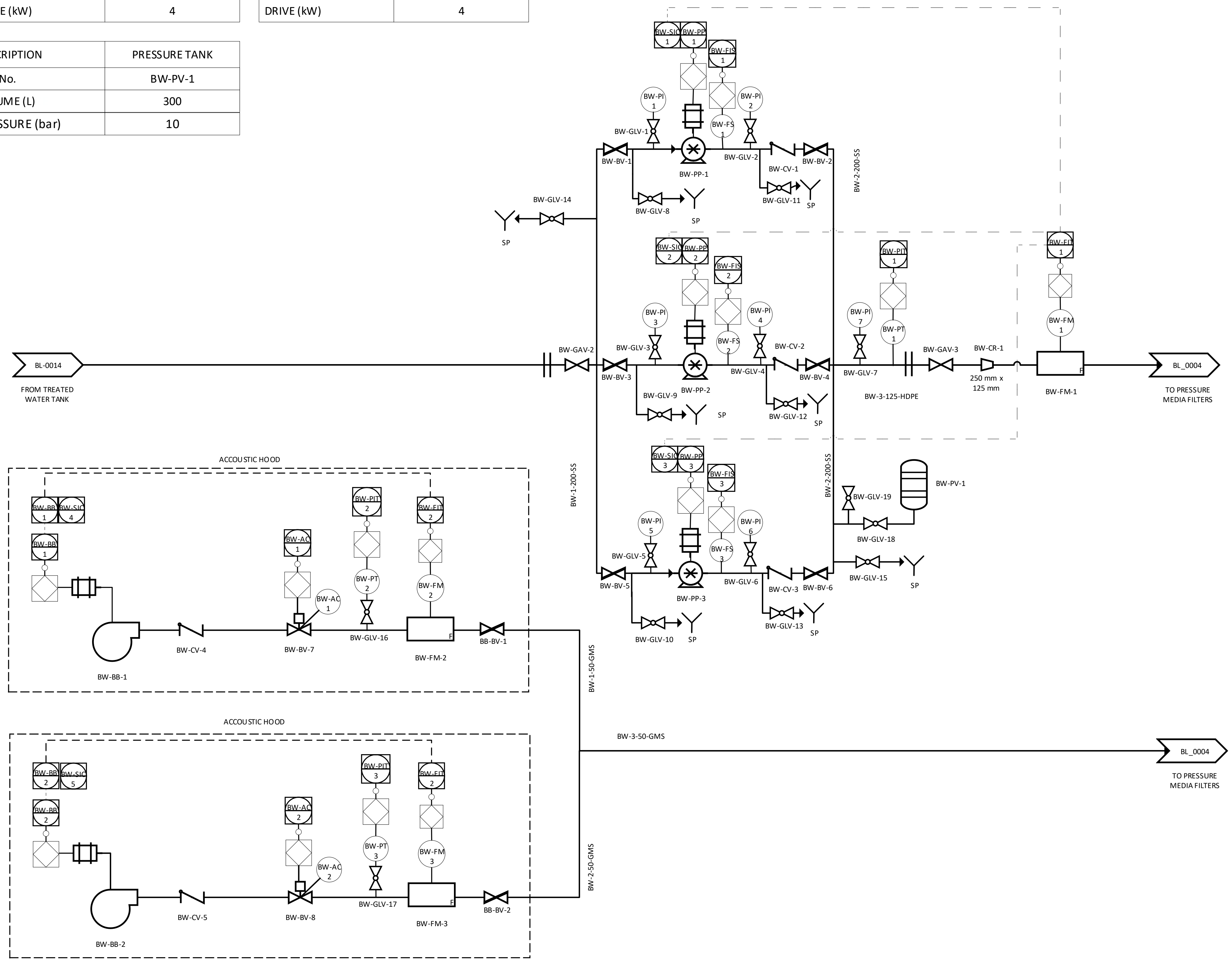


Figure B-15: P&ID of Boy Louw Sportsgrounds: backwash pumps and blowers of Boy Louw Sportsgrounds

DESCRIPTION	BACKWASH RECOVERY PUMPS
TAG No.	BWR-PP-1/2
FLOW (l/s)	23.6
HEAD (m)	7
DRIVE (kW)	5.5

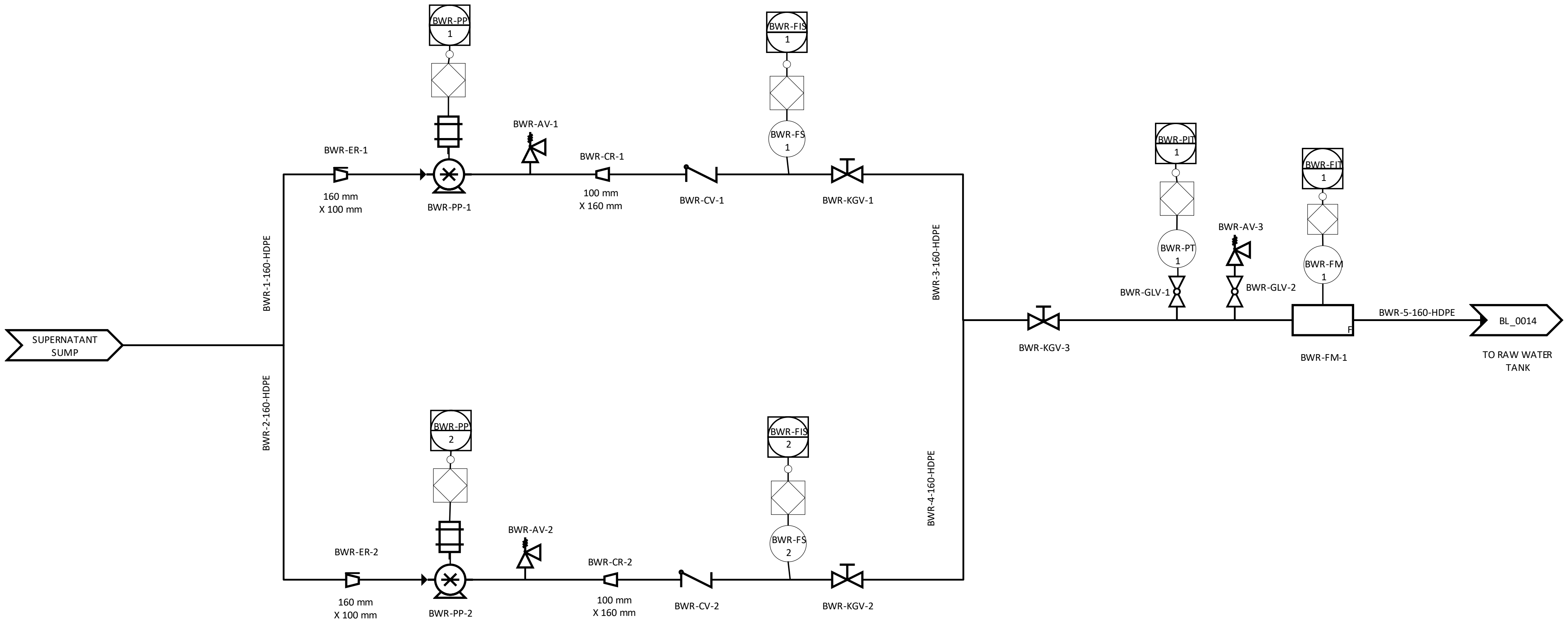


Figure B-16: P&ID of Boy Louw Sportsgrounds: backwash recovery pumps of Boy Louw Sportsgrounds

DESCRIPTION	CHLORINE DOSING PUMPS
TAG No.	CL1-DP-1/2
FUNCTION	PRE-CHLORINATION
FLOW (l/s)	TBC
HEAD (m)	TBC

DESCRIPTION	CHLORINE DOSING PUMPS
TAG No.	CL2-DP-1/2/3
FUNCTION	POST-CHLORINATION
FLOW (l/s)	TBC
HEAD (m)	TBC

DESCRIPTION	CHLORINE MAKE UP TANK
TAG No.	CL-TK-1
VOLUME (L)	500
TYPE	HORIZONTAL
STRENGTH	HEAVY DUTY

DESCRIPTION	KLORMAN UNITS
TAG No.	CL-KL-1/2/3
MEDIUM TYPE	Ca(ClO)2
MEDIUM MASS (kg)	22

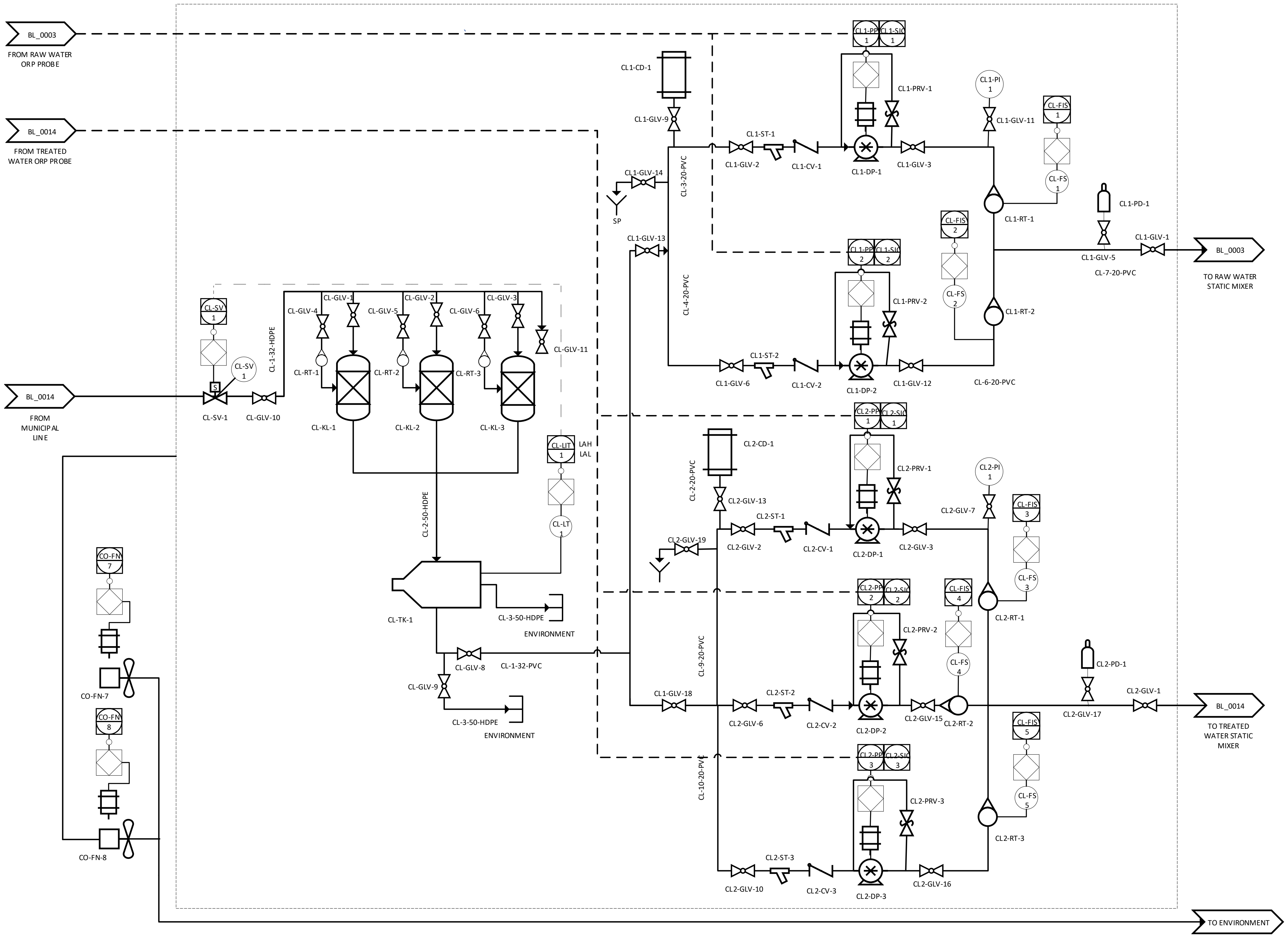


Figure B-17: P&ID of Boy Louw Sportsgrounds: chlorine dosing sets of Boy Louw Sportsgrounds

