Water Accountability and Efficiency at a Base Metals Refinery

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ABSTRACT

Most mineral processing plants have high water requirements for their operational activities. These plants often function in an environment where water is becoming increasingly scarce. An increase in population will result in an increased demand for water; potentially beyond the limits of supply and hence increased competition for the resource. In South Africa, Gauteng and the North West Province are likely to be first to experience a shortage of potable water.

In order to avoid a water crisis, efforts must be made to ensure the effective management of water resources and the minimisation of wastage. Hydrometallurgical plants have a responsibility to society and the environment to operate in a sustainable manner – reducing their water requirements will certainly assist towards developing a sustainable footprint.

This project improved site water management by:

- surveying the potable water and storm water systems with a view to assessing the current water accountability and determining methods to improve accountability
- determining the monthly and yearly water balance for the site and presenting it in the form of a water balance sheet
- drawing up an input–output and operational model in accordance with the Minerals Council of Australia's 'Water Accounting Framework for the Minerals Industry'
- calculating the water footprints of the refinery
- identifying ways in which water savings could be achieved
- recommending management systems for water usage monitoring.

This work was conducted in South Africa. The value of this work lies in that it established the current baseline and assisted in developing management systems that can reduce water usage sustainably.

INTRODUCTION

Access to safe water is a basic human need. However, globally, over a billion people are unable to access a safe water supply and of these people, 28 per cent are found on the African continent (World Health Organization, 2000). By 2015, it is forecasted that most of the world's population will be suffering severe water shortages due to population growth experienced and mismanagement of water resources. In South Africa, Gauteng and the North West Province will be the first to experience the shortage of potable water. In order to avoid a possible water crisis in the near future, efforts must be made to ensure the effective management of water resources and the minimisation of water wastage.

Most mineral processing and hydrometallurgical operations have large water requirements. These plants often function in an environment where access to water is becoming increasingly competitive. Hydrometallurgical plants have a responsibility to society and the environment to operate in a sustainable manner and consequently they seek to minimise their potable water consumption. Implementing water accounting and other best practice guidelines can assist in this aim.

Recognising the important role of water in the mining industry, the Minerals Council of Australia (MCA) developed a water accounting framework. The framework allows sites to account for, report on and compare site water management practises in a consistent manner. It is expressed in the form of a water balance displaying inputs, outputs, water storage or accumulations and water losses (MCA, 2012).

An alternative method of representing water usage is water footprinting (WF) (Hoekstra *et al*, 2011). WF is the total amount of fresh water that is consumed, directly and

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indirectly during a production process. WF is presented as units of water consumed per unit of product produced.

This research is aimed at the study of water usage and efficiency at a base metals refinery (BMR) in South Africa. The refinery operates using a hydrometallurgical process which is largely dependent on the availability of fresh water. The refinery wishes to reduce its potable water consumption. The first step towards meeting this aim is to be able to account for all the water used, which is referred to here as water accountability (analogous to metal accountability). The aim on site is to improve the water accountability to greater than 95 per cent. This is to be done by physically verifying the water reticulation system and recommending additional flowmeters. The second step is to draw up a basic water balance for the base metal refinery. The third step is to prepare a water balance in accordance with the MCA Water Accounting Framework. Thereafter, a water footprint is calculated. The final step is to recommend ways in which the BMR can reduce potable water usage.

WATER ACCOUNTING AND WATER FOOTPRINTING

Two tools were used in this study:

1. the MCA Water Accounting Framework, which targets the simple and efficient reporting of water usage
2. the water footprint, which quantifies the total amount of water required to produce one unit of a product.

These two methods are reviewed.

Water Accounting Framework

The Water Accounting Framework uses a combination of data and estimates of water usage in a standardised reporting platform. This standardised format allows the water accounts to be used across industries and governments in a more consistent and transparent manner.

The Water accounting framework consists of four reports:

1. The input–output statement describes the flows between the environment and the boundary of the site. It refers specifically to all inputs, outputs and diversions from site to the environment and vice-versa. Each water input or output is categorised as follows:
   - Category 1 water is very close to drinking water and requires minimal treatment (for example, disinfection)
   - Category 2 water requires treatment to remove dissolved solids and adjustment of other parameters before the water is classified as potable
   - Category 3 water is unsuitable for most purposes and has a salinity of greater than 5000 mg/L or has a pH of less than four or greater than ten. This water requires significant treatment before it can be classified as category 1 or 2 water.
2. The statement of operational efficiencies is presented in the form of an operational model which describes internal site water flows in a process. The operational model includes water flows between storage facilities on-site to tasks and treatment points.
3. Accuracy statement consists of a list of flows that were measured, calculated or estimated. This report is combined with the input–output model.
4. Contextual information reports on water resources of surrounding regions, such as infrastructure and catchments.

For this study, the input–output model combined with the accuracy statement was used. Contextual information is provided with the water balances and is not presented as a separate report.

Water footprinting

WF was developed as a method of measuring and understanding water usage in the production process (Hoekstra, 2003; Chapagain and Hoekstra, 2004). The water footprint is the total amount of water that is consumed, directly and indirectly, during a production process. The water consumption separates water usage by type and quality. A full water footprint evaluation considers not only the water consumption and its impact, but also recommends measures to reduce the consumption or impacts associated with production.

WF is presented in units of water consumed per unit of product produced. WF is quite different from carbon footprinting in that WF needs to be considered as a function of the locality in which the assessment is being performed and how different types of water are being used or squandered. WF creates awareness as to where the largest consumers of water are located.

The total water footprint is the sum of the blue, green and grey water footprints as shown in Figure 1 and Equation 1.

