Waste Discharge Charge System: The practical implication from a gold mining perspective

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List of Abbreviations

AGA	AngloGold Ashanti
CLR	Carbon Leader Reef
CMS	Catchment Management Strategy
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EMD	Environmental Management Department
MAE	Mean Annual Evaporation
MPRDA	Minerals and Petroleum Resource Development Act
NEMA	National Environmental Management Act
NPS	Non-Point Source
NWA	National Water Act
PSE	Purified Sewage Effluent
RQO	Resource Quality Objective
RWD	Return Water Dam
SCADA	Scan Control and Data Acquisition
TDS	Total Dissolved Solids
TSF	Tailings Storage Facility
VCR	Ventersdorp Contact Reef
WDCS	Waste Discharge Charge System
WRD	Waste Rock Dump
WRC	Water Research Comission
WRM	Water Resources Management
WRMP	Water Resource Management Plan
WUL	Water Use License
WW	West Wits

Abstract

The mining, agricultural and energy sectors, along with the Department of Water Affairs (DWA) are critical role players in managing South Africa's water resources. Water resources are under increasing pressure due to continuous population growth and economic development. It is critical to adopt a management policy that can lead to sustainable water supply. The National Water Act, 1998, (Act 36 of 1998), Section 56(1) instructs the Minister of Water Affairs to establish a Pricing Strategy for charges for any water use described in Section 21 of the Act. In light of this the Department implemented the Waste Discharge Charge System (WDCS). The WDCS is based on the polluter-pays principle and is focussed on load reduction on order to achieve or maintain resource quality objectives. One of the legal requirements in the mining industry is to have a water use license under Section 21 of the National Water Act of 1998 (South Africa, 1998b) which will lead to the application of the WDCS to the mining industry.

This mini-dissertation assesses how the WDCS can be practically implemented from a gold mining perspective. The WDCS require the identification of point and diffuse sources from various pollution sources. A case study was used to determine what information and instruments will be required at a gold mine to implement the WDCS. The determining of the point and diffuse discharges require multidisciplinary studies with the integration of different spheres of the environment. To assist with this a GoldSim model was developed. The main function of the model was to determine the seepage rates per day from pollution sources using the available information. The seepage rates and the water qualities were used to determine the waste loads discharged to the environment. Using the instruments above, a methodology was provided to determine the point and diffuse sources of pollution and calculate the load that will be discharged to the environment which will form the basis of the WDCS.

Key Words: Waste Discharge Charge System, Point Sources, Diffuse Sources, GoldSim, Water Resources, Gold Mining

Uittreksel

Die mynbou-, landbou-en energie sektore, saam met die Departement van Waterwese is kritieke rolspelers in die bestuur van Suid-Afrika se waterbronne. Waterhulpbronne is toenemend onder druk as gevolg van deurlopende bevolkinggroei en ekonomiese ontwikkeling. Dit is van kritieke belang om 'n bestuurbeleid wat kan lei tot 'n volhoubare watervoorsiening aan te neem. Die Nasionale Waterwet, 1998, (Wet 36 van 1998), Artikel 56 (1) beveel die Minister van om 'n Prysstrategie vir die koste vir enige watergebruik beskryf in Artikel 21 van die Wet tot stand te bring. In die lig hiervan het die Departement om die Afval Stort Heffings Stelsel (ASHS) geïmplementeer. Die ASHS is gebaseer op die besoedelaar-betaal-beginsel en is gefokus hulpbron kwaliteit doelwitte te bereik of in stand te hou. Een van die wetlike vereistes in die mynbedryf is 'n watergebruiklisensie kragtens artikel 21 van die Nasionale Waterwet van 1998 (Suid-Afrika, 1998b) wat sal lei tot die toepassing van die ASHS die mynbedryf te hê.

Hierdie mini-verhandeling evalueer hoe die ASHS prakties toegepas kan word van 'n goud mynbou-perspektief. Die ASHS vereis die identifisering van punt en nie-punt bronne van verskeie besoedelingsbronne. 'n Gvalle studie is gebruik om te bepaal watter inligting en instrumente nodig is om ASHS by n goud myn te implementeer. Die bepaling van die punt en nie-punt bronne vereis 'n multidissiplinêre studie met die integrasie van die verskillende omgewings aspekte. 'n GoldSim model is ontwikkel om al die inligting te inkoporeer. Die belangrikste funksie van die model was die sypeling tempo per dag van die besoedeling bron af te bepaal. Die sypeling tempo en die water kwaliteite is gebruik om die soute (afval) wat na die omgewing vrygestel word te bepaal. Deur gebruik te maak van die bo genoemde metode kan die besoedeling van punt en nie-punt bronne bepaal word. Dit form die basis ASHS te bepaal.

Sleutel Woorde: Afval Stort Heffings Stelsel, Punt Bronne, Nie-punt Bronne, GoldSim, Water Hulpbronne, Goud Myn

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1. Introduction and Orientation

1.1. Background and Context

South Africa is a developing country and deemed to be the economical hub of Africa. Like most developing countries, it has a growing population that is heavily dependent on its natural resources. South Africa is globally recognised as being a leading supplier of a variety of minerals and mineral products. Not only are gold, diamond, coal and platinum production responsible for the largest contribution to the national economy but in general, they are potential sources of water pollution (Coetser et al., 2007).

We are used to thinking about water as a commodity, something which is contained in rivers, lakes and groundwater, stored in dams and reservoirs, transported in pipes and canals, and purchased for various uses and services, such as drinking water, irrigation or industrial processes. We need to broaden our view, and see that in fact, the water itself is only one part of a large and complex ecosystem. It is this larger ecosystem which provides us, not only with the water which we see as a commodity, but also with many other services and benefits (Mackay, 2000). Water resources are the backbone of any economy. This makes the protection of water resources and safe water supply critical (Herold, 2009). Water resources are under increasing pressure due to continuous population growth and economic development. It is critical to adopt a management policy that can lead to sustainable water supply and use, i.e., a policy that meets ''the needs of the present without compromising the ability of future generations to meet their own needs'' (Gleick, 1998). The Constitution of the Republic of South Africa's provides the right to an environment that is not harmful to the health or well-being of an individual and that is protected for the present and future generations (South Africa, 1996). Water is the key to development and a good quality of life in South Africa. South Africa's water belongs to its people, and it is the task of the South African government to care for this water (DWAF, 2000).

South Africa is a semi-arid country receiving an average rainfall of 497 mm per annum which makes water a scarce and valuable commodity (DWAF, 2003). Increasing water scarcity creates enormous challenges in equitably allocating this precious resource to competing sectors. Some of the key concerns include the mismatch between water supply and demand, theft of water resources, decaying infrastructure and deteriorating water quality (Herold, 2009). Many economists argue that a root cause of environmental degradation is the fact that many aspects of the environment are not properly valued in economic terms (Middelton, 2003). The acceptable impact on the environment is determined by the wants and needs of the society. This entails that often a society in need of development will accept environmental degradation more readily than an already developed society (DWAF, 2007). Commonly owned resources such as water are particularly vulnerable to over exploitation. There is a growing recognition that greater emphasis must be placed on managing water as an economic resource to ensure that it is utilised as efficiently as possible, both in terms of the quantities of water used and the impacts on water quality. In pursuit of the objectives of water resource management, it is widely agreed that setting an appropriate price for a natural resource, such as water, can be an effective mechanism to achieve its efficient and productive use (DWAF, 2003).

From the contextual setting above the National Water Act (Act 36 of 1998) Section 56 (1) instructs the Minister of the Department of Water Affairs (DWA) to establish a pricing strategy for charges for any water use identified in Section 21 of the Act (South Africa, 1998b), in answer to Section 21 (f) and (g) DWA initiated the Waste Discharge Charge System (WDCS). DWA introduced the WDCS in January 1999 and forms part of its suite of systems to manage water resources efficiently and effectively. The WDCS has four key goals. These are to:

- promote sustainable development and efficient utilisation of water resources
- promote the internalisation of environmental costs by impactors
- create financial incentives for dischargers to reduce waste and use water resources in a more optimal way
- recover the costs of mitigating the impacts of waste discharge on water quality (DWA, 2007).

A properly implemented and managed WDCS would encourage desirable activities from waste dischargers, namely abatement of pollution at source, recycling of waste streams and wastewater, re-use of water, water conservation and return of water to its source (Baily, 2004). In developing the WDCS, the DWAF engaged in a detailed process of research, charge testing and internal review. This process has resulted in a draft strategy document, which will form the basis of the final WDCS strategy (Von der Heyden et al., 2007).

In developing the WDCS a few guiding principles should be adhered to. The WDCS should create a situation where economic, social and environmental forces unite to target sustainable development. The system should create a win-win situation both from an environmental and economic perspective. The WDCS should be well understood by DWA as well as the impactors (DWA, 2007). Above all, the WDCS should be easy to implement. During developing and implementing the WDCS an extensive consultation process with all interested and affected parties should be undertaken. This will ensure an environment of transparency and consistency.

The WDCS must introduce clearly stated incentive and disincentives in order to reduce waste and the use of revenues must be transparent and open for examination. The result of pollution charges is often that companies act more responsible and less wasteful. The WDCS does not absolve industry from long term liabilities. The WDCS applies to the load entering the resource in a current year (DWA, 2007).

The WDCS is the answer to an already existing pollution problem which is externalised on the environment and society (DWA, 2007). The WDCS is based on the polluter-pays principle and is focussed on load reduction in order to achieve or maintain Resource Quality Objectives (RQO's) within a given catchment. The RQO's for a water resource are a numerical or descriptive statement of the conditions which should be met in the receiving water resource, in terms of resource quality, in order to ensure that the water resource is protected (Mackay, 2000). The RQO's are the acceptable level of impact to a water resource. Once RQO's have been set for a resource, then those objectives would serve as a basis for water resource management. The RQO is catchment specific and balances the need between social, political, economic and environmental drivers (DWAF, 2007), RQO's are thus the basis for the WDCS. The WDCS is focused on reducing the discharge load to the water resources and thereby achieving and maintaining the RQO's. The WDCS applies to both surface and groundwater resources, where RQO's have been defined for a resource and will be further applied to catchment scale. One approach applies to the calculation of the WDCS for both ground and surface water. The WDCS is further based on load discharge which has the advantage of avoiding the dilution of effluent (DWAF, 2007). An important principle of the WDCS is that it does not absolve the industry from long-term liabilities. As can be seen from the information provided above, the WDCS is a tool in integrated water management.

A properly implemented and managed WDCS would encourage desirable activities from waste discharges, namely abatement of pollution at source, recycling of waste streams and waste water, re-use of water, water conservation and return of water to its source (Baily, 2004). Since the WDCS project has finite resources, it was necessary to select the pollutants that will be modelled and calibrated to determine their in-stream rate of decay along the watercourse as far as the receiving water body. This includes variables such as total dissolved solids (TDS), chloride (Cl), sodium (Na) and sulphate (SO_4). Sulphate is used as an indicator pollutant in the gold mining industry and will be used in the case study below (GCS, 2007).

The WDCS should not be viewed as an extra burden on the economy as it is based on the polluter pays principle. The WDCS will consist of two charges, an incentive charge and a mitigation charge. Either or both could be applied to a catchment. The incentive charge seeks to alter behaviour by providing an incentive to reduce and minimise pollution at the source itself. The incentive charge is considered an environmental tax. The incentive charge will reduce if the pollution load at source decreases. The mitigation charge will cover the cost of mitigation measures in the catchment, where it is economically more viable to do so (DWAF, 2007). It is therefore more likely that incentive charges will be applied to catchments where water quality problems occur and the mitigation charge will depend on the mitigation in the resource (Von der Heyden et al., 2007).

The WDCS is applied to point source or non-point sources (NPS's) also called diffuse sources. NPS's came to the fore as an important source of water quality impacts in the late 1980's (Humenik et al., 1987). NPS's are not always site specific which make it difficult to quantify. The WDCS was earmarked for implementation on a national basis as from April 2011.

The development of a WDCS is a highly complex undertaking, requiring multidisciplinary studies with intensive collaboration and integration between different sectors, disciplines and study outputs. The system relies on detailed inputs from the environmental, engineering, economic and institutional spheres. Very little literature exists on the practical implementation of pollution charge systems, (Oberholzer et al., 2002). Science is increasingly being called upon to provide information for complex environmental decision making (Browning-Aiken et al., 2004); however, despite recent remarkable advances in environmental science with growing availability of relevant knowledge, data, and information, how science can best support environmental decision making remains an outstanding question (Van der Sluijs, 2007).

One of the legal requirements in the mining industry is to have a water use license under Section 21 of the National Water Act of 1998 (South Africa, 1998b) which will lead to the application of the WDCS to the mining industry. This will have a considerable financial bearing on mining companies. The costs of the WDCS will also have to be stated in mining companies financial and other reports such as the reports to society, the information in these documents are audited by external auditing companies to insure the integrity thereof. It is thus extremely important to ensure that this data is scientifically sound and auditable.

1.2. Research Question, Aims and Objectives

From the contextual setting above the research problem can be outlined as follows:

How can the WDCS be practically implemented from a gold mining perspective?

To address the question stated above the following is envisaged:

1. What are the philosophies that drive the WDCS and why is it important for the implementation of the WDCS?
    a. To answer the question above this dissertation will explore the legal mandate of the WDCS. The focus will be on the National Water Act of 1998 (South Africa, 1998b).
    b. DWA also published various strategic documents regarding the development and implementation of the WDCS.

2. How will the WDCS impact the gold mining industry?
    a. This question will be answered by investigating how the WDCS will be applied to the gold mining industry.

3. The WDCS requires the calculation of the flux or load of pollutants that are discharged to the environment. To determine the load the quality (for example sulphate) is multiplied by the quantity (for example volume of water). What type of monitoring systems will be required to ensure accurate measurements of volume and quality?
    a. The monitoring systems will be divided into two types of monitoring systems:
        i. Direct type of monitoring systems
        ii. Calculation methods
    b. To determine discharge load to the environment

4. The measurement of point sources and especially diffuse sources discharges are not always possible or practical. What scientifically sound method can be used to determine point and diffuse source discharges to the water environment?
    a. Various environmental studies will be used. A case study on typical Gold Mine will be included. It will determine what type of information is required to measure point

and non-point discharges accurately. A GoldSim model will be designed and developed to simulate the concentrations of the sulphate at the various point and non-point discharges, and studies and information will be used to inform the GoldSim model. GoldSim is a powerful and flexible Windows-based program for carrying out probabilistic simulations of complex systems, and is used to solve a wide variety of problems and is particularly well suited for the mining industry.

5. External and internal audits will be required on the WDCS by mining companies to ensure the integrity of the system. What type of documentation will be required to ensure a suitable audit trail?

The WDCS is an instrument in an integrated approach to water resource management and should be viewed in an integrated fashion with other regulatory and non-regulatory measures. This is discussed in more detail in Chapter 2 as well as some concepts regarding the WDCS.

2. Literature Review

2.1 Legal Mandate

The overall objective of the WDCS is to solve the problem of excessive water pollution (Baily, 2004). One of the central philosophies driving the WDCS is the polluter pays principle. This entails that the party responsible for pollution should pay for the remediation cost (DWAF, 2007). The legal mandate serves to provide the context for the implementation of the WDCS.

2.1.1 Constitution of the Republic of South Africa, 1996 (Act 108 of 1996)

Although the Constitution does not directly refer to waste discharge charges per se, Section 24 states that everyone has the right:

a) to an environment that is not harmful to their health or well-being; and

b) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that –

   i) prevent pollution and ecological degradation;

   ii) promote conservation; and

   iii) secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development,

The environmental clause reflects characteristics of both fundamental and socio-economic rights, reflecting the pattern of the constitution as a whole, which includes both traditional fundamental rights as well as socio-economic rights (Glazewski, 2005).

2.1.2 The National Environmental Management Act (Act 107 of 1998)

The main objective of the National Environmental Management Act of 1998 (NEMA) is to provide for co-operative environmental governance by establishing principles for decision-making by government on matters affecting the environment. The act, however, also imposes specific obligations to be observed by all industries. These include:

- An obligation to avoid and minimise all potentially significant environmental pollution and/or degradation (the so-called "duty-of-care" obligation)
- Compulsory environmental impact assessment and prior authorisation for specified activities
- Provision for personal liability of employees, employers, managers and directors for environmental offences committed in the workplace. These are discussed in more detail below.

2.1.3 Mineral and Petroleum Resources Development Act (Act 28 of 2002)

The Mineral and Petroleum Resources Development Act of 2002 (MPRDA) imposes several environmental obligations on the holder of the mining authorisation. Although an agreement had been reached between the Ministers of Mineral Resources and the former Minister of Environmental Affairs and Tourism in 2009 to move all these provisions to the National Environmental Management Act of 1998, the Minister of Mineral Resources reneged on this agreement towards the end of 2010. Much duplication and confusion accordingly prevails, especially regarding environmental impact assessment requirements.

The main environmental provisions of the MPRDA concern:

- the development of environmental management programmes / plans
- performance assessments of such plans
- financial provision for premature and final mine closure
- responsibility for contractors' environmental performance.