DESCRIPTION	CAUSTIC DOSING PUMPS
TAG No.	CA-DP-1/2
FUNCTION	PRE-CAUSTIC DOSING
FLOW (l/h)	9.5
HEAD (bar)	6.9

DESCRIPTION	CAUSTIC STORAGE TANKS
TAG No.	CA-TK-1/2
VOLUME (L)	5000
TYPE	VERTICAL
STRENGTH	HEAVY DUTY

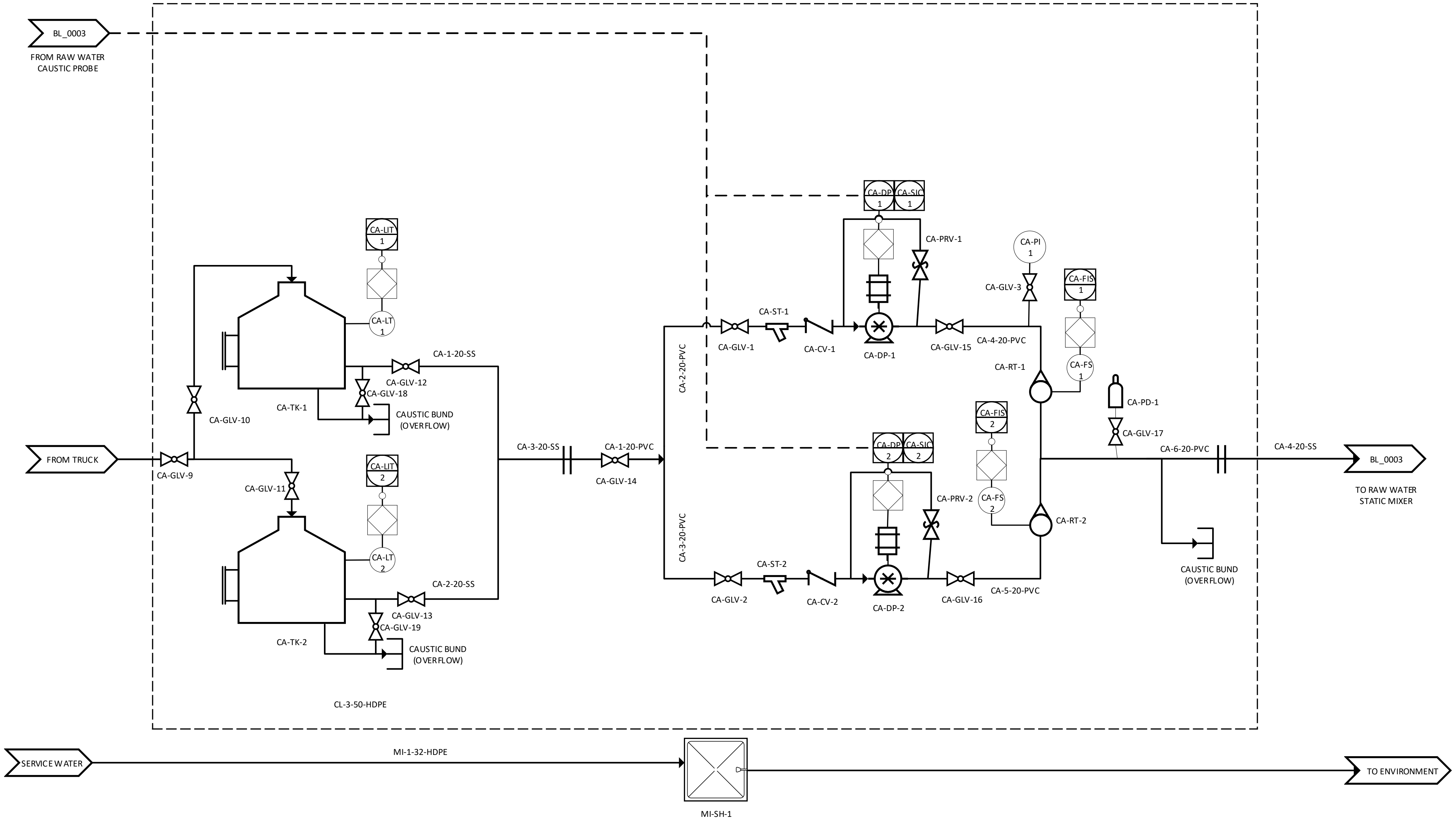


Figure B-18: P&ID of Boy Louw Sportsgrounds: caustic dosing set of Boy Louw Sportsgrounds

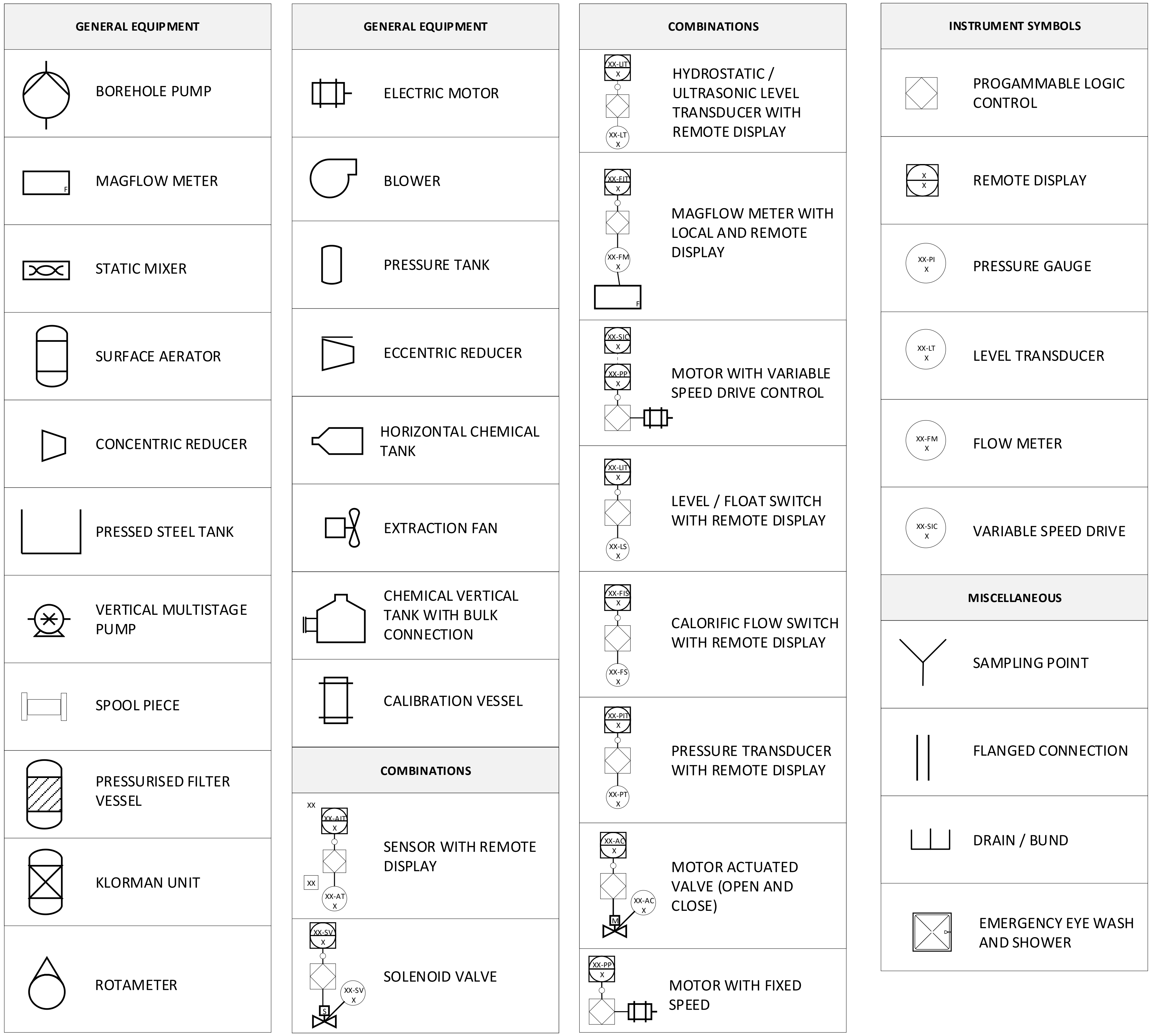
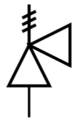
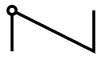
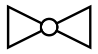
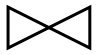
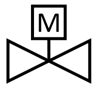
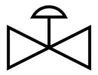
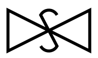
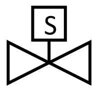
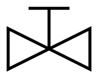


Figure B-19: P&ID of Boy Louw Sportsgrounds: P&ID key 1

VALVES	
	VACCUUM BREAKING AIR RELEASE VALVE
	SWING CHECK VALVE / NON-RETURN VALVE
	BALL VALVE
	METAL SEATED WEDGE GATE VALVE
	BUTTERFLY VALVE
	ACTUATED VALVE
	DIAPHRAGM VALVE
	PRESSURE REDUCING VALVE
	SOLENOID VALVE
	KNIFE GATE VALVE

NOMENCLATURE

MECHANICAL EQUIPMENT		VALVES		INSTRUMENTATION AND CONTROL		OTHER	
AC	ACTUATOR	AV	AIR VALVE	FS	FLOW SWITCH	AFM	ACTIVATED FILTER MEDIA
BB	BACKWASH BLOWER	BV	BUTTERFLY VALVE	LAL	LEVEL ALARM LOW	AGF	ACTIVATED GLASS FILTERS
BH	BOREHOLE	CV	CHECK VALVE	LAH	LEVEL ALARM HIGH	BW	BACK WASH
CR	CONCENTRIC REDUCER	DP	DIAPHRAGM VALVE	LH	LEVEL HIGH	BWR	BACK WASH RECOVERY
FM	FLOW METER	GAV	GATE VALVE	LL	LEVEL LOW	CA	CAUSTIC
KL	KLORMAN	GLV	GLOBE VALVE / BALL VALVE	LS	LEVEL SWITCH	CB	CHEMICAL BUND
P	PUMP	SV	SOLENOID VALVE	LT	LEVEL TRANSDUCER	CL	CHLORINE
PV	PRESSURE VESSEL			M	MOTOR	MF	MADDOX FILTERS
SA	SURFACE AERATOR			PI	PRESSURE INDICATION	RW	RAW WATER
SM	STATIC MIXER					S	SOLENOID
SP	SPOOL PIECE					SP	SAMPLING POINT
TK	TANK					SW	STORM WATER
VE	VESSEL					TW	TREATED WATER

MATERIAL	
HDPE	HIGH DENSITY POLYETHYLENE
PVC	POLYVINYL CHLORIDE
SS	STAINLESS STEEL

PIPEWORK LABELS	
RW-1-315-SS	
AREA CODE	(RW)
NUMBER	(1)
SIZE	(315)
MATERIAL	(SS)

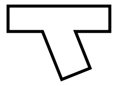
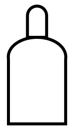
MISCELLANEOUS	
	STRAINER
	PULSATION DAMPENER