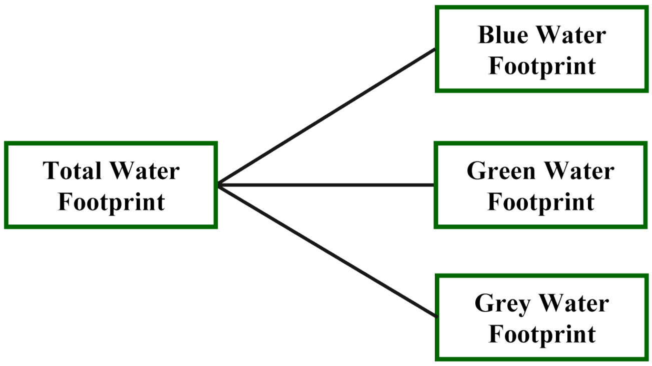

FIG 1 - The total water footprint is a sum of the blue, green and grey water footprints.

$$\text{Total Water Footprint} = \text{Blue Water} + \text{Green Water} + \text{Grey Water} \quad (1)$$

Blue water comprises fresh water resources such as surface and ground water that is not returned to the same source. Green water is rainwater used during the production process, which could have been stored in the soil or temporarily on top of the soil. Grey water refers to water that is polluted. It is quantified as the volume of freshwater that is required to dilute the pollutants to either the natural background concentration or the required water quality standards.

METHODOLOGY

This study was performed in the following five stages:

Stage 1: The flowmeters and pipelines of potable water, steam, process and rainwater (dam) lines were physically verified, a database of existing flowmeters drawn up and the water reticulation diagram updated.

Two aspects of the physical verification were addressed. The first aspect was the verification of the piping layout and the second was the verification of the flowmeters. The water reticulation system was verified by walking all the water lines from source to usage. The flowmeters were identified, photographed and recorded into a database.

The information from the physical verification was used to update the water reticulation diagram for the overall plant and each processing section.

Stage 2: A basic monthly and yearly water balance for the base metals refinery was established. For this work, it was presented in the form of a water balance sheet.

Site values from flowmeter readings were used to generate a site water balance. The balance was summarised in a monthly balance sheet which included changes in inventories (that is, dams) where possible. Changes in rainwater dam levels were used to calculate monthly inventory changes on the rainwater dams.

Stage 3: An input–output model and an operational model for the BMR in accordance with the MCA's Water Accounting methodology were created.

The input–output model and operational model used measured values obtained from the BMR flowmeters and calculated or estimated values where measured values were not available.

Stage 4: The water footprint of the base metals refinery was calculated.

The amount of blue, green and grey water required by the BMR for the production of nickel and copper was calculated from actual measurements.

Stage 5: Water usage at the BMR was evaluated. Ways in which water savings could be achieved were identified. From the reticulation diagrams and water balance, major consumers of water are identified. Possible water saving techniques were investigated and briefly discussed.

RESULTS

Verification and updating of water system

Physical verification

The first objective of this work was to analyse and update the current water reticulation system. All water lines were tracked from start to end point and verified against P&ID diagrams. A database of existing flowmeters was drawn up once the water lines and flowmeters had been verified. The database contained:

- the flowmeter numbers as displayed on reticulation diagrams
- the tag numbers
- a brief description
- the flowmeter type
- a photograph of the flowmeter.

A flowmeter list was also compiled as a reference for the database. An excerpt of the flowmeter list is shown in Table 1. An example from the database is shown in Figure 2.

Calculation of water accountability

The water reticulation diagrams display the water flow rates through flowmeters, the percentage of water that is drawn from the previous (parent) stream and the accountability of the stream. Table 2 displays the configuration used in the diagrams.

Accountability has been calculated in the following manner: The per cent accountability refers to the amount of water whose end points are exactly known. For example, in Figure 3 the flowrate through flowmeter 1 is 50 m^3/day, 5 m^3/day of that flows through flowmeter 2 and 10 m^3/day flows through flowmeter 3. As a result, only 15 m^3 of the total 50 m^3 flow through flowmeter 1 per day is known to its end point. The accountability of water flow at flowmeter 1 is equal to 15/50, that is, 30 per cent.

The percentage of parent refers to the amount of water that a particular stream or flowmeter receives from the stream that it originates from. For example, the percentage of parent stream for the stream containing flowmeter 2 is ten per cent of stream containing flowmeter 1.

The flow rates displayed on the reticulation diagrams are automatically updated from the daily flowmeter readings and are distributed to management on a daily basis.

Reticulation diagram

The water reticulation circuit is divided into seven diagrams. The blocks shown in Figure 4 represent the different sections for which reticulation diagrams were drawn up.

TABLE 1
List of flowmeters on water lines.

Number	Tag number	Description	Flowmeter type
1	T851_FI_007-PV	Main potable water flowmeter	Magnetic
2	T851_FI_003-PV	Potable water to E&S	Magnetic
3	T851_FI_008-PV	Potable water to leaching and utilities	Magnetic
4	PL855_FIT_005-PV	Potable water to Fire Tank 1	Magnetic
5	T851_FI_004-PV	Potable water to utilities	Magnetic

E&S: effluent and sulfate.

FIG 2 - Example of a photograph from the flowmeter database.

TABLE 2
Flow details used in diagrams.

Flow (m^3/day)	Per cent of parent (previous stream)	Per cent accountability

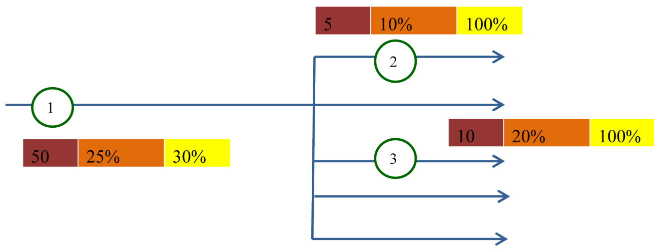

FIG 3 - Accountability example.