2.1.4 National Water Act (Act 36 of 1998)

As the public trustee of the nation's water resources the National Government, acting through the Minister of Water Affairs, must ensure that water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner, for the benefit of all persons and in accordance with its constitutional mandate. The National Water Act (NWA) does not prescribe in great detail the regulatory procedures, standards and tools which will be used in the protection, use, development, conservation, management and control of water resources. It provides a framework that deals with all types of water pollution (Mackay, 2000). The National Water Act of 1998 is the most important statute dealing with water pollution control. It takes into account factors such as:

(a) meeting the basic human needs of present and future generations
(b) promoting equitable access to water
(c) redressing the results of past racial and gender discrimination
(d) promoting the efficient, sustainable and beneficial use of water in the public interest
(e) facilitating social and economic development
(f) providing for growing demand for water use
(g) protecting aquatic and associated ecosystems and their biological diversity
(h) reducing and preventing pollution and degradation of water resources
(i) meeting international obligations
(j) promoting dam safety
(k) managing floods and droughts

(l) and for achieving this purpose, to establish suitable institutions and to ensure that they have appropriate community, racial and gender representation.

The National Water Act (Act 36 of 1998) Section 56 (1) instructs the Minister of the Department of Water Affairs (DWA) to establish a pricing strategy for charges for any water use identified in Section 21 of the Act (South Africa, 1998b). These include:

a) taking water from a water resource
b) storing water
c) impeding or diverting the flow of water in a watercourse
d) engaging in a stream flow reduction activity contemplated in section 36
e) engaging in a controlled activity identified as such in section 37(1) or declared under section 38(1)
f) discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit
g) disposing of waste in a manner which may detrimentally impact on a water resource
h) disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process
i) altering the bed, banks, course or characteristics of a watercourse
j) removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people
k) using water for recreational purposes.

According to NWA (Section 1 (1)(iv)), a charge includes a fee, price or tariff imposed under the Act. It is not a tax, levy or duty, which means it is a direct payment for a service. These include water resource management costs, losses incurred abstracting water of a poor quality, and downstream costs to deal with the waste. DWA regards a discharge as any waste stream that enters a water course or marine environment.

To get a better understanding of the WDCS it is necessary to reflect on the definitions provided in the NWA. Waste are produced by all living things, it can be excreted by an organism or thrown away by a society because it is no longer useful. The NWA defines waste as follows:

> *Waste includes any solid material or material that is suspended, dissolved or transported in water (including sediment) and which is spilled or deposited on land or into a water resource in*

such volume, composition or manner as to cause, or to be reasonably likely to cause, the water resource to be polluted.

The broad definition of anthropogenic waste includes both matter and energy, and would therefore include waste heat. For the purposes of the WDCS, such waste could be any waste that alters the properties of a water resource (DWAF, 2003).

According to the NWA, a water resource includes a watercourse, surface water, estuary or aquifer. It excludes municipal reservoirs, supply and waste reticulations and waste treatment facilities. A watercourse is defined in Section 1 (xxiv) of the NWA as:

(a) a river or spring

(b) a natural channel in which water flows regularly or intermittently

(c) a wetland, lake or dam into which, or from which, water flows; and

(d) any collection of water which the minister may, by notice in the gazette, declare to be a watercourse, and a reference to a watercourse includes, where relevant, its bed and banks.

The NWA further defines pollution as:

Pollution means the direct or indirect alteration of the physical, chemical or biological properties of a water resource so as to make it –

(a) less fit for any beneficial purpose for which it may reasonably be expected to be used; or

(b) harmful or potentially harmful -

(aa) to the welfare, health or safety of human beings

(bb) to any aquatic or non-aquatic organisms

(cc) to the resource quality

(dd) to property

Pollution in term of the WDCS can be regarded as the cumulative impacts on water resource. DWAF regards a discharge as any waste stream that enters a water resource or marine environment (DWAF, 2003). Four groups of NPS require registration under Section 21 of the NWA as water use activities. These are:

a) Disposal of effluent to facility or land (Governed by Section 21 (e), (g), (h) and (j)). These can include facilities such as tailings storage facilities and evaporation dams
b) Disposal of waste to facility or land (Governed by Section 21 (e) and (g)). These can include waste rock disposal and solid waste disposal
c) Land use activities that are registered. (Governed by Section 21 (e), (g), (h) and (j)). These can include facilities such as mining operations, industrial sites and waste water treatment sites.
d) In-stream activities (Governed by Section 21 (j)). These can include activities such as channel modification

The key water uses at AngloGold Ashanti (AGA) West Wits are the following:

(a) taking water from a water resource
(b) storing water
(c) impeding or diverting a watercourse
(e) engaging in an controlled activity as identified in section 37(1), which includes (a) irrigation of any land with waste or water containing waste generated through any industrial activity
(f) discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit"
(g) disposing of waste or water containing waste in a manner that may detrimentally impact on a water resource
(j) removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people.

2.2 Institutional arrangements of the Waste Discharge Charge System

The above provides the legal framework for the WDCS and the guidelines for the application of the WDCS. The WDCS is part of the pricing strategy for charges for water use charges established in terms of Section 56 of the National Water Act (South Africa, 1998b). The development and implementation of the WDCS has four phases. The phases include:

- Phase 1: Review of international experiences and formulation of a framework document
- Phase 2: Development of a draft WDCS strategy
- Phase 3: Establishment of the final strategy
- Phase 4: Implementation of the final strategy in pilot water management areas

DWA developed framework documents to determine what strategy they will follow to assist with the development and implementation of the WDCS.

The WDCS is aligned with the Water Resources Management (WRM) Systems. The WRM takes place within the context of water resource planning, including development of a catchment management strategy (CMS) and a water resource management plan (WRMP). Through the WRMP, the CMS articulate the resource quality objectives (RQO's). The RQO's are a statement about water resource quality and not only water quality. The RQO's has four components to cover each of the aspects of ecological integrity which is necessary to protect the resource base. RQO's for a water resource are set on the basis of acceptable risk: that is, the less risk we are prepared to accept of damaging the Resource Base and possibly losing the services provided by the water resource, the more stringent would be the objectives. A higher risk to the Resource Base might be accepted, in return for greater short term utilisation, and then the RQO's would be set at less stringent levels (Mackay, 2000). The RQO's in turn forms the basis for the WDCS. Accordingly the WDCS will be implemented in a catchment as part of a CMS and through a WRMP, and is premised on the RQO's as the measure of the acceptable impact. WDCS is only one type of tool to manage water quality problems (DWAF, 2007).

The implementation of the WDCS requires the development of a WDCS business plan. The WDCS business plan includes the procedures, implications and planning cycle of the WDCS. Waste discharges and tariff tables are developed in the WDCS business plan and is reviewed and approved by DWA.

The following variables, representing the dominant water quality problems in South Africa, are highlighted in the current version of the WDCS: nutrients (phosphate, nitrate and ammonia), salinity (total dissolved solids, electrical conductivity, chloride, sodium and sulphate), pH, heavy metals (arsenic, cadmium, chromium, copper, mercury, lead, nickel and zinc) and organic material such as chemical oxygen demand (COD). However, other constituents may also be added to WDCS such as those highlighted by interested and affected parties.

2.3 Waste discharge charge system concepts

The incorporation of the NPS into the WDCS requires that the load of the contaminants entering the resource be quantified and adding to that the incentive charge that requires the calculation of the cost of reducing discharge load from the NPS through various technical, operational or management interventions. Because NPS pollution impacts, site- or source-specific, are difficult to identify and challenging to quantify, assessments of the nature and extent of the water quality problems arising from NPS vary dramatically. Various strategies to address pollution from point sources are well established. However similar strategies have not been developed for NPS (Von der Heyden et al., 2007).

Waste discharges are generally classified according to the spatial nature of their source, and fall into two broad categories, namely, point sources and diffuse sources. In many cases, a diffuse source is initially discharged as a point source, after which it migrates towards the water resource and has a diffuse impact. NPS are included in the WDCS in essentially the same way as point discharges. As far as possible, diffuse impacts should be traced back to the point of discharge. However, diffuse source discharges are often difficult to link to the source, because they typically enter the water resource due to seepage, leaching and run-off (DWAF, 2007).

As NPS discharge is commonly associated with land-use and management practices, the estimation of NPS load entering the resource should take cognisance of differing management practices and technology deployed at the facility producing the NPS (Von der Heyden et al., 2007).

The charge is calculated based on the load discharged to the resource. Discharges are measured in waste load, where waste load is defined as: $L_i = C_i \times Q$

Where: L_i is the waste load for pollutant (i), measured in kg

C_i is the concentration of pollutant (i) in the effluent, measured in mg/l

Q is the volume of water, measured in m^3 (DWAF, 2003).

One of the crucial entities in the WDCS is the water quality monitoring system. A good monitoring system obtains information and is not only there to gather data. A monitoring system must have clear objectives and documented methods that will be used to analyse data (DWAF, 2006). Water quality monitoring is the foundation on which water quality management is based. Monitoring provides the information that permits rational decisions to be made on the following:

- Describing water resources and identifying actual and emerging problems of water pollution.
- Formulating plans and setting priorities for water quality management.
- Developing and implementing water quality management programmes.
- Evaluating the effectiveness of management actions (Bartram & Balance, 1996).

Typically a mining company will set up a water quality monitoring system, as part of their Water Use License (WUL) and is therefore a legal requirement. DWA will indicate surface and groundwater sampling points that require sampling on periodic basis. The sampling information will be reported to DWA on as described in the WUL.

In estimating the diffuse source contribution to the resource two elements should be considered:

a) Seepage of rainfall and runoff of storm water from the facility producing the diffuse seepage.
b) Seepage or runoff of effluents discharged to the facility that produces diffuse seepage (DWAF, 2007).

The above is illustrated in Figure 1. The WDCS estimates groundwater seepage based on the amount of seepage from the facility (as illustrated in (Y)) and the amount of seepage entering the surface water as (W). The seepage that enters the deep aquifer is illustrated in (Z).

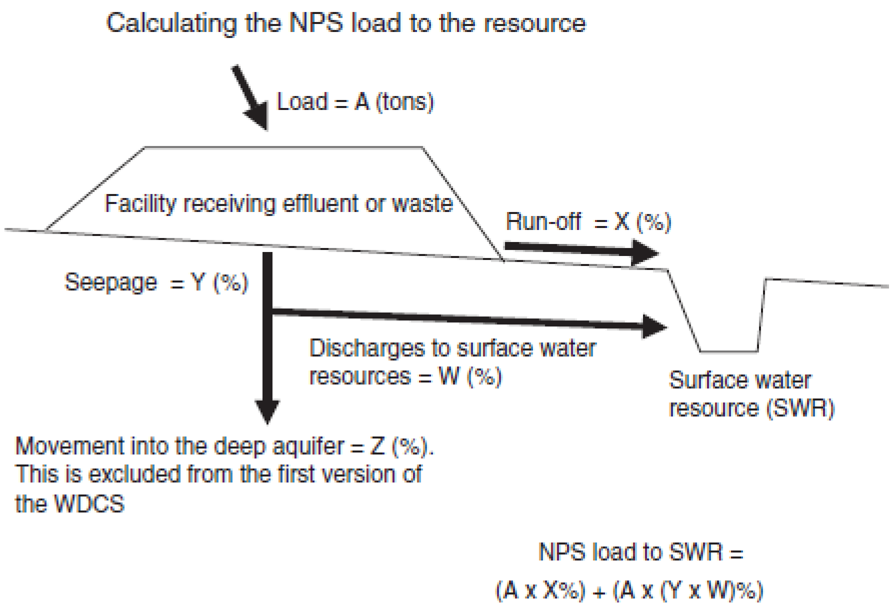

Figure 1: Approach to estimating NPS load discharges to the resource (Von der Heyden *et al*., 2007)

In estimating the NPS load entering the resource, a proportion is developed that relates to the load discharged onto the facility including the rainfall. The illustration in Figure 1 however is only for one tailings facility. At the scale of an entire mine, comprising several waste sources and complex water management requirements, the determination of future water qualities is a challenging undertaking

(Usher et al., 2010). The sources are represented by mine waste (i.e. tailings) that has the potential to release pollutants through the interaction with water. Pathways are any route that links the source and the receptor. The receptors consist of the groundwater or surface water bodies such as rivers and streams.

To answer the research question stated in section 1.2, this mini-dissertation will examine a case study for the AGA West Wits operations. It was decided to use the West Wits operations as it represents a typical gold mine with associated pollution sources. AGA has good historical data available and was also willing to make the relevant information available. Chapter 3 provides some background information on the site and the relevant information that is available.

3. Background

3.1 Background information and setting of case study

AGA has 20 operations on four continents with its headquarters in Johannesburg. AGA's South African operations include six deep level mines and surface operations. Three of these deep level mines, Mponeng, Tau Tona and Savuka are situated at the West Wits Operations. West Wits is located 75 kilometres (km) west of Johannesburg and 7 km south of Carletonville, within the Gauteng Province. Other neighbouring towns are Fochville and Potchefstroom, which are situated 12 and 50 km to the south and west respectively of the mine. West Wits is situated in the Merafong City Local municipality. The land use of the surrounding area consists mostly of mining and agriculture. The locality of the West Wits operations is illustrated in Figure 2. The land occupied by the West Wits Operations is approximately 4 600 hectares and straddles the boundary between Gauteng and the North West Provinces. Approximately 1 700 hectares are impacted by the current mining activities and supporting infrastructure. The operations include:

- Three deep level mines (Mponeng, Tau Tona and Savuka)
- Two Gold Plants (Mponeng and Savuka Gold Plants). Both gold plants have pollution control dams inside the plant boundaries. Process water, spillages and contaminated storm water are captured in these dams.
- Two active tailings storage facilities (TSF's) (Mponeng TSF and Savuka TSF)
- One dormant TSF (Old North Complex)
- Various surface water dams
- Other water reticulation infrastructure
- Three waste rock dumps
    - Mponeng waste rock dump (active)
    - Tau Tona waste rock dump (dormant)
    - Savuka waste rock dump (reworked)
- Properties and residences
- Mine Service

The West Witwatersrand Ridge, locally known as the Gatsrand, intersects the area in an east-west direction. Regional surface drainage can be viewed as being to the north and the south of the Gatsrand watershed. Gold is the main commodity produced at the West Wits operations. The Mponeng Mine, Gold Plant and TSF are on the southern side and the Tau Tona Mine, Savuka Mine and Savuka Gold Plant on the northern side (EMD, 2012). A layout of the West Wits Operations is illustrated in Figure 3.

