TECHNICAL NOTE

An assessment of Kalgoorlie Consolidated Gold Mines and Boddington Gold Mine water sources and proposed water auditing framework underpinning improved water allocation compliance and reporting

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Introduction

In Australia, State water sectors are experiencing reforms associated with the National Water Initiative (NWI) that will change the regulatory environment to modernise the water sector and encourage acceptance of dependable approaches. The NWI relates directly to one of the (WA) State Water Allocation Strategies and that is to improve water resource auditing, which will underpin sustainable water resource management and efficient water markets (WRIC, 2007). Subsequently, WA's regional consumptive pools of water used by a broad range of stakeholders are shaping up to achieve water security via water balance auditing and water efficiencies leading to water conservation (Department of Water (DoW), 2007). Measuring the water 'life cycle' of one component within the spread of allocations enables the sustainable development reporting mechanism to function as an example for other mine sites to follow suit (Cote *et al,* 2007). This paper is part of a progressive evaluation of five case study Newmont mine sites that differ in respect of mining and hydrometallurgical recovery of gold within negative and positive water balance scenarios. The KCGM case study looks at water flow volumes in the dry desert region of Kalgoorlie. The areas negative water account based on low average rainfall impacts on a range of water sources, uses and discharges at KCGM. The second case study involving BGM enables Newmont and CSRP to evaluate a potentially water positive placed mine site in the medium to high rainfall region of Peel, 150 km south of Perth. Once BGM commence mining operations both KCGM and BGM gold mines will be on a similar scale in terms of gold productivity yielded annually. This paper examines water distribution at both mine sites and evaluates the regional impacts of their water requirements and capabilities to accurately report on water use moving forward. Each case study is based on sustainable water sourcing, usage, recycling and reusing of (worked) potable and non-potable water to maximize water use. Recycled water is the proportion of water that is used in a unit operation after it has had some form of remedial treatment whereas, water reuse is the component of worked water reused in an operational task without any pretreatment. Water reuse is the sum of raw water over the sum of worked water used in a measured period of time (Sturman, Ho and Mathew, 2004). At both gold mine operations conceptual water flow diagrams were generated to determine the potential to conduct site wide mass water balances and auditing exercises. By conducting quantitative life cycle analyses through the production of flow diagrams an optimal target of water use, reuse and recycling can be achieved. Based on KCGM's forecast of increased intensity of gold production and a decrease in raw and potable water inputs (see Figure 1) other options were considered to further diminish raw and scheme water usage. For example, the recycling of treated town wastewater or at BGM, treated village accommodation wastewater for process water make-up decreases the need for raw water demand. That is, the increased use of Kalgoorlie/ Boulders discharged treated wastewater to boost process water stocks and similarly at BGM via their recently commissioned large-scale accommodation village. Through cause and effect, improved technology in extractive hydrometallurgical processes has increased the use and potential recycling of non-potable water (Habashi, 2003). For example, at KCGM targets were achieved to decrease overall water use while extraction of ore and recovery of gold intensified (Figure 1).

The aim of this paper is to develop a framework for water balance assessment at both KCGM and BGM case scenarios. Through a replicable, structured analysis of water reporting it provides the basis of a water management strategy that includes a water quality hierarchy and possible assessment tool coupled with set of water auditing procedures (Guerin, 2006). In light of climate change and probable water scarcity, the water auditing framework will, in the future, provide accurate water usage data and other steady-state inputs for probabilistic forecasting. This form of water modelling asserts a mine sites future water needs and water availability based on climatic predictions, impacts on groundwater and aquifer draw-down and relative levels (RL) of tailings storage facilities and residue deposit areas.

Methodology

The water auditing process

With environmental auditing as described in ISO 14000 the process of conducting a separate water audit is recommended (Whitelaw, 2004; Sturman, Ho and Mathew, 2004). In order to conduct a thorough water audit the processes can be described as follows; water auditing is a repetitive, systematic and documented operation of objectively measuring the balance between water inputs and outputs within a specified time and audit domain (Sturman, Ho and Mathew, 2004). A water audit is undertaken for several reasons and may include the need for a corporate enterprise to further enhance a green image with their environmental reporting. The reputational benefit that this provides eases community pressures and concerns about for example; drought conditions being experienced and the ability of an enterprise to maintain sustainable environmental water flows both above and below ground. Accurate measurement and responsible management of water sourcing and use may also be necessary with the introduction of new water allocation regulations and laws (Water Reform Implementation Committee (WRIC), 2007) as agreed under the NWI (DoW, 2007).