Figure B-20: P&ID of Boy Louw Sportsgrounds: P&ID key 2

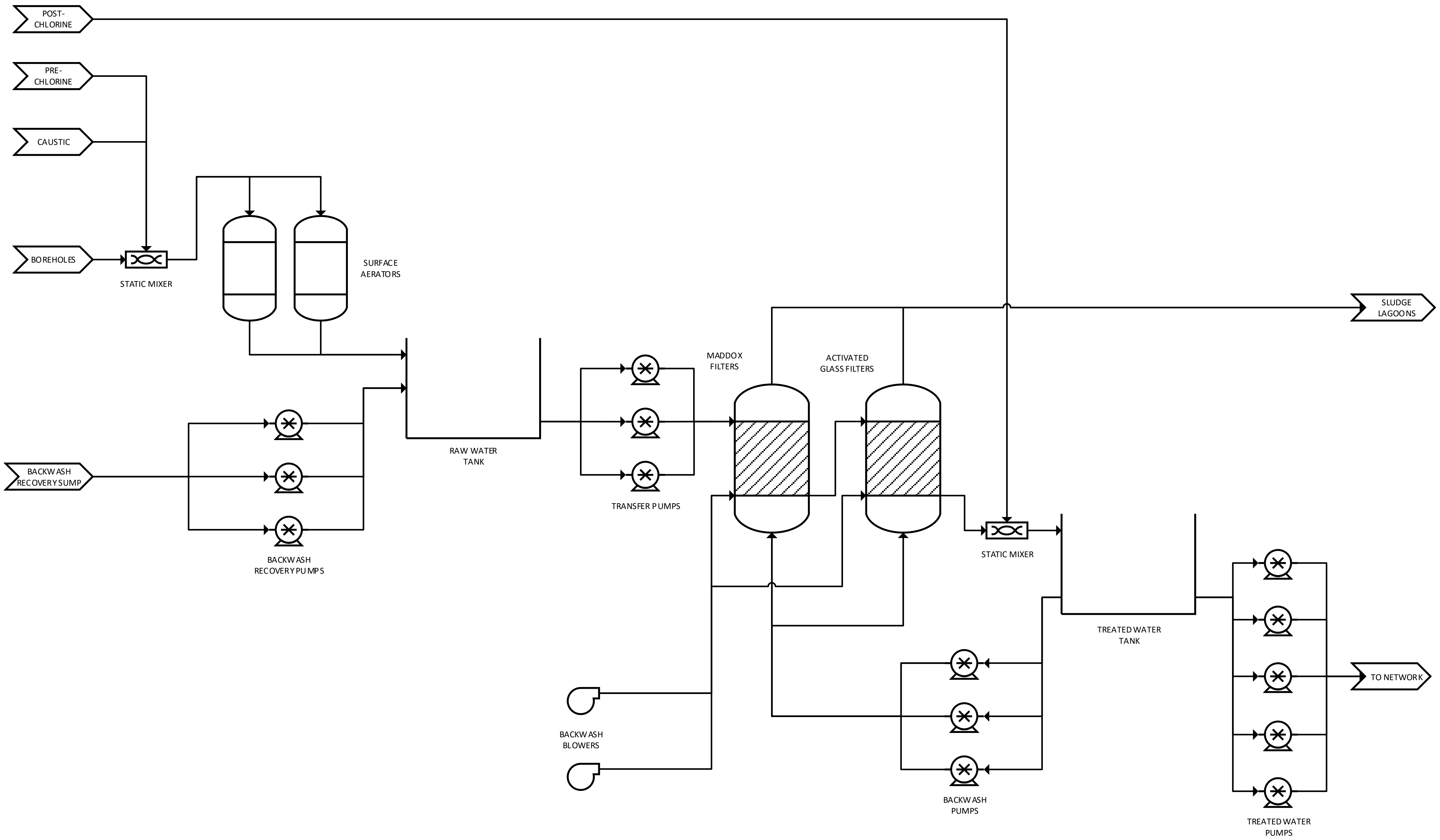


Figure B-21: PFD of Boy Louw Sportsgrounds

DESCRIPTION	BOREHOLE PUMP
TAG No.	BH1-PP-1
FLOW (l/s)	4.5
HEAD (m)	66.6
DRIVE (kW)	5.5

DESCRIPTION	BOREHOLE PUMP
TAG No.	BH2-PP-1
FLOW (l/s)	1.8
HEAD (m)	44.6
DRIVE (kW)	2.2

DESCRIPTION	DRAIN PUMP
TAG No.	BH1-PP-2
FLOW (l/s)	2
HEAD (m)	2
DRIVE (kW)	0.3

DESCRIPTION	DRAIN PUMP
TAG No.	BH2-PP-2
FLOW (l/s)	2
HEAD (m)	2
DRIVE (kW)	0.3

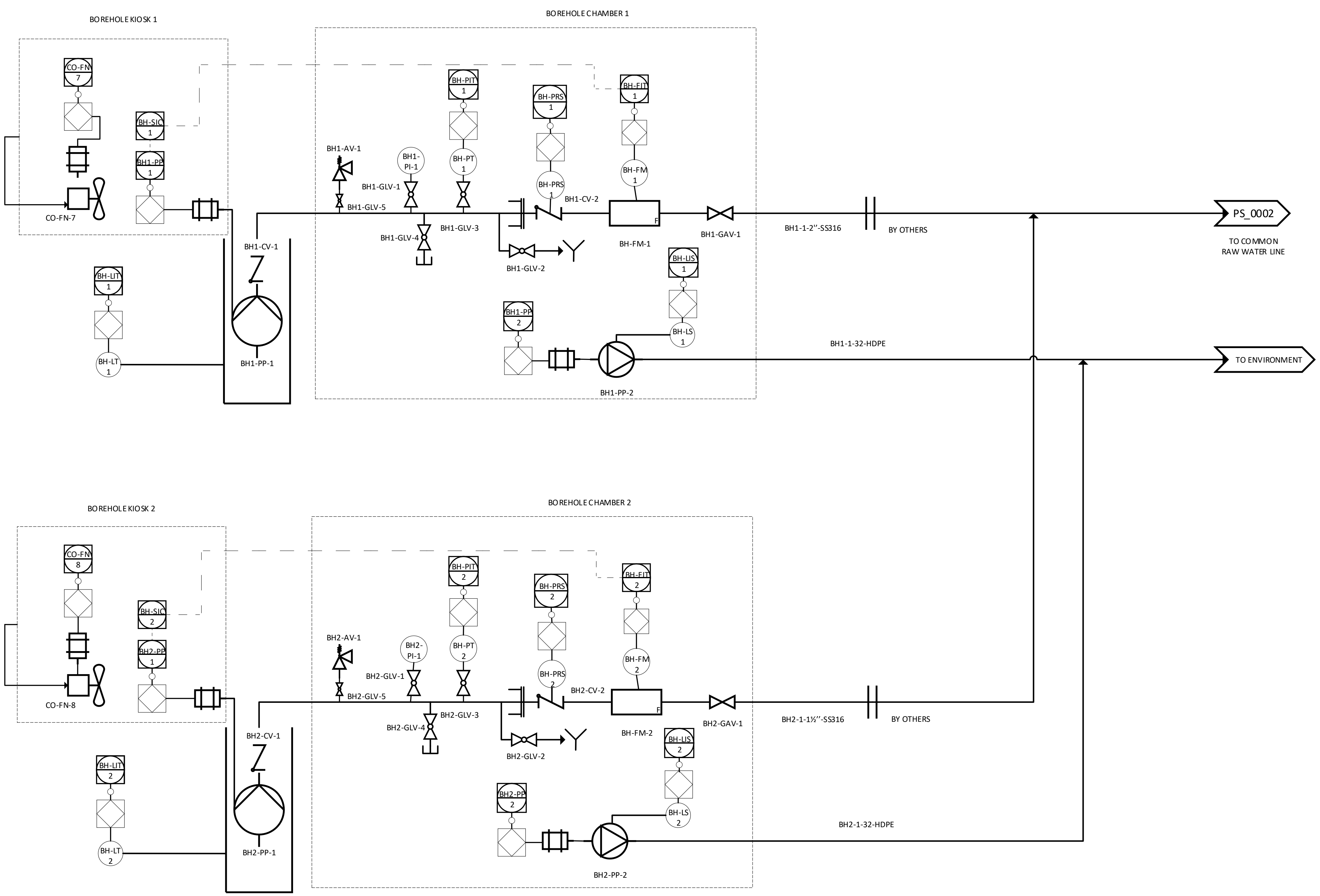


Figure B-22: P&ID of Parys Sportsgrounds: abstraction points A and B of Parys Sportsgrounds

DESCRIPTION	BOREHOLE PUMP
TAG No.	BH3-PP-1
FLOW (l/s)	4.7
HEAD (m)	56.3
DRIVE (kW)	5.5

DESCRIPTION	BOREHOLE PUMP
TAG No.	BH4-PP-1
FLOW (l/s)	7.2
HEAD (m)	51.9
DRIVE (kW)	7.5

DESCRIPTION	DRAIN PUMP
TAG No.	BH3-PP-2
FLOW (l/s)	2
HEAD (m)	2
DRIVE (kW)	0.3

DESCRIPTION	DRAIN PUMP
TAG No.	BH4-PP-2
FLOW (l/s)	2
HEAD (m)	2
DRIVE (kW)	0.3

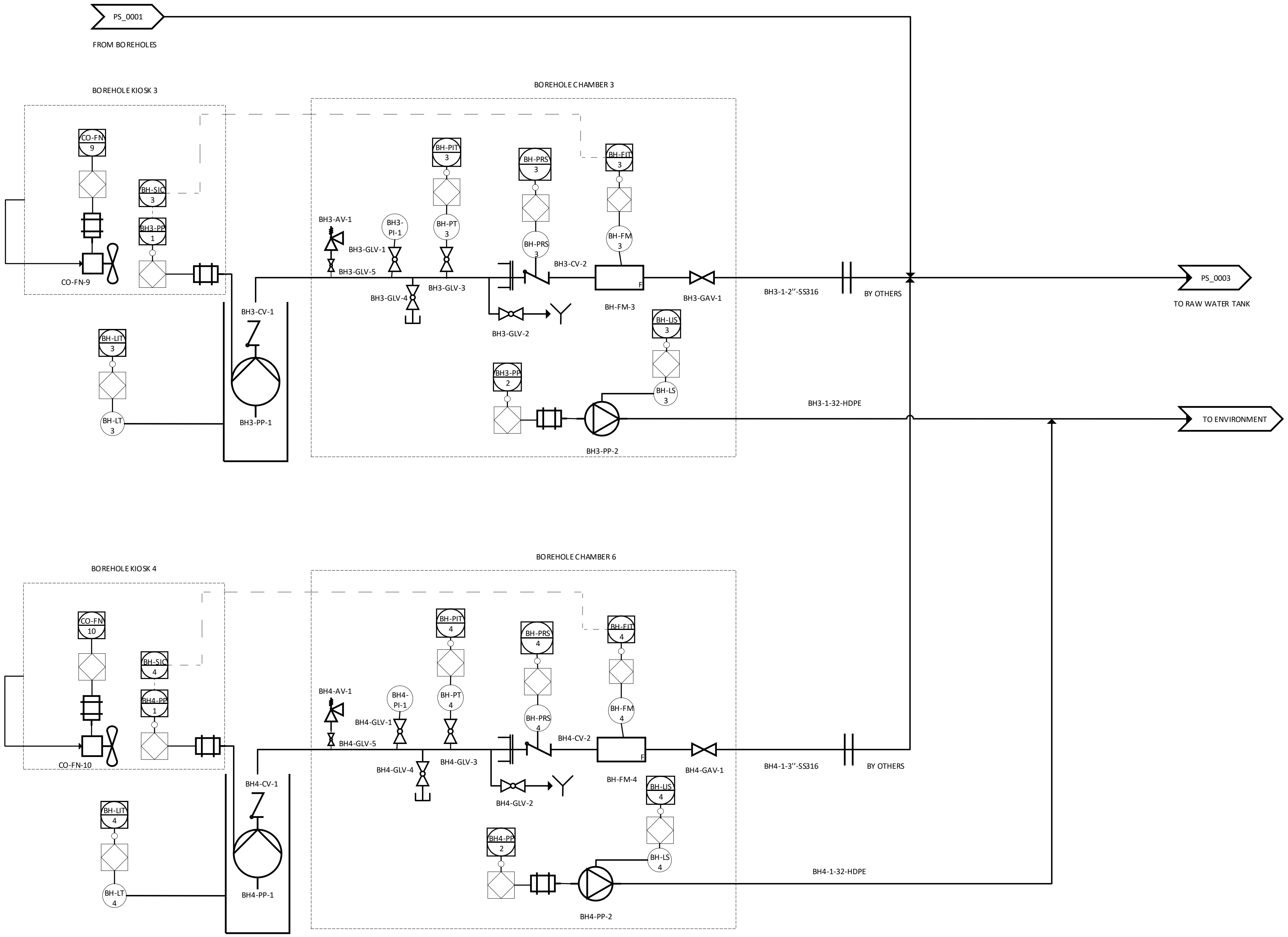


Figure B-23: P&ID of Parys Sportsgrounds: abstraction points C and D of Parys Sportsgrounds

