Appendix V

Site-wide Water and Mass Balance Modelling

DISCLAIMER

This disclaimer applies to and governs the disclosure and use of this Environmental Impact Statement ("EIS"), and by reading, using or relying on any part(s) of the EIS you accept this disclaimer in full.

This Environmental Impact Statement, including the Executive Summary, and all chapters of and attachments and appendices to it and all drawings, plans, models, designs, specifications, reports, photographs, surveys, calculations and other data and information in any format contained and/or referenced in it, is together with this disclaimer referred to as the "**EIS**".

Purpose of EIS

The EIS has been prepared by, for and on behalf of Wafi Mining Limited and Newcrest PNG 2 Limited (together the "**WGJV Participants**"), being the participants in the Wafi-Golpu Joint Venture ("**WGJV**") and the registered holders of exploration licences EL 440 and EL1105, for the sole purpose of an application (the "**Permit Application**") by them for environmental approval under the Environment Act 2000 (the "**Act**") for the proposed construction, operation and (ultimately) closure of an underground copper-gold mine and associated ore processing, concentrate transport and handling, power generation, water and tailings management, and related support facilities and services (the "**Project**") in Morobe Province, Independent State of Papua New Guinea. The EIS was prepared with input from consultants engaged by the WGJV Participants and/or their related bodies corporate ("**Consultants**").

The Permit Application is to be lodged with the Conservation and Environment Protection Authority ("**CEPA**"), Independent State of Papua New Guinea.

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The EIS is intended and will be made available to CEPA, for review by CEPA and other applicable agencies of the Government of the Independent State of Papua New Guinea ("**Authorised Agencies**"), for the purpose of considering and assessing the Permit Application in accordance with the Act ("**Authorised Purpose**"), and for no other purpose whatsoever.

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- expressly disclaim any liability for any consequential, special, contingent or penal damages whatsoever.

The basis of the Consultants' engagement is that the Consultants' liability, whether under the law of contract, tort, statute, equity or otherwise, is limited as set out in the terms of their engagement with the WGJV Participants and/or their related bodies corporate.

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- copied, reproduced and reprinted;
- published or disclosed in whole or in part, including being made available to the general public in accordance with section 55 of the Act. All publications and disclosures are subject to this disclaimer.

Development of Project subject to Approvals, Further Studies and Market and Operating Conditions

Any future development of the Project is subject to further studies, completion of statutory processes, receipt of all necessary or desirable Papua New Guinea Government and WGJV Participant approvals, and market and operating conditions.

Engineering design and other studies are continuing and aspects of the proposed Project design and timetable may change.

NEWCREST MINING LIMITED DISCLAIMER

Newcrest Mining Limited ("**Newcrest**") is the ultimate holding company of Newcrest PNG 2 Limited and any reference below to "Newcrest" or the "Company" includes both Newcrest Mining Limited and Newcrest PNG 2 Limited.

Forward Looking Statements

The EIS includes forward looking statements. Forward looking statements can generally be identified by the use of words such as "may", "will", "expect", "intend", "plan", "estimate", "anticipate", "continue", "outlook" and "guidance", or other similar words and may include, without limitation, statements regarding plans, strategies and objectives of management, anticipated production or construction commencement dates and expected costs or production outputs. The Company continues to distinguish between outlook and guidance. Guidance statements relate to the current financial year. Outlook statements relate to years subsequent to the current financial year.

Forward looking statements inherently involve known and unknown risks, uncertainties and other factors that may cause the Company's actual results, performance and achievements to differ materially from statements in this EIS. Relevant factors may include, but are not limited to, changes in commodity prices, foreign exchange fluctuations and general economic conditions, increased costs and demand for production inputs, the speculative nature of exploration and project development, including the risks of obtaining necessary licences and permits and diminishing quantities or grades of reserves, political and social risks, changes to the regulatory framework within which the Company operates or may in the future operate, environmental conditions including extreme weather conditions, recruitment and retention of personnel, industrial relations issues and litigation.

Forward looking statements are based on the Company's good faith assumptions as to the financial, market, regulatory and other relevant environments that will exist and affect the Company's business and operations in the future.

The Company does not give any assurance that the assumptions will prove to be correct. There may be other factors that could cause actual results or events not to be as anticipated, and many events are beyond the reasonable control of the Company. Readers are cautioned not to place undue reliance on forward looking statements. Forward looking statements in the EIS speak only at the date of issue. Except as required by applicable laws or regulations, the Company does not undertake any obligation to publicly update or revise any of the forward looking statements or to advise of any change in assumptions on which any such statement is based.

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Newcrest results are reported under International Financial Reporting Standards (IFRS) including EBIT and EBITDA. The EIS also includes non-IFRS information including Underlying profit (profit after tax before significant items attributable to owners of the parent company), All-In Sustaining Cost (determined in accordance with the World Gold Council Guidance Note on Non-GAAP Metrics released June 2013), AISC Margin (realised gold price less AISC per ounce sold (where expressed as USD), or realised gold price less AISC per ounce sold divided by realised gold price (where expressed as a %), Interest Coverage Ratio (EBITDA/Interest payable for the relevant period), Free cash flow (cash flow from operating activities less cash flow related to investing activities), EBITDA margin (EBITDA expressed as a percentage of revenue) and EBIT margin (EBIT expressed as a percentage of revenue). These measures are used internally by Management to assess the performance of the business and make decisions on the allocation of resources and are included in the EIS to provide greater understanding of the underlying performance of Newcrest's operations. The non-IFRS information has not been subject to audit or review by Newcrest's external auditor and should be used in addition to IFRS information.

Ore Reserves and Mineral Resources Reporting Requirements

As an Australian Company with securities listed on the Australian Securities Exchange (ASX), Newcrest is subject to Australian disclosure requirements and standards, including the requirements of the Corporations Act 2001 and the ASX. Investors should note that it is a requirement of the ASX listing rules that the reporting of Ore Reserves and Mineral Resources in Australia comply with the 2012 Edition of the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (the JORC Code) and that Newcrest's Ore Reserve and Mineral Resource estimates comply with the JORC Code.

Competent Person's Statement

The information in the EIS that relates to Golpu Ore Reserves is based on information compiled by the Competent Person, Mr Pasqualino Manca, who is a member of The Australasian Institute of Mining and Metallurgy. Mr Pasqualino Manca, is a full-time employee of Newcrest Mining Limited or its relevant subsidiaries, holds options and/or shares in Newcrest Mining Limited and is entitled to participate in Newcrest's executive equity long term incentive plan, details of which are included in Newcrest's 2017 Remuneration Report. Ore Reserve growth is one of the performance measures under recent long term incentive plans. Mr Pasqualino Manca has sufficient experience which is relevant to the styles of mineralisation and type of deposit under consideration and to the activity which he is undertaking to qualify as a Competent Person as defined in the JORC Code 2012. Mr Pasqualino Manca consents to the inclusion of material of the matters based on his information in the form and context in which it appears.

HARMONY GOLD MINING COMPANY LIMITED DISCLAIMER

Harmony Gold Mining Company Limited ("**Harmony**") is the ultimate holding company of Wafi Mining Limited and any reference below to "Harmony" or the "Company" includes both Harmony Gold Mining Company Limited and Wafi Mining Limited.

Forward Looking Statements

These materials contain forward-looking statements within the meaning of the safe harbor provided by Section 21E of the Securities Exchange Act of 1934, as amended, and Section 27A of the Securities Act of 1933, as amended, with respect to our financial condition, results of operations, business strategies, operating efficiencies, competitive positions, growth opportunities for existing services, plans and objectives of management, markets for stock and other matters. These include all statements other than statements of historical fact, including, without limitation, any statements preceded by, followed by, or that include the words "targets", "believes", "expects", "aims", "intends", "will", "may", "anticipates", "would", "should", "could", "estimates", "forecast", "predict", "continue" or similar expressions or the negative thereof.

These forward-looking statements, including, among others, those relating to our future business prospects, revenues and income, wherever they may occur in this EIS and the exhibits to this EIS, are essentially estimates reflecting the best judgment of our senior management and involve a number of risks and uncertainties that could cause actual results to differ materially from those suggested by the forward-looking statements. As a consequence, these forward-looking statements should be considered in light of various important factors, including those set forth in these materials. Important factors that could cause actual results to differ materially from estimates or projections contained in the forward-looking statements include, without limitation: overall economic and business conditions in South Africa, Papua New Guinea, Australia and elsewhere, estimates of future earnings, and the sensitivity of earnings to the gold and other metals prices, estimates of future gold and other metals production and sales, estimates of future cash costs, estimates of future cash flows, and the sensitivity of cash flows to the gold and other metals prices, statements regarding future debt repayments, estimates of future capital expenditures, the success of our business strategy, development activities and other initiatives, estimates of reserves statements regarding future exploration results and the replacement of reserves, the ability to achieve anticipated efficiencies and other cost savings in connection with past and future acquisitions, fluctuations in the market price of gold, the occurrence of hazards associated with underground and surface gold mining, the occurrence of labour disruptions, power cost increases as well as power stoppages, fluctuations and usage constraints, supply chain shortages and increases in the prices of production imports, availability, terms and deployment of capital, changes in government regulation, particularly mining rights and environmental regulation, fluctuations in exchange rates, the adequacy of the Group's insurance coverage and socio-economic or political instability in South Africa and Papua New Guinea and other countries in which we operate.

For a more detailed discussion of such risks and other factors (such as availability of credit or other sources of financing), see the Company's latest Integrated Annual Report and Form 20-F which is on file with the Securities and Exchange Commission, as well as the Company's other Securities and Exchange Commission filings. The Company undertakes no obligation to update publicly or release any revisions to these forward-looking statements to reflect events or circumstances after the date of this EIS or to reflect the occurrence of unanticipated events, except as required by law.

Competent Person's Statement

The Wafi-Golpu Joint Venture is an unincorporated joint venture between a wholly-owned subsidiary of Harmony Gold Mining Company Limited and a wholly-owned subsidiary of Newcrest Mining Limited.

The information in the EIS that relates to Golpu Ore Reserves is based on information compiled by the Competent Person, Mr Pasqualino Manca, who is a member of The Australasian Institute of Mining and Metallurgy. Mr Pasqualino Manca, is a full-time employee of Newcrest Mining Limited or its relevant subsidiaries, holds options and/ or shares in Newcrest Mining Limited and is entitled to participate in Newcrest's executive equity long term incentive plan, details of which are included in Newcrest's 2017 Remuneration Report. Ore Reserve growth is one of the performance measures under recent long term incentive plans. Mr Pasqualino Manca has sufficient experience which is relevant to the styles of mineralisation and type of deposit under consideration and to the activity which he is undertaking to qualify as a Competent Person as defined in the JORC Code 2012. Mr Pasqualino Manca consents to the inclusion of material of the matters based on his information in the form and context in which it appears.