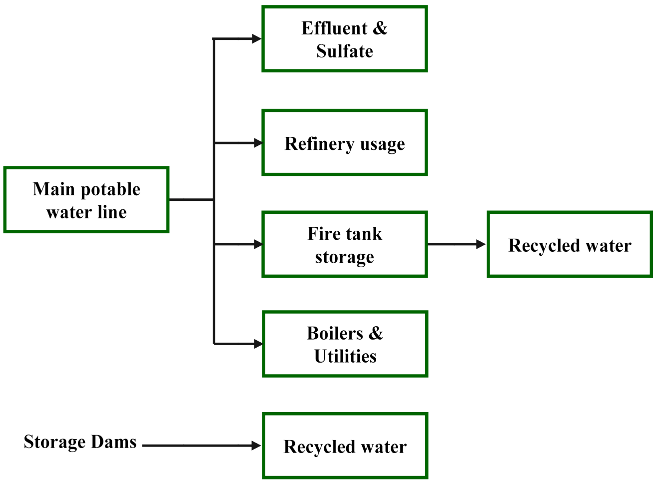

FIG 4 - The water reticulation circuit of the BMR is split into seven diagrams. The blocks in the figure show the seven diagrams and their connection to the main potable water line.

The first reticulation diagram, Figure 5, shows the distribution of potable water from the main potable water supply to the different parts of the site. Flowmeter readings are taken from daily totalised reports. The values shown in the accountability calculations in Figure 5 are the average of the totalised values for March 2011.

The main supply line splits to the concentrator section and the contractor toilets before the first flowmeter. This first take off is not measured. Lines to the change room and airlock at gate 2 are rubber lines that run underground and may be found after the first flowmeter. Water flow to the baghouse is not monitored. Main water lines to effluent and sulfate (E&S), fire water storage tanks, leaching and purification sections, Concentrator Plant and utilities (boilers and hotwells) are found on this diagram.

Water balance

Data from the flowmeter totaliser recordings was used to calculate a site water balance. The balance was performed for the site to account for all water entering or leaving site. Values were obtained from daily flowmeter spread sheets and added up to provide a monthly total. Rainfall data was obtained from the Environmental Department.

Flows into the plant are:

- potable water
- rainfall
- Site 3 steam return
- water entering with reagents
- rainfall to dams.

Flows out of the plant are:

- evaporation
- water leaving with products formed
- water leaving from ablutions to sewerage facilities
- steam to Site 3.

An annual balance for the period November 2010 to October 2011 is given in Table 3. Details of the calculations and values used in the balance are given in notes 1 to 19 after the balance.

As can be seen from the balance shown in Table 3, the major inflows into the plant are potable water (832 363 m^3) and rainfall (261 970 m^3). The major consumers of potable water are the utilities section (401 800 m^3) and process water (179 720 m^3). The major outputs of water from the site are evaporation (937 058 m^3) and accumulation in dams (119 830 m^3). These inputs and outputs are shown in Figures 6 and 7.

The difference between the inputs and outputs for the annual balance is 16 183 m^3. This equates to about 44 m^3 per day. As can be seen in Table 3, the utilities water consumption is 401 800 m^3 for the year. This value is high because it supplies the plant and compressor cooling towers, the blend tank and