The purpose of a water audit report is to identify with the processes required to carry out an audit and to detail the degree of accuracy of water use within a specified audit domain. It commences by drawing up a contents list that covers such items as the number of participants, a briefing report, a description of the audit domain including future changes to infrastructure and processes. Once a water flow diagram has been designed and produced the audit domain is identified and specific systems and processes are highlighted. These include water sources and sinks, recycled and reused water cycles, flow quantities, options for improved water use efficiency and a management strategy including a water audit process review (Sturman, Ho and Mathew, 2004).

Audit brief

The initial audit brief is designed to identify the scope of the audit and its objectives. It leaves the reader in no doubt as to the starting point conditions through to final closure. It may contain requests from the auditor based on a previous site visit and the initial field trip report where concerns are first identified in terms of achieving water audit closure. Audit closure is achieved when the comparison of water input flow rates and water output flow rates are balanced within a prescribed tolerance of <10 per cent gain or loss (Sturman, Ho and Mathew, 2004).

Introduction

The introduction is supported by the brief and documents reasons why the audit should be undertaken. An overview of the auditee's current water management strategy is discussed and any relevant criteria are raised to underpin the audit's influence over predicted improvements in efficiencies and water conservation measures. In addition, the inclusion of any foreseen structural changes and corresponding economic and financial impacts forms an important backdrop to the audit and decisions relating to any recommended changes to the water management strategy as a result of the audit.

Description of Kalgoorlie consolidated gold mines and Boddington gold mine sites

Normally a description of site is covered in the introduction however, given the complexity and vastness of both the KCGM and BGM operations, requires a separate narrative of the water audit domains. For instance, at KCGM two process circuits treat gold ore and a separate roasting facility, the Gidji Roaster, is 20 km away from the main Fimiston treatment plant. Ore is extracted from the Fimiston Superpit and the Mt. Charlotte underground mine. At BGM the site footprint has remained fairly constant however, infrastructure changes have taken on a vast and complex refit during the expansion project. Future changes taking place in terms of water sources, uses and discharges include the potential for increased use of recycled treated wastewater at both sites. A reduction in potable water intake is due to improved processing technologies and increased recycled and reused water for KCGM. Furthermore, the addition of the recommissioned Kaltails tailings storage facility (TSF) to run in parallel with the Fimiston TSF will impact in a positive way (Van Maanen, 2007). Water sources include scheme water piped from Perth, saline water abstracted from nearby bore fields and deeper abstraction of hyper-saline (paleo) water. In addition to these water sources, seepage recovery takes place and is pumped to the process water dam and (supernatant) tailings water is decanted and reused from the tailing storage acilities (Van Maanen, 2007). Water quality is also discussed and plays an integral role in terms of classifying water towards unit operations, recycling/reuse and fit for purpose usage (Sturman, Ho and Mathew, 2004). At BGM one of the main raw water dam's capacities has been reduced by backfilling up to half its volume to make way for a waste rock stockpile. As a result, increased raw of local surface flow into two large pits at BGM, will be augmented through a water allocation application to the DoW as with the previous application, for water to be abstracted from the nearby Hotham River system.

Site visit, pictorial report and flow diagram

This section lays the foundations for a water audit to take place. It determines the sources and of water availability, the input flow rate, process (unit operation) flow rates, discharges and in the case of mining water uses, seepage recovery and decant return. It evaluates rainfall/run-off, evaporation/seepage, non-potable and potable water uses. The flow measurement instrumentation and accuracy are discussed and recommendations are put forward in terms of compiling relevant information and data to perform the auditing exercise. This form of reporting can be presented by way of a pictorial field trip report that can illustrate the areas of deficiency for a particular area of concern.