PITEAU ASSOCIATES SOUTH AFRICA
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25 RUDD ROAD, ILLOVO, JOHANNESBURG,
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File: 3695TM04v5_SiteWideWaterBalance.docx

30th May 2018

Wafi-Golpu Australia Services Pty Ltd
ACN 166 518 305
Level 2, 189 Coronation Drive
Milton, QLD4064
Australia

Attention: Mr Aymeric Beaulavon

Dear Mr Beaulavon,

Re: Wafi-Golpu Site-wide Water and Mass Balance Model Life of Mine Projected Flow and Chemistry

EXECUTIVE SUMMARY

In support of the EIS for WGJV, Piteau were commissioned to simulate predicted flows and dissolved water chemistry for construction and operation phases. To do this, the existing site-wide water and chemical mass balance model (constructed in GoldSim) was populated by Piteau with assumptions defined by the EIS team.

Where possible, groundwater inflow to the underground workings will be used as the primary water supply for the site. Water from underground will be treated for use as mine service water and, once processing begins, as the primary water source for the plant. Excess treated water will be discharged to the Watut from a pipeline. Contact water from areas including the waste rock dumps will be discharged to the environment if the applicable quality standards are met; otherwise these waters will also be treated. Potable supply and any additional make up water will be sourced from the Watut River.

Central inputs to the model comprise: i) key dates associated with the mine plan; ii) ore processing schedule; iii) groundwater inflow to the declines and mine; iv) projected precipitation; v) runoff and infiltration response to rainfall; vi) chemical source terms; and vii) water management, treatment and distribution assumptions. A daily timestep is used in the predictive modelling which runs from 1st July 2020 to 1st July 2056, spanning the Project duration from commencement of decline development to planned closure. These are assumed dates for the purpose of modelling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction.

At the request of the EIS team, the physical water balance flow results are presented as daily values while the chemistry is annual average. The key findings are as follows.

- Nambonga decline groundwater inflow peaks in June 2022 at 144 m^3/hr and the Watut declines in June 2024 at 360 m^3/hr. The block caves produce the greatest proportion of groundwater inflow, peaking at 587 m^3/hr in July 2034.
- Waste rock dump runoff and seepage increase through its construction phase as the dump increases in size, then flows remain seasonally-constant for the reminder of mine life at around 18 m^3/hr at the 50th percentile.

- Runoff and seepage from the stockpile are greatest between 2025 and 2027 with a maximum flow of 5 m^3/hr at the 90th percentile. During this period, a considerable amount of ore is being stockpiled and so the stockpile has a large footprint, increasing both runoff and seepage. After 2027, the stockpile geometry does not vary significantly, and flows remain within a seasonally-constant range of between zero and 1 m^3/hr at the 50th percentile.
- Total treatment requirement peaks at around 890 m^3/hr at the 90th percentile in 2029. From 2033, the feed is seasonally-stable with inflows ranging between 730 and 780 m^3/hr at the 90th percentile. This assumes that all contact water requires treatment.
- The HDS treatment produces around 12,400 tonnes of sludge solids through the construction period. Following consolidation of the geotubes, the volume of water remaining within the pore space is predicted to be 2,500 m^3.
- Flows from the pipeline (comprising excess treated water and treated sewage) occur, most notably, during the construction phase when there is no processing demand. Flows also occur during financial years 32, 41 and 56 when mill feed is reduced during periods of block cave transition.
- Chemical mass in the groundwater inflow to the declines and mine increase through development but stabilise with moderately high concentrations (for example, sulphate around 1,800 mg/L and copper ranging from 5 mg/L in the declines to 40 mg/L in the mine).
- Peak concentration of the subsidence zone catchment water inflow are an order of magnitude higher than the groundwater inflows (for example, sulphate peaking at 20,000 mg/L and copper at 300 mg/L).
- Water quality of the waste rock dump runoff and seepage peaks during the construction phase due to exposed PAF material from the declines. Once this is encapsulated by a clay layer and non-acid forming (NAF) material, the values are considerably reduced and remain consistent for the reminder of mine life.
- Treated water quality is defined by test work undertaken by Clean TeQ and so is constant over time.

1. INTRODUCTION

A water and mass balance model was initially developed on behalf of Wafi-Golpu Joint Venture (WGJV) in 2016 by Achim Wurster of Water Treatment Process Engineering under the auspices of Worley Parsons. The model, developed in the industry-standard GoldSim software, was produced primarily as a process water planning tool for the Wafi-Golpu Project. Since its development, the model's requirements have changed, with a greater focus on underground dewatering, re-use of contact water and environmental discharge water quality. In addition, changes have been made to the mine plan, most notably a switch from the use of a terrestrial tailings storage facility to deep sea tailings placement (DSTP), the inclusion of the Nambonga Decline and a significantly revised mine plan.

Piteau Associates was commissioned in 2017 to update and reconfigure the pre-existing model to produce a probabilistic and dynamic water management plan decision making tool which can rapidly simulate different water management and treatment scenarios and evaluate their impacts on the project.

A detailed site-wide water and chemical mass balance model (version 1.0) was constructed in March 2017 to be a 'live' model, evolving through time as additional data are made available, and as better understanding of the mine operation is gained. Since the construction of the v.1.0 model, a number of changes have been made to the mine plan and treatment options. The model has correspondingly been updated to reflect these changes. The model version described in this report is denominated v.2.1 and carries the filename WafiGolpu_SiteWideWaterBalance_v2.1.gsm. Subsequent versions of the model may cause aspects of this report to become redundant or outdated.

This report was prepared to present the site-wide water and chemical mass balance for the current project to support the Environment Impact Statement (EIS). It details the latest mine plan and schedule defined by WGJV, assumptions made by Piteau and results requested by the EIS team.

2. WAFI-GOLPU OPERATION

2.1. Site layout

The site-wide water balance model is configured to encompass six key facility areas:

- underground mine, comprising declines and block caves;
- portal area for infrastructure and waste rock dump;
- process plant including stockpiled ore;
- water treatment plant (WTP);
- High Density Sludge (HDS) sludge geotube storage area; and
- mine camp including sewage treatment plant (STP).

Both concentrate and tailings from the process plant will be piped (separately) to the coast.

2.2. Water management system

The water management system changes between construction and operation phases. A schematic of the water management system on which the construction phase of the model is based is provided in Figure 2-1 and the operations phase in Figure 2-2. Water flows are divided into contact, non-contact, tailings and concentrate water. Contact water is any water which can potentially have been contaminated through contact with ore, waste or process reagents on site, whereas non-contact water is assumed to be subject to no interaction with any potential source of contamination. Water entrained with sediment is not defined as being contact water unless this is associated through contact with ore or waste (or the facilities in which they are stored).

Where possible, groundwater inflow to the underground operation will be used as the primary water supply for the site. Water from underground will be treated for use as mine service water and, once processing begins, as the primary water source for the plant. Excess treated water will be discharged to the Watut River from a pipeline.

The WTP will be operational before significant underground decline development begins. Any runoff from surface construction activities at the portal and plant terraces prior to this will be discharged directly to the environment via the sediment settlement pond (plant area) or storm water pond (camp areas) provided that the water is in compliance with the permit criteria. Runoff from surface construction works at the Nambonga decline area will be managed via a sediment pond at or immediately adjacent to the Nambonga decline terrace. Sludge produced from the WTP will be pumped into geotubes during the construction phase and sent to the process plant during operations. Excess water from the geotube storage area (seepage from the geotubes and rainfall-runoff) will be treated in the WTP.

Additional contact water sources include: i) runoff and seepage from the waste rock dumps and stockpile; and ii) runoff from the plant area and portal. With the exception of stockpile water, these flows will be discharged to surface (following sediment removal) if the water quality allows, otherwise they will be treated before discharge or re-use. Stockpile water will be treated during the construction phase and sent to the process plant during operations. Water quality guidelines have not been provided, therefore the model assumes that all water will require treatment.

Runoff from the camps will be routed via a storm water pond to mitigate against peak flows before being discharged to the environment, provided that the water is in compliance with the permit criteria.

Potable supply will be sourced from the Watut River. There is also an option for rainwater harvesting to be used at the camp as a supplementary potable water supply. Treated sewage from the STP will be discharged to the Watut River from a pipeline during the construction phase and sent to the process plant during operations.

The model provides a makeup demand for planning purposes through the calculation of total demand and available contact or treated water to meet this demand. Any water requirement not met by these sources is assumed to be met by a ‘raw water dam’ makeup supply. Details of the specific makeup sources and their storage are not included in the model.

The 'Water treatment and storage' box in Figure 2-1 is the central part of the model dealing with treatment and distribution of water. The ‘raw water pond’ arrow pointing to the box is to supplement treated water being distributed around the model – it is not a water stream that is being treated in the WTP (but may require treatment to remove suspended solids or for potable use).