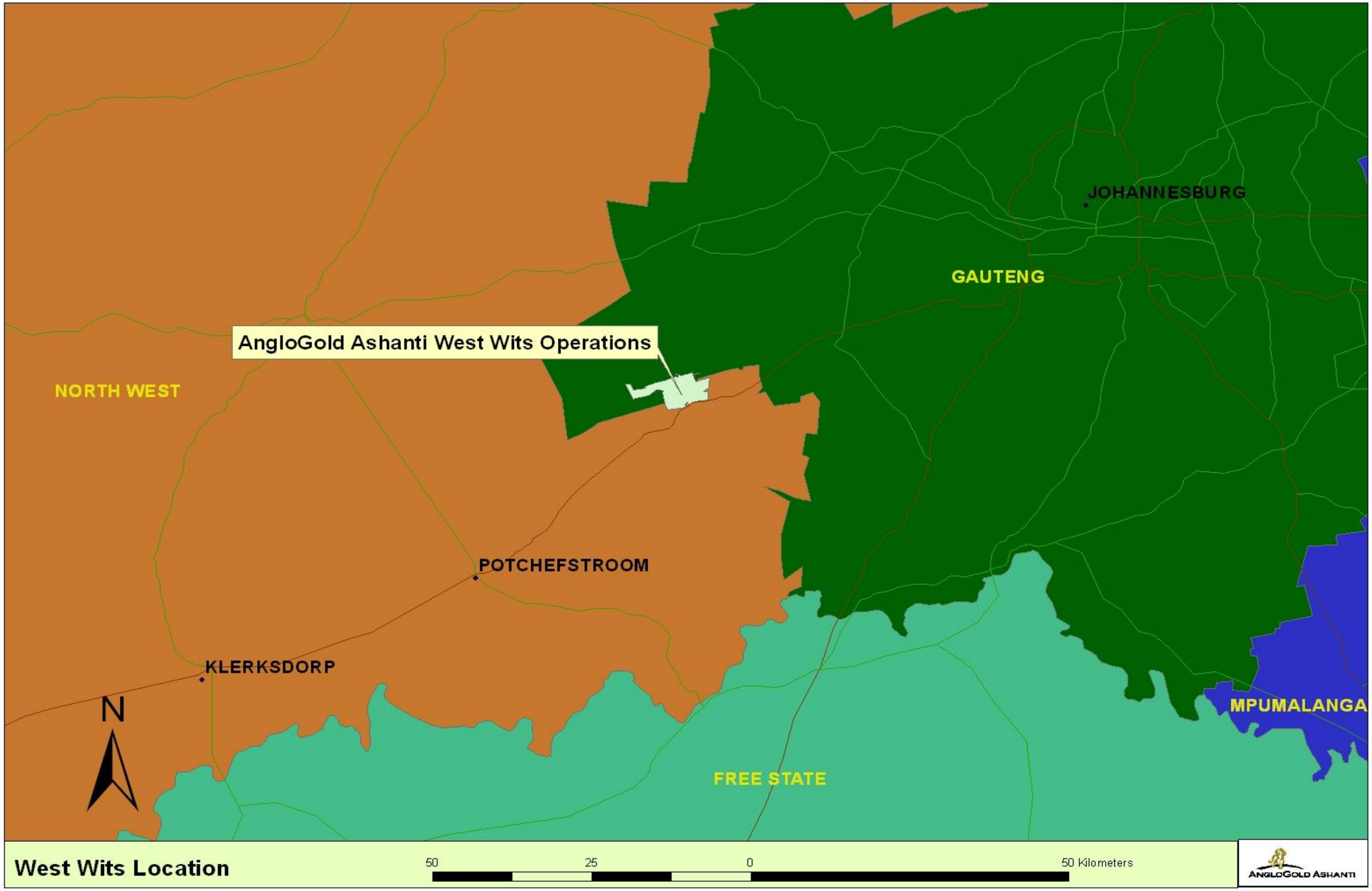

Figure 2: AngloGold Ashanti West Wits operations location

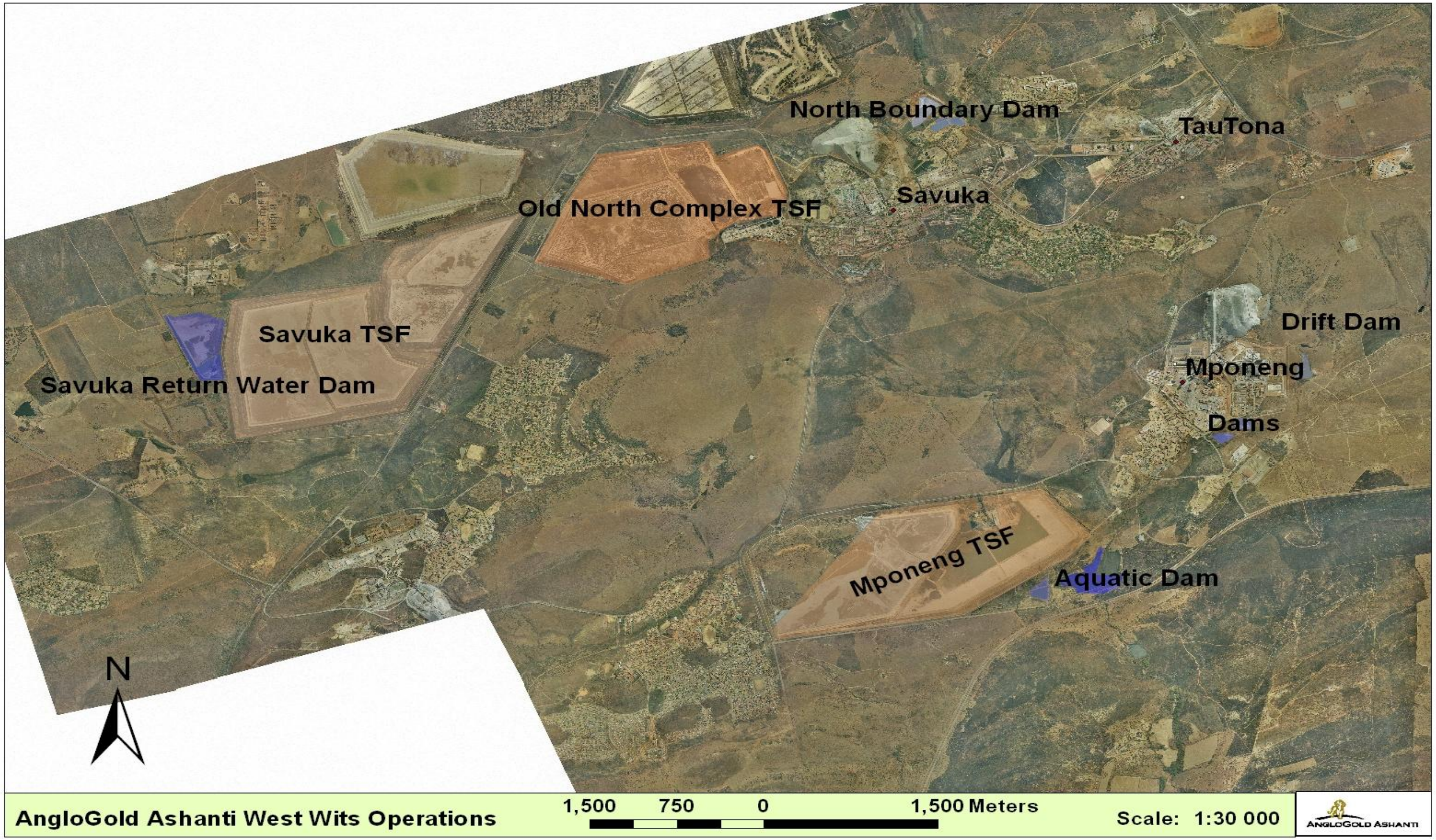

Figure 3: The West Wits mining operations (EMD, 2011b)

3.1.1 Underground Mining

Gold is the main commodity produced at the West Wits operations. Two reef horizons are exploited at the West Wits operations: the Ventersdorp Contact Reef (VCR), located at the top of the Central Rand Group, and the Carbon Leader Reef (CLR) near the base. The separation between the two reefs increases from north to south, from 400 m to 900 m, owing to non-conformity of the VCR horizon. Tau Tona and Savuka exploit both reefs, while Mponeng currently only mines the VCR. The structure is relatively simple, with rare instances of faults greater than 70 m (EMD, 2012).

In order to access the reef and extract the ore, underground mining takes place at depths of more than 2 500 m in the three operational mines. Water is gravitated underground for cooling the working areas, for dust suppression and used in some underground equipment. Pumps are used to transport 'hot' used water to the surface for re-cooling through the surface refrigeration plant for re-use underground as a cooling medium. Most mines use water as their primary cooling medium. The water is cooled in a refrigeration plant (situated either on surface or underground) and is distributed to various locations in the mine (EMD, 2012).

3.1.2 Gold Plants

The metallurgy business unit is responsible for all plants at the West Wits operations. The plants process reef from underground and waste rock from the inactive WRD's. The processing of ore involves the following main activities:

- Ore reception and storage;
- Milling;
- Thickening;
- Leaching/Adsorption;
- Residue or tailings section;
- Elution;
- Carbon regeneration; and
- Smelting/Electrowinning

The final treated pulp residue from the gold processing activities is pumped via pipelines to the prescribed TSF's where settling of solids takes place. The penstocks decant the water that collects in a central pond, into return water dams. The water in the return water dam is pumped back to the gold plant as process water for re-use in the process. The delivery pipelines to the TSF's are open end discharges and the tipping area is controlled by manual operation of the discharge valves.

3.1.3 Tailings Storage Facilities

Final treated pulp residue from Savuka Gold Plant is pumped to the Savuka TSF complex and the final pulp residue from Mponeng Gold Plant is pumped to Mponeng TSF complex. Conventional hand packing and mechanical ditching methods construct the sidewalls. AGA also manages an inactive TSF, the Old North Complex which comprise of compartments 1, 2, 3, 4A, 4B and 6. All the TSF's at the West Wits operations are constructed with traditional day/night paddocks and beaching to a central penstock (EMD, 2012). Information regarding the operational TSF's is provided in Table 1. This information will be used to populate the GoldSim model.

Table 1: Annual Tailings Deposition on the two TSF complexes

Tailings Storage Facilities Compartment	TSF Complex	Total Tons deposited per year	Area (ha)
5A; 5B; 7A; 7B	Savuka Complex	1 625 370	170.46
Mponeng	Mponeng Complex	1 222 522	72.43

3.1.4 Water dams

Various water pollution control dams return water dams and other surface water management infrastructures are used to manage water within the West Wits operations. The water dams, capacities and areas on the West Wits operations are provided in Table 2. The dam areas and capacities were provided by the hydrological study done in 2009.

Table 2: Capacities and areas of the process water dams in the study area (Aurecon, 2009)

Dam	Capacity (m^3)	Area (ha)	Lined/Unlined
Mponeng Holding dam	362 000	129.00	Situated on top of Mponeng TSF
Mponeng Return Water dam	36 200	1.80	Unlined
Mponeng Gold Plant Pollution Control dam	16 400	0.55	Lined
Lower Purified Sewage Effluent dam	30 000	1.00	Unlined
Savuka Return Water dam and Storm Water dam	273 000	13.90	Unlined
Nursery dams (x2)	46 000	2.30	Unlined
North Boundary dam	328 000	9.10	Lined
Savuka Gold Plant Pollution Control dam	5 372	0.30	Lined
Total	**1 096 972**	**158**	

3.1.5 Water care works

West Wits operations have two water care works that are used to treat domestic waste water from the residences and mines. Table 3 details the different water care works, their capacities and design capacities.

Table 3: Water care works at West Wits

Water Care Works	Stage	Capacity	Discharge Rate
North water care works	Primary Sedimentation Tanks	7 800 m^3/day	6 000 m^3/day
South water care works	Primary Sedimentation Tanks	3 300 m^3/day	2 800 m^3/day

3.2 Present Environmental Situation

3.2.1 Climate

3.2.1.1 Rainfall

The AGA West Wits Operations is situated in a summer rainfall area with an average annual precipitation of approximately 725 mm (West Wits internal records). The rainfall is almost exclusively due to showers and thunderstorms and falls mainly in summer months from October to April, with the maximum falls occurring in January. Table 4 summarises the mean monthly and annual rainfall figures for West Wits for the period 1995 to 2011.

Table 4: Monthly Rainfall (mm/month) for the West Wits operations (EMD, 2011)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1995	113	28	98	20	60	0	0	0	0	163	105	139	726
1996	196	159	52	112	17	1	0	21	0	78	81	104	821
1997	80	18	207	94	98	0	0	0	90	34	87	62	770
1998	128	117	76	13	0	0	0	0	17	61	89	149	649
1999	62	58	48	27	30	1	0	0	18	14	72	149	477
2000	201	232	166	91	46	10	5	0	6	95	126	141	1117
2001	83	108	83	48	2	2	0	0	46	162	193	136	863
2002	204	112	89	22	27	79	0	23	18	57	14	112	757
2003	74	71	77	6	0	8	0	12	4	126	93	34	505
2004	109	208	163	56	0	0	17	23	23	27	62	148	836
2005	220	110	108	120	8	0	0	0	0	9	56	113	742
2006	344	217	104	73	9	9	1	23	5	71	225	132	1212
2007	83	127	26	66	0	30	0	0	70	100	123	97	723
2008	144	121	110	6	33	15	0	0	0	79	171	91	738
2009	348	91	59	8	41	22	0	59	3	152	168	60	1011
2010	245	138	103	139	30	0	0	0	0	12	122	169	958
2011	86	133	55	57	52	46	0	0	0	67	64	60	620

The rainfall figures indicate that the area has a summer rainfall and receives an annual precipitation in the range of between 505 mm to 1212 mm per annum. The rainfall data is read from a spreadsheet and is used as the rainfall input to the simulations of the different components of the system. The Mponeng rain gauge is used on the southern side of the complex and the Savuka rain gauge is used on the Savuka TSF and return water dam complex. The Domain 3 rain gauge is used for the Tau Tona mine, Savuka mine and Savuka Gold Plant. The rainfall is used in the GoldSim model.

3.2.1.2 Evaporation

The monthly average evaporation is taken from Water Resource of South Africa manuals used to model the evaporation of the mine complex (WRC, 1994). The West Wits complex is situated mainly in evaporation zone 10A. The Mean Annual Evaporation (MAE) was determined as 1670 mm. Table **5** below provides the average monthly evaporation depths used in the GoldSim model.

Table 5: Average monthly evaporation depths (mm/month) used in the model

Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
189	148	134	104	87	69	81	115	154	183	189	196

3.2.2 Hydrological assessment

A hydrological assessment was conducted in 2009 and was used to determine the catchment areas used in the runoff modelling. Regulation 704 of 1999 of the National Water Act (36 of 1998) states that a person controlling a mine must separate the flow of polluted and clean stormwater from each other. It further states that it must be done with infrastructure which can sustain their function so that it does not cross contaminate more than once in 50 years. The compilation of a hydrological model entails the definition and delineation of all catchment areas within the regional catchment boundaries, and the determination of flood discharges in all major watercourses on a holistic basis by means of a dynamic hydrological computer model, to obtain a master drainage analysis for the area. The areas used in the GoldSim model for the different catchments are provided in Table 6 (Aurecon, 2009).

Table 6: Catchments are used in the catchment and waste rock dump modules (Aurecon, 2009)

Complex	Area Type	Area (ha)
Mponeng Gold Plant	Impervious	14.1
	Pervious	11.6
Mponeng Mine	Impervious	30.3
	Pervious	13.0
Mponeng Waste Rock Dump	Pervious	27.2
Savuka Gold Plant	Impervious	11.2
	Pervious	2.9
Savuka Mine	Impervious	20.7
	Pervious	8.9
Tau Tona Mine	Impervious	24.7
	Pervious	6.9
Savuka Waste Rock Dump	Pervious	39.1

The West Wits operations can be divided into three major water sheds:

- System 1 (Varkenslaagte): Represents the catchment on the west side of West Wits. The catchment is also known as the Varkenslaagte catchment and the discharge point is a natural stream. This system has a catchment of 13.3 km^2. Refer to Figure 6 for illustration of the catchment.
- System 2 (Aquatic Dam): This is a large catchment which drains the south east portion of West Wits and is known as the Aquatic dam catchment. The catchment size is 26.4 km^2. This system discharge to a point downstream of the Aquatic dam. Refer to Figure 7 for illustration of the catchment.
- System 3 (North Boundary Dam): This is a smaller catchment which is 6.97 km^2 in extent and drains the northern side of West Wits. This is also known is the North Boundary Dam catchment. Refer to Figure 8 for illustration of the catchment.

Table 7 to Table 10 illustrate a summary of the specific parameters for each system at the West Wits operations. These parameters are used as input in the hydrological model. The information above will be included in the GoldSim model.

Table 7: Summary of West Wits Specific Parameters for sub-catchments - totals (Aurecon, 2009)

	System 1 (Varkenslaagte)	System 2 (Aquatic dam)	System 3 (North Boundary dam)	Total
Total catchment area (ha)	1330	2641	679	4668
Number	96	186	73	355

Table 8: Summary of West Wits Specific Parameters for sub-catchments - averages (Aurecon, 2009)

	System 1 (Varkenslaagte)	System 2 (Aquatic dam)	System 3 (North Boundary dam)	Averages
Average area in hectares	13.9	14.2	9.5	13.1
Average slope in %	5.5%	7.5%	8.8%	7.2%
Average overland flow length in meters	384	365	272	351
Average % imperviousness	9.3%	9.2%	11.5%	9.7%
Weighted average % imperviousness	8%	8%	8%	8%

Table 9: Summary of West Wits Specific Parameters for Conduits for each system - totals (Aurecon, 2009)

	System 1 (Varkenslaagte)	System 2 (Aquatic dam)	System 3 (North Boundary dam)	Total
Number of conduits	88	134	57	279
Total Length (m)	30 750	48 903	18 809	98 462

Table 10: Summary of West Wits Specific Parameters for Conduits for each system - averages (Aurecon, 2009)

	System 1 (Varkenslaagte)	System 2 (Aquatic dam)	System 3 (North Boundary dam)	Averages
Average length (m)	349	365	330	353
Average slope in %	8.7%	4.9%	3.65	3.9%
Average Manning	0.5	0.5	0.5	0.5

3.2.3 The Mean Annual Runoff

The Mean Annual Runoff for the West Wits operations has been calculated using data obtained from the Water and Research Commission of South Africa website (WRC, 2012). South Africa is divided into quaternary regions according to the various catchments. Each of these catchments are provided with a number. The Mean Annual Runoff for quaternary regions C23J is 38.3 mm and for C23E are 25.9 mm. System 1 and 3 fall under quaternary region C23E and System 2 under quaternary region C23J. Data for the two quaternary catchments that the West Wits operations fall within was used and then this data was extrapolated for the area of the West Wits operations. The Mean annual runoff within quaternary catchments C23E and C23J are presented in Table 11. This information will also be applied in the GoldSim model.

Table 11: Mean annual runoff within quaternary catchments C23E and C23J (Aurecon, 2009)

	System 1 (Varkenslaagte)	System 2 (Aquatic dam)	System 3 (North Boundary dam)	TOTAL
Total catchment area (ha)	1330	2641	679	4668
MAR (mm/year)	25.9	38.3	25.9	
MAR/annum (m^3)	**344 470**	**1 011 503**	**175 861**	**1 531 503**

3.2.4 Structural Geology

The regional large-scale structural geology of the study area must be considered in the light of the large-scale structures associated with the Vredefort impact structure and its related secondary features. Structures associated with this feature which is important to the geology and geohydrology of the area are thrust faults, which occur in the project area as east-west trending features following the general strike direction as the sedimentary formations. The Foch Thrust zone consists of a swarm of faults, none of which are extensional. Structural mapping of these faults are difficult because much of the tectonic movement took place along poorly exposed shear zones within the shale horizons of the Pretoria Group, nearly parallel to the strike direction. The main structural features, which could influence groundwater occurrence and movement in are:

- North-east trending fractures associated with dyke intrusion with occasional possible smaller dyke intrusions associated with it
- North westerly trending fractures and faults
- East-west trending shear zones associated with bedding planes mainly in shale formations
- North-east trending syenite dyke intrusions (EMD, 2012).