Data gathering and water measurement evaluation

A site visit prior to the production of a water balance model is critical both in terms of determining what infrastructure is in place to accurately record water movement and what needs to be added to existing pipe work in order to complete the full picture of water usage and water quality. At both KCGM and BGM water transfer pipelines are monitored via electro-magnetic flow meters that report to a centralised electronic display and database. With smaller sized pipelines rotary flow (turbine) meters that measure the water flows in cubic metres are either read manually or data-logged, reporting to an electronic data-base in the respective control room operations. The data is detailed in a way to provide information not only on the breakdown of volumes and flow rates of water use per unit operation, it also highlights areas deficient in regular reporting of water flows and for example; lesser quality water used in dust suppression. The unit operations are well documented and each flow rate reports electronically via data displays and readouts either to mill operations or the environmental departments on a regular basis. In the context of a future water audit preparation, other retrieved data is scaled down from ML to kL from yearly water usage reporting in environmental and operational departments of Newmont's goldmine sites. In most mine sites, water use records are maintained via Data Acquisition Workbooks (DAW). However, yearly production of water use data in a DAW does not provide a satisfactory account of for example, weekly water cycles and particularly for a peremptory flow chart diagram that supports a short term water audit exercise. The timeframe is such that a snapshot of water use over the water audit domain within for example; one week of normal operations, aims to achieve closure of the audit within a ±10 per cent tolerance of water losses or gains.

Results

The water audit process commences with a review of the audit scope and objectives. It is seen as a separate process to environmental auditing ISO14000 in that quantifying and qualifying water use for the purposes of auditing water is covered in part by ISO 14010 and 14011:1996 (Whitelaw, 2004) and then fully documented in the form of a systematic, water audit process. Once the guidelines have been established the schedule is drawn up and may include a selection list of the people that would contribute to, and or be part of a water audit team. Resources are also tabulated in the context of availability and resources that may be required and would need to be introduced into the audit process and for example water meter calibration using either a clamp-on acoustic doppler velocimeter or ultrasonic meter for both large and small-scale volume water measurement. In preparation of a proposed water audit, a flow diagram of the water audit domain is prepared and identifies water sources including rainfall, the number of unit operations, water reuse/recycling and water sinks including seepage/evaporation (see Figures 2 and 3).

Once a site-wide water balance schematic has been produced, future changes to operations and processes are weighed against the financial capacity for implementing change and the economic justification to do so within the scope of water conservation. The collation of data from an initial site visit underpins a methodological approach towards conducting a water audit and achieving a foreseeable outcome in terms of audit closure. This also integrates with the resources on hand and the ability of the mining company to provide additional support for ongoing measurement and assessment of the water balance account.

In a typical water balance flow chart water inputs and recycled water are highlighted in blue and water usage, losses and discharges are in red font. As with all water balance models a temporal perspective is denoted and a time frame of water usage for the whole of the KCGM operation is illustrated (Figure 2). Whereas, BGM is yet to commence operations and therefore a schematic has been prepared in order to complete the water flow volumes when operations are underway.

Water quality testing and appraisal is integral to water auditing and provides a fit for purpose classification schedule that determines the scale of water recycling and reuse. Therefore, water sampling and monitoring is inclusive of the methodology required for water efficient and conservative measures to be adopted within the water audit domain (Table 1).

The material mass-balance of water is therefore a quantitative and qualitative measurement of flow dynamics and water make-up. Water input is quantified and classified from its origin or source, filtration measures are accounted for including for example; discharged brine wastewater. Water outputs are metered and assessed for level of quality as to either a water sink or for reuse. Decanted water from the TSF is metered and piped back to the process water tank to be recycled into the front end of the process. Once all water streams have been accounted for including evaporation rates, seepage recovery and water used in dust suppression the water audit may achieve closure. A water audit framework is summarised in Table 2 and draws in all the aspects from initial steps required to prepare for an audit through to activities undertaken during the audit and actions needed to be presented in order to summarise the results in the form of a water management strategy.

Evidence supporting water audit closure is provided in a final report. This underpins a guarantee that minimal water losses are incurred through an accountable raft of data and findings. A diagrammatic overview can be produced and is summarised by a final phase of audit reporting. This may include reporting via a feedback mechanism and liaison with the water audit team followed up by a summary and recommendations of water efficiencies leading to water conservation for the site. The final outcome is a presentation of findings and appropriate closure format directed to the client/auditee. This would include a water management strategy that describes a reporting mechanism towards continuous improvement in water allocation compliance and reporting.