DESCRIPTION	RAW WATER TANK
TAG No.	RW-TK-1
VOLUME (m³)	46 (effective)
SHAPE	ROUND
MOC	STEEL

DESCRIPTION	TRANSFER PUMPS
TAG No.	RW-PP-1/2/3
FLOW (l/s)	18.85
HEAD (m)	30
DRIVE (kW)	5.5

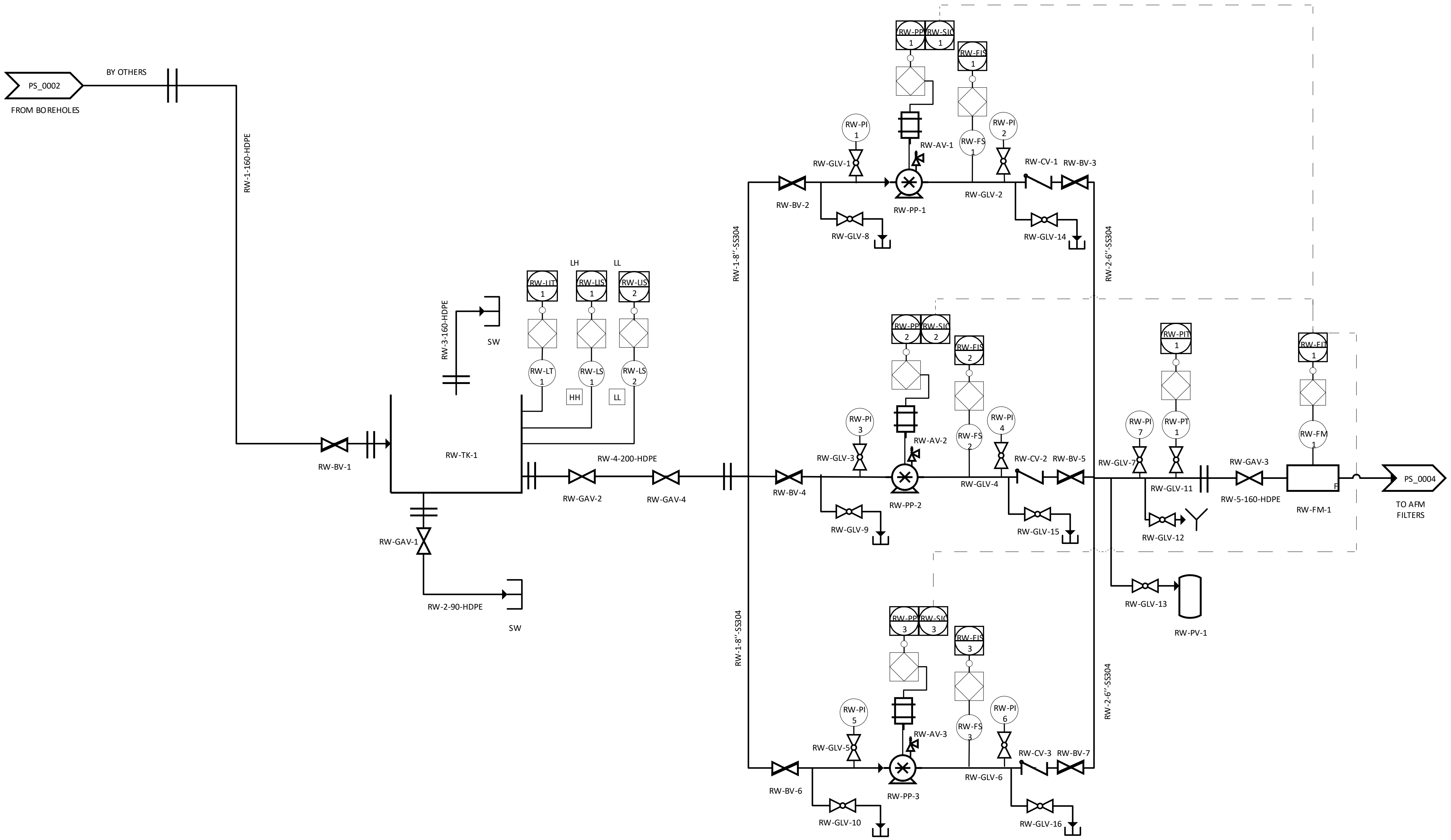


Figure B-24: P&ID of Parys Sportsgrounds: raw water storage tank and pumps of Parys Sportsgrounds

DESCRIPTION	AFM FILTERS
TAG No.	AF-VE-1/2
DIAMETER (mm)	1200
HEIGHT (mm)	2285
TYPE	PRESSURISED

DESCRIPTION	SPOOL PIECE
TAG No.	RW-SP-1
LENGTH (mm)	TBC
DIAMETER (mm)	160
MOC	SS304

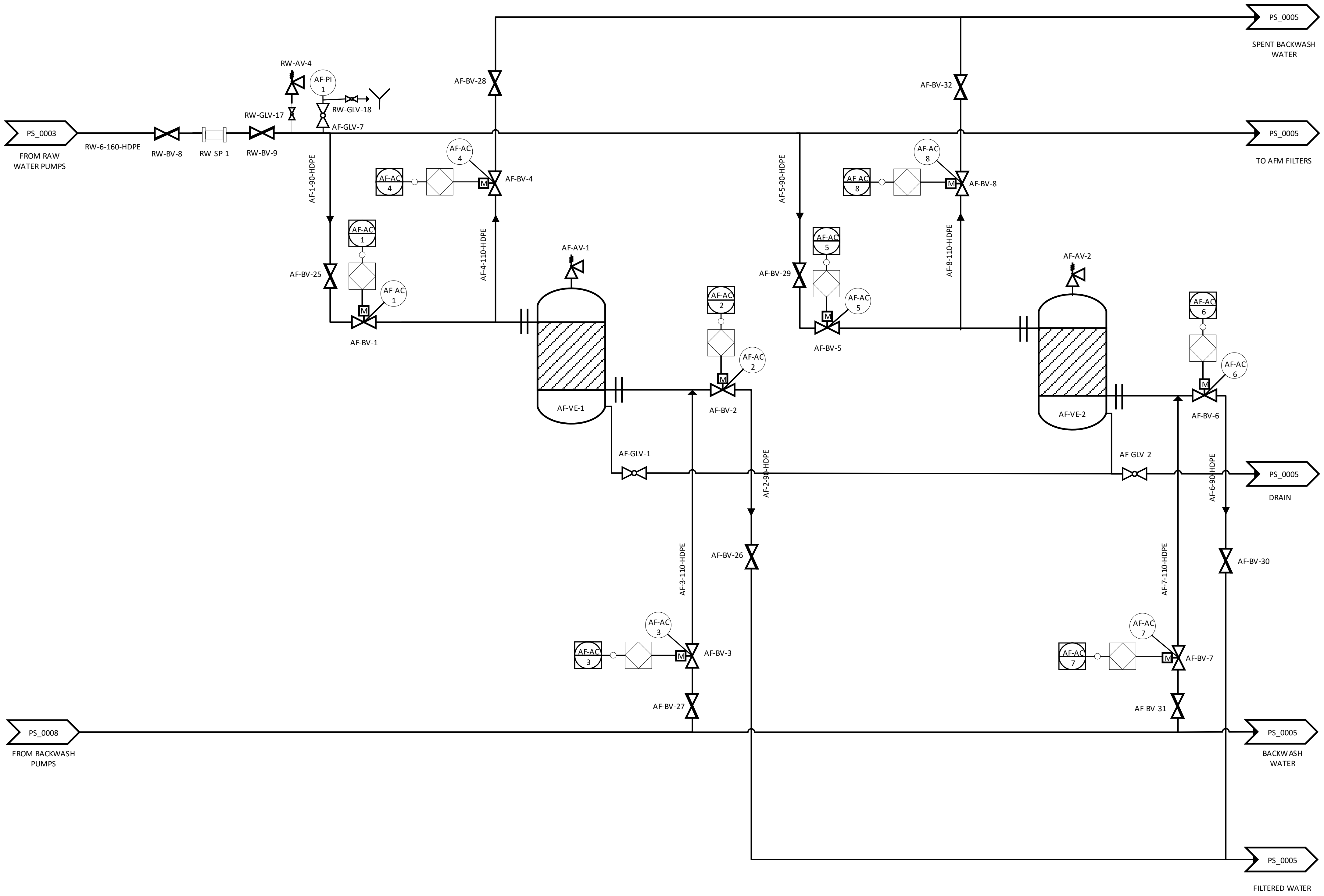


Figure B-25: P&ID of Parys Sportsgrounds: activated glass filters 1 and 2 of Parys Sportsgrounds

DESCRIPTION	AFM FILTERS
TAG No.	AF-VE-3/4
DIAMETER (mm)	1200
HEIGHT (mm)	2285
TYPE	PRESSURISED

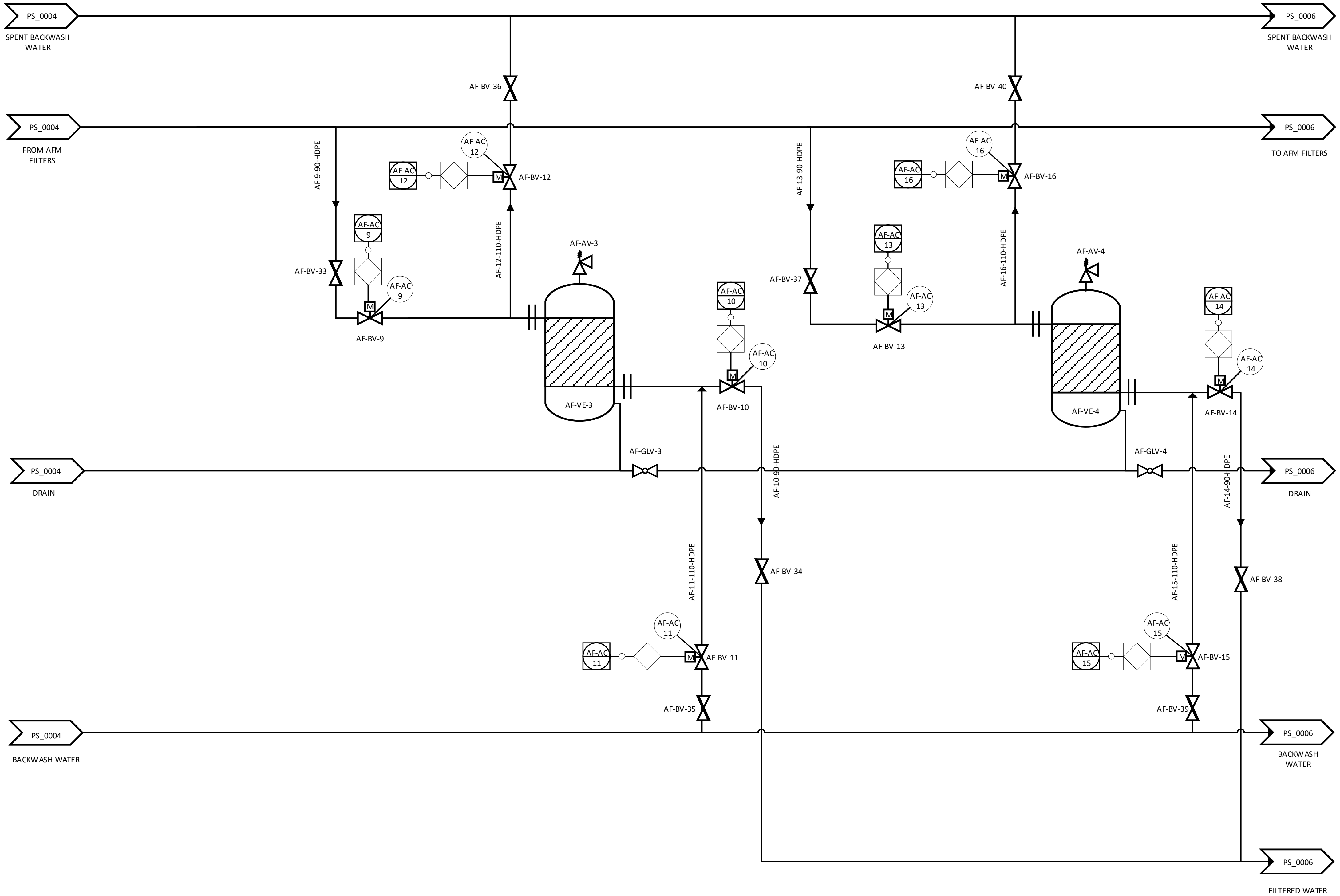


Figure B-26: P&ID of Parys Sportsgrounds: activated glass filters 3 and 4 of Parys Sportsgrounds