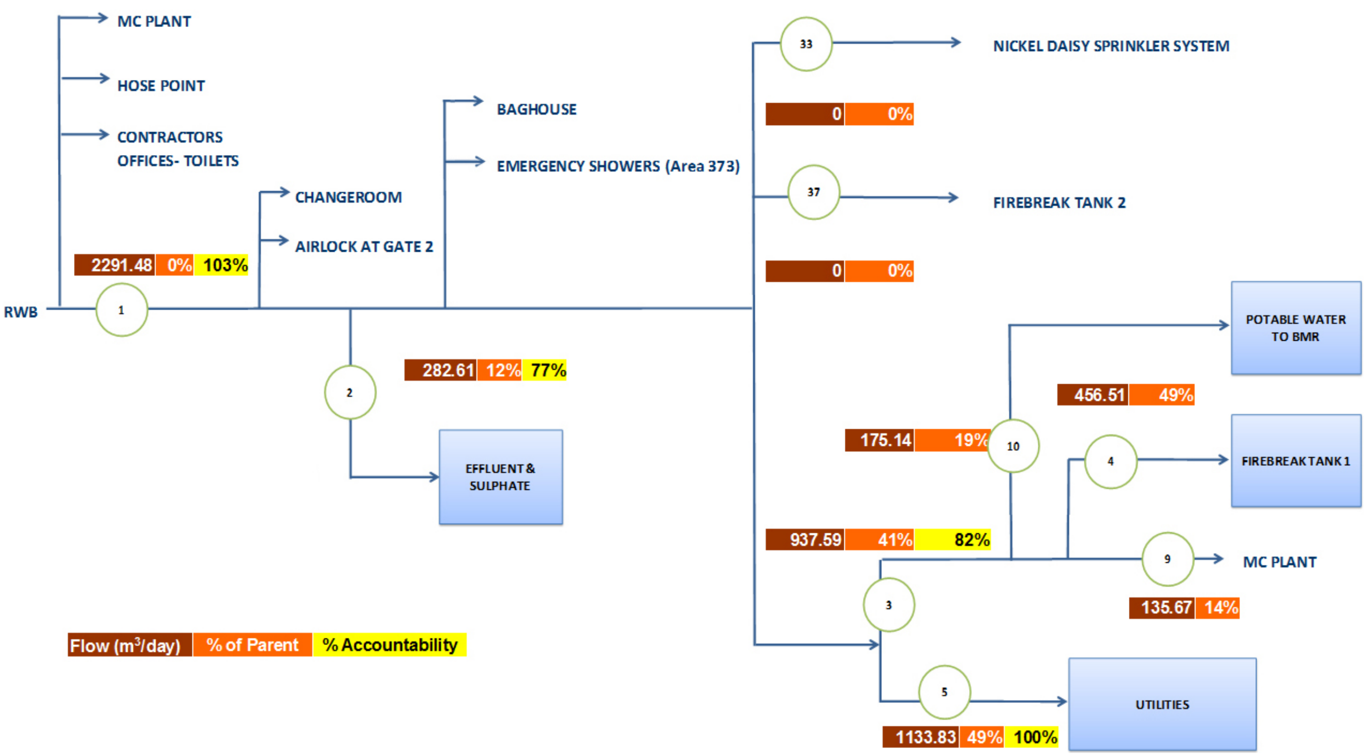

FIG 5 - Main Rand Water Board reticulation diagram showing water lines to effluent and sulfate (E&S), fire water storage tanks, leaching and purification sections, matte Concentrator Plant and utilities (boilers and hotwells) are found on this diagram.

TABLE 3

Annual mass balance for November 2010 to October 2011.

November 2010 to October 2011			
Inflows	**Notes #**	**m^3**	
Municipal water			832 363
Processing	1	59 077	
Utilities	2	401 800	
Process water	3	179 720	
E&S	4	94 066	
MC plant	5	52 839	
Baghouse, ablutions, airlock	6	44 860	
Rainwater (catchment)			261 970
Monthly rainfall	7	261 970	
Return flows			25 501
Site 2 condensate return	8	25 501	
Reagents			14 513
Monthly reagents required	9	14 513	
Production			
Water produced during reactions	10	0	
Rainwater dam decrease			150 830
Level decrease in Dam 3A and 3B	11	150 830	
Difference			16 183
Difference between inputs and outputs	12	16 183	
Total inflows			1 301 358
Outflows	**Notes #**	**m^3**	
Evaporation	13		937 058
Tank/process evaporation		757 617	
Dam evaporation		179 441	
Product			11 274
Filter cake and ash residue	14	11 274	
Sewerage			87 600
Water for ablutions	15	87 600	
Site 3 steam			49 425
Steam sent	16	49 425	
Water used in reactions			
Water reacted during production	17	0	
Rainwater to Site 2			96 172
Water from Dam 3B to site	18	96 172	
Rainwater dam accumulation			119 830
Accumulation in Dam 3A and 3B	19	119 830	
Total outflows			1 301 358

1. BMR potable water: values are obtained from flowmeter daily reports which are then summed up to obtain a monthly and yearly value. Values for the BMR water usage are obtained from flowmeter 10.
2. Utilities potable water: values are obtained from flowmeter daily reports which are then summed up to obtain a monthly value. Utilities water requirements are quite high due to water potable water used to top up the hot water softener feed tank for the boilers. Potable water to the cooling towers is also fed from this line.
3. Potable water to fire break tank (process water): values for process water were obtained from flowmeter measuring the municipal water to the fire break tank.
4. Potable water to E&S: values are based on flowmeter measuring water to the effluent and sulfate section.

TABLE 3

Cont...

5. Potable water to Concentrator Plant: values are based on flowmeter measuring water to the MC Plant.
6. Potable water to baghouse, ablutions and airlock: for the water balance, the baghouse and ablutions value is taken as the difference between the main potable water flowmeter and the sum of the potable water to leaching, utilities, fire tank (process water), E&S and Concentrator Plant.
7. Rainfall: recorded data of the yearly rainfall for 2011 was used in the actual site balance. Rainfall capture was calculated by assuming that 70% of site area run-off would report to the rainwater dams. The other 30% area would run-off site. Of this 70% area, the actual percentage of run-off reporting to the dams was calculated by performing a balance over Dam 3B over a 24 hour period. The percentage run-off from the 70% area was calculated to be 57% representing a capture of 81% (= 57/70) of the rainfall.

   Stormwater system: the stormwater system is connected to a valve present near the Concentrator Plant. This valve controls when water is sent to the rainwater dams to prevent flooding of the dams during rainy season. When this valve is open, water is diverted to the river. When the valve is closed, water is directed to the dams. This system traps almost 100% of site rainfall and run-off. Water from the E&S is pumped to the rainwater dams using this system. Records are not kept of when the valve is open and when it is closed thus the 57% value calculated is used for total rainfall captured.
8. Site 3 condensate: Site 3 condensate return values were taken from actual site flowmeter readings.
9. Reagents: water enters with sodium hydroxide which has a 50% dilution rate. Actual site purchase values were used.
10. Water produced during reactions: water produced during reactions is neglected for the water balance. The values were calculated during a simulation of plant operations and were found to be negligible.
11. Changes in dam level: monthly volume changes were calculated using dam levels at the beginning and end of each month together with the dam surface area. This was done for rainwater Dams 3A and 3B. The monthly changes in dam level may be seen in Figure 8.
12. Difference: the difference between the inputs and outputs is 16 183 m^3/a with the outputs greater than the inputs. This equates to 44 m^3 per day.
13. Evaporation: site evaporation is calculated in detail for the water balance of 2006. These calculations were modified and used together with an evaporation rates obtained from the Kroondal weather station. Evaporation was calculated per tank and per dam using surface areas. The values obtained are displayed in the balance. The rainfall and evaporation rates are shown in Figure 9.
14. Products: filter cake and ash residue values were obtained from metal accountants on-site. Water is added to ash to prevent fly away and is also found in the filter cake residue.
15. Sewerage: an average value of 10 m^3/h was as ablution/sewerage water leaving site is assumed.
16. Site 3 steam: values for steam sent to Site 3 were used for the site balance.
17. Water used in reactions: water reacted during reactions is neglected for the actual balance. The values were calculated during a simulation of plant operations and were found to be negligible.
18. Water to Site 2: water is infrequently pumped to Site 2 prior to or during the rainy season to prevent dams from overflowing.
19. Rainwater dam accumulation: monthly volume changes were calculated using dam levels at the beginning and end of each month together with the dam surface area. This was done for rainwater Dams 3A and 3B.

the hot water softener feed tank and ultimately the boilers. By increasing the return of condensed steam to the hotwells, it may be possible to reduce the amount of fresh water needed by the boilers. Reducing the consumption of demineralised water will also decrease the amount of potable water to the utilities section.