Discussion

Water management strategy

Meteoric inflow and groundwater flows are monitored in terms of providing make-up water such as seepage recovery and decant return at both KCGM and BGM for the duration of mine operations. Therefore, strategies are in place to manage a site's environmental performance regarding water use and discharges in relation to specific mine and metallurgical processing. They include the provision of a site-wide water balance to make available effective monitoring of water flows based on establishing best practise towards operational goals in water management. The inclusion of key performance indicators to be put in place to define and measure progress towards mine water usage and management, then ultimately achieving environmentally sound water recycling and reuse (Loh, Deegan and Kite, 2000). Ongoing monitoring programs assist with providing information towards this operational goal. The scope of a site's environmental program underlines the need to proactively manage impacted water through the agency of a site-wide water balance and a site-wide planning tool. Some examples of a strategic approach include the boosting of non-process water influxes via the use of treated wastewater from a local town or nearby village accommodation. A probabilistic methodology is applied to water auditing and availability of site data for ongoing operations leading to mine closure. It includes the risks and costs related to for example; acid water collection and its conveyance and treatment under normal and extreme events. The design and engineering of TSF/RDA dams is such that excess non-process water directional flows are intercepted by lined holding ponds at downstream junction points at certain intervals from the TSF/RDA embankments. The strategy must also include the potential impacts of mine and metallurgical operations on downstream users and the downstream hydrological regime. Therefore, a probabilistic evaluation of regional watershed infiltration, base flow and interflow is simulated to assist with forecasting stormwater runoff, seepage volumes from tailings, pits/declines and undisturbed watersheds.

Site-wide water management planning assists with understanding and quantifying the mine's hydrological environment. It analyses the potential impacts of uncertainty on complex interrelated water systems in which the mine and metallurgical process operates. It proactively determines the impacts of mining on water quality and quantity serving as a platform for continuous improvement towards successful environmental monitoring programs that require forecasts of capital and operational costs related to water management. An assessment model of a site-wide water balance is conceived to form a clear understanding of the system to be modelled. Building a conceptual model involves dividing the system into a series of linked subsystems, defining the key components and there relationships, highlighting all relevant feedback mechanisms (Letcher, Croke and Jakeman, 2007). Mitigation measures are built into design features of life-of-mine (LOM) plans and include optimisation of systems to collect, convey and treat acid rock drainage ARD and other impacted water (Madin, 2007).

The appropriate management of water diversion, collection and treatment is central to the effective control of environmental conditions over KCGM/BGM's mining lease areas. Typically, sites with an effective water management strategy, underpinned by an ongoing water auditing process, maintain a water balance model as an effective tool for informed risk-based decision making. However, the effectiveness of this is complex when considering the definitions and processes of all parameters and can be summarised by the following impacts to gold production and probabilistic modelling. Climate, surface water, groundwater, facility layout and material or geological characteristics of gold ore are a combination of all the major elements. The combinations of these physical impacts are assembled in such a way as to provide a practical and consistent water management strategy format. The model recognises uncertainty and is probabilistic in nature taking into account the variability inherent in the prediction of various inputs to the model (Cote et al, 2006). Therefore, the model is simulated at time step frequencies appropriate for the location and maintained through inspections, monitoring and physical updates as a function of changes in mine plans or facility conditions. Continuous improvement of maintenance procedures support site operating procedures and a structured methodology monitors key performance indicators for ongoing full compliance of water allocation quotas and discharge consent. Water management strategies are most successful when using a structured methodology and the framework supports the full spectrum of mine planning and decision support activities.

Conclusion

A water management strategy is underpinned by the ongoing support of structured, repeatable and thorough water auditing processes (Sturman, Ho and Mathew, 2004) that will enable any one mine site to align with environmental compliance and reporting on their water intake, usage and discharge. A theoretical water audit framework has been established to provide both KCGM and BGM sites with a general overview of water source and usage options. The paper was written to establish a framework of water auditing in line with proposed changes to water rights and water allocation for mining operations in WA. State water sectors are now generating reforms and improvements to all water users who are dependant of an over-arching State consumptive pool. Through the framework of the NWI, State water strategies aim to sustain and modernise the regulatory environment of water sourcing, use and discharge of worked or impacted water from human activities. The measurement or auditing of quantitative and qualitative aspects of water ‘life cycles’ in mining, within the spread of water allocation, strengthens the requirement for future water availability of LOM leading towards inevitable mine closure.