DESCRIPTION	AFM FILTERS
TAG No.	AF-VE-5/6
DIAMETER (mm)	1200
HEIGHT (mm)	2285
TYPE	PRESSURISED

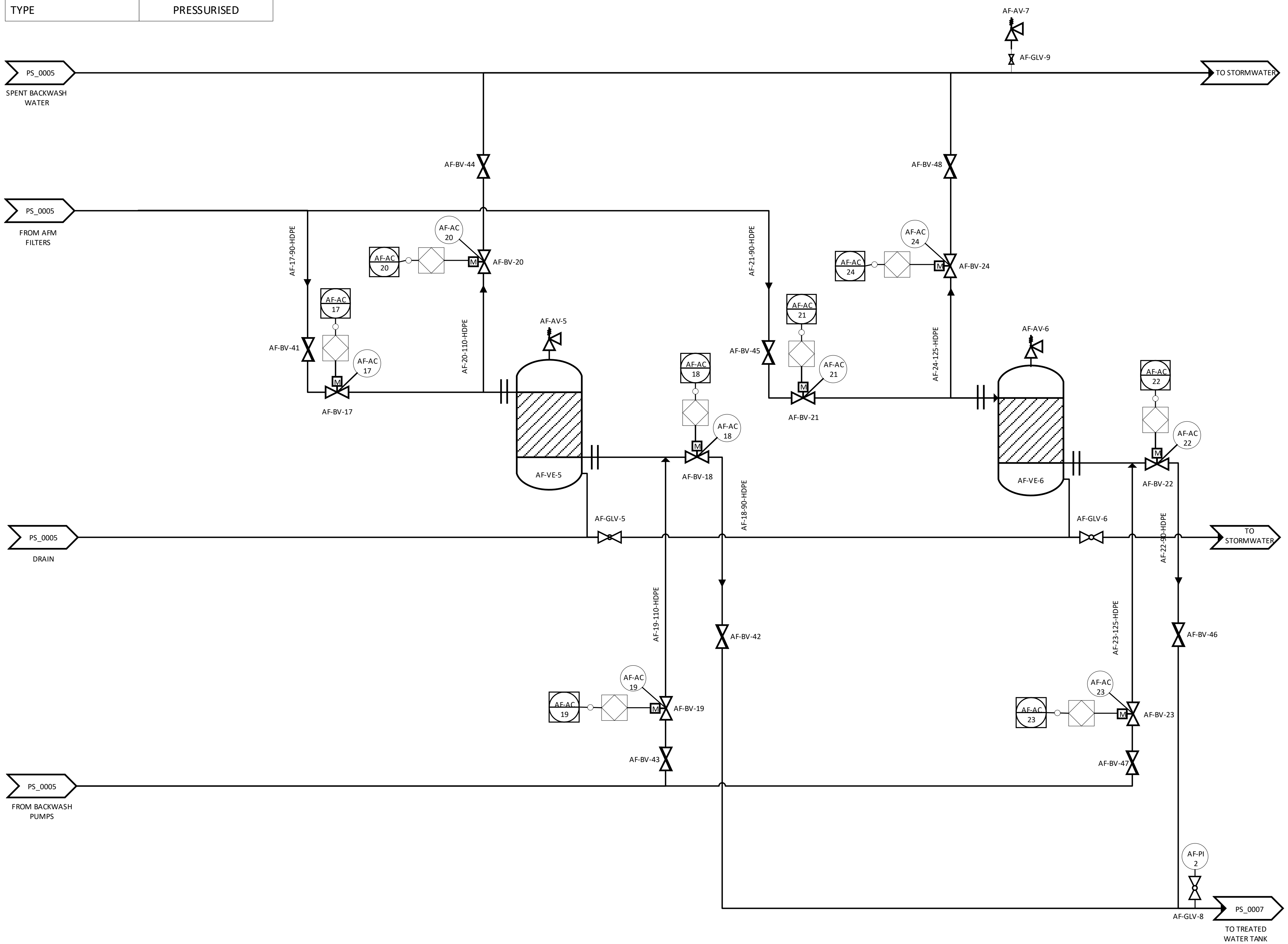


Figure B-27: P&ID of Parys Sportsgrounds: activated glass filters 5 and 6 of Parys Sportsgrounds

DESCRIPTION	STATIC MIXER
TAG No.	TW-SM-1
DIAMETER (mm)	160

DESCRIPTION	TREATED WATER TANK
TAG No.	TW-TK-1
VOLUME (m³)	46 (effective)
SHAPE	ROUND
MOC	STEEL

DESCRIPTION	TREATED WATER PUMPS
TAG No.	TW-PP-1/2/3
FLOW (l/s)	18.85
HEAD (m)	90
DRIVE (kW)	15

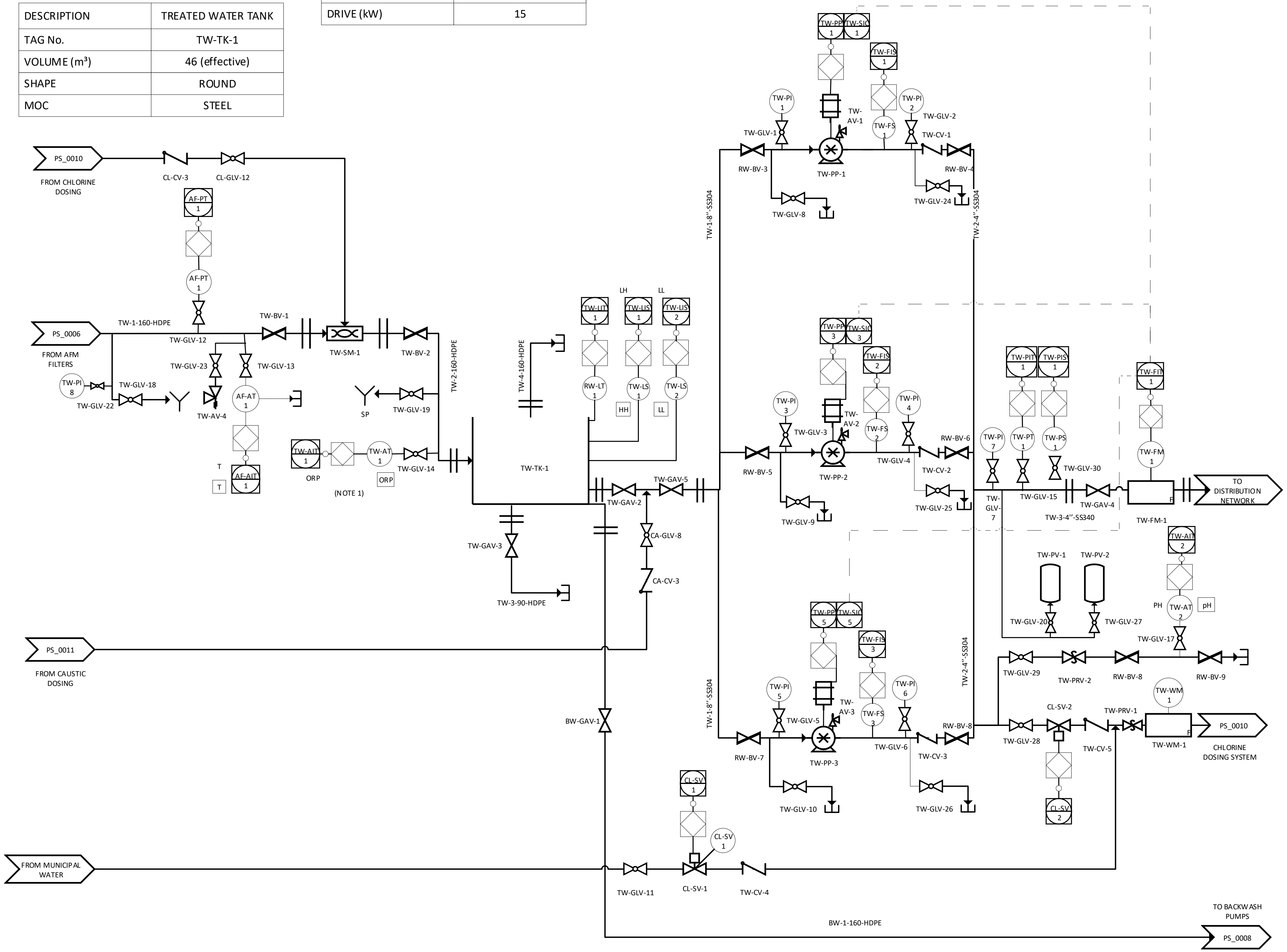


Figure B-28: P&ID of Parys Sportsgrounds: treated water storage tank and pumps of Parys Sportsgrounds