The WDCS is calculated based on the load discharged to the resource. Discharges are measured in waste load which is the concentration of pollutant multiplied by the volume. This information is provided by a water and salt balance. The water balance and water quality monitoring program is discussed below.

3.2.5 Geohydrology

The Geology has an important influence on the geohydrology and the potential for groundwater pollution and contamination migration. Regionally the groundwater system can be classified into two definite aquifers, namely the dolomite aquifer to the north and the fractured shale, quartzite, diabase and lava aquifers to the south. There are two important dykes present, namely the north-south trending Oberholzer dyke, which separates the watered Boskop/Turfontein compartment (in the west) from the de-watered Oberholzer compartment in the east, and the north-east south-west trending Bank dyke which in turn separates the Oberholzer compartment from the de-watered Bank compartment. None of the AGA West Wits operations and infrastructure is located on the Dolomites with the exception of a small portion of unused land to the west. The operations are located on the Pretoria Group Sediments and associated aquifers. All of the tailings dam complexes are mainly underlain by fractured shale formations. Although fractured shales are expected to be reasonably pervious, the closing of joints due to the pressure of an overlying tailings dam is expected (Wagener, 1979).

3.3 Water Balance

An accurate water balance forms an integral part of water management, assisting operations in optimising their water use and achievement of their water management objectives. The West Wits operations water balance will be one of the fundamental instruments in informing the GoldSim model. The water balances for the West Wits Operations are constructed, managed and operated in accordance with the DWA, 2006 Best Practice Guideline G2: Water and Salt Balances (DWAF, 2006a). The basic principle of mass conservation forms the foundation of mass balances. The principle can be simplified to the basic equation for a mass of species multiplied (x) a process unit: (rate of x into process unit) = (rate of x out of a process unit). The mass balance concept (Figure 4) can be illustrated in a simplified manner as:

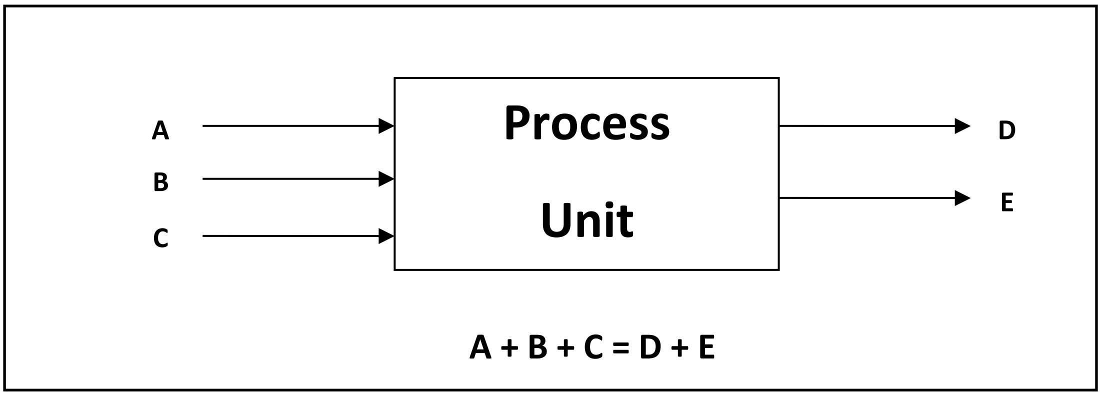

Figure 4: Simplified mass balance concept

Accuracy and resolution of a site water balance must be appropriate to the nature and scale of operations and allow for effective water resource management. The following boundaries were determined for the water balance:

- Water Storage Dams
- Tailings Storage Facilities and Return Water dams
- Metallurgical Plants
- Mine Shaft Areas
- Water Care Works

Inflows may include but are not limited to the following:

- Potable water
- Process water
- Rain
- Reagents
- Water in ore
- Backfill
- Fissure water
- Run off water from adjacent areas

Outflows may include but are not limited to the following:

- Process water
- Water in Tailings
- Sewage water
- Storm water runoff

- Evaporation
- Seepage

The individual water balances are updated on a monthly interval. Water readings are populated from the physical reading of meters and from the Scan Control and Data Acquisition (SCADA) system at the business units. The shaft/plant water balances are required to be maintained within the ±10% accuracy range. Continued deviation outside this range will trigger a review and update if found necessary. Water volume records are maintained in an accessible and protected electronic format, suitable for ease of communication to internal and external parties. These records are maintained as accessible archive records for at least 5 years. Hard copies of the volume water records are kept for at least one year for audit purposes.

The water balance is currently being maintained as an Excel spreadsheet representing a facility (plant or shaft). The spreadsheets indicate the inflows (potable water, process water, fissure water, rainfall, etc) and outflows (process water, bleed-off water, evaporation, seepage, sewerage, etc), demarcating imbalance percentages for each month. A summary of the incoming and outgoing water is given in an individual tab on the spreadsheet thereby placing greater emphasis on the usage of water. Each individual business unit is responsible for the input of flow data on a monthly basis. The information generated by the water balance is used to populate the GoldSim model. Figure 5 illustrates the West Wits water reticulation and flow.

The definition of the pollution sources is critical in the WDCS. The next section identifies the pollution sources at the West Wits operations.

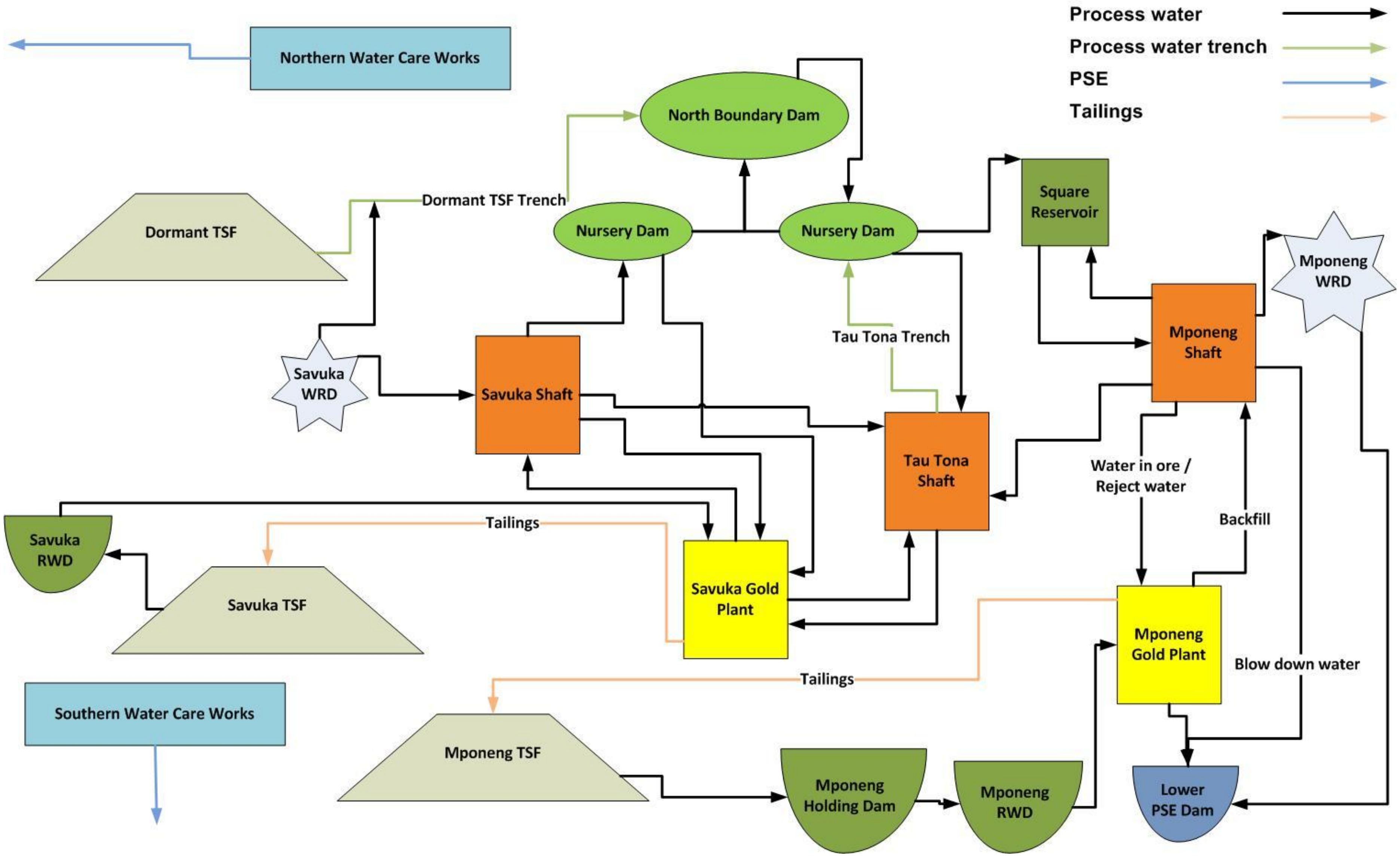

Figure 5: West Wits Operations water reticulation diagram

3.4 Pollution Sources

The West Wits operations are divided into three sub catchments as discussed in Section 3.2.2. The sub-catchment will be discussed by looking in detail at the sources of pollution, the pathway or aquifer and the receivers or receptors.

3.4.1 Varkenslaagte sub-catchment

The Varkenslaagte sub-catchment area occupies the north western portion of the West Wits operations. The sub-catchment is bounded by the Gatsrand Ridge to the south east and south and a topographical high in the north. The Varkenslaagte stream is the main drainage path and drains the sub-catchment from east to west.

The main sources of pollution are the Savuka TSF complex, the Savuka Return Water and Storm Water dams. The Savuka TSF Complex consists of No. 5a and b to the north and No. 7a and b to the south. The Savuka Return Water and Storm Water dams are situated to the west of the Savuka TSF complex. The Old North Complex comprising of Compartments 1, 2, 3, 4A, 4B and 6 and is situated to the north of Varkenslaagte. It must be noted that this complex is constructed on a water divide and therefore only seepage from the southern part of the dam reports to the Varkenslaagte catchment area.

The pathway, in this case, is mainly seepage from the TSF's, and return water dams via the top unsaturated soil/gravel zones and into the underlying weathered/fractured aquifer system. Flow in the local aquifer system will follow a general shallow path within the top weathered shale and quartzite zones (usually the top 40 m from where the rock becomes more solid and fractures dominate flow) (GCS, 2007).

The receiver is the Varkenslaagte stream which drains toward the west. The stream is a tributary to the Wonderfonteinspruit. Recent information suggests that the Varkenslaagte stream does not reach the Wonderfonteinspruit, but dries up over dolomitic terrain. Figure 6 illustrates the layout in the sub-catchment

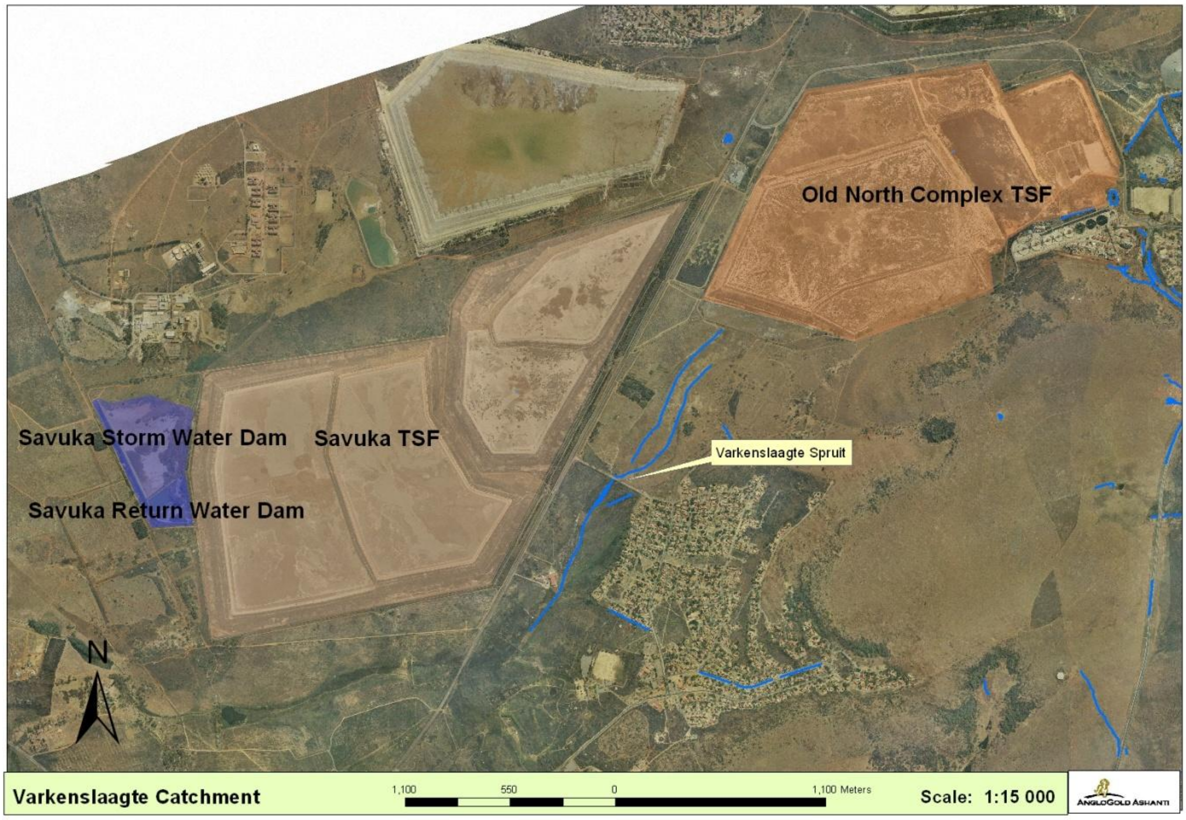

Figure 6: Varkenslaagte sub-catchment (EMD, 2011b)

3.4.2 Aquatic dam sub-catchment

The Aquatic dam sub-catchment is situated in the south of the West Wits operations. The sub-catchment is bounded by the Gatsrand Ridge to the north and topographical highs in the west and east. The Elandsfontein Spruit, which defines the drainage pattern of the Aquatic Dam sub-catchment, drains the sub-catchment from north to south. The Elandsfontein Spruit originates as springs all over the Gatsrand Ridge and drains into the Aquatic dam which is situated in the Elandsfontein Spruit.

The main sources of pollution are the Mponeng TSF complex, the Mponeng Return Water dams (north and south), Mponeng Holding dam (situated on top of Mponeng TSF) and Mponeng Waste rock dump. There are also two lined pollution control dams in Mponeng Gold Plant. Figure 7 illustrates the layout in the sub-catchment.

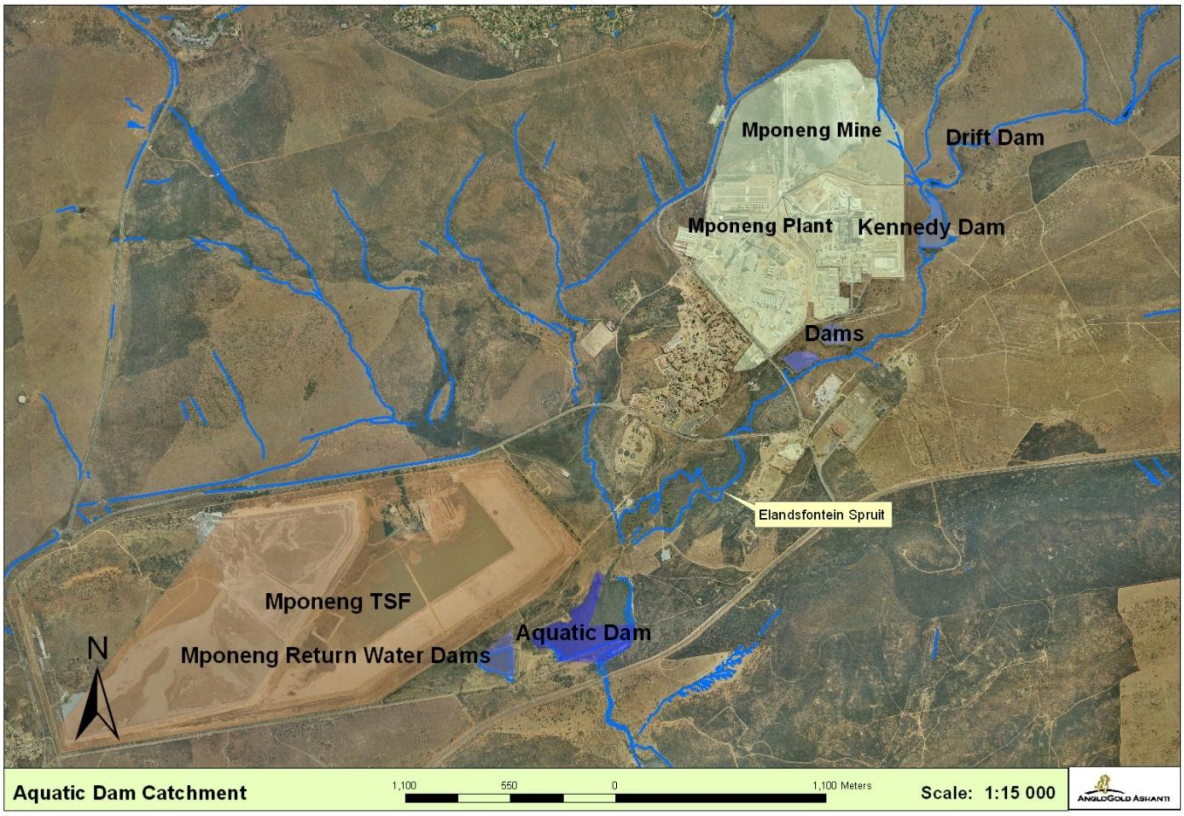

Figure 7: Aquatic dam sub-catchment (EMD, 2011b)

3.4.3 North Boundary dam sub-catchment

The North Boundary sub-catchment is situated within the north eastern portion of the West Wits operations and is delineated according to the surface drainage patterns towards the North Boundary Dam (refer to Figure 8). The sub-catchment is bounded by the Gatsrand Ridge to the south and topographical highs in the west and east. The tributary of the Wonderfontein Spruit, which defines the drainage pattern of the North Boundary Dam sub-catchment, drains the sub-catchment from south east and south east into a northern direction. The tributary ends up in the Wonderfontein Spruit which flows from east to west approximately 8 km to the north.