Acknowledgement

This article was originally presented at the Australasian Institute of Mining and Metallurgy (AusIMM), Water in Mining conference, which took place in Perth, Australia on 15th – 17th September 2009 (www.ausimm.com.au/wim2009/).

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Figure 1. Comparison of Kalgoorlie Consolidated Gold Mines (KCGM) water uses and ore/gold throughput

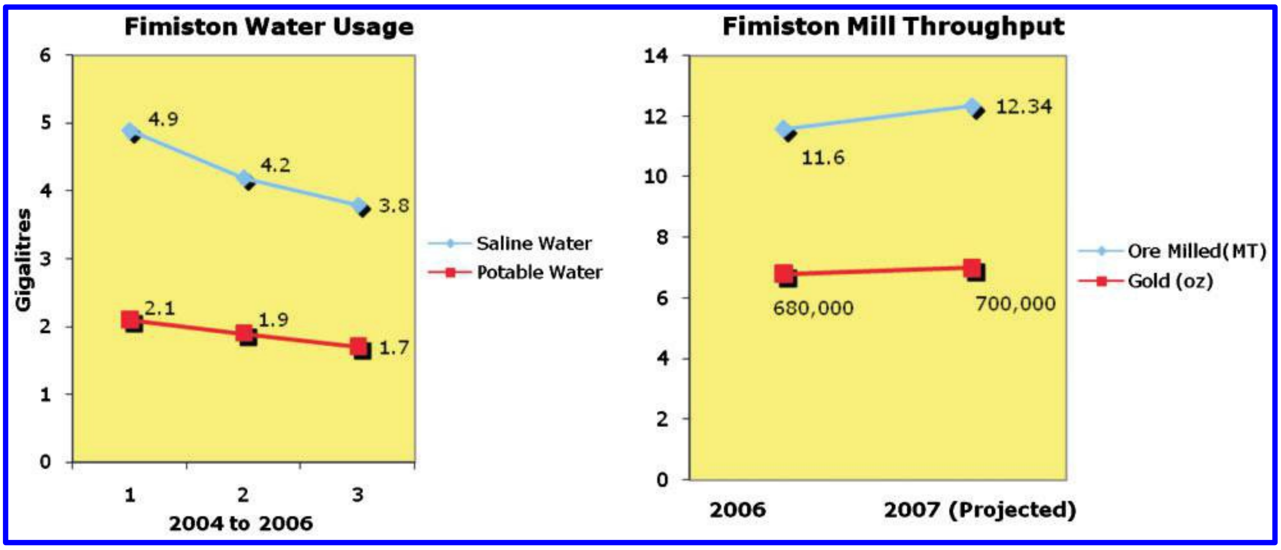

Figure 2. KCGM (Kalgold) – Fimiston, Mt Charlotte and Gidji roaster operations water circuit diagram (annual usage 2007)