DESCRIPTION	BACKWASH PUMPS
TAG No.	BW-PP-1/2/3
FLOW (l/s)	12.57
HEAD (m)	17.5
DRIVE (kW)	2.2

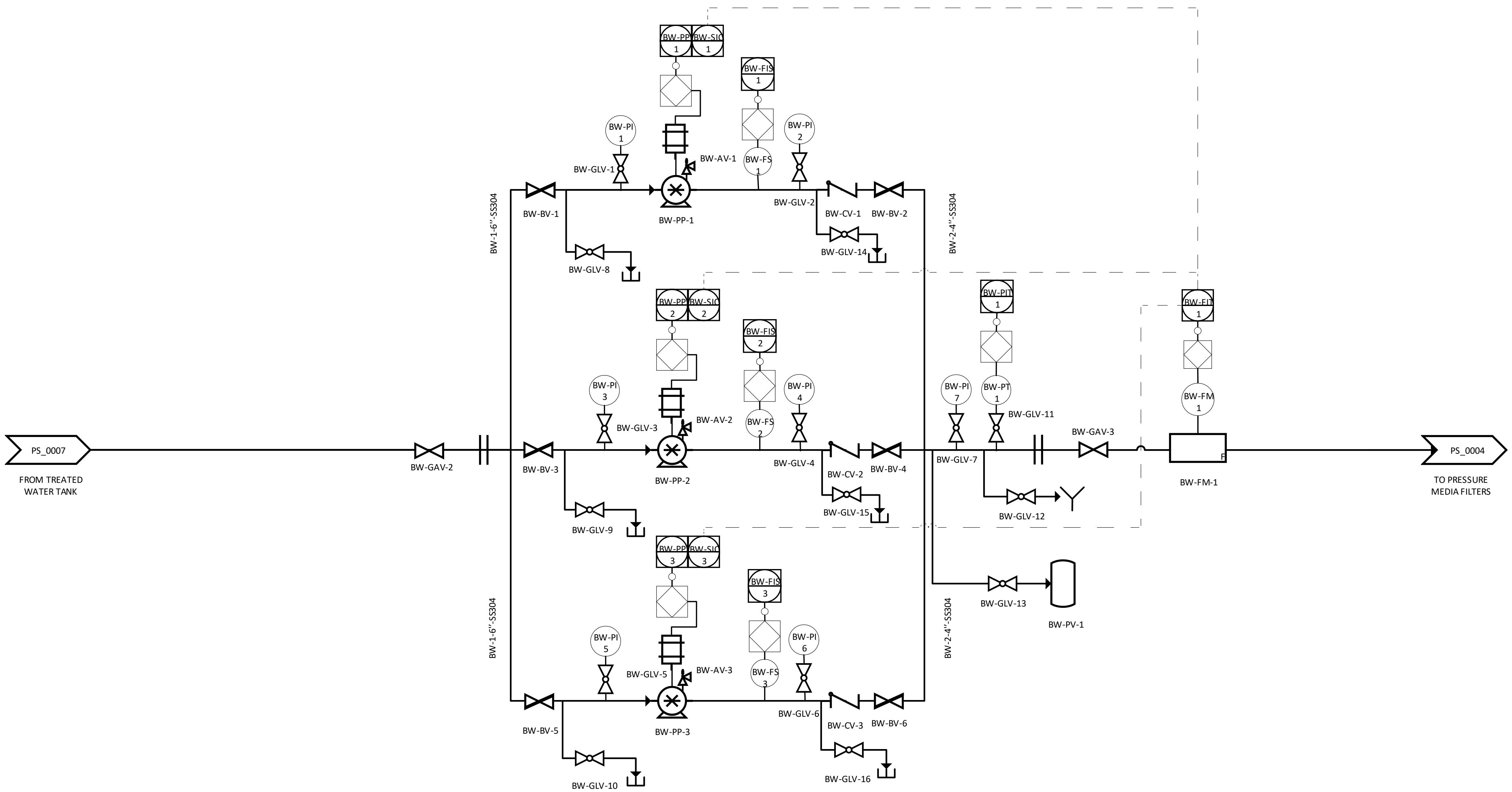


Figure B-29: P&ID of Parys Sportsgrounds: backwash pumps of Parys Sportsgrounds

DESCRIPTION	CHLORINE DOSING PUMPS
TAG No.	CL-DP-1/2
FUNCTION	CHLORINE DOSING
FLOW (l/h)	590
HEAD (m)	70

DESCRIPTION	CHLORINE MAKE UP TANK
TAG No.	CL-TK-1
VOLUME (L)	500
TYPE	HORIZONTAL
STRENGTH	HEAVY DUTY

DESCRIPTION	KLORMAN UNITS
TAG No.	CL-KL-1/2
MEDIUM TYPE	Ca(ClO)2
MEDIUM MASS (kg)	22

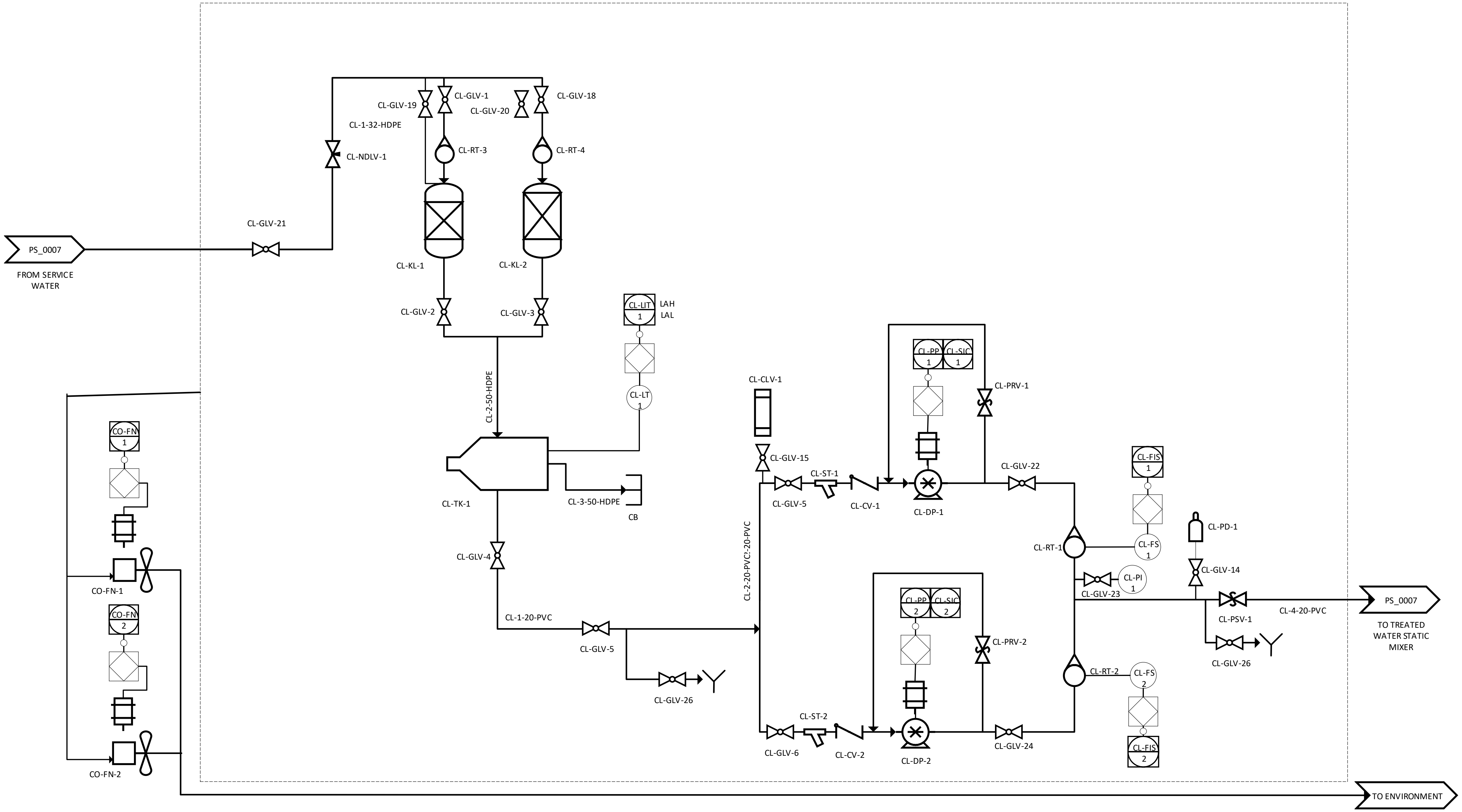


Figure B-30: P&ID of Parys Sportsgrounds: chlorine dosing set of Parys Sportsgrounds

DESCRIPTION	CAUSTIC DOSING PUMPS
TAG No.	CA-DP-1/2
FUNCTION	CAUSTIC DOSING
FLOW (l/h)	9.5
HEAD (bar)	69

DESCRIPTION	CAUSTIC STORAGE TANKS
TAG No.	CA-TK-1/2
VOLUME (L)	2500
TYPE	VERTICAL
STRENGTH	HEAVY DUTY

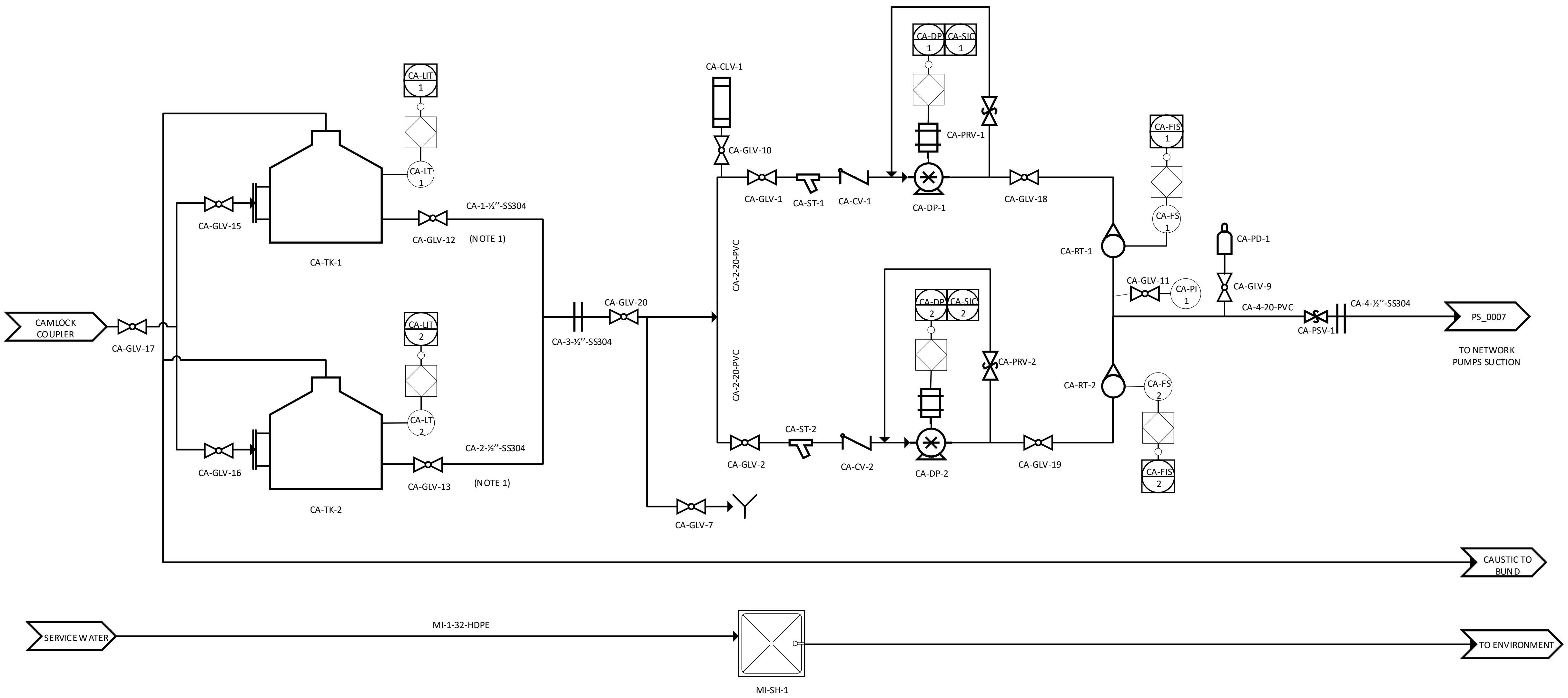


Figure B-31: P&ID of Parys Sportsgrounds: caustic dosing set of Parys Sportsgrounds