The main sources of pollution are the Old North TSF complex, the nursery dams (x2) and North Boundary Dam. The pathway, in this case is the same as the Varkenslaagte area, where seepage from the identified pollution sources flow via the top unsaturated soil/gravel zones and into the underlying weathered/fractured aquifer system.

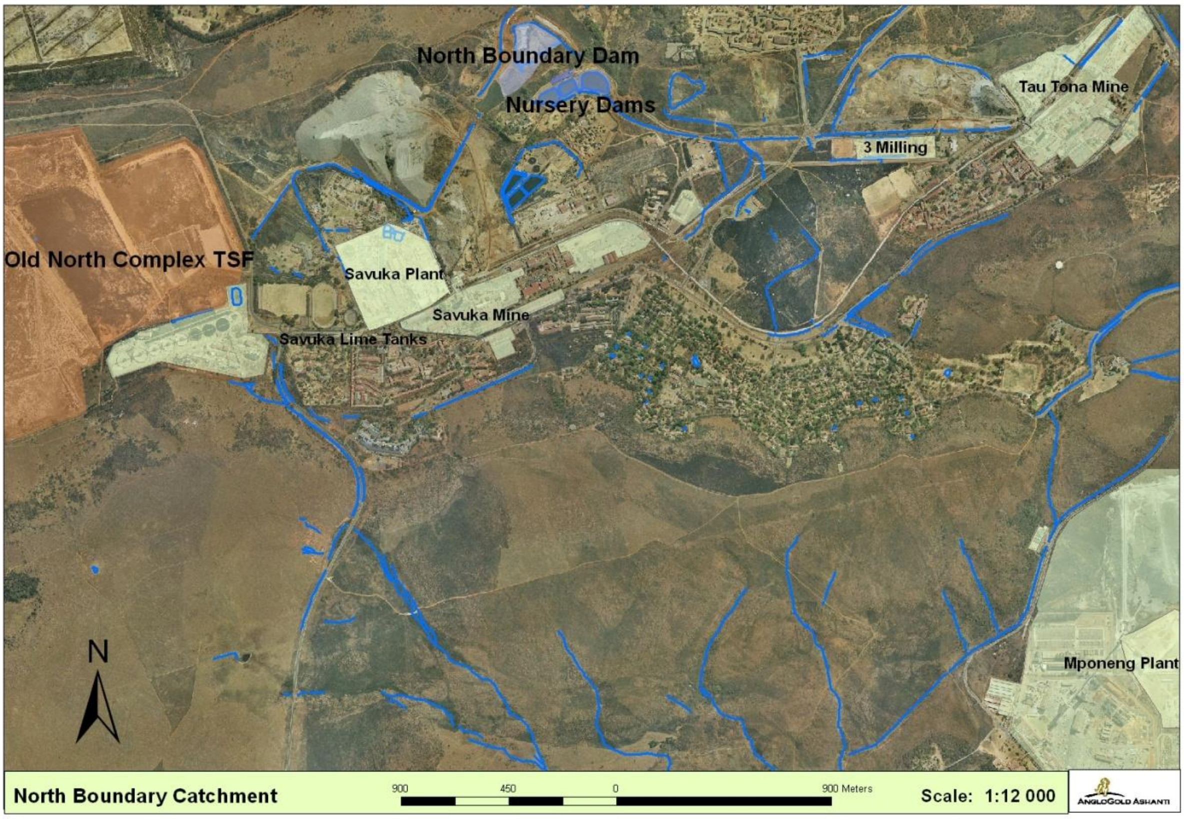

Figure 8: North Boundary sub-catchment (EMD, 2011b)

3.5 Water Quality Monitoring

3.5.1 Surface Water Quality Monitoring programs

Water quality monitoring programs are undertaken to provide information in order to answer questions relating to the management of water bodies and catchments. It may be a single exercise to scrutinize a particular issue, or it may be an on-going monitoring programme to ensure that an acceptable water quality is maintained (Burden et al., 2002). In the preparation of a sampling plan, goals, strategies and methods must be considered in conjunction with an understanding of the target environment, including the physical, chemical and biological variables and processes involved (Artiola et al., 2004).

The monitoring of surface water quality is an important environmental management tool as the West Wits Operations are located in close vicinity to water courses and streams (receptors). Surface water sampling and analysis has been conducted since 1995 according to a sampling programme and schedule and is conducted according to an approved procedure. This schedule has been developed in accordance with the monitoring requirements dictated in the West Wits Water Use License (WW WUL). The objectives of the surface water monitoring programme are to assess compliance with set standards and legislations (WW WUL). The other objectives is to access the impact of AGA's activities on the surface water resources (river) and if the management plans put in place are helping to reduce the impacts on the surface water resources. The surface water monitoring programme is refined as the management plans change and develop.

The West Wits Operations have a total of 41 surface water monitoring points in order to achieve above objectives. Eleven (11) points are sampled monthly, 26 are sampled quarterly and the rest are incidents that are sampled if and when an incident occurs. The samples are analysed at a local independent SANAS accredited laboratory and the results are stored in a water quality database. The parameters analysed for include TDS and SO_4. The surface sampling points are illustrated in Figure 9 to Figure 11. Surface water monitoring includes monitoring of the following:

- Licensed discharge of purified sewage effluent (PSE) into the Elandsfonteinspruit to the south and the Blyvoor canal to the north;
- Stream sampling up and down stream of the West Wits operations;
- Sampling of water in return water dams/pollution control dams and trenches;
- Eyes or fountains which originate on the West Wits property
- Incident sampling if overflows occur in a storm event or other events;
- Other ad-hoc sampling

Surface water samples are done by grab samples. The water samples are taken in a 2 litre bottle which is delivered within 24 hours to an accredited laboratory for analysis. The sample date and number is written on the sample bottle.

Continuous flow meters are in place at key areas on the West Wits operations. These include the North Boundary Dam, the Aquatic dam and the two water care works. No water may be discharged from the North Boundary dam. The Aquatic Dam is a clean water dam while the two water care works discharge the water into the environment.

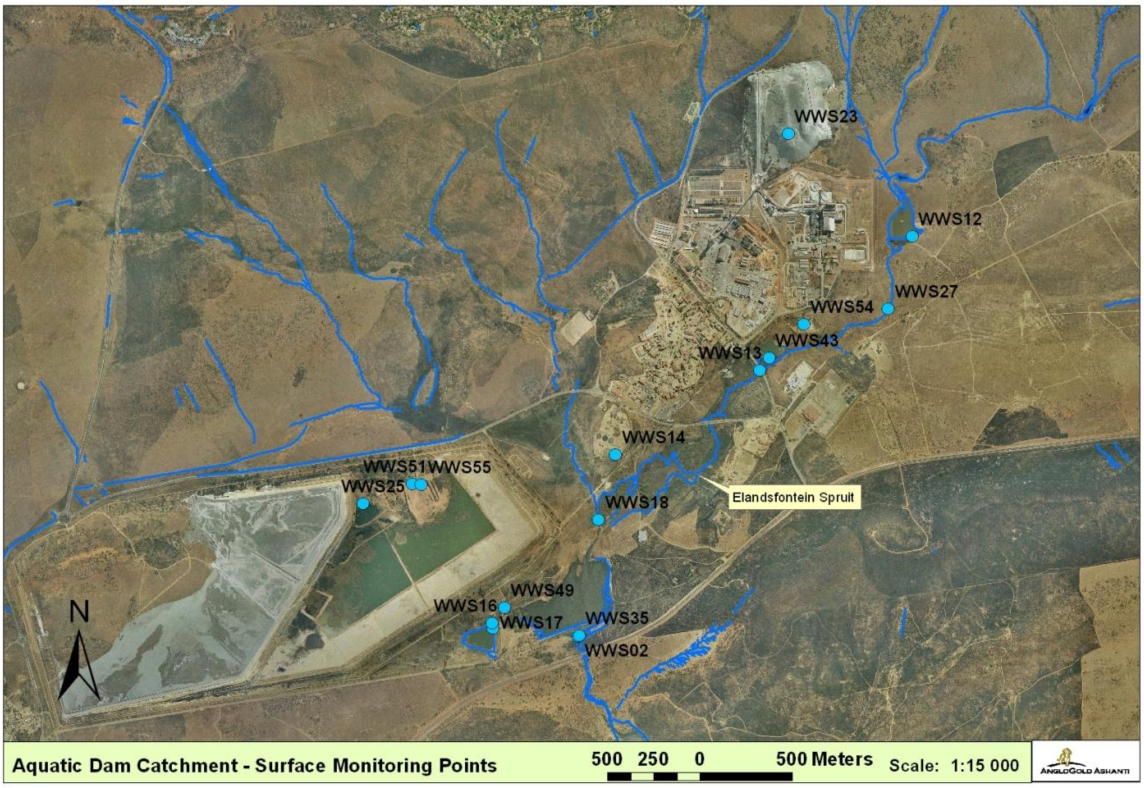

Figure 9: Surface sampling points at the West Wits operations – Aquatic Dam Catchment (EMD, 2011b)

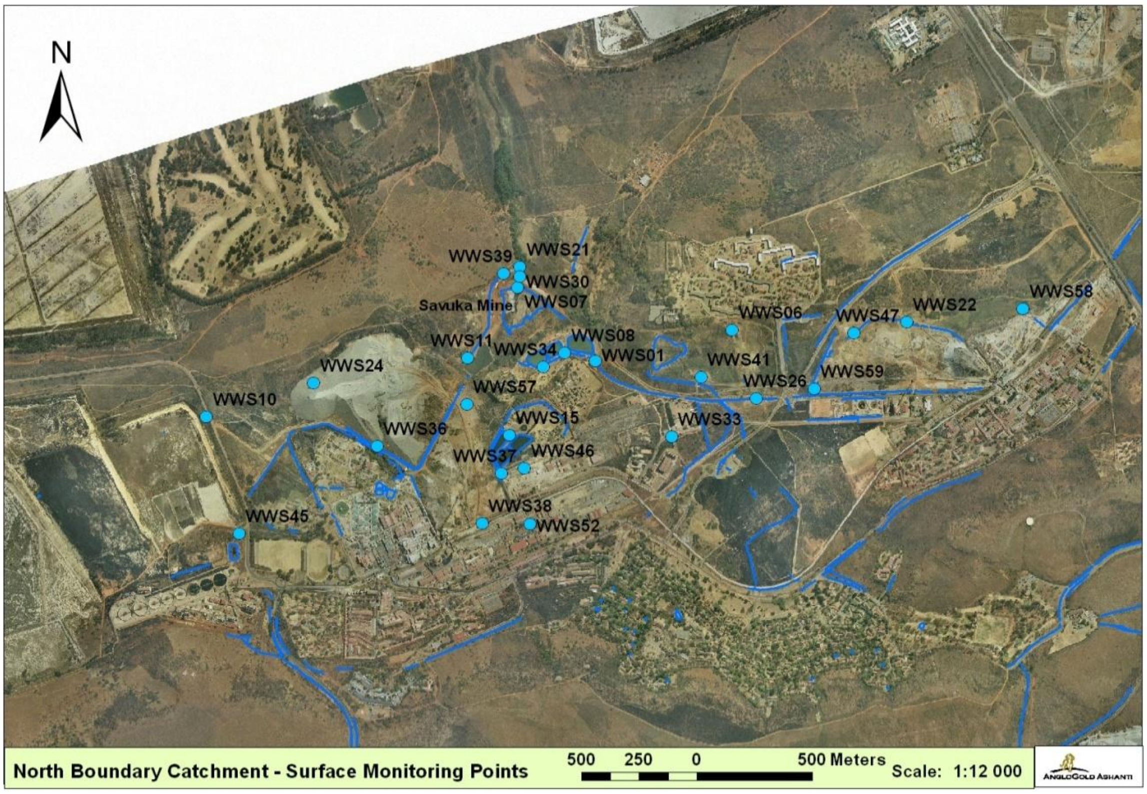

Figure 10: Surface sampling points at the West Wits operations – North Boundary Dam Catchment (EMD, 2011b)

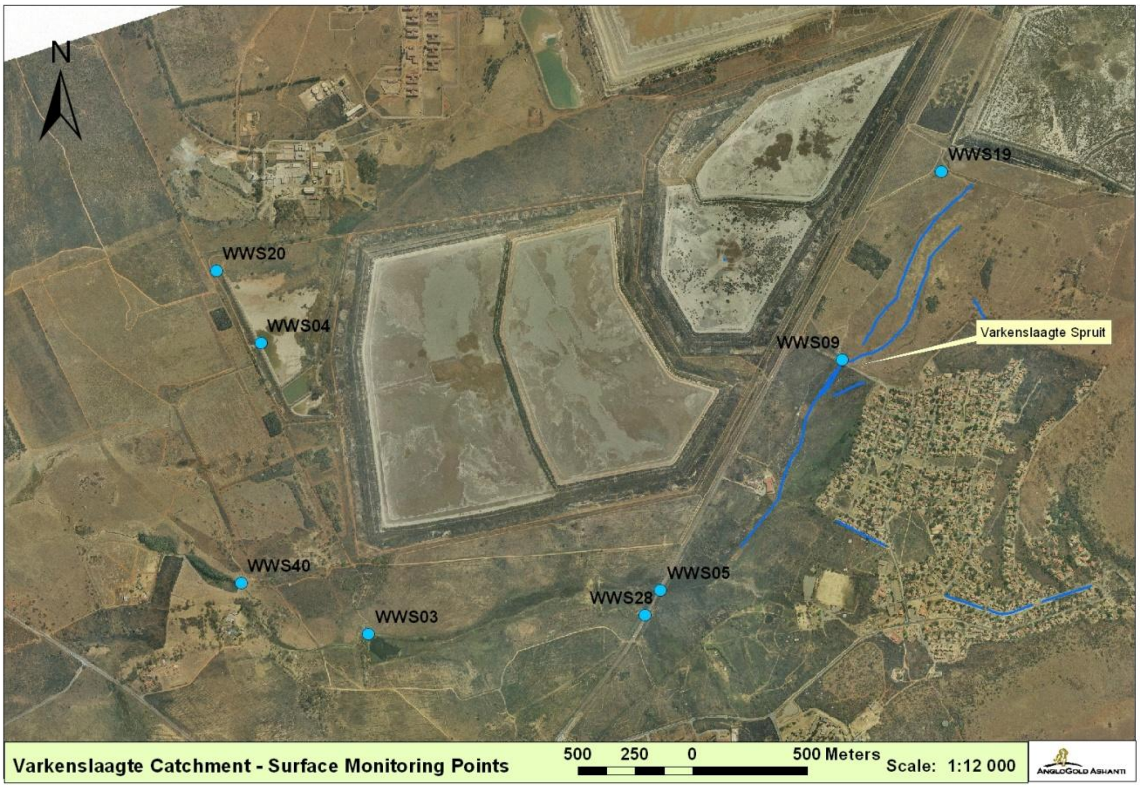

Figure 11: Surface sampling points at the West Wits operations – Varkenslaagte Catchment (EMD, 2011b)

3.5.2 Receiving Resource Water Quality Objectives and Reserve

RQO's for a water resource are a numerical or descriptive statement of the conditions which should be met in the receiving water resource, in terms of resource quality, in order to ensure that the water resource is protected. RQO's are scientifically derived criteria, based on the best available scientific knowledge and understanding (Mackay, 2000). Although RQO's have not yet been determined, interim in-stream RQO's have been set by DWA in the WUL. The current RQO's for the Upper Vaal Water Management area and the Wonderfonteinspruit catchment are illustrated in Table 12. These RQO's have been set in line with the Present Ecological State and Ecological Importance and Sensitivity Classification for the region which is discussed further below (EMD, 2012).