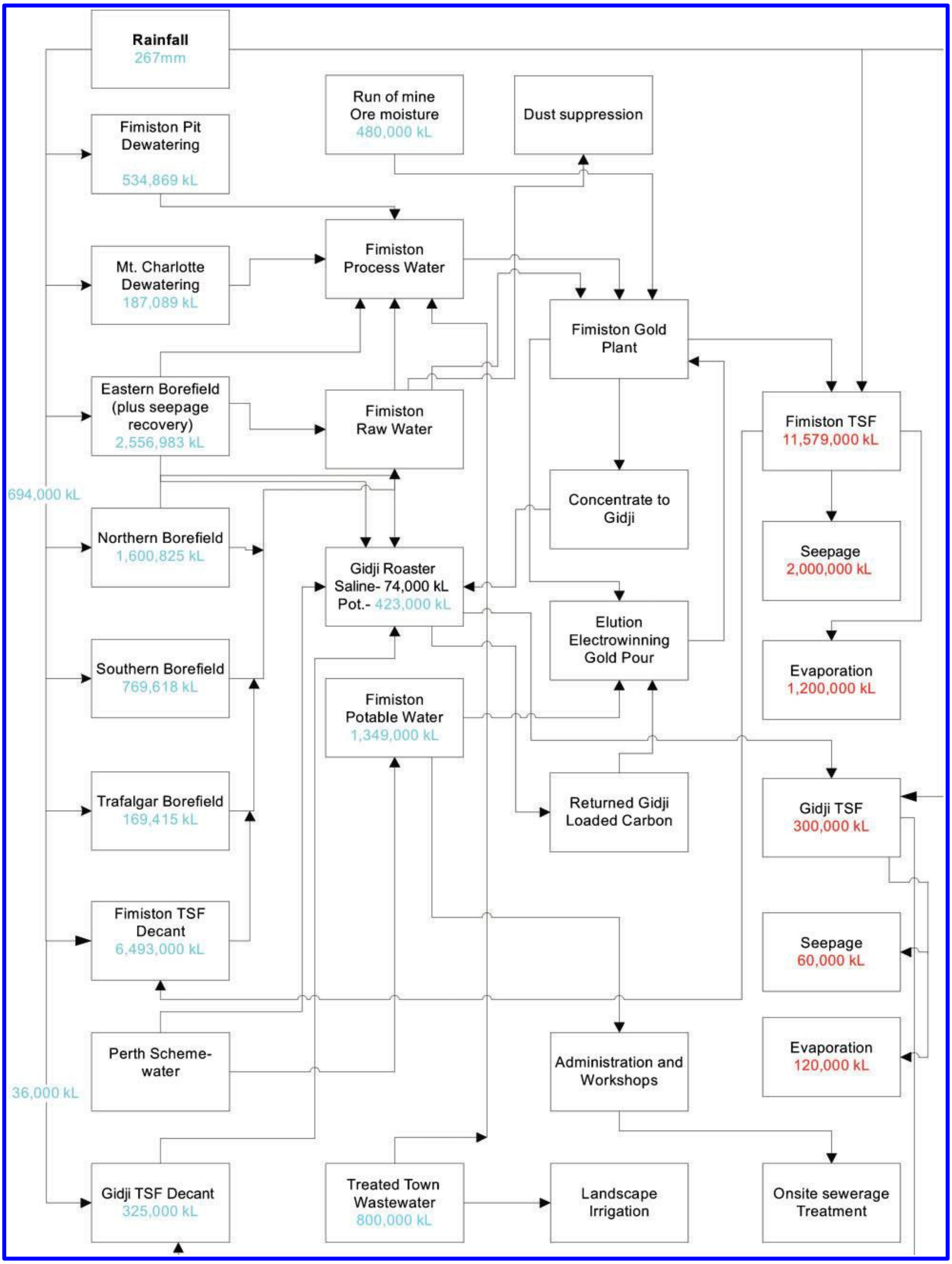

Figure 3. Boddington Gold Mine water circuit diagram (Expansion Project, 2009)