Figure 2-1: Schematic diagram of the construction phase water management system

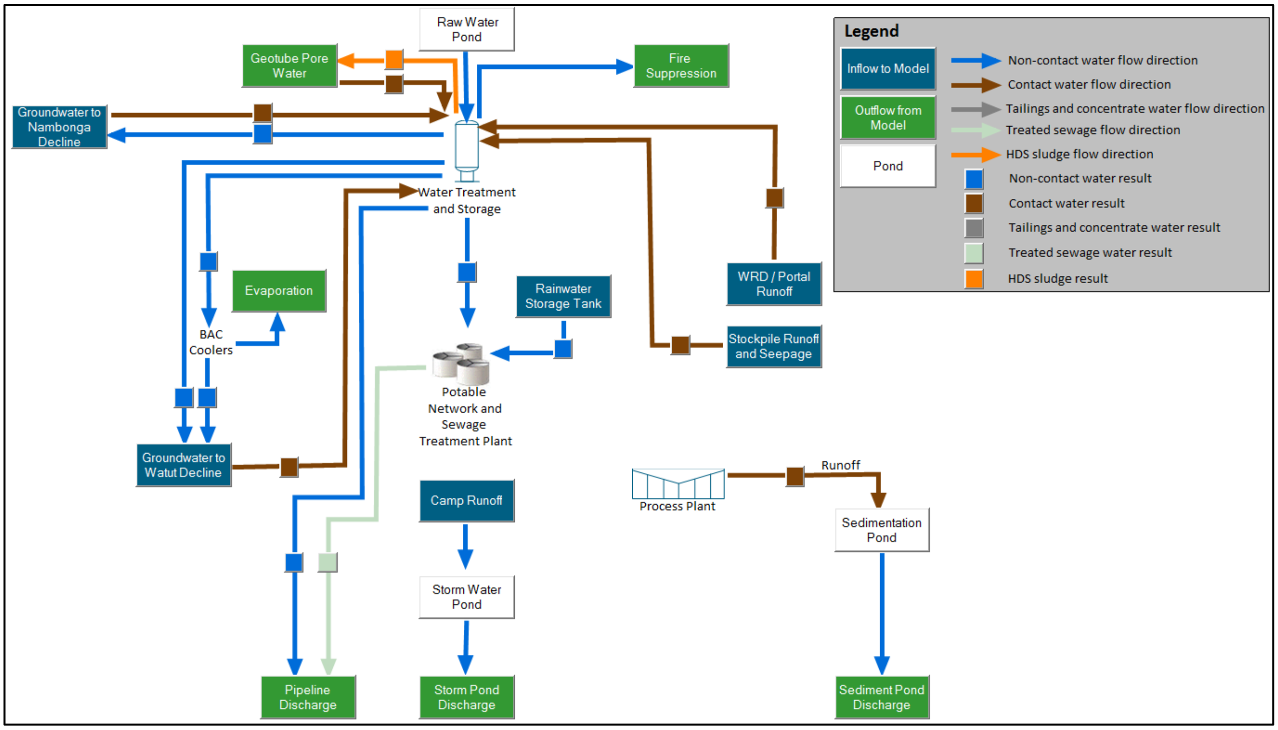
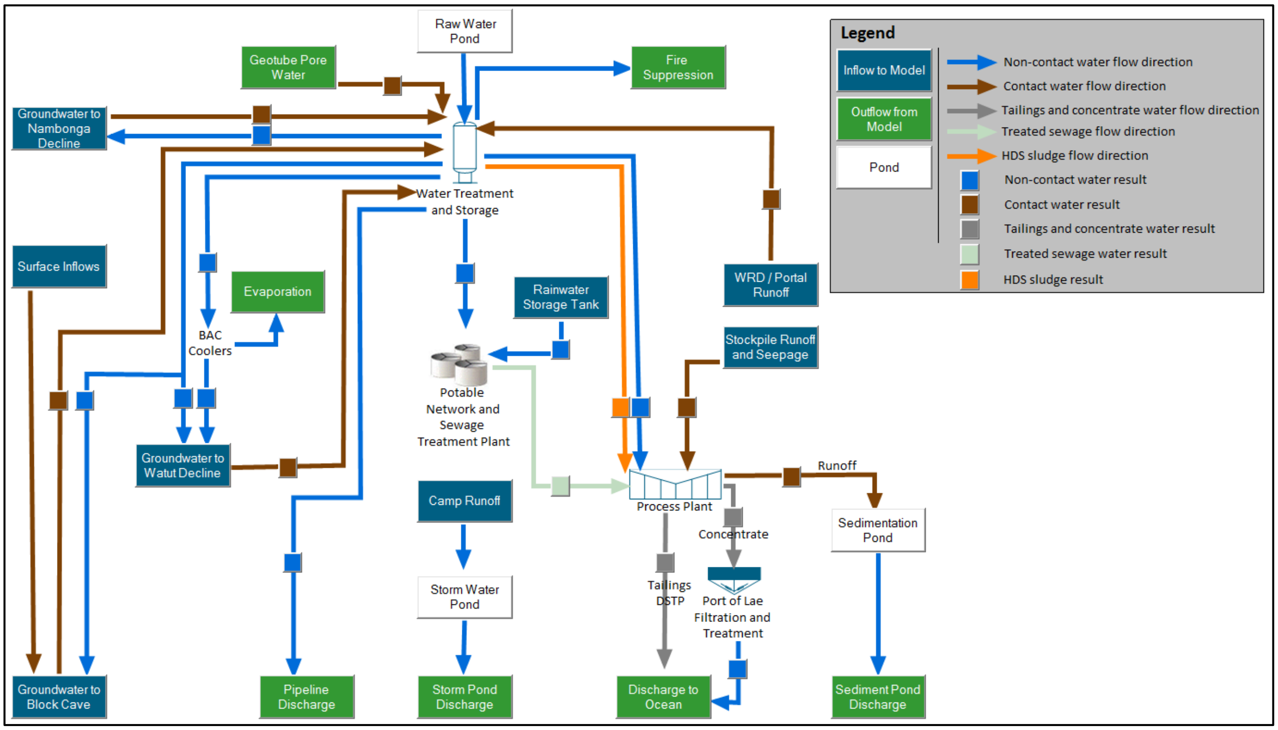


Figure 2-2: Schematic diagram of the operational phase water management system



3. MODEL DEVELOPMENT

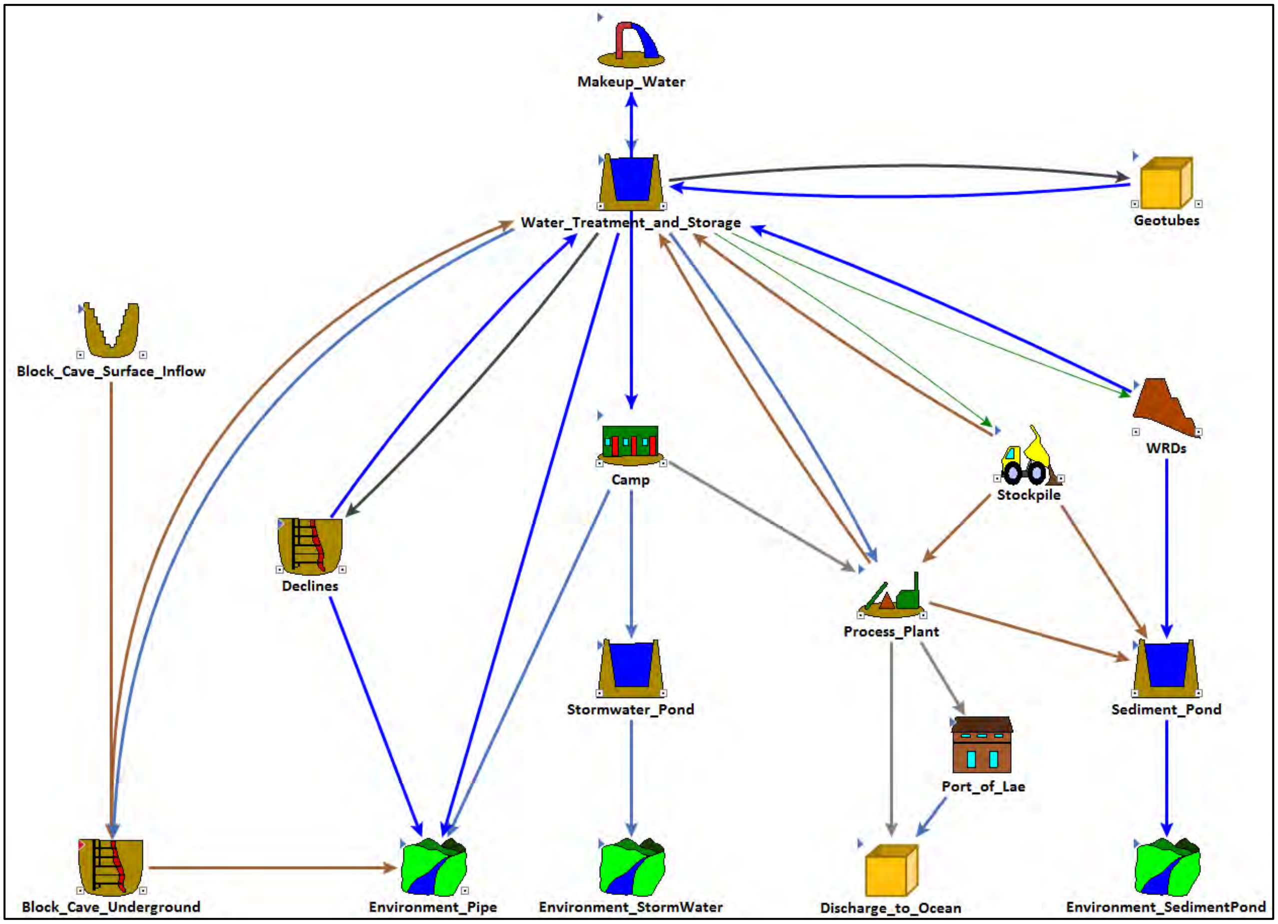
3.1. GoldSim simulation software platform

The WGJV site-wide water and mass balance model is constructed in the GoldSim™ software platform (GoldSim Technology Group, 2017). GoldSim is an analytical modelling package which allows the simulation of highly dynamic flow network systems. The system is simulated using empirical or mathematical representation, the scope of which depends upon: i) the complexity of the system (or sub-system) being simulated; ii) the level of understanding or available data for the system; and iii) the level of precision required.

A GoldSim model is constructed using 'elements', each of which can provide graphic output including a time-series and probability distribution. A large library of elements performing different functions is available, presented as images with inter-relationships between elements displayed to provide a graphical view of the model structure (Figure 3-1). This ensures that the model can be scrutinised by users with limited GoldSim experience.

The chemical mass balance component of the model is constructed using the GoldSim Contaminant Transport Module (GCTM). This allows chemical mass to be attributed to any flows, allowing the dynamic simulation of water chemistry (mass and concentration) throughout the model.

Figure 3-1: Top level of the Water_Balance container



3.2. Simulation settings

The model can be adjusted to run for any time period or any number of Monte-Carlo probabilistic simulations as desired. However, the model for Wafi-Golpu has specifically been designed to start on 1st July 2020 (start of FY21) and step forward in daily increments. Although the end date of the simulation can be modified to shorten and lengthen the simulation time, the start date should not be changed. The start date, however, is nominal and should be considered to be the start of year 1 construction.

For predictive modelling, the end time of the simulation has been set to 1st July 2056 (end of FY56), the planned end of ore processing for the purpose of the model. The model is configured to run for 50 realisations when run probabilistically. This is appropriate to establish probabilistic results between the 10th and 90th percentiles. Additional realisations to extend the confidence of the predictive modelling may not be warranted at this time based on the continued modification of the mine plan.

The default settings for the model uses the key dates as shown in Table 3.1.

Table 3.1: Key dates associated with the mine plan

Activity	Date*
Start of simulation	Jul-20
WTP operational	Sep-20
Nambonga decline construction	Sep-20 to Oct-22
First PAF intersected in Nambonga	Oct-20
Watut twin declines construction	Mar-21 to Mar-23
First PAF intersected in Watut	Jun-22
Cave Engineering Level construction	Dec-22 to Oct-25
BC44 start of construction	Nov-22
Start of processing	Jul-24
BC44 operation	Jan-26 to Dec-31
Subsidence zone breaks through at surface	Jan-28
BC42 start of construction	Oct-28
BC42 operation	Apr-31 to Jun-41
BC40 start of construction	Jul-37
BC40 operation	Oct-40 to Jun-56
End of processing	Jul-56

**These are assumed dates for the purpose of modelling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction.*

3.3. Data sources

The WGJV site-wide water balance model has been designed to simulate the performance of the water management system across the operation. Data provided by the WGJV personnel has been analysed and formatted to provide inputs to the model. A summary of key data provided to Piteau and used in the model is presented below.