Table 12: In stream RQO's for the Wonderfonteinspruit in the Upper Vaal Water Management Area (EMD, 2012).

Variable	RQO
pH	5.5 - 9.5
Total Dissolved Solids (TDS)	630 mg/l
Sulphate	400 mg/l
Chloride	200 mg/l
Sodium (Na)	100 mg/l
Magnesium (Mg)	1.0 mg/l
Calcium (Ca)	80 mg/l
Nitrate (NO_3)	20 mg/l
Electrical conductivity	90 mg/l
Iron (Fe)	1.0 mg/l
Manganese (Mn)	1.0 mg/l
Phosphate	0.26 mg/l
Ammonia (NH3)	2.0 mg/l
Fluoride (F)	1.0 mg/l
Boron (B)	2.0 mg/l
Aluminium (Al)	0.5 mg/l
Lead (Pb)	10 mg/l
Cadmium	5 mg/l
Uranium (u)	0.07 mg/l

3.5.3 Ground water monitoring program

The monitoring of groundwater is important as these observations indicate the natural groundwater condition (if available) and the extent of pollution to groundwater. Groundwater levels and quality are observed at a specific frequency as per the ground water sampling schedule which has been developed for the West Wits Operations. The characterization of aquifer investigations was conducted in the 1980's. This information of more than 30 years is available on databases. A total of approximately 70 boreholes were identified, drilled and described and captured on groundwater databases (EMD, 2011). Grab samples are taken through lowering a pump connected to a hose into the monitoring borehole. The monitoring borehole is purged until the pH and total dissolved solids (TDS) stabilize. The pH and TDS are measured with a hand held instrument. The water samples are taken in a 2 litre bottle which is delivered to an accredited laboratory for analysis within 24 hours. The sample date and number is written on the sample bottle.

The quality of groundwater at the West Wits operations is moderately impacted proximate to pollution sources. No baseline information is available. From extrapolations and qualities of isolated non polluted sources it can be deducted that the quality of groundwater pre-mining was good for all use or at least Class 1 domestic use. The quality of groundwater from the quartzite's of the Gatsrand ridge is pristine and of exceptional quality currently.

The operations are divided into 3 management units for more effective management. Figure 12 to 14 indicate the positions of the monitoring boreholes at the West Wits Operations.

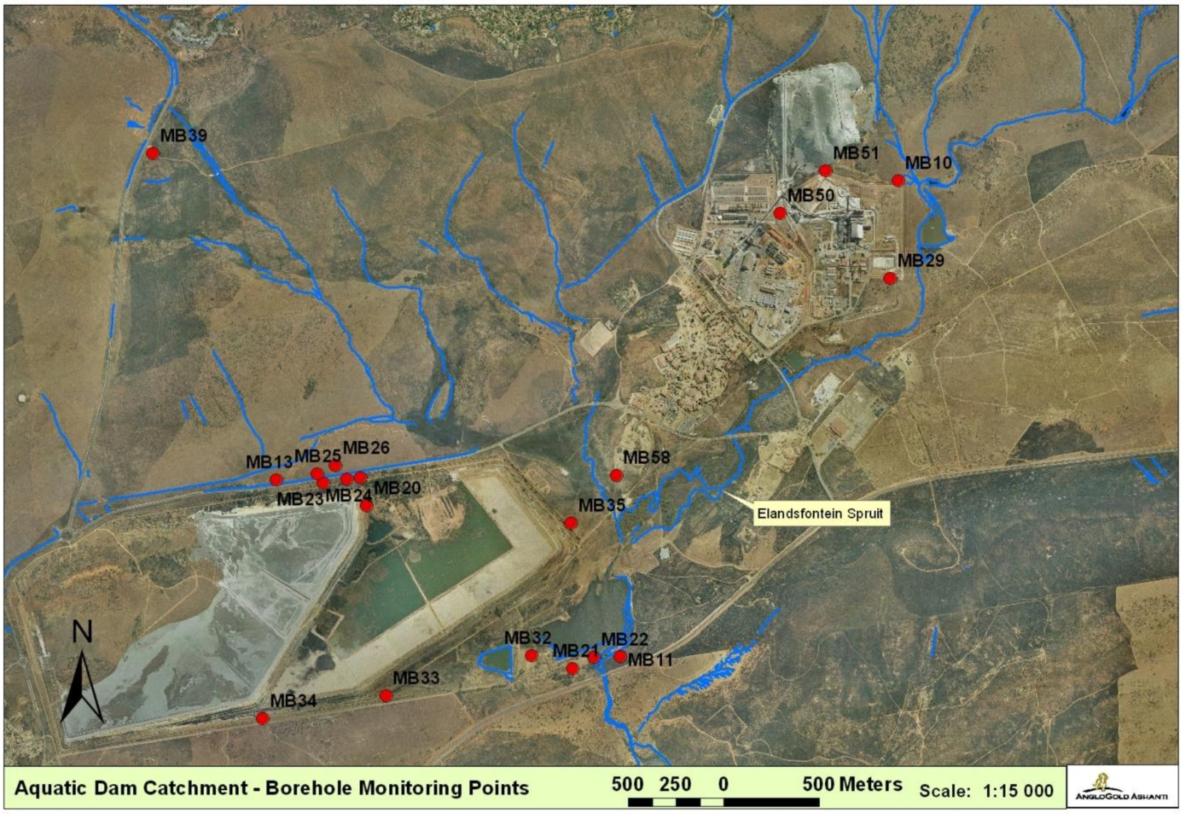

Figure 12: Ground water sampling points at the West Wits operations – Aquatic Dam Catchment (EMD, 2011b)

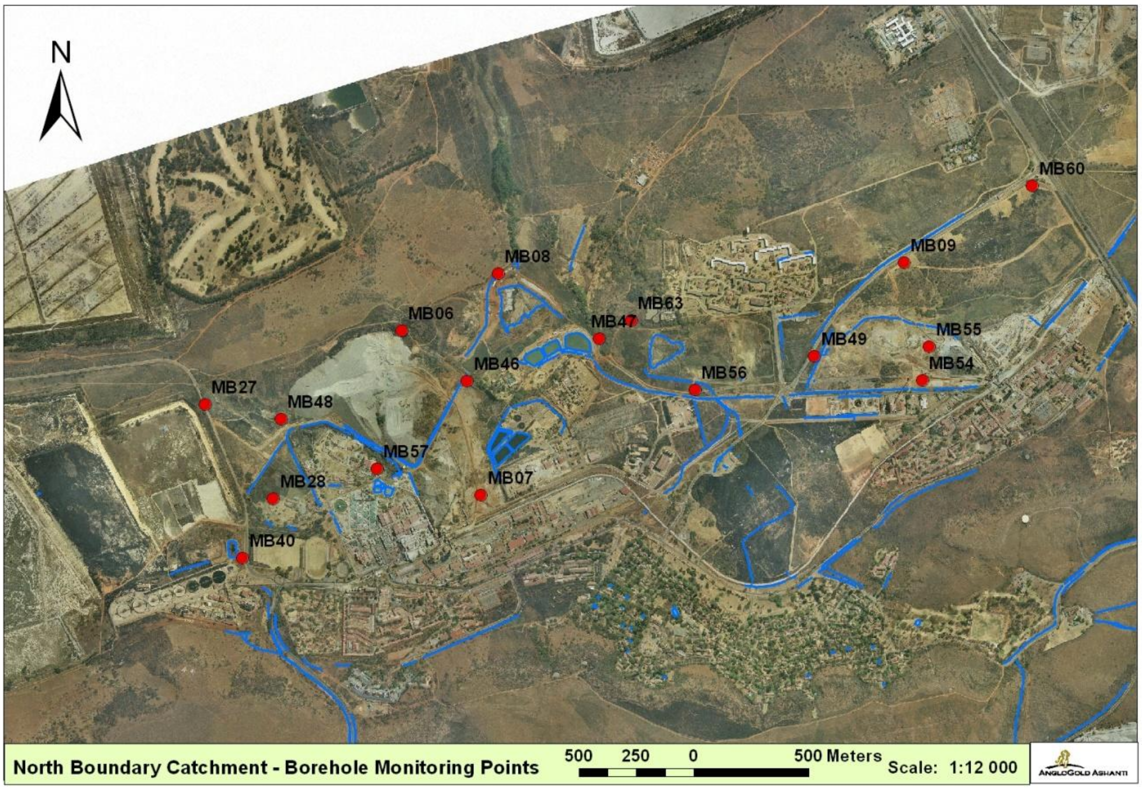

Figure 13: Ground water sampling points at the West Wits operations – North Boundary Catchment (EMD, 2011b)

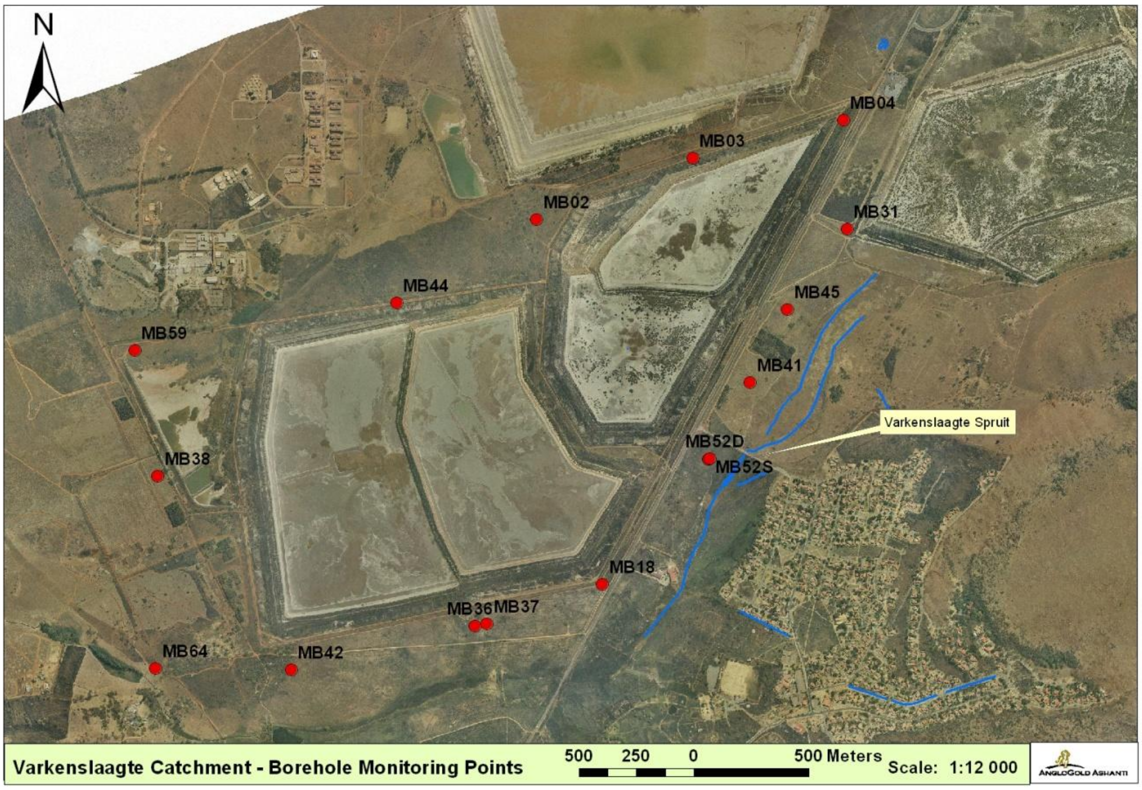

Figure 14: Ground water sampling points at the West Wits operations – Varkenslaagte Catchment (EMD, 2011b)

The chapter above provides an overview of the information available. It provides the linkages between the source, pathway and receptor. The source is presented by the pollution sources. The medium for the pathway in this case water and the receptor is the environment. The GoldSim module provides a probabilistic modelling platform that links these three components. The next chapter describes the modules used in the Goldsim model and how the information above will be used to populate the model.

4. Research Methodology

4.1 The GoldSim model

A number of models are available for simulating the impacts on the water environment. It was decided to use the GoldSim model at the West Wits operations. GoldSim is a powerful and flexible Windows-based computer program for carrying out probabilistic simulations of complex nature to support management and decision making. GoldSim can be used to solve a wide variety of problems but is particularly well suited for the mining industry. It allows one to create realistic models of mine systems in order to carry out risk analyses, evaluate potential environmental impacts and support strategic planning which ensures better resource management (GoldSim, 2005). The components of a probabilistic model are illustrated in Figure 15. The main function of the model is to allow the user to simulate scenarios where water management is modified, causing a change to either flow volumes or water quality (Usher *et.al*, 2010). A GoldSim model developed for the West Wits operations provides a platform to the integration of water quality and water balance. The GoldSim model has been used extensively in mine water balance studies in North and South America, Europe, Africa and Australia (Nalecki & Gowan, 2008). Further reasons for the development of the model include:

- The level of complexity of the model is almost limitless
- It incorporates Monte Carlo simulation which increases the reliability of the model generated outputs. In Monte Carlo simulation, the entire system is simulated a large number of times. Each simulation is assumed to be equally likely
- It saves on modelling time
- It allows focus on different scenarios
- It is relatively user friendly

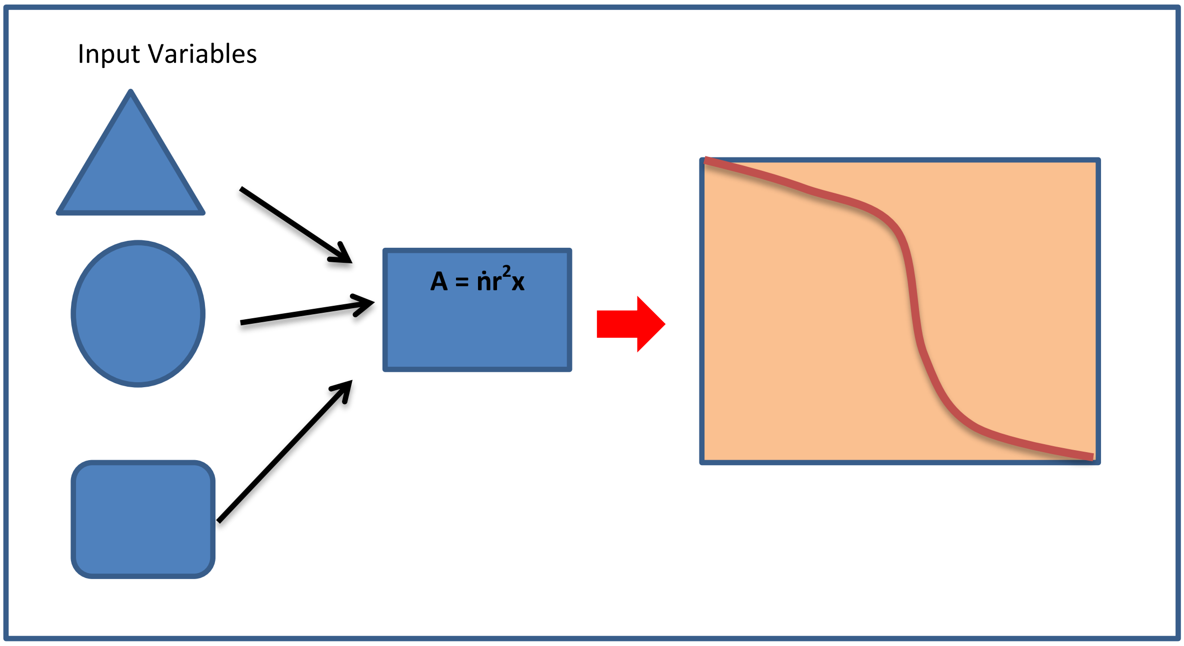

Figure 15: The components of a probabilistic model (Digges La Touche *et al*., 2007)

The GoldSim software is most successful when applied using a structured methodology. The overall objective of the GoldSim model is to provide decision makers with methodology or an instrument to select a strategy that offers the highest likelihood of success. One of the most important parts of the simulation process is building a conceptual model. It will provide a good understanding of the system and the critical factors in the system (GoldSim, 2005). A conceptual model is a simplified description of the water reticulation of the West Wits operations and serves as a basis for developing a model. This will provide a better understanding during the process of modelling. It will give structure to the model and break it down in manageable units. It will further provide an indication of how these units are linked to each other and how they influence each other. The conceptual model for West Wits is provided in Figure 5.

The model is structured to simulate water quality and quantity. There are two components to the model. The model simulates the history of the system based on the measured information and simulates the system according to an operating rule for simulations of the future behaviour of the water system. The model is populated by an Excel spreadsheet, which includes all the required historical data. The GoldSim model will assist in helping to determine the waste discharge charge to the environment. The model requires a range of inputs which requires monitoring of environmental criteria. The model input modules are discussed below.

4.1.1 Climate model

- Rainfall - The rain information includes the rainfall measurements for three gauges on site as well as a stochastic rainfall generator are built into the model. The simulations for the future behaviour of the water management system use the stochastic rainfall generator.
- Evaporation – the evaporation is also included in the model as discussed under section 3.2.1. Table 5 above provides the average monthly evaporation depths. The climatic model in the GoldSim model is illustrated in Figure 16.