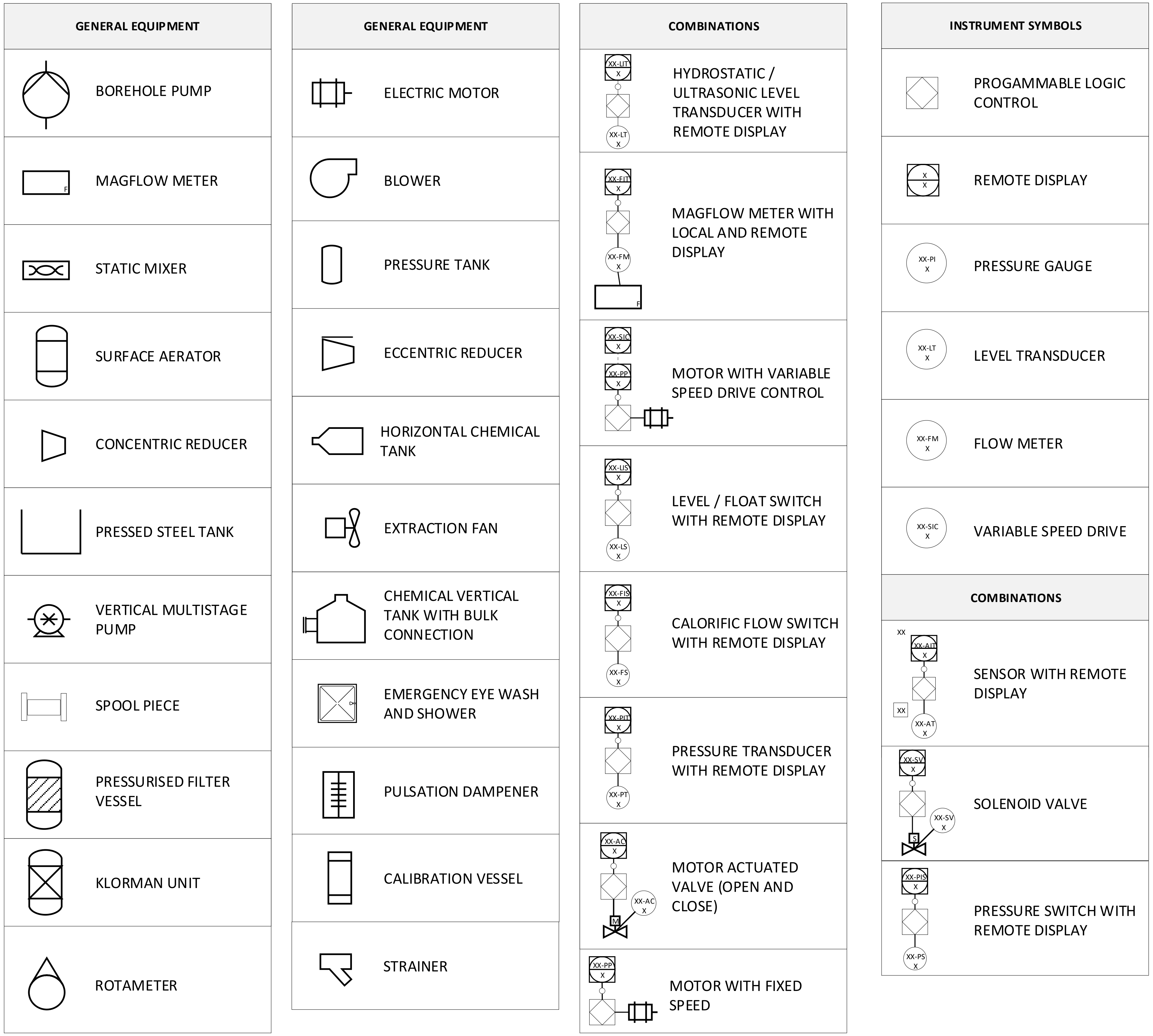
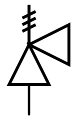
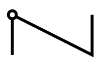
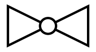
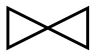
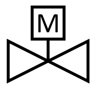
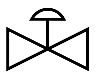
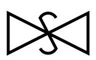
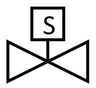
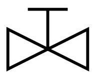
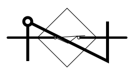


Figure B-32: P&ID of Parys Sportsgrounds: P&ID key 1

VALVES	
	VACCUUM BREAKING AIR RELEASE VALVE
	SWING CHECK VALVE / NON-RETURN VALVE
	BALL VALVE
	METAL SEATED WEDGE GATE VALVE
	BUTTERFLY VALVE
	ACTUATED VALVE
	DIAPHRAGM VALVE
	PRESSURE REDUCING VALVE / PRESSURE SUSTAINING VALVE
	SOLENOID VALVE
	KNIFE GATE VALVE
	NON-RETURN VALVE WITH PROXIMITY SWITCH

NOMENCLATURE

MECHANICAL EQUIPMENT	
AC	ACTUATOR
BB	BACKWASH BLOWER
BH	BOREHOLE
CR	CONCENTRIC REDUCER
FM	FLOW METER
KL	KLORMAN
P	PUMP
PV	PRESSURE VESSEL
SA	SURFACE AERATOR
SM	STATIC MIXER
SP	SPOOL PIECE
TK	TANK
VE	VESSEL

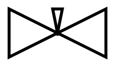
VALVES	
AV	AIR VALVE
BV	BUTTERFLY VALVE
CV	CHECK VALVE
DP	DIAPHRAGM VALVE
GAV	GATE VALVE
GLV	GLOBE VALVE / BALL VALVE
SV	SOLENOID VALVE

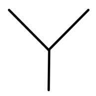
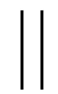
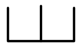
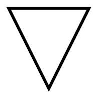
INSTRUMENTATION AND CONTROL	
FS	FLOW SWITCH
LAL	LEVEL ALARM LOW
LAH	LEVEL ALARM HIGH
LH	LEVEL HIGH
LL	LEVEL LOW
LS	LEVEL SWITCH
LT	LEVEL TRANSDUCER
M	MOTOR
PI	PRESSURE INDICATION
PRS	PROXY SWITCH

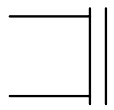
OTHER	
AFM	ACTIVATED FILTER MEDIA
AGF	ACTIVATED GLASS FILTERS
BW	BACK WASH
BWR	BACK WASH RECOVERY
CA	CAUSTIC
CB	CHEMICAL BUND
CL	CHLORINE
MF	MADDOX FILTERS
RW	RAW WATER
S	SOLENOID
SP	SAMPLING POINT
SW	STORM WATER
TW	TREATED WATER

MATERIAL	
HDPE	HIGH DENSITY POLYETHYLENE
PVC	POLYVINYL CHLORIDE
SS	STAINLESS STEEL

PIPEWORK LABELS	(RW-1-315-SS)
AREA CODE	(RW)
NUMBER	(1)
SIZE	(315)
MATERIAL	(SS)