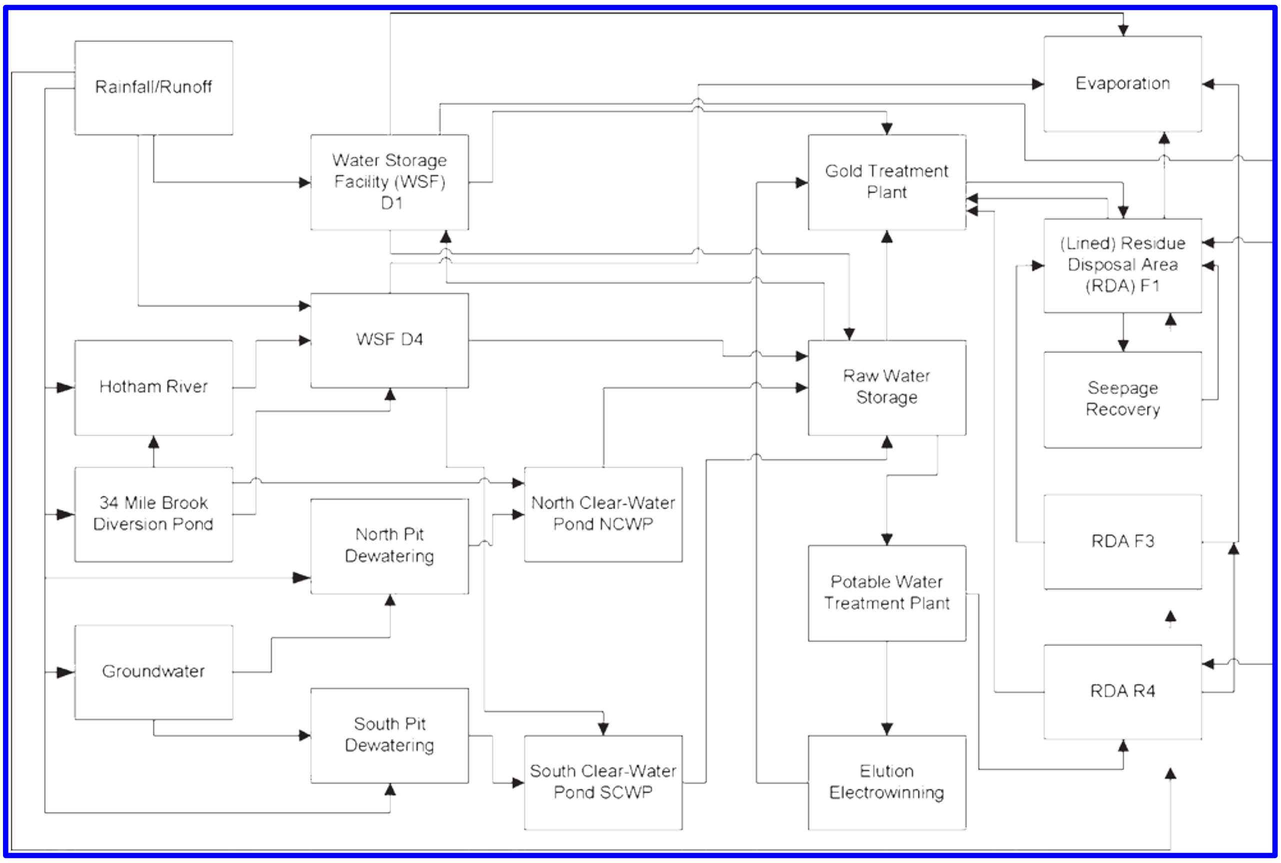

Table 1 Hierarchical water classification table for goldmine water usage

Water Source	TDS	Mine function	Approximate age	Classification
Potable	<1500 mg/L	Accom/ops elution	1%	Scheme
Bore potable	<1500 mg/L	Accom/ops RO – elution	5%	Fresh/filtered
Bore brackish	1500–15 000 mg/L	Hydrocyclones	20%	Raw
Barren eluate	<15 000 mg/L	Sag/ball mills	Up to six cycles of reuse	Reused process
Meteoric	Variable	Tailings dam Water storage	Variable	Raw
Tailings decant	15 000–35 000 mg/L	Sag/ball mills	Up to 60% of raw water inflo	w Recycled process
Bore saline	<35 000 mg/L	SAG/ball mills Dust control	20%	Process
Paleo-channel hyper-saline	35 000–120 000 mg/L	Dust Control	Variable	Non-process
Treated wastewater	<15 000 mg/L	Revegetation/tailings dam	<1%	Recycled

Table 2 A summary of a water audit process

Water audit steps	1	2	3	4
Preparation	Initial site visit and data collation exercise	Prepare site wide water schematic and *Contents list	Calibrate all testing equipment	Arrange drug/alcohol screening, flights and accommodation
*Contents list	Identify audit participants	Site (domain) description	Identify water sources/sink	Prepare and send water audit brief
Site arrival preaudit setup	Locate accommodation and commence site induction process	Meet with water audit participants and identify various roles	Prepare strategy for temporal/spatial water audit process	Undergo site-wide entry permit process
Commence water audit	Synchronise and record water audit meter readings with team	Prepare excel spreadsheet for data entry	Identify and monitor unit operations	Measure and record tank/ reservoir capacities
Meter calibration	Locate and fix pendant data loggers to turbine meters	Locate and prepare all ultrasonic meter testing sites	Input pipe specifications, set transducer spacings	Clamp-on or tie-on transducers and record flow-rates
Water quality	Log in all water quality testing sited	Test and record water types for turbity, pH, temperature and TDS	Measure and record flow rates for non-water audit quality testing sites	Produce site water classification table
Achieve water audit closure and prepare audit process review	Synchronise and record all water audit meter readings with team	Summarise and calculate water flow volumes from excel spreadsheet	Identify water audit barriers and challenges for reporting mec hanism	Produce water audit closure table and process review
Water management strategy	Collate all qualitative and quantitive data	Online water efficiency strategies	Summarise water audit process and steps for continuous improvement	Produce paper/ppt for mine site feedback mechanis