Water accounts

Input–output model with accuracy statement

Data obtained during the physical verification was used to construct the input–output and the operational model. The input–output model is shown in Table 4.

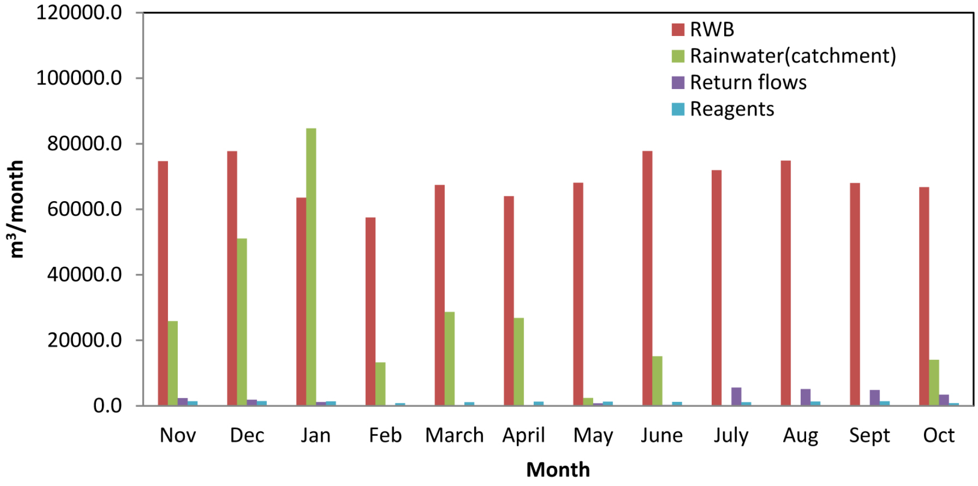

FIG 6 - Monthly inputs for November 2010 to October 2011.

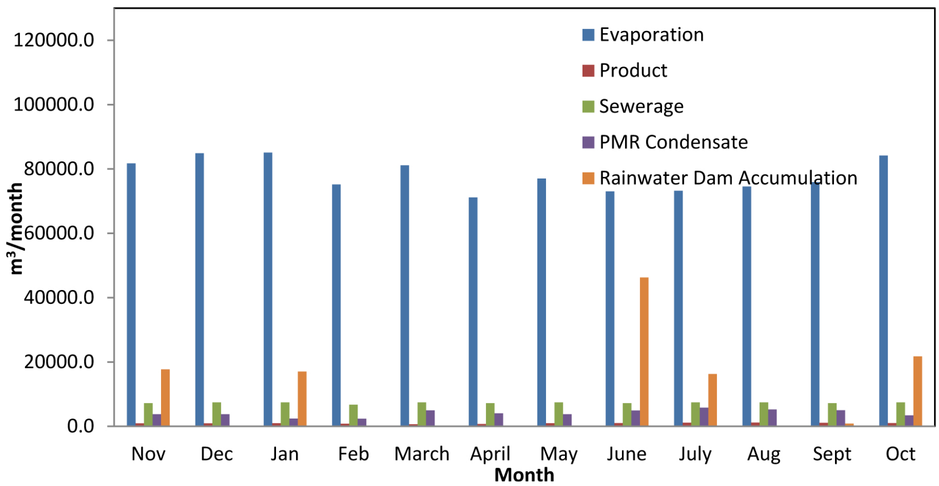

FIG 7 - Monthly outputs for November 2010 to October 2011.

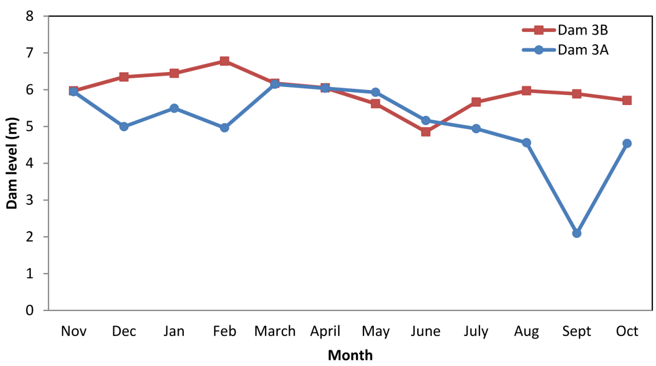

FIG 8 - Changes in dam levels from November 2010 to October 2011.

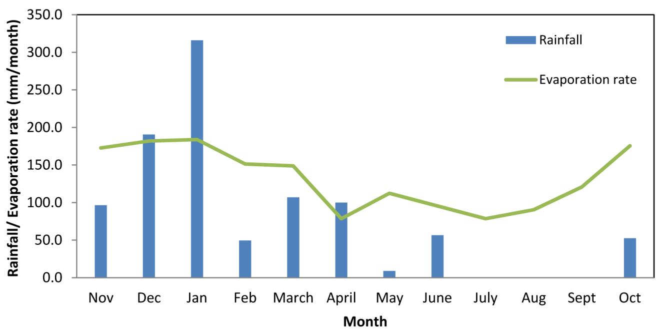

FIG 9 - Rainfall and evaporation rates for November 2010 to October 2011.