VALVES	
	NEEDLE VALVE

MISCELLANEOUS	
	SAMPLING POINT
	FLANGED CONNECTION
	DRAIN / BUND
	TAP

MISCELLANEOUS	
	FLANGE ADAPTER

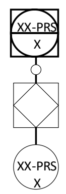
COMBINATIONS	
	PROXIMITY SWITCH WITH REMOTE DISPLAY

Figure B-33: P&ID of Parys Sportsgrounds: P&ID key 2

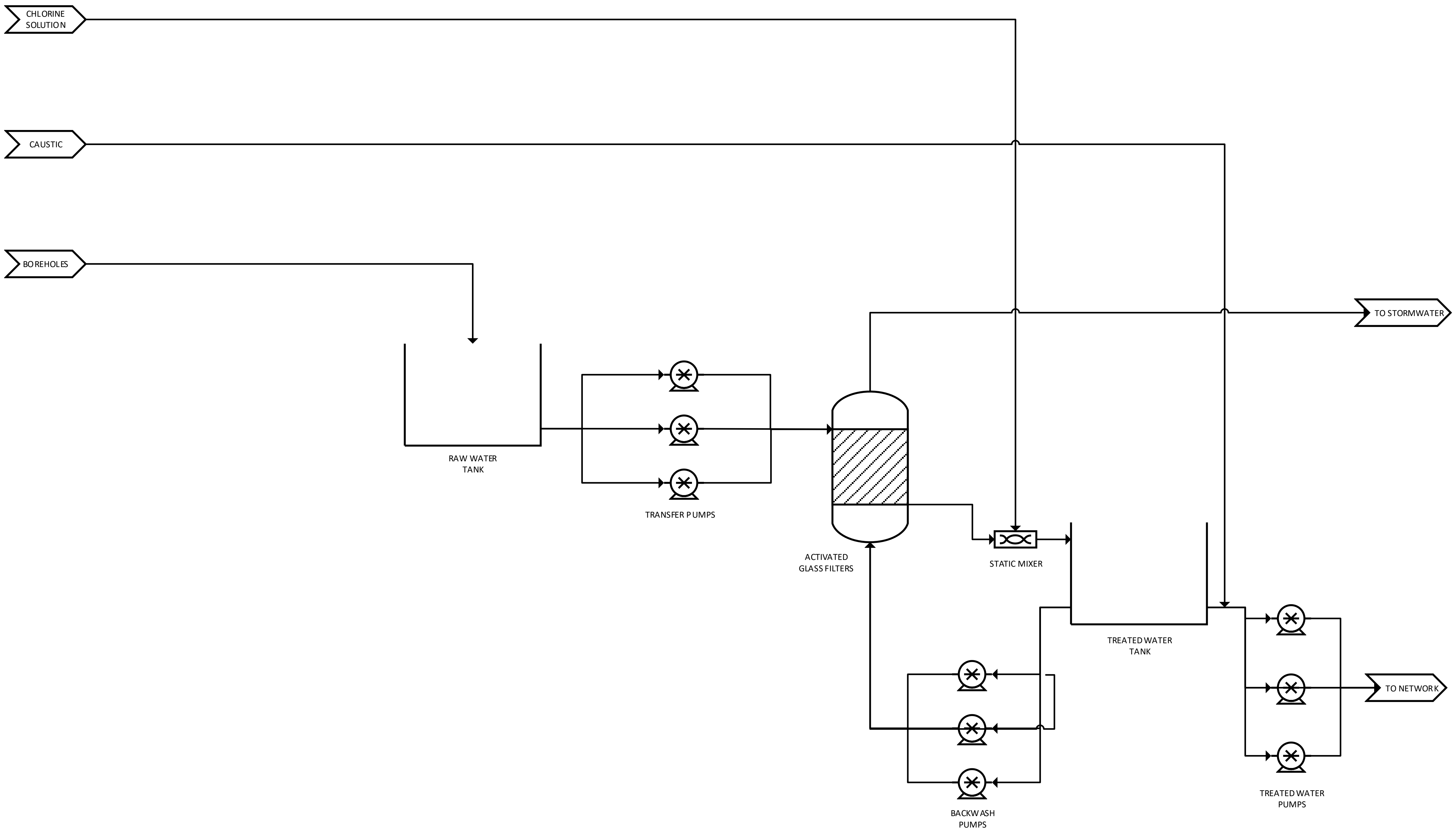


Figure B-34: PFD of Parys Sportsgrounds

Appendix B3 – Groundwater Abstraction Water Treatment Plant Site Layout

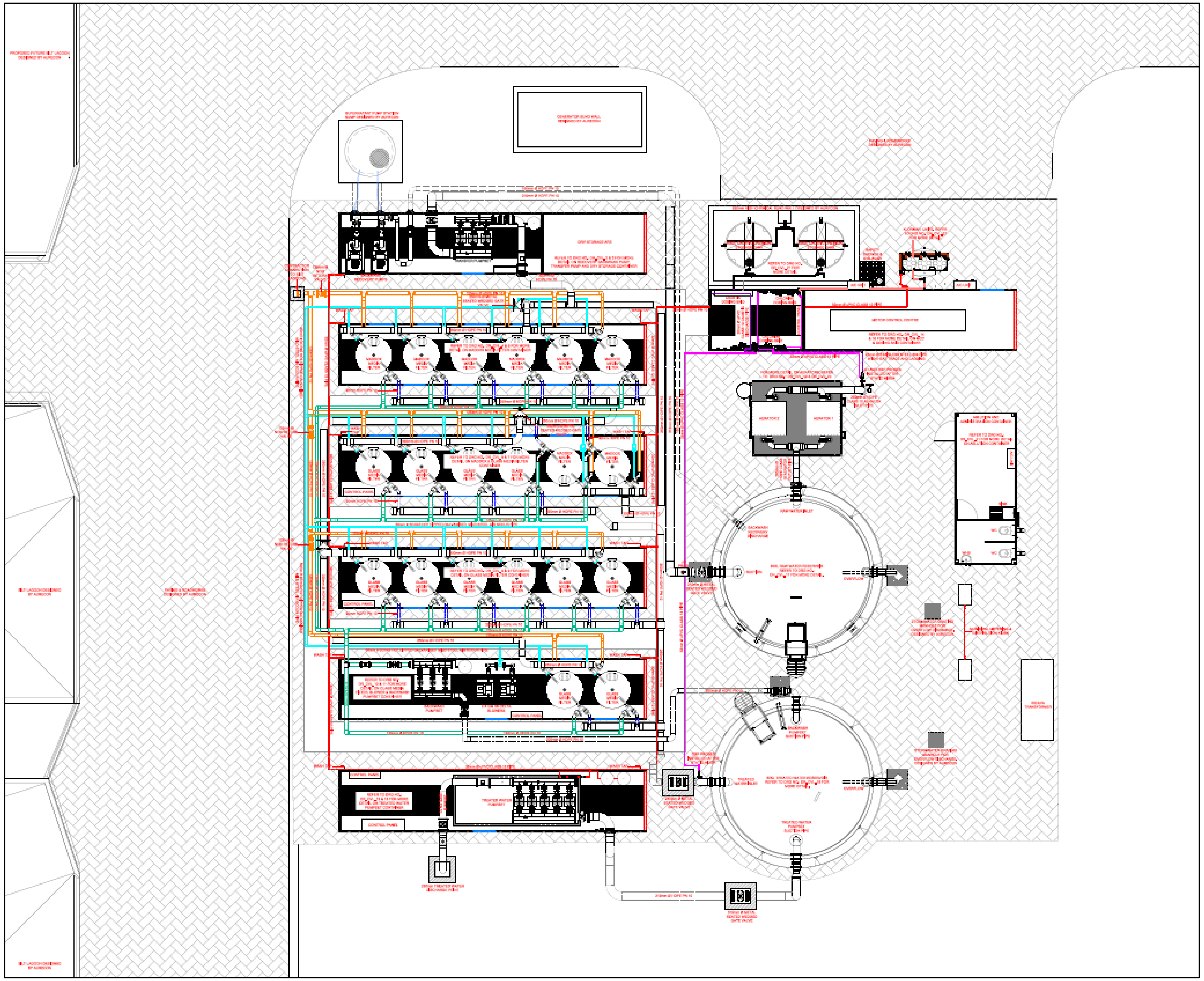


Figure B-35: Layout of Boy Louw Sportsgrounds

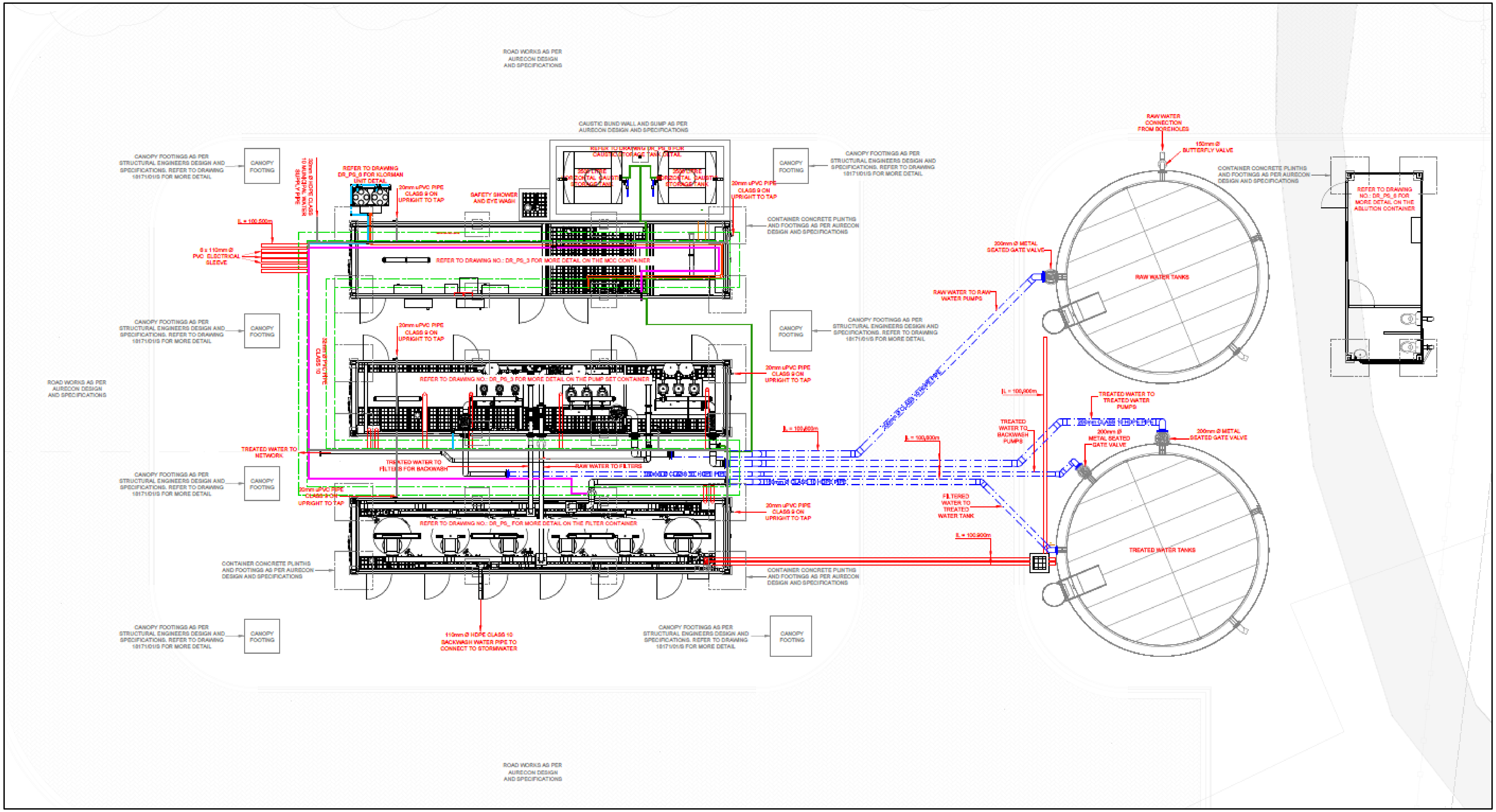


Figure B-36: Layout of Parys Sportsgrounds

Appendix B4 – Groundwater Abstraction Treated Water Quality

Table B-3: Treated water quality of the water treatment plant at Boy Louw Sportsgrounds

Parameter	Unit	Result	Limit
Chemistry Parameters			
Alkalinity - Total as $CaCO_3$	mg/L	69.60	-
pH @ 25°C	pH units	9.10	5 - 9.7
Total Dissolved Solids	mg/L	281	<1200
Physical Parameters			
Colour	Pt-Co-true	11	<15
Electrical Conductivity @ 25°C	mS/m	40.10	<170
Turbidity	NTU	0.16	<1
Cations and Anions Parameters			
Calcium as Ca	mg/L	16.20	-
Sodium as Na	mg/L	50	<200
Magnesium as Mg	mg/L	5.90	-
Potassium as K	mg/L	3.87	-
Chloride as Cl^-	mg/L	73.50	<300
Fluoride as F^-	mg/L	0.21	<1.50
Sulphate as SO_4^{2-}	mg/L	19	<250
Ammonia as N	mg/L	<0.16	<1.50
Nitrate / Nitrite	Calc	0.19	<1
Elemental Parameters			
Antimony as Sb	µg/L	<20	<20
Arsenic as As	µg/L	<10	<10
Barium as Ba	µg/L	256	<700
Chromium as Cr	µg/L	<10	<50
Copper as Cu	µg/L	<10	<2000
Iron as Fe (Total)	µg/L	<50	<2000
Iron as Fe	µg/L	<50	<300
Manganese as Mn	µg/L	<10	<100
Manganese as Mn (Total)	µg/L	<10	<400
Mercury as Hg	µg/L	<6	<6
Nickel as Ni	µg/L	<20	<70
Selenium as Se	µg/L	<40	<40
Zinc as Zn	mg/L	<0.05	<5
Micro Parameters			
Total Coliforms	cfu's/100 ml	Not Detected	<10
Faecal Coliforms	cfu's/100 ml	Not Detected	0
Organic Parameters			
Cyanide as CN^-	µg/L	<10	<200
Chloroform	µg/L	<20	<300
Bromodichloromethane	µg/L	<20	<60
Dibromochloromethane	µg/L	<20	<100
Bromoform	µg/L	41	<100
Trihalomethane as Total THM	µg/L	<80	
Total THM ratio	Calc	0.70	<1

Table B-4: Treated water quality of the water treatment plant at Parys Sportsgrounds

Parameter	Unit	Result	Limit
Chemistry Parameters			
Alkalinity - Total as $CaCO_3$	mg/L	63.10	-
pH @ 25°C	pH units	6.86	5 - 9.7
Total Dissolved Solids	mg/L	165	<1200
Physical Parameters			
Colour	Pt-Co-true	<10	<15
Electrical Conductivity @ 25°C	mS/m	23.70	<170
Turbidity	NTU	0.39	<1
Cations and Anions Parameters			
Calcium as Ca	mg/L	9.14	-
Magnesium as Mg	mg/L	6.26	-
Chloride as Cl^-	mg/L	27.70	<300
Fluoride as F^-	mg/L	0.22	<1.50
Elemental Parameters			
Aluminium as Al (Total)	µg/L	<50	-
Iron as Fe (Total)	µg/L	320	<2000
Iron as Fe	µg/L	<50	<300
Manganese as Mn	µg/L	60.50	<100
Manganese as Mn (Total)	µg/L	52.30	<400
Indexes			
Calcium Hardness	mg/L as CaCO3	26.30	-
Magnesium Hardness as $CaCO_3$	mg/L as CaCO3	29.80	-
Total Hardness as $CaCO_3$	mg/L	56.10	-
Micro Parameters			
Total Coliforms	cfu's/100 ml	Not Detected	<10
Faecal Coliforms	cfu's/100 ml	Not Detected	0
Heterotrophic Plate Count	cfu's/1 ml	20.00	<1000
Organic Parameters			
Dissolved Organic Carbon	mg/L	<2	-
Dissolved Oxygen	mg/L	7.53	-
Chloroform	µg/L	<20	<300
Bromodichloromethane	µg/L	<20	<60
Dibromochloromethane	µg/L	<20	<100
Bromoform	µg/L	<20	<100
Trihalomethane as Total THM	µg/L	<80	
Total THM ratio	Calc	0.10	<1

Appendix C – Groundwater Abstraction Project Feasibility

Appendix C1 – Varying Groundwater Abstraction Project Payback Periods

Table C-1: Varying groundwater abstraction project payback periods

Project Total	**Total Volume (m^3)**	**CAPEX Rate (R/m^3)**	**TOP OPEX Rate (R/m^3)**	**Municipal Rate (R/m^3)**	**Payback Period (years)**
R69 492 000	204000	R340.65	0.90	8.94	3.18
R69 492 000	204000	R340.65	0.90	8	3.56
R69 492 000	204000	R340.65	0.90	7	4.07
R69 492 000	204000	R340.65	0.90	6	4.74
R69 492 000	204000	R340.65	0.90	5	5.69
R69 492 000	204000	R340.65	0.90	4	7.12
R69 492 000	204000	R340.65	0.90	3	9.49
R69 492 000	204000	R340.65	0.90	2.99	9.52
R69 492 000	204000	R340.65	0.90	2.98	9.55
R69 492 000	204000	R340.65	0.90	2.97	9.58
R69 492 000	204000	R340.65	0.90	2.96	9.62
R69 492 000	204000	R340.65	0.90	2.95	9.65
R69 492 000	204000	R340.65	0.90	2.94	9.68
R69 492 000	204000	R340.65	0.90	2.93	9.71
R69 492 000	204000	R340.65	0.90	2.92	9.75
R69 492 000	204000	R340.65	0.90	2.91	9.78
R69 492 000	204000	R340.65	0.90	2.9	9.81
R69 492 000	204000	R340.65	0.90	2.89	9.85
R69 492 000	204000	R340.65	0.90	2.88	9.88
R69 492 000	204000	R340.65	0.90	2.87	9.92
R69 492 000	204000	R340.65	0.90	2.86	9.95
R69 492 000	204000	R340.65	0.90	2.85	9.99
R69 492 000	204000	R340.65	0.90	2.84	10.02