- Daily precipitation from 1990 to 2015 for Wafi Camp from *Hydrology Assessment for the Golpu Project* (Highlands Hydrology, October 2015).

- Daily precipitation (where available) from 2009 to 2016 for four onsite rain gauges: Bavaga Village, Mount Golpu, Hekeng Village and Nambonga Village from ALS monitoring.
- Estimated monthly pan evaporation values from a composite of Bulolo and Erap evaporation pans from *Hydrology Assessment for the Golpu Project* (Highlands Hydrology, October 2015).
- Annual mill feed from personal communication with Aymeric Beaulavon.
- Concentrate solids and tailings percent solids estimated based on data from *532-1002-FS-CAL-0003_0_Tailings Production Profile.pdf*.
- Service water requirements for the underground operation from *532-1002-FS-CAL-0023 Water Management Summary (Scenarios D, E and F).xlsx* and personal communication with Rudi Pope.
- Bulk Air Cooler (BAC) cooler water requirements from personal communication with Rudi Pope.

- Surface area of cave zone and upgradient catchments determined from areas of subsidence zones for each cave phase, provided to Piteau as *BC44_crater_cut_AMG66_6-10-17.dxf*, *BC42_crater_cut_AMG66_6-10-17.dxf* and *BC40_crater_cut_AMG66_6-10-17.dxf*.
- Waste rock dump and stockpile geometry from *532-7121-AL-MOD-0001 REV A14.nwd*.
- Coefficients and constant flow rates from FS documents, the original water balance model and personal communication with Rudi Pope.
- Location and capacity of the ponds from personal communication with Aymeric Beaulavon.
- Preliminary groundwater inflow rates from Piteau draft numerical groundwater modelling report 3839R1v7_3D_Model_Draft_Full.pdf (November 2017).
- Geochemistry inputs from interpretation undertaken by Piteau in *Construction of predictive water quality model for Wafi-Golpu Project: rev II* (April 2017).
- Water treatment design and efficiency from report *Wafi-Golpu Mine Water Treatment HDS & DeSALx Piloting Report* (Clean TeQ, July 2017).

3.4. Model layout

3.4.1. Model structure

Principal containers

GoldSim models are typically organised hierarchically, using ‘Container’ elements to organise the function elements in a logical manner. The top level of the model comprises five principal containers: Meteorology, Hydrology, Water Balance, Mass Balance and Results.

- Meteorology – precipitation and pan evaporation inputs are defined in the Meteorology container. The model has the capability to include observed data from the onsite rain gauges and evaporation pan if required. Stochastic inputs are used for future prediction realisations using Monte Carlo simulation. The methodology for defining and testing the probability distributions for the stochastic inputs is provided in Section 4.

- Hydrology – includes algorithms for the Australian Water Balance Model (AWBM) and curve number runoff method for hydrological inputs in the water balance model. These methods are detailed in Section 5.
- Water Balance – the physical water balance comprising mine facility and catchment modules as shown in Figure 3-1. The interactions between the modules are shown by arrows called ‘influence connections’. These have been colour-coded so that: i) blue connections show the direction of non-contact or treated water; ii) brown shows the direction of contact water; iii) grey shows tailings or concentrate; and iv) white arrows (hidden) represent the exchange of information. Within each module, black arrows are used for all connections. Details of each module and associated algorithms and inter-relationships are detailed in Section 6.
- Mass Balance – for clarity, the chemical mass balance mirrors the water balance but with some additional features to allow chemical mass to be coupled to the flow. These include source terms to introduce mass into the system and sinks to remove it. Further details on the mass balance algorithms and inter-relationships are detailed in Section 7 and full details of the source term inputs are reported in *Construction of predictive water quality model for Wafi-Golpu Project: rev II* (Piteau report number 3695TM02v2, April 2017).
- Results – collated time series graphs of key information (primarily water flows and storage volumes) to allow ease of access and quick comparisons with results from different areas of the model.

In addition, there are four dashboards to allow easy access to the model for modifying key parameters and viewing results. The dashboards are:

- Main – provides links to the model settings and other dashboards;
- Key Parameter Settings – allows changes to the main parameters in the model;
- Meteorology and Hydrology Settings – allows user-defined storm events to be simulated and modifications to be made to the AWBM and curve number inputs; and
- Water Balance Results – provides quick links to all key flow, volume and chemistry results through a flow diagram (two additional results dashboards are also provided with the construction and operation flow diagrams).

Mine facilities

The structure of the WGJV site-wide water balance has been designed to provide consistency in layout and calculation methodology. The top level of each facility container has four boxes (Figure 3-2):

- Inflows From – box for elements defining water (or solids) entering the container;
- Outflows To – box for elements defining water (or solids) leaving the container;
- Demands From – box for elements which receive requests for water from other containers (for example, in the Water_Treatment_and_Storage container there are demands from fire water, process, BAC coolers and mine services); and

- Demands To – box for elements which send requests for water to other containers (for example, in the Water_Treatment_and_Storage container there are demands to makeup for additional water if/when it is required).

As illustrated in Figure 3-2 the area outside of these boxes is used for all algorithms required to simulate the processes within the container and, when required, to summarise inflows and outflows.

Some facilities have additional containers used for organising input data (such as geometry and initial conditions), or for algorithms. While each mine facility and catchment is modelled separately in individual containers, many of the same algorithms are used. Further details are provided in Section 6.1.

3.4.2. Model inputs

Spreadsheet inputs

Projected time series data are input into the model via an Excel spreadsheet called *WafiGolpu_SiteWideWaterBalance_Inputs.xlsx.*

The 'UPDATES' worksheet in the spreadsheet includes a key to the colour-coding and allows for details of changes made as new data are added or projections changed. When making updates the worksheet names and main file names cannot be changed, doing so would prevent the data from uploading to GoldSim correctly.

The data are divided between worksheets based on the data type or facility. The source of the data is summarised above each column of data to allow it to be tracked to the original files or documents. The name of the associated GoldSim element is also included to allow quick navigation to the correct location within the model (Figure 3-3).

Stochastic inputs

The WGJV site-wide water balance has been designed as a probabilistic, dynamic simulator, running continuously through the construction and into future mine life using a daily timestep. Uncertainty is incorporated into the future by using a Monte Carlo simulation where each uncertain value is defined using a probability distribution in a 'Stochastic' element. The probability distribution defines and bounds the value that is expected for any parameter that is stochastically modelled. When run probabilistically the Monte Carlo simulation samples the probability distributions setting up the model to be evaluated with that set of input parameters. Once the model run has finished, each probability distribution will be resampled to produce a second set of input parameters and the model re-run. Each single run with a set of input parameters is referred to as a 'realisation'. A Monte Carlo simulation will typically run tens or hundreds of realisations. The product of a Monte Carlo simulation is a large number of separate and independent results, each representing a possible 'future' for the system (i.e. one possible path the system may follow through time). The results of the independent realisations are statistically assembled into probability distributions of possible outcomes.

All of the uncertainty within the model is addressed in the meteorological inputs to the model (i.e. stochastic inputs are not used anywhere else in the model). Daily precipitation is stochastically sampled from distributions that have been developed using observed data from the Wafi Camp rain gauge. Further details are provided in Section 4.

Constant-value inputs

The model includes a large number constant value inputs such as catchment areas, percent moisture contents and pump capacities. These values do not change over the duration of the model simulation and are detailed in Appendix A. The dashboards within the model provide quick links to many of these elements to allow the data to be easily modified when modelling different scenarios. Appendix A also includes a table indicating the critical dates applied to the model, such as the commencement of decline development, of plant operation and of block caving for example.

Figure 3-2: Typical structure of modules in the Water_Balance container

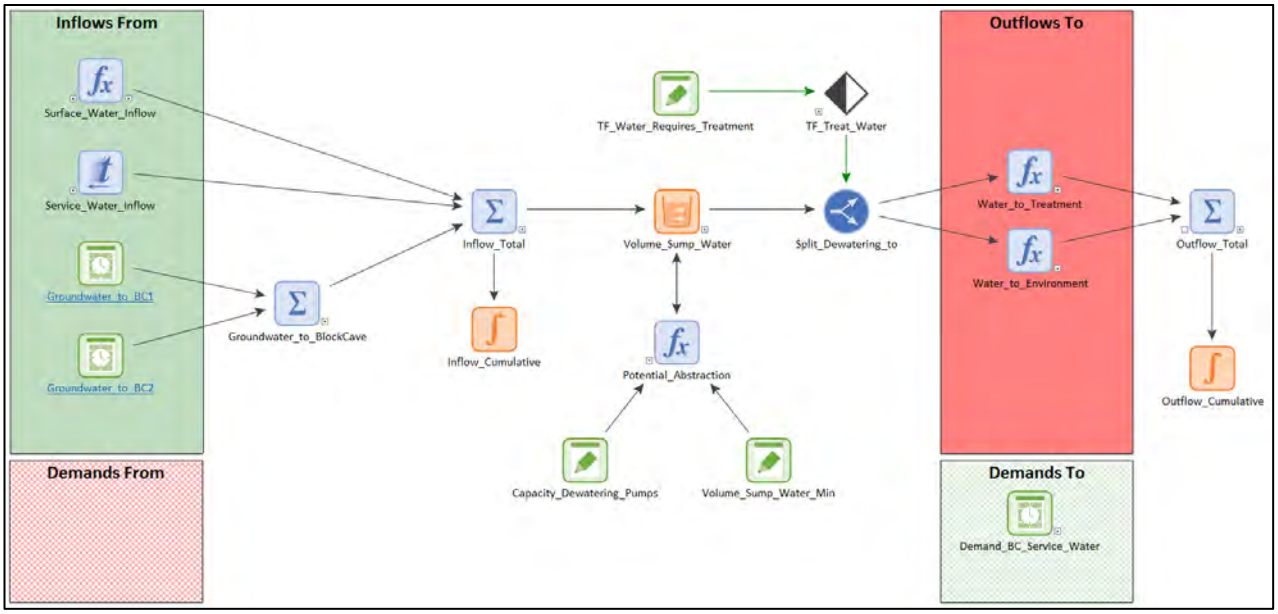
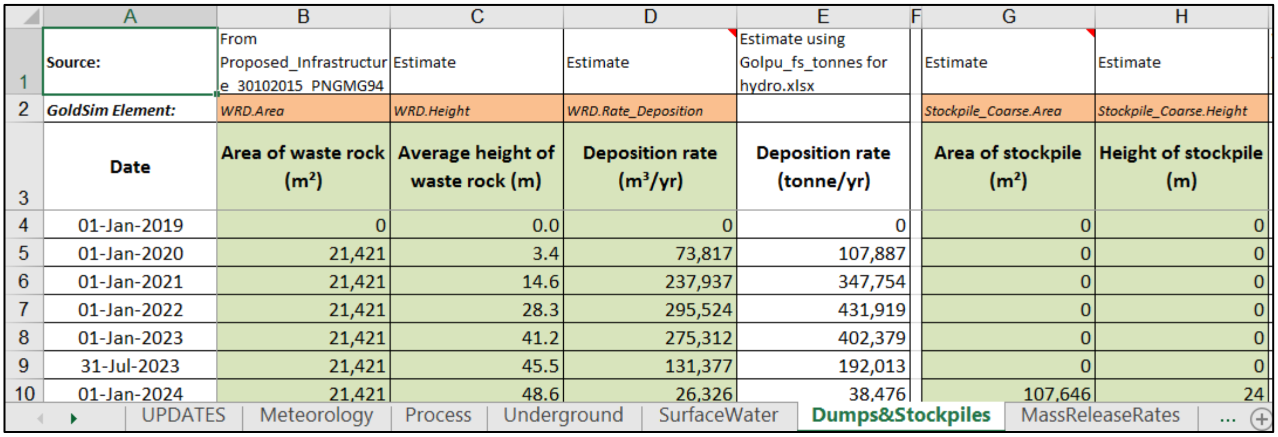