The values used in the input–output model are the total yearly water flows, measured in m^3/year.

Operational model

The operational model is shown in Figure 10. Raw water is received at an input and has not been used. Worked water has been through equipment or a process. Treated water has been treated to provide water suitable for a particular task, for example, demineralised water for steam turbines. In order to represent inputs, outputs and operational water in accordance with the framework, the following guideline been used:

- inputs are coloured green
- outputs are coloured red
- diversions are coloured yellow
- stores are coloured blue
- tasks are coloured grey
- treatment plants are coloured purple.

Flow rates used in completing the operational model were obtained from the flowmeter readings. The total monthly flowrate for March 2011 was used to obtain an average daily flowrate for March 2011. The average daily flow rates are shown in Figure 10 and are measured in m^3/day.

Water footprint

WF is defined as the total amount of fresh water consumed for a production process. The main products produced by

TABLE 4

Input–output model describing total yearly flows in and out of the base metals refinery site measured in m³/year.

Reporting period November 2010 to October 2011								
			Water quality					
Input/output	**Element**	**Sub-element**	**Category 1**	**Category 2**	**Category 3**	**Notes**	**How were the flows obtained**	**Confidence level**
Inputs	Third party water	Municipal water	832 363				Measured	High
	Surface water	Rainfall run-off		261 970			Estimated	Medium
		Total inputs	832 363	261 970	0			
Outputs	Third party water	Sewerage			87 600		Estimated	Medium
	Surface water	Water to Site 2			96 172		Measured	High
	Other	Evaporation	937 058				Calculated	Medium
		Total outputs	937 058	0	183 772			

the BMR are nickel and copper and form 98 per cent of the base metal product. Cobalt is produced in minimal quantities. Sodium sulfate is produced as a by-product of the process. The water footprint will be calculated for the base metals, nickel, copper and cobalt only as these are the key products produced by the BMR. Table 5 shows the production values of the base metals for the period November 2010 to October 2011.

Blue water footprint

Due to a mixture of blue and green water sources, it is not possible to separate evaporation values for the individual footprints. The blue and green water footprints are thus calculated based on consumption. Table 6 shows the calculation of the blue water footprint for the BMR.

The freshwater consumed during this period is 832 363 m^3. This will result in a water footprint of 33.4 m^3 per tonne of base metal product produced.

Green water footprint

The green water footprint is calculated based on the amount of rainfall that is captured on-site and used during processing or stored. Table 7 shows the calculation of the green water footprint for the BMR.

The rainwater consumed during this period is 261 790 m^3. This will result in a green water footprint of 10.5 m^3 per tonne of base metal product produced.

Grey water footprint

Grey water is the amount of water required to assimilate or dilute pollutants before discharge. The BMR does not discharge any waste water so no dilution water is required. The grey water footprint corresponding to this is 0 m^3/t of base metal produced.

Total water footprint

The total water footprint is the sum of the blue, green and grey water footprint. Adding the blue water footprint of 33.4 m^3/t, the green water footprint of 10.5 m^3/t and the grey water footprint of 0 m^3/t, the total water footprint is 43.9 m^3 of water per tonne of base metal produced.

DISCUSSION

Verification and updating of water system

The BMR consumes about 2500 m^3 of water per day during processing. One of the aims of the project was to physically verify the water reticulation system and recommend flowmeters to improve the water accountability of the BMR to 95 per cent.

Water pipelines and flowmeters were physically verified. Water lines that were tracked include potable water, demineralised water, process water from the fire break tank, condensate and dam water lines. The lines were compared to piping and instrumentation diagrams and checked to see that they can be found and function without major leakages or issues. A flowmeter database was created which includes the tag number, location, type and photograph of the flowmeter. Once the lines and flowmeters were verified, they could be used in drawing up new water reticulation diagrams and water balances.

Water accountability for the BMR at the first split is calculated to be 100 per cent, as can be seen in Figure 5. As the main lines split further, the accountability decreases. It is desired by the BMR to achieve greater than 95 per cent overall accountability, that is, to know where 95 per cent of the potable water is used to it end point. Installation of more flowmeters will assist in achieving this.

Water balance

An actual balance was performed in order to calculate the amount of water consumed by the plant. Values for the balance were obtained from totalised flowmeter readings or calculated.

Balances were performed from November 2010 to October 2011 for the actual balance. From the annual balance, it is seen that major inflows into the plant are potable water (832 363 m^3) and rainfall (261 970 m^3). The major consumers of potable water are the utilities section (401 800 m^3) and process water (179 720 m^3). The major outputs of water from the site are evaporation (937 058 m^3) and accumulation in dams (119 830 m^3). These inputs and outputs may be seen graphically in Figures 6 and 7 shown after the annual balance.

The difference between the inputs and outputs for the annual balance is 16 183 m^3. This equates to about 44 m^3 per day. As can be seen from the annual balance, the utilities water consumption is 401 800 m^3 for the year. This value is high because it supplies the plant and compressor cooling towers, the blend tank and the hot water softener feed (RO) tank. By increasing the return of condensate to the hotwells, it may be possible to reduce this value. Reducing the consumption of demineralised water will also decrease the amount of potable water to the utilities section.