4.1.2 Catchment module

The catchment module consists of a runoff model for impervious and pervious catchment areas. The pervious catchment model consists of a soil layer, accounting for the evapotranspiration from the soil moisture store, interception storage and percolation to the groundwater system. The catchment model is based on the SCA-SA method to convert daily rainfall depth to a daily runoff depth. The remaining depth infiltrates into the soil. The inputs into the catchment model are the catchment area, depth of soil store, porosity, field capacity, initial moisture content, interception storage and leafy index (Golder, 2010). The areas used in the GoldSim model for the different catchments are provided in Table 6 above.

4.1.3 Water dams

The following inputs and outputs are included in the dam module:

- The capacity and the area of the dam
- The depth of the dam
- Whether the dam is lined or not (permeability)
- Inflows into the dam. This can include:
    - Surface water runoff
    - Water pumped into the dam
    - Direct rainfall on the surface of the dam
- Outflow from the dam. This can include:
    - Evaporation from the surface of the dam
    - Seepage from the dam
    - Spills from the dam
    - Water pumped from the dam to various facilities to meet their water demand.

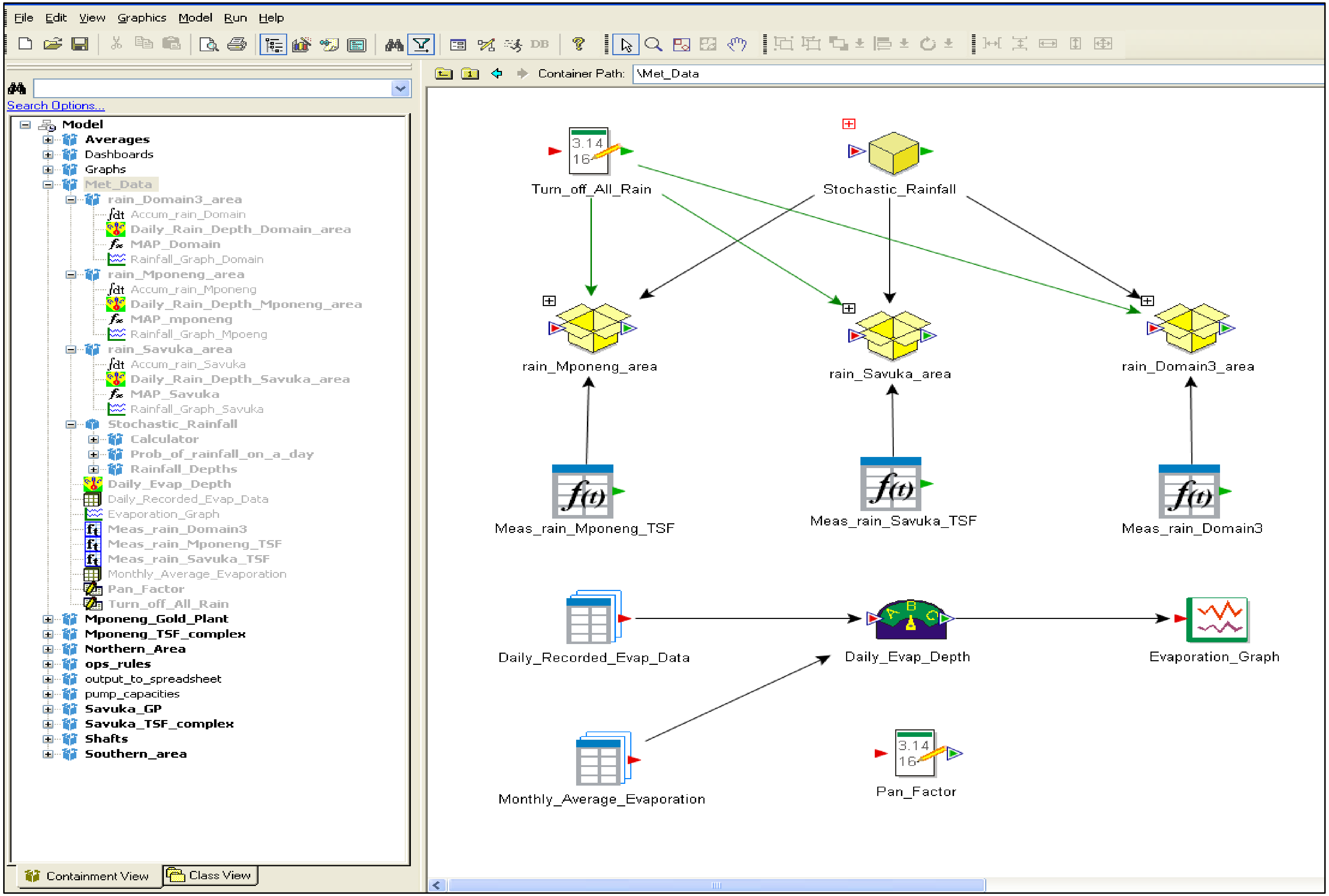

Figure 16: The Climatic module in the GoldSim model for the West Wits operation

4.1.4 Waste rock dump module

The waste rock dump module consists of two layers. A surface layer and a base flow layer which represents the body of the waste rock dump from which seepage occurs. The catchment module is used for the surface layer. The areas used for the waste rock dump is provided in Table 6 above.

4.1.5 Tailings Storage Facilities

It is known that the water balance of a TSF is influenced by the depositional history of the deposit and its physical characteristics (dimensions, particle size distribution, differential particle deposition arising from different operational strategies, etc.). The TSF surface is divided into a wet beach, dry beach and pool area. Figure 17 illustrates the water balance for a TSF. In both decommissioned and operational tailings dams, there would be a spatial variation of the water balance components from the edge to the centre of the dam. This is mainly attributed to the moisture available in the profile, which is governed by the presence and depth of the phreatic surface. Thus infiltration at the edge of the pool is at a maximum and at a minimum at the centre of the pool whereas evaporation would be at its maximum at the centre of the pool and at its minimum at the edge of the pool. The depth of the phreatic surface and rate of drop of this surface is difficult to estimate accurately (Pulles *et.al*, 2011). The TSF module in the GoldSim model is illustrated in Figure 18. The inputs and outputs included in the TSF module are:

- The runoff from the wet and dry beach areas. The runoff reports to the pool.
- The tailings dam surface area
- Direct rainfall on the pool surface.
- Evaporation from the dry and wet beaches.
- Evaporation from the water surface of the pool.
- Entrainment of water in the placed material.
- The return water flow from the pool via the penstocks to the return water dam.
- Seepage from the TSF collected in the under drains. This seepage is sent to the return water dams associated with the TSF.
- Seepage to groundwater.
- The deposition rate and the relative density of the material deposited in to the TSF.

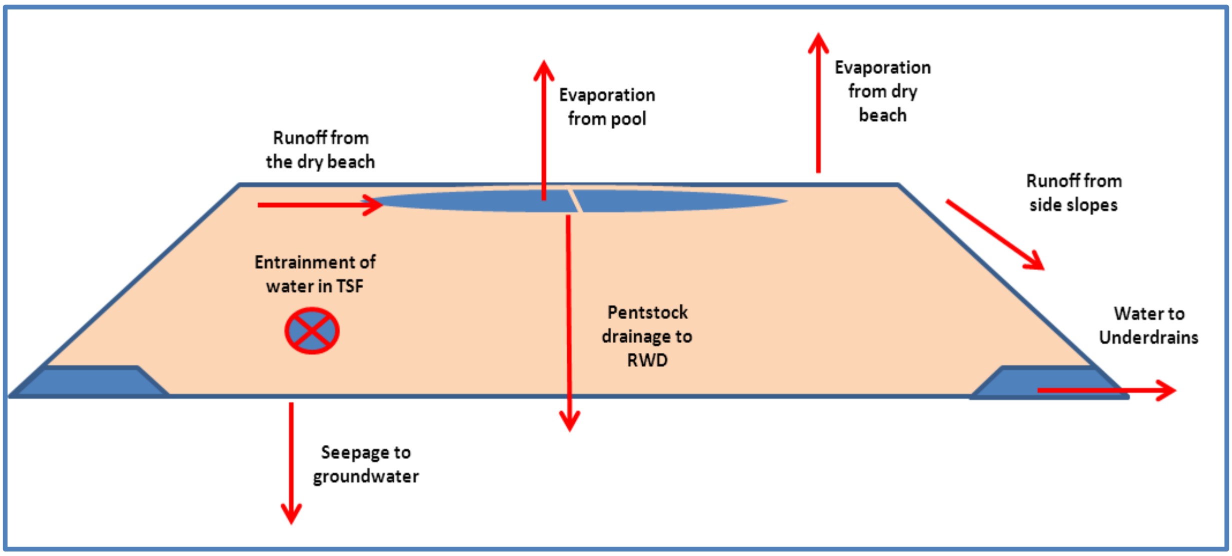

Figure 17: A water balance for a tailings storage facility.

4.1.6 Mines

The details of the underground water system are not specifically modelled. The mine is seen as a black box with water in and water out. An unknown factor on the mines is the fissure water which is difficult to measure specifically. An overall water balance is determined based on the measured inputs and outputs from the underground workings at each of the mines to estimate the fissure water make up. The result of the balance is the fissure water ingress into the workings.

4.1.7 Gold Plants

The gold plants are modelled as a unit without consideration for the details of the water circuits inside the plant boundaries. As with the mines the gold plants is seen as a black box. The runoff from the plant area reports to the gold plant pollution control dams from where water is abstracted for use in the plant. The gold plants receive both potable and process water. The potable water is used in the offices, workshops and change houses. This water is used consumptively and is discharged via the sewage system. Potable water is also used in the gold plant processes such as the elution circuits, chemical make-up and smelting (Mponeng Gold Plant). The potable water used for the process is assumed to leave the gold plants as part of the tailings. The major water demand at the plant is for process water to transport the tailings to the TSF. The available data indicates that about 70% of the potable water is used consumptively with the remaining 30% leaving with the tailings. The process water demand at the Gold Plants can then be calculated as the difference between the outputs and inputs. The outputs are the volume of water associated with the tailings, water in the backfill and the consumptive use (70%) of potable water. The inputs are the water in the ore and sludge, process water from the return water dams and potable water.

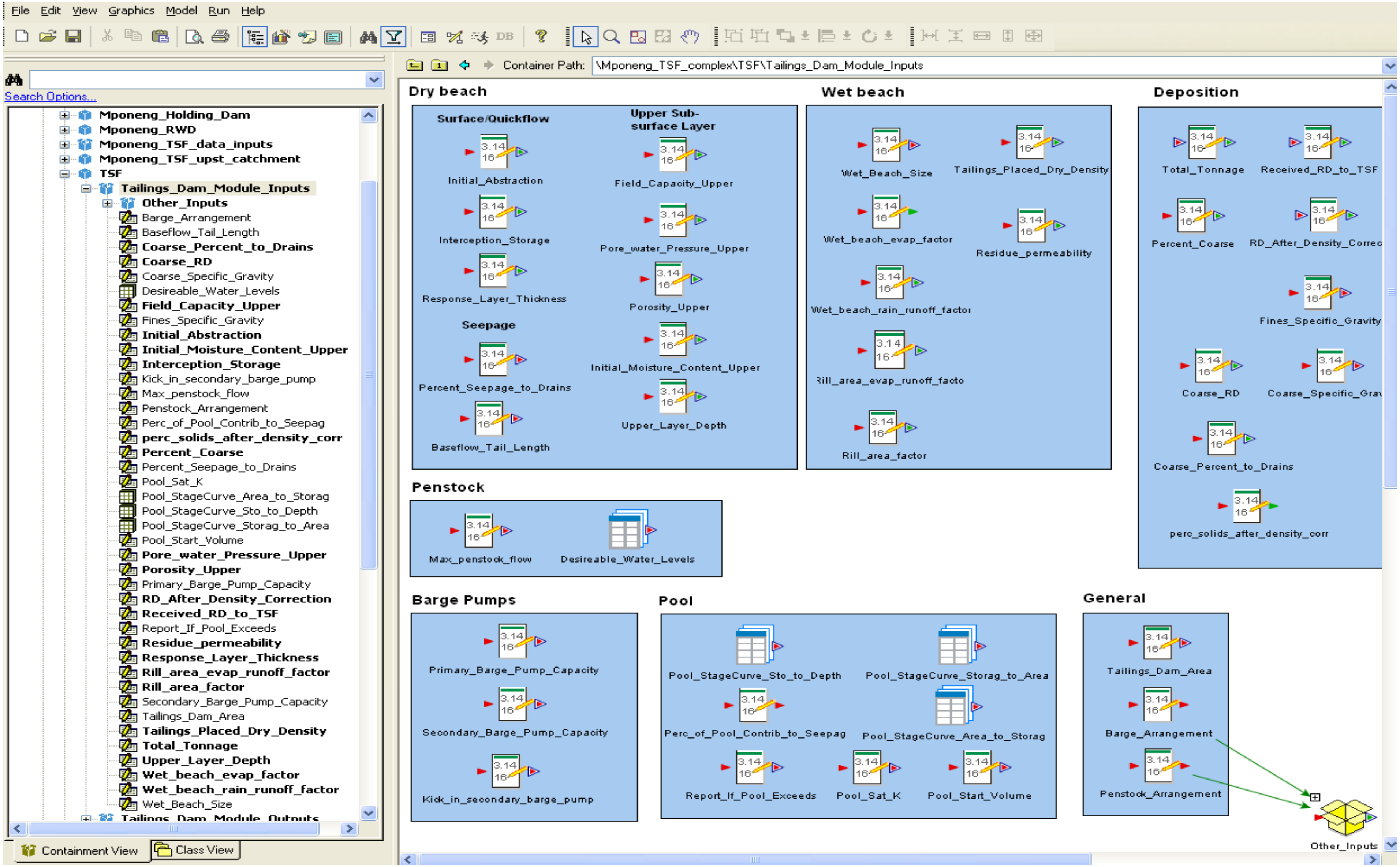

Figure 18: The tailings storage facility module in the GoldSim model for the West Wits operations

4.1.8 Pump capacities

The capacities of the various pipelines and pumping systems are also included into the input spreadsheet. The pump capacities are presented in Table 13.

Table 13: Pump Capacities

Pump line		Capacity (m^3/hr)
From	**To**	
Mponeng Gold Plant Pollution Control Dam	Mponeng Gold Plant	250
Lower Purified Sewage Effluent dam	Numba Wani Residence	10
South Waste Water Treatment Works	Lower Purified Sewage Effluent dam	95
South Waste Water Treatment Works	Aquatic dam	10
North Waste Water Treatment Works	East brick reservoir	26
North Waste Water Treatment Works	West brick reservoir	121
Savuka Gold Plant Pollution Control Dam	Savuka Gold Plant	150
Mponeng Tailings Storage Facility Return Water Dam	Mponeng Gold Plant	185
Savuka Tailings Storage Facility Return Water Dam	Savuka Gold Plant	360
North Boundary Dam	Nursery dams	425
Mponeng Mine Pollution Control Dam	Square Reservoir	250

5. Research Results

5.1 Model application

The WDCS requires the calculation of the waste load to the environment. The waste load is calculated by:

$$L_i = C_i \times Q$$

Where: L_i is the waste load for pollutant (i), measured in kg

C_i is the concentration of pollutant (i) in the effluent, measured in mg/l

Q is the volume of water, measured in m^3 (DWAF, 2003).

In order to achieve this, the GoldSim model was used. All the information as described in Chapter 4 was used to populate the model. The model was applied to the West Wits Complex using the measured meter information covering the period January 2011 to December 2012. A year period was selected as the WDCS will be applied on a yearly cycle. Figure 19 illustrates the GoldSim model as it set up for the West Wits Operations.