Figure 3-3: Layout and colour code system of the input spreadsheet



	A	B	C	D	E	F	G	H
1	Source:	From Proposed_Infrastructure_30102015_PNGMG94	Estimate	Estimate	Estimate using Golpu_fs_tonnes for hydro.xlsx		Estimate	Estimate
2	*GoldSim Element:*	*WRD.Area*	*WRD.Height*	*WRD.Rate_Deposition*			*Stockpile_Coarse.Area*	*Stockpile_Coarse.Height*
3	**Date**	**Area of waste rock (m²)**	**Average height of waste rock (m)**	**Deposition rate (m³/yr)**	**Deposition rate (tonne/yr)**		**Area of stockpile (m²)**	**Height of stockpile (m)**
4	01-Jan-2019	0	0.0	0	0		0	0
5	01-Jan-2020	21,421	3.4	73,817	107,887		0	0
6	01-Jan-2021	21,421	14.6	237,937	347,754		0	0
7	01-Jan-2022	21,421	28.3	295,524	431,919		0	0
8	01-Jan-2023	21,421	41.2	275,312	402,379		0	0
9	31-Jul-2023	21,421	45.5	131,377	192,013		0	0
10	01-Jan-2024	21,421	48.6	26,326	38,476		107,646	24

4. METEOROLOGY INPUTS, ALGORITHMS AND CALIBRATION

4.1. Precipitation

Modules using a second-order Markov chain derived from the WGEN model (USDA, 1984[1]) were developed in GoldSim for stochastic precipitation generation. This includes i) a Boolean probability distribution to predict the occurrence of rain on a particular day; and ii) a probabilistic distribution to express the amount of rain on any given day; both are generated using a Monte Carlo simulation. The WGEN model has been shown to adequately simulate precipitation trends in climates subject to infrequent precipitation, high-intensity storms, or multiple/successive days of rain.

For the WGJV stochastic precipitation generator, input values are assigned on a monthly basis (Table 4.1) derived from the Wafi Camp daily total precipitation data from the 26-year record (1990 to 2015). The Wafi Camp dataset is sporadic, the data gaps were infilled based on upscaled monthly data from Climate Forecast System Reanalysis (CFSR) as described in *Hydrology Assessment for the Golpu Project* (Highlands Hydrology, October 2015). The infilling exercise has not been reviewed as part of this analysis.

Table 4.1: Inputs to the GoldSim stochastic precipitation generator

Month	Boolean probability distribution inputs to define the occurrence of rain on a particular day			Gamma probability distribution inputs to define the amount of rain on any given day	
	Probability of a wet day following a dry day	Probability of two wet days following a dry day	Probability of three consecutive wet days	Mean wet day precipitation (mm/d)	Standard deviation wet day precipitation (mm/d)*
January	0.5918	0.4233	0.2970	15.63	17.51
February	0.6635	0.4797	0.3288	14.79	18.38
March	0.6635	0.4786	0.3646	14.84	17.48
April	0.5484	0.3791	0.2817	14.46	17.99
May	0.5904	0.3284	0.2435	10.58	13.56
June	0.5254	0.3017	0.2122	8.44	11.92
July	0.5425	0.3203	0.2167	7.00	8.19
August	0.5430	0.3987	0.2568	7.76	10.57
September	0.5207	0.2827	0.2077	7.17	9.43
October	0.5385	0.3445	0.2319	10.68	13.15
November	0.5382	0.3273	0.2372	13.02	15.18
December	0.6552	0.5271	0.3987	15.66	16.94

* Values are the result of a 7.5% reduction in actual standard deviation to provide a better calibration

To validate the stochastic precipitation generator, the model was run for 1,000 years and the results compared to Wafi Camp rain gauge data to ensure that the precipitation generated is representative of the observed dataset. Three key validation comparisons were made: i) wet days per month; ii) monthly precipitation at varying percentiles; and iii) annual maximum daily precipitation. These are presented in Figure 4-1 to Figure 4-3.

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[1] USDA, 1984. WGEN: A model for generating daily weather variables. United States Department of Agriculture.

Figure 4-1 presents a comparison of wet days per month with error bounds of ±2.5%. It shows that the Boolean probability generator is able to replicate the mean number of wet days per month seen in the observed data.

Figure 4-2 presents a comparison of monthly total precipitation at the 25th, 50th, 75th and 95th percentiles. It shows that the stochastic precipitation generator is able to replicate the variation in monthly total rainfall seen in the observed data.

Figure 4-3 presents a comparison of annual maximum daily precipitation for a range of return periods. It shows that the stochastic precipitation generator is able to replicate storm events of comparable magnitude to those predicted by Gumbel extreme value distribution analysis.