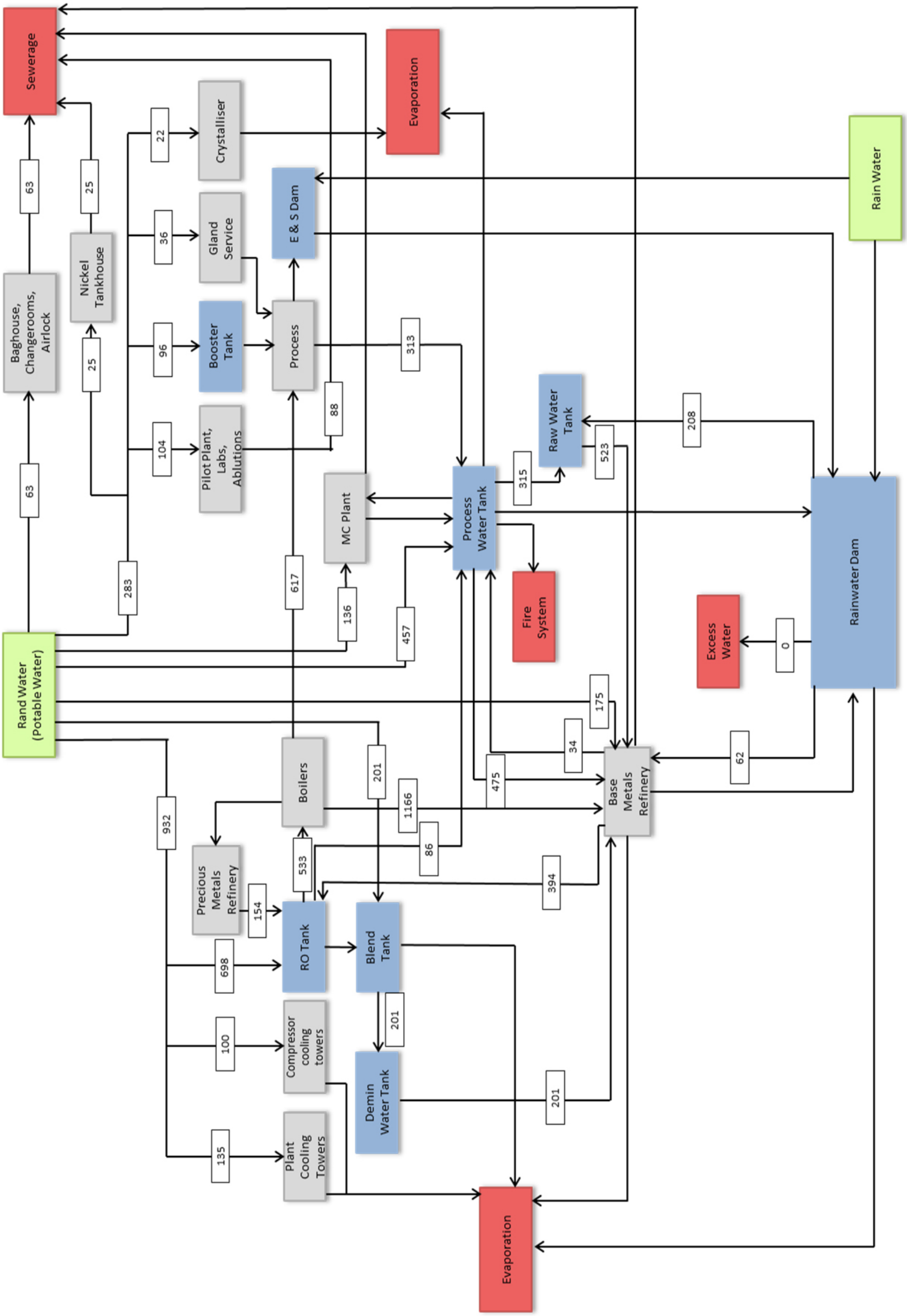

FIG 10 - Operational model describing internal water flows during processing.

TABLE 5
Base metal production values for November 2010 to October 2010.

Base metal	Mass (tonnes/annum)
Nickel (Ni)	16 247
Copper (Cu)	8180
Cobalt ($CoSO_4.7H_20$)	489
Total	24 916

TABLE 6
Calculation of the blue water footprint of the base metals refinery.

Detail	Unit	Value
Base metal produced	t/a	24 916
Freshwater consumed	m^3/a	832 363
Water footprint	m^3/t	33.4

TABLE 7
Calculation of the green water footprint of the base metals refinery.

Detail	Unit	Value
Base metal produced	t/a	24 916
Rainfall collected	m^3/a	261 970
Water footprint	m^3/t	10.5

Rainfall was calculated by assuming that 70 per cent of site area run-off would report to the rainwater dams. The other 30 per cent area would run-off site or to the E&S dams. Of this 70 per cent area, the actual percentage of run-off reporting to the dams was calculated by performing a balance over Dam 3B over a 24 hour period. The percentage run-off from the 70 per cent area was calculated to be 57 per cent.

In order to complete accurate dam balances, random emptying of the E&S dams to rainwater dams should be recorded and flows measured. The stormwater valve controls flow of water to the river or rainwater dams. The opening and closing of the stormwater valve should be recorded and water flow rates to the river measured. This would assist in accurately quantifying water collected on site or lost to the river.

Water accountability – Minerals Council of Australia

Data obtained during the physical verification was used to draw up the input–output model. The input–output model is shown in Table 4. Each water input or output has a category allocated to it from a range of 1 to 3. Water inputs to site are municipal (potable) water of 832 363 m^3 and rainfall of 261 970 m^3 per year. Municipal water is classified as category 1 water as it is safe for consumption and is measured using flowmeters. Rainfall is collected as run-off and classified as category 2 water as it would require filtration and possibly more processing before it would be fit for consumption. Sewerage discharge water was estimated to be 87 600 m^3 and stored dam water that is measured to 96 172 m^3 is classified as category 3 water. This water would require significant processing before it would be considered fit for human consumption. Evaporation is calculated to be 937 058 m^3 and is the biggest loss of water from the BMR. Evaporation is classified as category 1 water. From the input–output model, the total inputs are 1 094 333 m^3 and the total outputs are 1 120 830 m^3. There is a two per cent difference between the inputs and outputs. This may be as a result of estimating certain values.