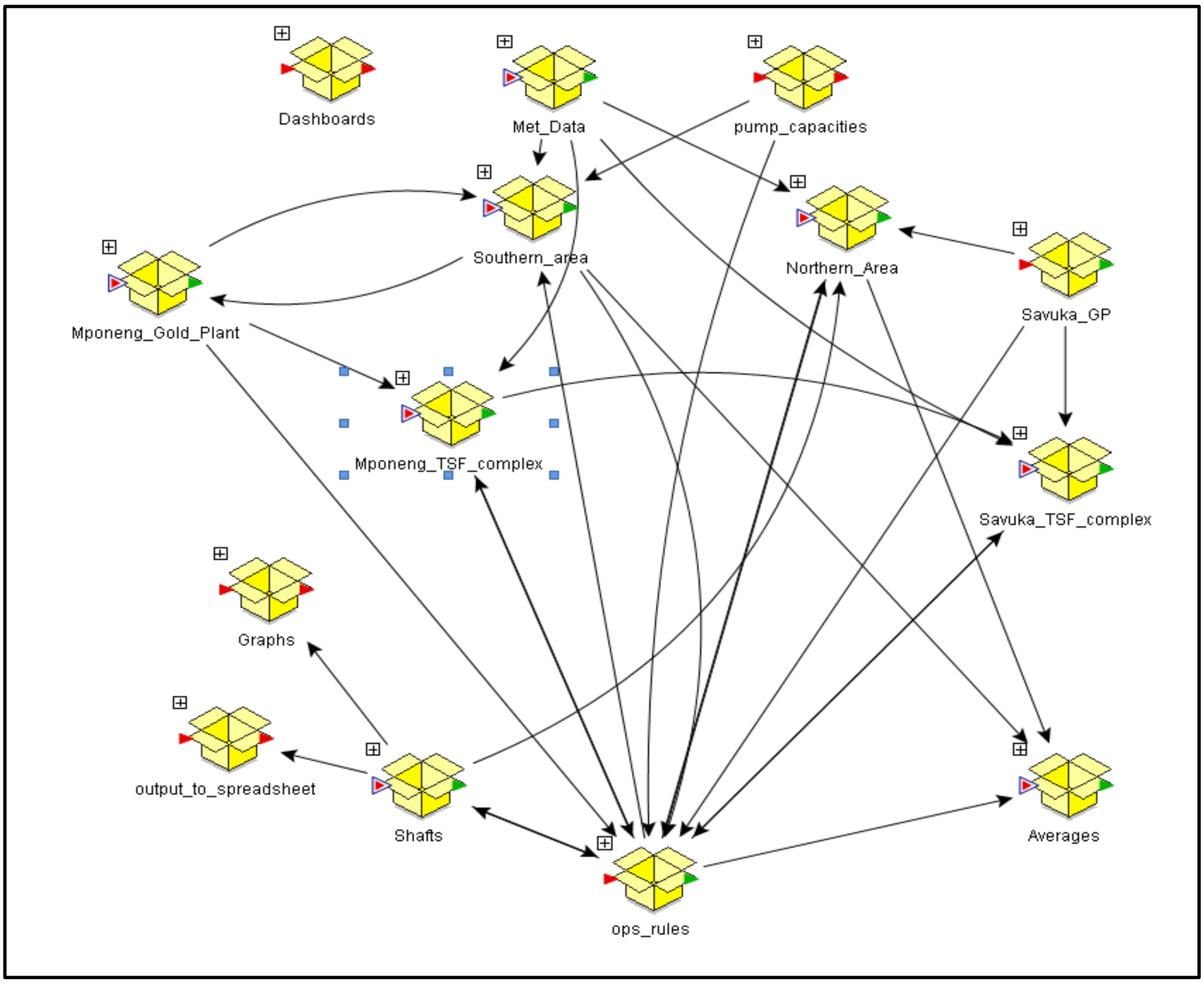

Figure 19: The GoldSim model for the West Wits Operations

The GoldSim model was used to determine the seepage rates from the various identified pollution sources. Figure 20 illustrates how the seepage rates for the identified pollution sources are calculated using the GoldSim model.

A typical constituent that is likely to persist within a gold tailings environment is sulphate. Sulphate is introduced into this environment through the association of sulphides (mainly pyrite) with the gold ore body. Sulphate–rich leachate is generated from gold tailings and waste rock facilities when the sulphide minerals in the dumps are weathered under oxidising conditions in the presence of water (Naickera *et al*, 2003). TSF's at West Wits operations typically contain > 0.7% pyrite. Tailings slurry water and all process water also exhibit significant sulphate values. Sulphate is therefore a convenient constituent to study the movement of pollution from gold mine waste facilities, because:

- is readily available and soluble
- does not decay with time.
- does form readily soluble precipitates and adsorb onto clay particles in the soil and aquifer to a certain extent (GCS, 2007).

For the Mponeng TSF the only available monitoring borehole was MB35 (Figure 12). For the Savuka TSF monitoring boreholes 2, 3, 4, 18, 31, 36, 37, 42, 44 and 45 were used. For the Dormant TSF monitoring boreholes 27 and 31 were used. The sulphate values measured inside the water dams were as used for the quality. The average values for 2011 were used in this exercise. Table 14 presents the diffuse pollution sources and Table 15 the point sources as a balance for each of the identified pollution sources. Waste rock dumps were not looked at in this mini-dissertation due to a lack of information.

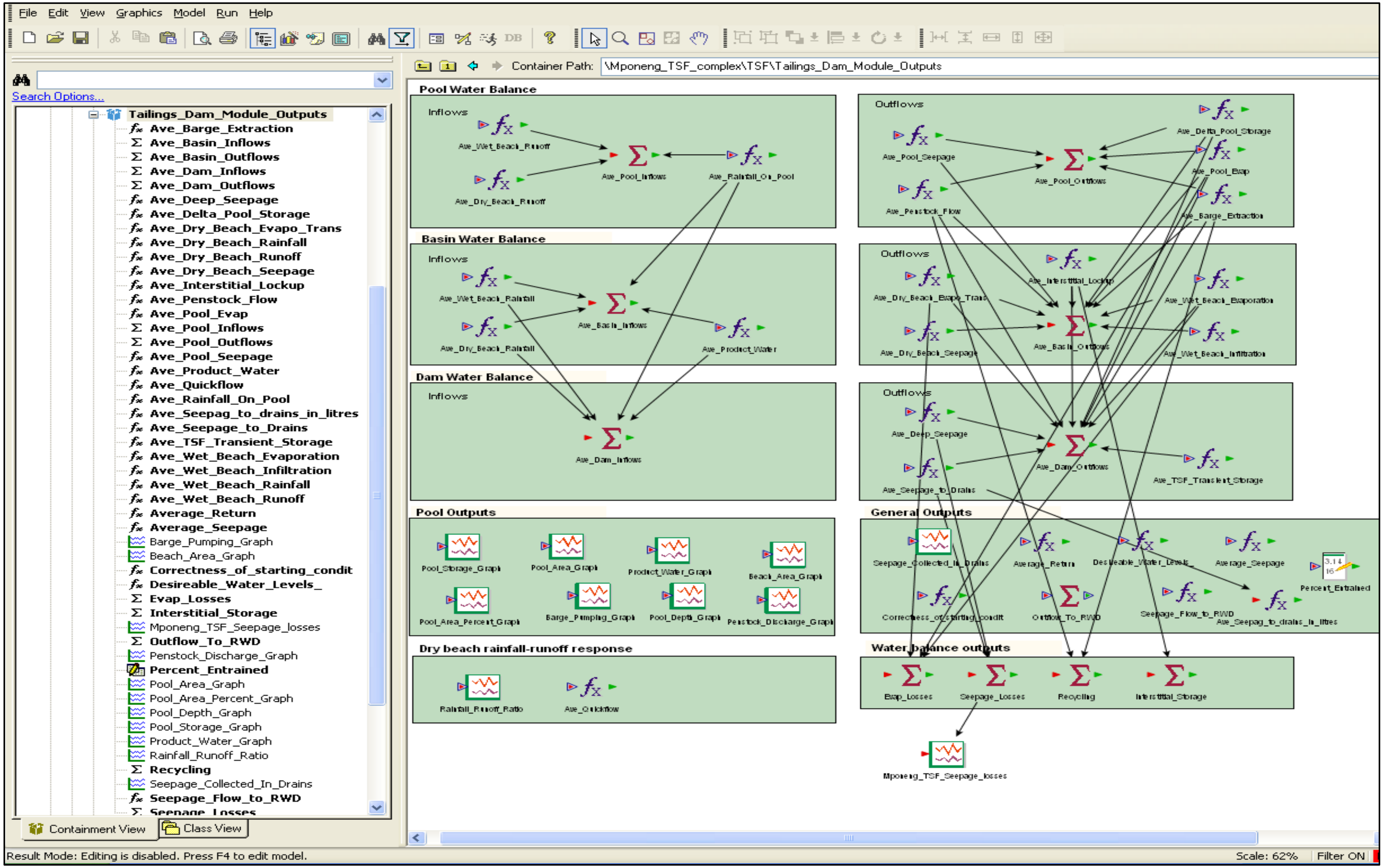

Figure 20: Determining the seepage rate per day using the GoldSim model for the West Wits operations

Table 14: Identified diffuse sources at the West Wits Operations

Diffuse Sources	Seepage Rate m^3/day	Concentration Sulphate (mg/l)	kg/day	kg/year
Mponeng TSF (including Mponeng Holding dam)	2 007 m^3/day	561 mg/l	1 126 kg	410 963 kg
Mponeng Return Water dam	156 m^3/day	1335 mg/l	208 kg	76 015 kg
Lower Purified Sewage Effluent dam	141 m^3/day	1250 mg/l	176 kg	64 331 kg
Savuka TSF	2 637 m^3/day	831 mg/l	2 191 kg	799 842 kg
Savuka Return Water dam and Storm Water dam	1 207 m^3/day	1055 mg/l	1 273 kg	464 786 kg
Nursery dams	199 m^3/day	801 mg/l	159 kg	58 181 kg
North Boundary dam	859 m^3/day	378 mg/l	325 kg	118 516 kg
Dormant TSF	1000 m^3/day	807 mg/l	807 kg	294 555 kg

There are only two point sources at the West Wits operations as per Table 15.

Table 15: Identified point sources at the West Wits Operations

Point Sources	Discharge Rate m^3/day	Concentration Sulphate (mg/l)	kg/day	kg/year
South water care works	2 800 m^3/day	98 mg/l	274 kg	100 156 kg
North water care works	6 000 m^3/day	65 mg/l	390 kg	142 350 kg

5.2 Discussion

A great deal of environmental monitoring data is required for detailed water quality predictions on a mining operation such as West Wits. The GoldSim model can be applied to various situations and scenarios. In the process of constructing the model and scrutinising the data particular areas of importance were identified. The water monitoring programme needs to be accurate as this is a vital component of WDCS. It must be recognized and understood that the successful development and implementation of an appropriate, accurate and reliable monitoring programme requires that a defined structured procedure be followed (DWAF, 2006b). It must be noted that the current water monitoring programme at West Wits was developed over a number of years. The current water monitoring points defined were derived because of a number of issues. These include the following:

- Legal requirements – previous water permits and the current water use license indicate surface and ground water sampling points. These include all the major process water dams. It also indicates the monitoring water volumes that require measurements.
- Pollution sources – the pollution sources with highest risk were identified and monitoring programmes were developed around these.
- Public pressure – to the south of the West Wits operations is the Elandsfontein South farming community who use the water for agricultural purposes. The North Boundary Dam in the northern catchment drains towards the Wonderfontein Spruit. Both these discharge points are constantly in the public eye. The monitoring plan was developed to address the concerns that may occur from interested and affected parties.
- Company procedures – the company procedures and guidelines require adequate representation of the actual situation. This is especially applicable to the groundwater monitoring programme as it informs the ground water models.
- Baseline data – samples are also taken upstream of mining operations to determine the baseline data. The baseline data is used to determine what the impact of the mining operation is.
- Incident sampling – sampling also takes place when an incident occurs. The type, form and extent of sampling are dependent on the incident.
- Environmental management plans – samples are also taken when environmental action plans are implemented. This provides an indication of the success of the implemented environmental action plans

All of monitoring points above forms part of the West Wits operations water monitoring plan, however there will be an overlap between all these points. The locations of the water monitoring points and the frequency of the sampling are derived from the above. Surface water samples are usually taken on a monthly basis, and ground water samples are taken on a quarterly or biannual basis due to the history of sampling and the geological aspects of the West Wits operations. The pollution plumes move relative slowly due to the low resistivity of the geology. These water samples are taken by a qualified person and then taken to a water laboratory with the necessary accreditations.

The WDCS system requires that specific water monitoring is performed at specific points. When a mining operation takes into consideration their water monitoring system in future, they will also have to consider the water monitoring requirements of the WDCS, especially the ground water monitoring programme. New monitoring boreholes should be placed at the most suitable locations to collect the correct data for the WDCS. A monitoring borehole placed in the wrong area or which is too shallow or deep, might provide the wrong quality or flow data.

The mine operation must identify all the known point and diffuse sources of pollution. It must be further established if there will be any long term changes to the point and diffuse sources. Environmental mitigation actions may decrease the pollution while new mining activities could increase the pollution. It is important that a mining operation's monitoring and measurement programme be able to make a distinction between a neighbour's pollution and its own pollution. This will be specially challenging in dealing with diffuse pollution. This makes upstream and downstream sampling exceptionally important. The revised water monitoring should be representative to make sure it includes the water parameters required by the WDCS. This will have obvious financial implications which may include the collection of additional samples when required.

Effective monitoring systems require the following components:

- Surface and ground water quality monitoring systems – it is important that water samples are taken according to standardised procedures to make sure that the results deliver the data and information required
- Surface water flow monitoring system – these flow monitoring instruments must be installed correctly and be placed in the right areas to provide an accurate measurement
- Data and information management systems – it is important to know what the end use of the data will be and who will use the data

A vital part of the data collection process is the analysis of the samples and it is recommended that reliable, accredited laboratories be used that have internal and external quality assurance programmes (DWAF, 2006b). The integrity of the samples can be checked for example by taking a blank sample using distilled water or taking a duplicate sample at the same sampling point.

The values of the data and the reliability of the assessment made are totally dependent on the accuracy and reliability of the collected data.

Probabilistic models, are generally highly complex, data intensive and costly to apply, requiring the services of experts to set up and test each option. This is the same for the GoldSim model. The person managing and using the model requires an appropriate amount of knowledge about the mining environment and the mode itself. It is important to know the flow of water through the mining environment. Any changes must be documented which makes a change management procedure extremely important. Any changes made to the infrastructure must be incorporated into the model to give a true reflection of the output required by the model.

External and internal audits will be required on the WDCS by gold mining companies (in this instance AGA) to ensure the integrity of the system and that the correct and accurate payments are made. Thus the auditing of the water monitoring system will be required. This can be internal and external entities. The auditing of the water monitoring programme will review the methods used in the water monitoring programme and also provide an indication of any gaps in the information. It will have to check the reliability and accuracy of the water monitoring system. It will have to ensure that databases, where the data is stored is secure and that no historical data is lost. The outcome of the audits may ultimately require a change in the water monitoring system.

6. Synthesis

6.1 Conclusions

The aim of this mini-dissertation was to determine the way in which WDCS can be practically implemented in the gold mining industry. Five sub-research questions were formulated in order to answer the main research question. These questions were:

1. **What are the drivers or objectives behind the WDCS and why is it important for the implementation of the WDCS?**

   This question was answered in chapter 2, where the legal mandate was discussed. The legal mandate serves to provide the context for the implementation of the WDCS. The National Water Act (Act 36 of 1998) Section 56 (1) instructs the Minister of the Department of Water Affairs (DWA) to establish a pricing strategy for charges for any water use identified in Section 21 of the Act (South Africa, 1998b). In response to Section 21 DWAF initiated a project to develop the WDCS.

2. **How will the WDCS impact the mining industry?**

   The probable impact of WDCS in the gold mining industry was discussed in chapter 5. A great deal of environmental monitoring data is required for detailed water quality predictions on a mining operation. This data needs to be accurate and reliable, and requires a mine to have sufficient sampling and monitoring equipment in place, placing an extra financial burden on the mine.

3. **What type of monitoring systems will be required to ensure accurate measurements of volume and quality?**

   Monitoring systems and data requirements to facilitate accurate WDCM calculations were discussed in chapter 5. The water monitoring programme needs to be accurate, because it is a vital component of WDCS. Effective monitoring systems require good surface and ground water quality monitoring systems and good surface water flow monitoring systems.

4. **What scientifically sound method can be used to determine point and diffuse source discharges to the water environment?**

   To assist in answering the above a case study was conducted for the AGA West Wits operations as the AGA operations have good historical environmental data available. To assist in determining the point and diffuse source discharges a GoldSim model was developed for the West Wits Operations. Chapter 3 provides some background information on the site and the relevant information that is available for the GoldSim model. Chapter 4 described the modules used in the model and how the model is populated with information. The application of the model is presented in section 5.1. The sulphate concentrations are used as a typical constituent that is likely to persist within a gold tailings environment.

   The GoldSim model is used to determine the daily seepage rates and multiplied with the water quality data to determine the point and diffuse discharges to the environment. This method provides a scientifically sound method to determine point and diffuse discharges.

5. **What type of documentation will be required to ensure a suitable audit trail?**

   External and internal audits will be required on the WDCS by gold mining companies to ensure the integrity of the system and that the correct and accurate payments are made. The method above describes a suitable audit trial.

From the above discussion, it is clear that all objectives as stated in Chapter 1 have been reached. In implementing the WDCS various factors have to be considered that include legal aspects, environmental monitoring and auditing.

6.2 Recommendations

The implementation of the WDCS in the gold mining industry can be a complex undertaking. It needs to be simple enough for DWA to implement a system that is fair and transparent across all mining operations. The system should be understandable to both DWA and the industry. However, it also requires a system that is detailed enough to provide a true reflection of the discharge to the environment. The WDCS should be related to the direct impact cost of the impact caused by the discharge of waste. The charge should therefore be proportional to the impact experienced by the affected parties and must be site specific.

The determining of the point and diffuse discharges require multidisciplinary studies with the integration of different spheres of the environment required. Environmental information about climate, hydrology, geohydrology, water balances and water quality monitoring are required. It is very easy to get lost in all this information. A structured method is required to manage this information. This is what makes the GoldSim model so beneficial to use. It has been shown that where high quality data is combined with conceptual models, and with a versatile platform such as the GoldSim model, it is possible to develop a water quality prediction tool. Using a probabilistic model with Monte Carlo simulations allows for a flexible approach. The WCDS requires an integration of a wide range of data in the environmental field. These tools could help AGA to predict the diffuse and point pollution sources from a range of pollution sources.

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