Figure 4-1: Observed and simulated mean wet days per month

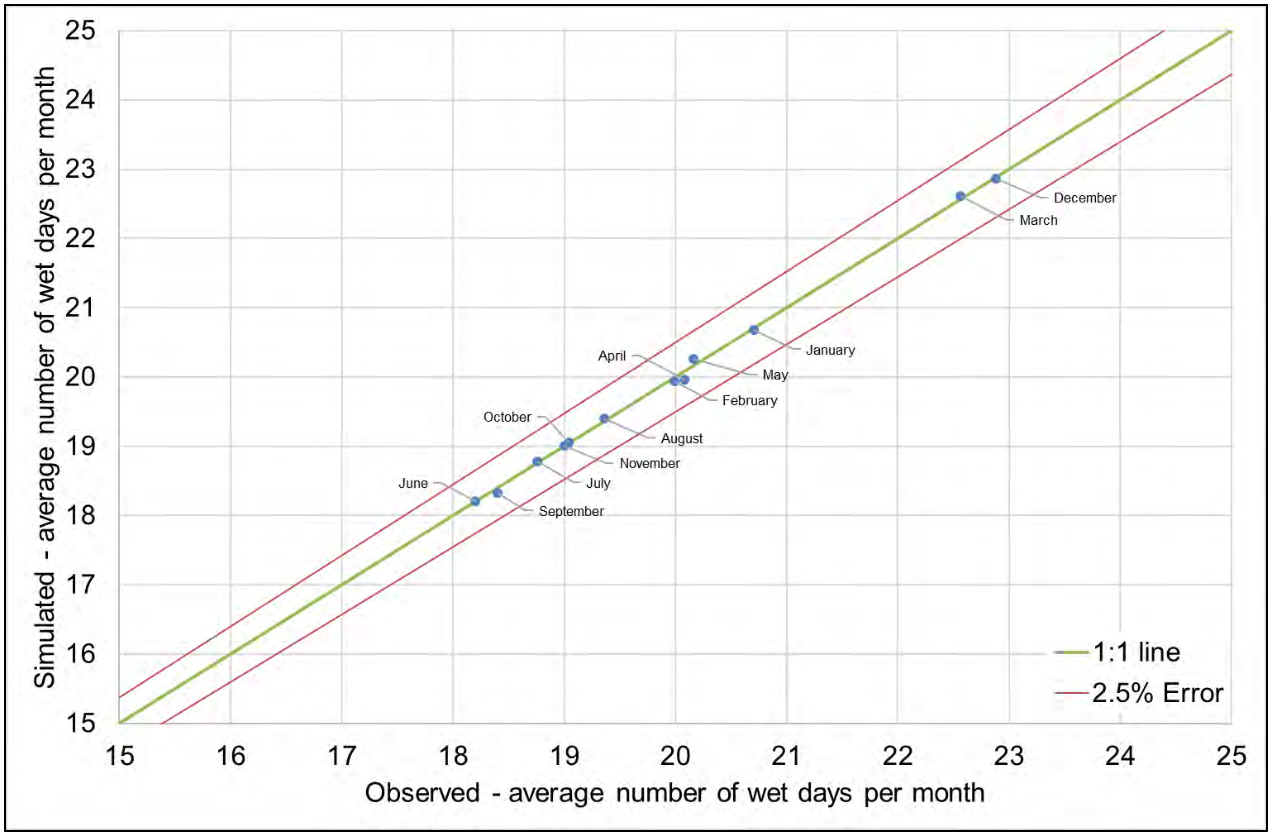


Figure 4-2: Observed and simulated total monthly precipitation

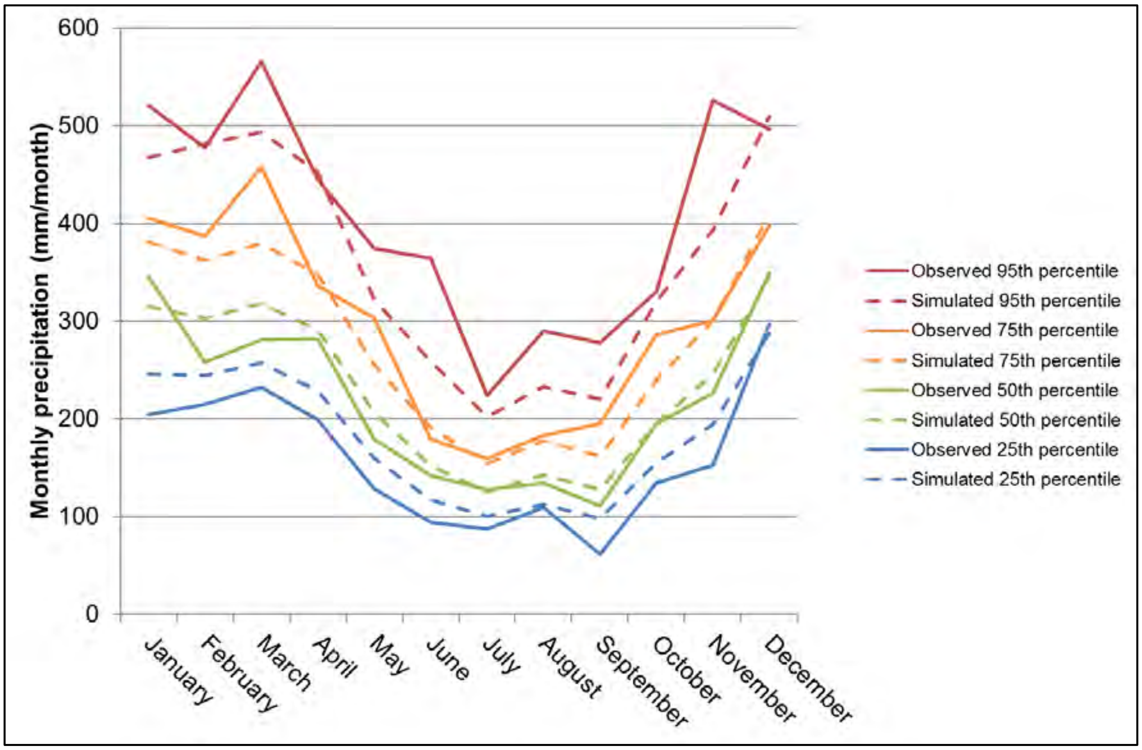
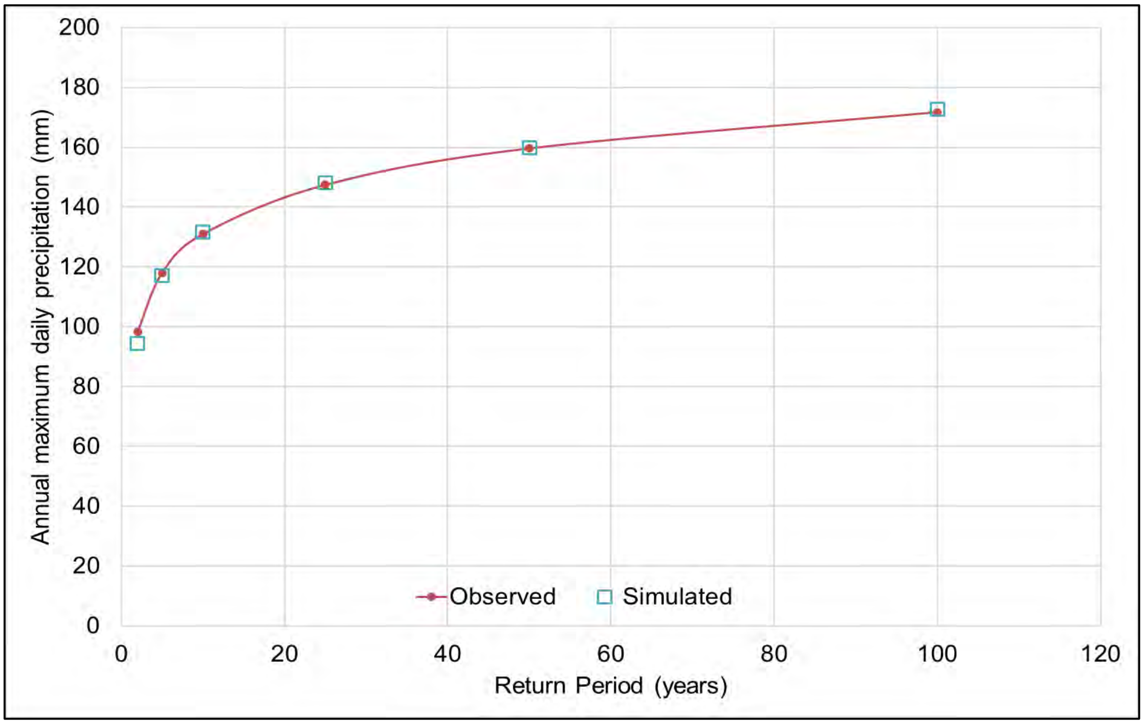


Figure 4-3: Derived and simulated annual daily maximum precipitation



4.2. Evaporation

There is no daily evaporation data recorded at the WGJV site so the composite Bulolo and Erap record of monthly mean dataset has been used, as defined in *Hydrology Assessment for the Golpu Project* (Highlands Hydrology, October 2015). The model has been constructed so that, if a weather station or evaporation pan are installed on the site, daily evaporation data can be easily uploaded via the input Excel spreadsheet.

Table 4.2: GoldSim pan evaporation dataset (from Highlands Hydrology, 2015)

Month	Mean pan evaporation (mm/d)
January	6.13
February	6.12
March	5.84
April	5.63
May	5.23
June	4.57
July	4.90
August	5.23
September	5.57
October	6.06
November	6.80
December	6.35

5. HYDROLOGY INPUTS, ALGORITHMS AND CALIBRATION

5.1. Australian Water Balance Model for runoff

The Australian Water Balance Model (AWBM) has been used to calculate the natural catchment runoff reporting to the subsidence zone.

AWBM uses three surface stores to simulate partial areas of runoff. The water balance of each surface store is calculated independently of the others. At each daily time step, precipitation is added to each of the three surface moisture stores and evapotranspiration is subtracted. If the value of moisture in the store exceeds the capacity, the excess moisture becomes runoff. The total runoff from the three stores is divided into baseflow and surface water components, using the baseflow index (BFI), adding to the respective store. Each store is depleted at a variable rate defined by a regression constant and the volume of water in the respective stores, so the higher the volume in storage, the greater the depletion rate (outflow). Total outflow is the combined depletion rates for baseflow and surface runoff. The greatest when there is a larger volume of water in storage.

The AWBM module within the Australian eWater Rainfall Runoff Library (RRL) software package was used to calibrate a runoff model for the Bavaga River at Bavaga Village (2015 to 2017). The calibrated values (Table 5.1) were then used as inputs to a GoldSim version of the AWBM within the WGJV site-wide water balance model. The AWBM was calibrated to replicate the flow duration curve (Figure 5-1) while maintaining typical responses to rainfall events (Figure 5-2).

Table 5.1: Calibrated AWBM inputs for the Bavaga River at Bavaga Village

Parameter	Value		Parameter	Value		Parameter	Value
A1	0.32		**C1**	5 mm		**BFI**	0.42
A2	0.20		**C2**	200 mm		**K_{surf}**	0.97
A3	0.48		**C3**	700 mm		**K_{base}**	0.65

Figure 5-1: Observed and calibrated flow duration curve for Bavaga River

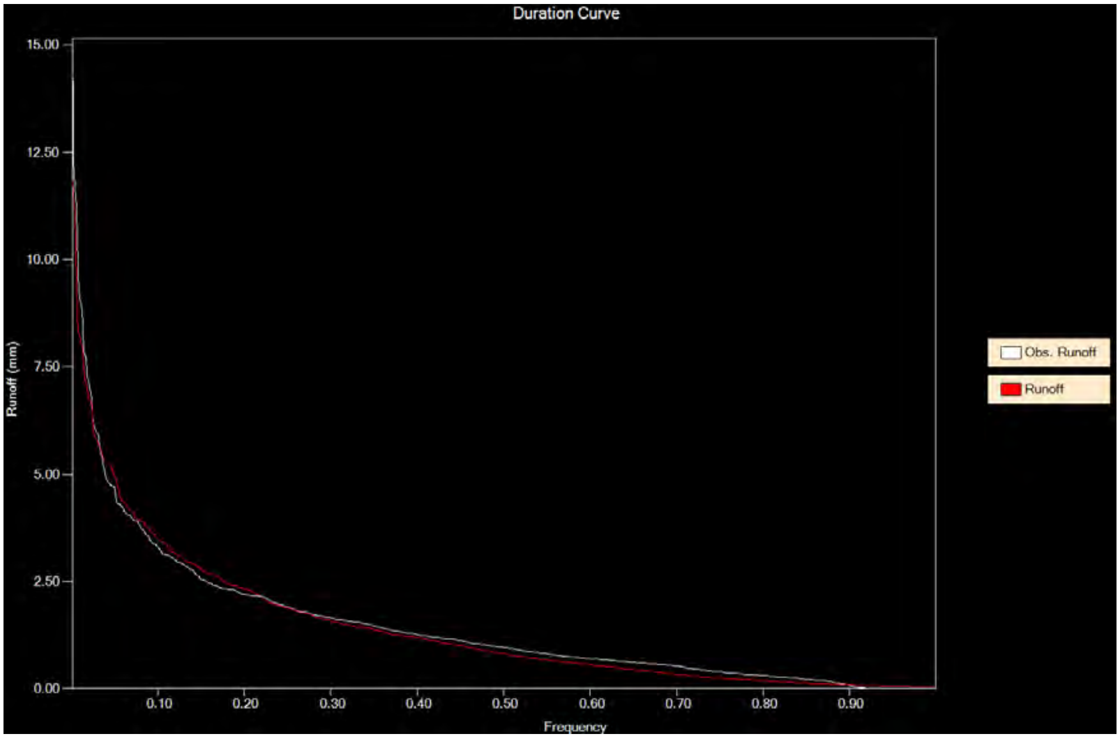
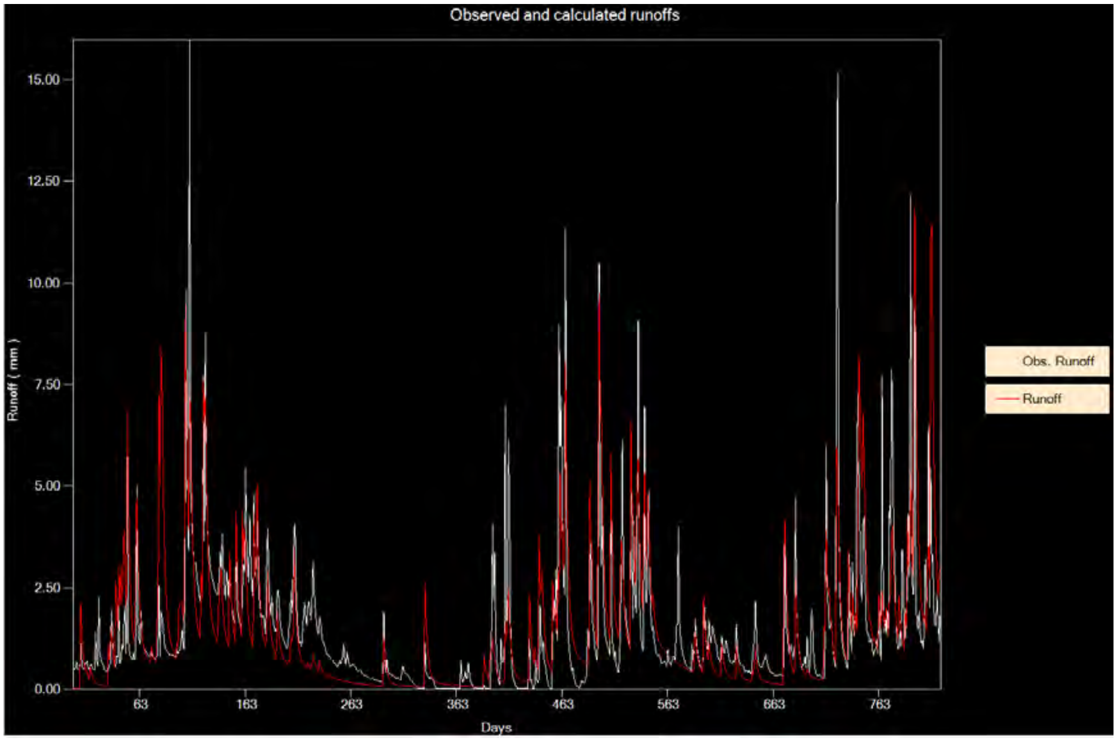


Figure 5-2: Observed and calibrated daily flow for Bavaga River



5.2. Curve number methodology for runoff

Where runoff from a facility within the mine occurs (as opposed to a natural catchment), it is calculated using the US Soil Conservation Service (SCS, now known as the Natural Resources Conservation Service) curve number method (USDA, 2004). This requires a representative curve number to be assigned to the catchment area based on its land use. Low curve numbers (typically no lower than 30) represent catchments where the proportion of runoff is typically low, for example areas of dense woodland or where soils have a high infiltration capacity. Conversely, high curve numbers (up to 100) represent catchments where the proportion of runoff is typically high, for example rooftops and paved roads.