An operational model was drawn up in accordance with the MCA water accounting framework. The operational model describes internal site water flows during a process. The operational model includes water flows between storage facilities on-site to tasks and treatment facilities. Values used for the operational model are the averages of the totalised flows for March 2011. From Figure 10, it is seen that most of the potable water is used in the utilities section. This water is sent to the boilers which produce steam required for heating equipment, gland seals and heat exchangers. It is also seen that not all the steam is returned to the hotwells and boilers. If the steam has been contaminated, it is sent to the fire break tank for use as process water.

Water footprint

The water footprint of the BMR was calculated as the volume of freshwater required to produce a tonne of base metal. The base metals are nickel, copper and cobalt. It is not possible to calculate the water footprint of each metal individually as they share common resources on-site. Sodium sulfate is also produced as a by-product of the process but it was not included in the water footprint calculation.

The blue water footprint was calculated to be 33.4 m^3/t while the green and grey water footprints were calculated to be 10.5 m^3/t and 0 m^3/t respectively. The total water footprint is 43.9 m^3 of water per tonne of base metal produced.

There is no record of water footprints calculated previously for base metal production, so it is not possible to compare this value to other plants. The water footprint has only been calculated for one part of the base metal refining process. The water footprint of mining activities, smelting and concentrating which take place prior to the refining should be calculated in order to obtain the total water footprint of base metal refining.

Methods to achieve savings in fresh water usage

There are four ways in which savings to water might be made. These are:

- increasing return of steam condensate and gland seal steam to hotwells
- use of dam water as top-up to fire break tanks
- reverse osmosis for treatment of process condensate
- detailed water balances.

Increasing return of steam condensate and gland seal steam to hotwells

Live steam fed to the process cannot be recovered as condensate; however, steam condensate used for heating in heat exchangers and glands seals should have a 100 per cent recovery. Contamination occurs with inefficiency or leaks in equipment. These leaks should be addressed as they result in constant contamination which consequently results in more potable water required as a top up to the hotwells.

Stop the use of fire break water to top up rainwater tank

Water from the rainwater dams is pumped to the rainwater tank. The rainwater tank is topped up with water from the fire break tank which is in turn topped up with potable water. The pumping of water from dams to the rainwater tank should be increased so that process water top up is not required.

Reverse osmosis for treatment of process condensate

Process condensate from evaporators and crystallisers is pumped to the fire break tank to be used for process water. A reverse osmosis plant using a high temperature membrane would treat the condensate at higher temperatures allowing maintenance of calorific value. This water would then be fit for use in the hotwells. Problems with reverse osmosis include blocking of the membrane which could be solved by filtering solutions before processing and a slow process rate which may lead to the requirement of a storage tank. Reverse osmosis is also an energy intensive process due to the high pressures required for effective processing. Should pressure not be high enough, efficiency could decrease from 90 per cent down to ten or 15 per cent. These factors need to be further investigated before a conclusive decision is made.

Detailed water balances

Detailed water balances should be performed to calculate the required amount of water for each section. These balances would assist in understanding precisely where additional water is used. The balances would also provide accurate water requirement figures per section which may then be used to monitor and minimise fresh water usage.

CONCLUSIONS

The study began with a ground up approach with the verification of water lines and flow measuring devices. A flowmeter database was drawn up, the water reticulation diagram was updated and recommendations were made to improve water accountability.

The difference between the inputs and outputs for the annual balance is 16 183 m^3. This equates to about 44 m^3 per day. As can be seen from the annual balance, the utilities water consumption is 401 800 m^3 for the year. This value is high because it supplies the plant and compressor cooling towers, the blend tank and the hot water softener feed tank. By increasing the return of condensate to the hotwells, it may be possible to reduce this value.

Rainfall was calculated by assuming that 70 per cent of site area run-off would report to the rainwater dams. The other 30 per cent area would run-off site or to the E&S dams. Of this 70 per cent area, the actual percentage of run-off reporting to the dams was calculated by performing a balance over Dam 3B over a 24 hour period. The percentage run-off from the 70 per cent area was calculated to be 57 per cent.

In order to complete accurate dam balances, random emptying of the E&S dams to rainwater dams should be recorded and flows measured. The stormwater valve controls flow of water to the river or rainwater dams. The opening and closing of the stormwater valve should be recorded and water flow rates to the river measured. This would assist in accurately quantifying water collected on site or lost to the river.

An input–output statement and operational model was drawn up in accordance with the water accounting framework. From the input–output model, the total inputs are 1 094 333 m^3 and the total outputs are 1 120 830 m^3. A two per cent difference occurred between inputs and outputs possibly due to the estimation of some values.

An operational model was drawn up in accordance with the water accounting framework. From the operational model, it is seen that most of the potable water is used in the utilities section. This water is sent to the boilers which produce steam required for heating equipment, gland seals and heat exchangers. It is also seen that not all the steam is returned to the hotwells and boilers. If the steam has been contaminated, it is sent to the fire break tank for use as process water.

The blue water footprint was calculated to be 33.4 m^3/t while the green and grey water footprints were calculated to be 10.5 m^3/t and 0 m^3/t respectively. The total water footprint of the refining process is 43.9 m^3 of water per tonne of base metal produced.

There are four ways in which savings to water might be made. These are:

- increasing return of steam condensate and gland seal steam to hotwells to reduce the amount of fresh water top-up that is required
- increase the volume of dam water that is recycled to the rainwater tanks to reduce the amount of process water top-up obtained from the firebreak tanks
- a reverse osmosis plant using a high temperature membrane to treat condensate at higher temperatures should be investigated
- detailed water balances need to be performed for individual sections to determine the water requirements of each section; this would assist in monitoring and minimising excess water usage.

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