The WGJV site-wide water balance model has curve numbers defined for seven land use categories (Table 5.2) derived based on literature values and experience from similar sites in comparable climatic regimes.

The curve number method defines the proportion of precipitation which becomes runoff based on the depth of precipitation during the day. As the depth of rainfall increases, so the proportion of runoff also increases. For example, with a curve number of 90, the proportion of runoff after 5 mm of rain is 0%, after 10 mm it is 6% and after 15 mm it is 16%. The unit runoff is calculated using the equation:

$$RO = (P - Ia)^2 \div (P - Ia + S)$$

Where: RO is unit runoff (in/d); P is precipitation (in/d); S = 1000/CN-10 and is the potential maximum soil moisture retention after runoff begins (in); and Ia = 0.2S and is the initial abstraction, which relates to the volume intercepted by vegetation or which infiltrates into the soil. If P is less than or equal to 'Ia', then RO is equal to zero. The curve number method uses imperial units of inches, GoldSim automatically converts precipitation from mm/d to in/d, then unit runoff from in/d to mm/d for use in the model.

Antecedent moisture condition can also be incorporated into the methodology, however, this has not been used as part of the WGJV model due to lack of monitoring data. Further information regarding the modifications to the curve number under different conditions may be found in chapter 10 of the USDA (2004) National Engineering Handbook Part 630.

Table 5.2: Land use curve numbers and maximum surface areas

Land Use Category	Curve Number	Maximum Area (ha)
Plant (excluding stockpile)	90	7.50
Camp	90	2.90
Waste Rock Dump	65	9.00
Port	90	2.50
Stockpile	65	1.50
Roof for rainwater harvesting	98	0.10

6. WATER BALANCE INPUTS AND ALGORITHMS

6.1. Common algorithms

6.1.1. Pond-tank-sump

The algorithm used to simulate the interaction of inflows, outflows, changes in storage and spills (where applicable) is the same for all ponds, tanks and sumps within the WGJV water balance model. The central component to the algorithm is a Pool element. This requires five key inputs:

- Initial Quantity – volume of water at the start of the simulation;
- Lower Bound – minimum volume of water which can be stored (i.e. 0 m^3);
- Upper Bound – maximum volume of water which can be stored (this can change over time, for example, as the decline advances it increases in potential storage volume);
- Inflows – all inflows such as runoff, water pumped in, groundwater inflows, etc.; and
- Outflows – maximum potential flow for each outflow component.

The Pool element allows each of the individual outflows to be placed in an order of priority. Natural outflows (evaporation and seepage) always have top priority because there is no control over their withdrawal. If there is water remaining after the natural outflows, the abstractions are placed in order of priority.

Each daily time step, the Pool element calculates the volume of available water based on the volume from the previous day and the inflows for the current day. The Pool element then allows outflows to occur based on their priority. If there is insufficient water available to satisfy all the outflows, only the available volume of water is withdrawn and the pond/tank/sump is assumed to then be dry. If, following the withdrawal of all outflows, the volume of water exceeds the Upper Bound, then the excess water is also forced out as Overflow.

6.1.2. Infiltration and seepage

The algorithm used to simulate the infiltration through a mass of rock is the same for the waste dump, stockpile and subsidence zone catchment water to the mine. Calculation is undertaken in the following steps.

1. Calculate water retention from the volume of rock deposited (waste rock) or rock fracturing (block cave) multiplied by the percent water retention of that rock.
2. Accumulate water retention over the life time of the model to define the maximum retention for the facility.
3. Use a Reservoir element with infiltration as the Addition (inflow) and the Upper Bound set to the maximum (accumulated) water retention. Any infiltration water in excess of the infiltration will ‘Overflow’ to become seepage.
4. Using a Material Delay Property element, produce a breakthrough curve of seepage with a Delay Time defined by the vertical distance the water must travel and the hydraulic conductivity of the material.

6.2. Water treatment and storage

The water treatment and storage module controls water supply to the whole mine site, except for potable water which is sourced through rain harvesting and makeup from the Watut.

At the request of WGJV, no capacity has been applied to the treatment plant, therefore all water requiring treatment in a given timestep is treated, no contact water is stored in a pond before treatment. The treatment and distribution process is as follows.

1. All water requiring treatment from across the site is first routed to high density sludge (HDS) where sludge is precipitated out (based on solubility limits defined by Clean TeQ, see Section 7.4) with moisture content by weight of 60%. This sludge is deposited in geotubes during the construction phase and sent to the process plant during operations.
2. The overflow is divided so that 50% of the flow passes through DeSALx ion exchange (based on treatment efficiencies defined by Clean TeQ, see Section 7.4) then mixed with the other 50%.
3. Treated water is first used to fulfil demands from across the mine site. If there is excess water, it is discharged to the Watut via the pipeline. If there is insufficient to supply all of the demands, makeup water from the Watut River is used to supplement the supply.

Various additional options for water treatment are available via the *Key Parameter Settings* dashboard. The options are as follows.

- **Treatment type –** options are: no treatment, HDS and DeSALx, HDS only or DeSALx only (for more information see *Wafi-Golpu Mine Water Treatment HDS & DeSALx Piloting Report*, Clean TeQ, July 2017). The provision of the final two options are intended to provide comparisons for evaluation purposes rather than viable treatment options.
- **Start date for treatment** – the default setting in the model is for the treatment plant to become operation on 1st August 2020, in advance of PAF rock being intercepted in the decline.
- **HDS sludge percent solids and density –** allows the user to vary sludge solids content and corresponding sludge density.
- **Percent bypassing DeSALx –** for the HDS and DeSALx treatment option, a proportion of the HDS overflow can bypass the DeSALx treatment and the two streams blended downstream.
- **Water requiring treatment** – the water sources routed to the treatment plant can be selected; options are: decline water, mine water, waste dump/portal runoff and stockpile runoff. It should be noted that the runoff from the stockpile is automatically sent to the process plant once this is operational.

The geochemical aspects of water treatment are based on the Clean TeQ investigations and are described further Section 7.4.

6.3. Geotube consolidation and storage area

At the time of writing, the design for the geotube storage area had not been finalised. It is assumed that it is a fully lined facility with a surface area of 0.38 ha. While in the geotubes, the sludge consolidates from 60% water content by weight, to 20% (both values are provided by WGJV. Consolidation occurs at a rate such that the percent water content halves every year.

All water produced by the consolidation of sludge is assumed to mix with rainfall-runoff from the lined facility and together they are treated in the WTP.

6.4. Declines and Portal

The declines (Nambonga and Watut) are simulated using the pond-tank-sump algorithm described in Section 6.1. Inflows are:

- service water inflow – water required for mining activity such as drilling and dust suppression;
- groundwater inflow – based on numerical groundwater modelling performed by Piteau; and
- BAC cooler water blowdown – water discharged from the coolers to prevent excessive solute build up.

The outflows are:

- pumped water from the decline – to the WTP; and
- losses to evaporation from the BAC coolers.

Demands are for service water and BAC cooler water, both of which are requested from the treated water tank.

6.5. Mine

6.5.1. Surface inflow

Subsidence zone catchment water reporting to the mine is calculated using the AWBM (outlined in Section 5.1) and the surface catchment area of the subsidence zone. Inflow increases over time as the subsidence zone increases.

A Reservoir element is included to simulate the creation of residual porosity within the cave zone as the fracture network increases. This retains a small proportion of the inflow within the rock mass before allowing the remaining inflow to report to the extraction levels.

The rate at which water flows through the block cave is simulated using a Material Delay element.

6.5.2. Mine operations

The mine is simulated using the pond-tank-sump algorithm described in Section 6.1. Inflows are:

- service water inflow – water required for mining activity such as drilling and dust suppression;

- surface water inflow – rainfall-runoff which infiltrates into the mine from surface following breakthrough of the cave zone; and
- groundwater inflow to mine and access decline – based on numerical groundwater modelling performed by Piteau.

The outflow is pumped water from the mine to the WTP.

Demands for service water are requested from the treated water tank.

6.6. Process plant

The principal driver of the process plant is the ore feed. This defines the water demand and, ultimately, the bulk concentrate and tailings flows. Total water demand is defined by the concentrate and tailings percent solids and losses within the plant, adjusted to account for any inflows as ore moisture, as well as service water.

Water is ‘pushed’ into the plant as:

- Treated sewage water;
- runoff from the ore stockpile;
- ore moisture; and
- HDS sludge.

If additional water is required to meet the demand, it is requested from the treated water tank.

All inflows are summed together then allocated in the following order of priority:

1. plant losses;
2. concentrate water; and
3. tailings water.

Therefore, should the inflows exceed the demand (due to high inflow from the stockpile runoff), all excess water is discharged with the tailings.

6.7. DSTP

The DSTP is for the discharge of tailings slurry from the process plant. The model only simulates the water content of this flow.

6.8. Port of Lae

The Port of Lae simulates the thickening of the concentrate using a factor defined in the original (Worley Parsons) water balance model. Any excess water from the thickening is assumed to be discharged to the ocean after treatment.

6.9. Camp and storm water pond

6.9.1. Potable supply

Potable supply is demanded at a constant rate of 10 m^3/hr through mine life. A rainwater harvesting module has been included to supplement the supply but most of the potable water is supplied by the treated water tank.

A proportion of the potable supply is removed from the model as a loss and the remaining treated sewage portion sent to the process plant (once operational), and the Watut River via waste water discharge pipeline before this time.

6.9.2. Storm water pond

Runoff from the camp is calculated using the curve number method (see Section 5) with a defined area for the camp. All runoff reports to the storm water pond which uses pond-tank-sump module to simulate losses to evaporation and seepage and overflow from the pond to the environment.

6.10. Runoff from the plant and portal

Runoff from the process plant is calculated using the curve number method (see Section 5) with defined area. All runoff reports to the environment via the sedimentation pond. The sedimentation pond uses the pond-tank-sump module to simulate losses to evaporation and seepage and overflow from the pond to the environment. The size of the sedimentation pond has been assigned a value of 4,128 m^3 as per drawings provided by WGJV.

6.11. Runoff and seepage from the waste rock dump (WRD)

Runoff from the WRD is calculated using the curve number method but also uses the infiltration and seepage module to calculate seepage from the base of the dump.

All runoff and seepage may be discharged directly to the Watut if the quality is within statutory limits; however, as a conservative approach, it is assumed that all water is sent to the WTP.

7. CHEMICAL MASS BALANCE ALGORITHMS

7.1. Overview

In conjunction with development of the physical water balance, a chemical mass balance model was developed to permit simulation of the movement of chemical mass through all stages of WGJV site-wide water reticulation, storage and discharge system. The mass balance model was constructed using the GoldSim contaminant transport module (GCTM) which runs concurrently with the physical water balance to yield predictions of water quality throughout the system at daily timesteps. The mass balance model replicates the layout of the physical water balance. The following chemical parameters (known as “species” in GoldSim) are included as being dissolved in the mass balance model: pH, Alkalinity, As, Ca, Cd, Cr, Cu, Fe, Hg, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, SO_4 and Zn. However, only As, Ca, Cd, Cl, Cr, Cu, Fe, Hg, Mn, Na, Ni, Pb, Se, SO_4 and Zn have sufficient water quality and testwork data for use as model inputs to provide confidence in the results.

As with the physical water balance, following the execution of any model run, GoldSim can generate graphs or tables of results for any element of the model. Commonly-used, quick-access results have been provided through the dashboard, although results for any variable within the model structure can be viewed. GCTM results can be presented as either mass or concentration time series plots extending over any timeframe within the simulation period.

7.2. Source terms

7.2.1. Definition

Source terms are points of chemical mass input to the model. These essentially mirror all points within the model where water is introduced, such as makeup water or inflow through the block cave subsidence zone. Source-term chemistry input values may be constant over time or variable with flow, or with discrete stages of mine development.

The mode of assignment of chemical inputs to source terms is in two forms:

- solid phase inputs – mass released per unit area of rock in contact with water; and
- aqueous inputs – concentrations of solutes (dissolved) within any given inflow.

7.2.2. Solid phase inputs

Solid phase inputs were calculated from on-going column tests and geochemical modelling as described in *Construction of predictive water quality model for Wafi-Golpu Project: rev II* (Piteau report number 3695TM02v2, April 2017). Inputs to the mass balance model are defined for:

- decline (early and late stages);
- mine groundwater inflow;
- subsidence zone catchment water; and
- waste rock dumps (NAF and PAF material).

These are used in conjunction with the surface area of rock which interacts with the flow to produce a mass per day input.

7.2.3. Aqueous inputs

Aqueous inputs to the mass balance model are:

- natural runoff (for makeup water) – typical values taken from onsite surface water monitoring;
- facility runoff – currently assumed to be the same as natural runoff;
- treated sewage – typical values used; and
- precipitation – assumed to have no mass.

These are used in conjunction with the flow rate for each of the sources to produce a mass per day input.

7.3. Mixing functions

Following the introduction of chemical mass, its movement through each transport and mixing stage of the physical water balance model is simulated primarily through simple arithmetic mixing functions within the GCTM. Thus, in instances in which two or more flows aggregate, the mass within each flow component is combined and then used to recalculate a concentration through direct integration with the aggregate flow. In locations involving storage, a revised chemical mass inventory is calculated at each daily time step and this is 'dissolved' into the volume of water in storage determined by the physical water balance for the corresponding time step.

The GCTM module does not by default include any capacity for performing solubility calculations based on thermodynamics (or kinetics) for the aqueous system. In instances in which mineral solubility may significantly constrain the aqueous concentrations of individual parameters, functions are, however, built into the model to provide a broad approximation of thermodynamic controls.

7.4. Treatment terms

A number of options have been and will continue to be assessed to determine the most appropriate solution for managing waste water quality to achieve water quality discharge compliance. For the purposes of EIS modelling and as part of Project Feasibility Study Update engineering design and capital cost estimates, HDS and DeSALx ion exchange technologies are currently proposed as an appropriate method to treat mine waste water, as required. The water treatment plant structure is based on a design for which performance testing has been undertaken by Clean TeQ in mid-2017. Simulation of the process is performed using inputs presented in Table 7.1, and as described below:

- All water requiring treatment is subject to lime addition at a rate on 3 g/L in the HDS process. This increases the pH and facilitates the precipitation of metal hydroxides and, under suitable conditions, gypsum. This is simulated using a 'solubility ceiling' for all parameters as defined by Clean TeQ. If the concentration of the feed water is greater than the ceiling, the concentration in the overflow is fixed at the ceiling value and the remaining mass is precipitated into the sludge. If the concentration of the feed water is below the ceiling, no mass is precipitated in the HDS.

- HDS sludge (including water content) is deposited in geotubes during the construction phase and sent to the process plant and added to the concentrator during operations.
- Half of the overflow from HDS is sent to the DeSALx, with the other half being allowed to bypass and then be blended back into the treated DeSALx stream prior to final discharge.
- The DeSALx is simulated using a solubility ceiling. However, rather than sludge being produced, any mass in excess of the ceiling is assumed to be adsorbed to anion and cation resins and subsequently flushed during rejuvenation with alkaline and acid stripping solutions respectively. The waste solutions from the rejuvenation are assumed in the model to carry all mass removed from the DeSALx columns, plus an additional sulphate loading from sulphuric acid stripping. These waste solutions are added to the HDS stream.

Table 7.1: Water treatment plant inputs (defined By Clean TeQ, 2017)

Parameter	HDS solubility ceiling (mg/L)	DeSALx solubility ceiling (mg/L)
As	0.0005	0.0001
Ca	674	41
Cl	None	21
Cr	0.005	0.045
Cu	0.1	0.01
Fe	0.06	0.01
Hg	0.0005	0.0001
Mn	0.13	0.01
Na	24	2
Ni	0.0005	0.005
Pb	0.0005	0.0001
Se	0.005	0.007
SO_4	2200	25
Zn	0.13	0.01

7.5. Sludge volume simulations

The GoldSim-GCTM model has recently been configured to calculate both the volume and chemical composition of sludge produced by the HDS process at each daily model time-step. This functions by quantifying the mass of metals, plus residual lime and gypsum, removed during the HDS from the final clarifier overflow. For the principal metals, Fe and Cu, mass is calculated on the basis of the stoichiometry of $Fe(OH)_3$ and $Cu(OH)_2$. A similar process is undertaken to calculate the mass of gypsum and calcite in the sludge. Trace metals are assumed to pass to the sludge in adsorbed form. Consequently, their mass is determined on a direct abundance-removed basis.

Water comprises a large proportion of all HDS sludge. Due to uncertainties over the residual water content of sludge to be produced at Golpu, a variable water content option is included in the model dashboard.

8. PREDICTIVE SIMULATIONS

8.1. Overview

The WGJV site-wide water balance is specifically designed to simulate future flows and changes in water storage over a wide range of potential precipitation conditions. The model makes future predictions using projected values based on the algorithms and inputs described in the preceding sections. Base case data inputs for the predictive simulations are provided in Appendix A.

The following sections provide key results for flow and dissolved water quality at locations across the mine site defined by the EIS team, for the construction and operational phases.

The model can be adjusted to run for any duration or number of Monte-Carlo probabilistic simulations ('realisations') as desired. However, the model has specifically been designed to start on 1st July 2020.

All the results presented in the following sections used 50 realisations. This is appropriate to establish probabilistic results between the 10th and 90th percentiles.

The results for the physical water balance (daily timestep) are presented in Figure 8-1 to Figure 8-12 and in Figure 8-13 to Figure 8-20 for the mass balance (annual average for sulphate and coper concentration). pH has not been simulated by the GoldSim model because it requires thermodynamic simulation.

8.2. Physical water balance

The following discussion on flows, discharges and treatment volumes, and the accompanying figures (Figure 8-1 to Figure 8-12) are based on the assumed dates adopted for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction.

8.2.1. Underground inflows

Groundwater inflows to the underground (declines and mine) are defined by numerical groundwater modelling undertaken by Piteau in 2017. The flows are not directly impacted by variations in precipitation and, therefore, the results are not probabilistic. Subsidence zone catchment water is the only underground inflow which is directly affected by precipitation.

Figure 8-1 shows that the Nambonga decline groundwater inflow peaks in June 2022 at 144 m^3/hr and the Watut declines in June 2024 at 360 m^3/hr. The block caves produce the greatest proportion of groundwater inflow, peaking at 587 m^3/hr in July 2034. Small troughs in the block cave groundwater inflow are seen in 2033 and 2038 due to changes in the underground operations during those periods.

Figure 8-2 shows the daily, seasonal and life of mine (LOM) variability of surface inflows through the subsidence zone. Inflows are at their greatest from January to May with flows up to 300 m^3/hr (at the 90th percentile) towards the end of mine life when the subsidence zone is at its greatest extent. Figure 8-2 also shows that, at the 90th percentile, there will be a constant inflow through the subsidence zone once it has broken surface. Although at the 10th percentile these flows are small at between 1 and 5 m^3/hr. Although the flow variation appears large, the impact on total dewatering (including groundwater inflows and service water) is relatively modest.

8.2.2. Waste rock dump and stockpiles

Figure 8-3 and Figure 8-4 shows runoff and seepage from the waste rock dump, respectively. At the time of writing, detailed designs for the dump were not available so the values should be seen as indicative. They show that flow increases during the construction phase as the waste dump increases in size, then flows remain seasonally-constant for the reminder of mine life. For runoff, flows are only storm related and are typically between 5 and 10 m³/hr at the 90th percentile. For seepage flow ranges from zero to 15 m³/hr at the 50th percentile and from 1 to 30 m³/hr at the 90th.

Runoff and seepage from the stockpile are greatest between 2025 and 2027 with a maximum flow of 5 m³/hr at the 90th percentile, as shown in Figure 8-5. During this period, a considerable amount of ore is being stockpiled and so the stockpile has a large footprint, increasing both runoff and seepage. After 2027, the stockpile geometry does not vary significantly, and flows remain within a seasonally-constant range of between zero and 1 m³/hr at the 50th percentile.

8.2.3. Water treatment and supply

Inflow to the water treatment plant (Figure 8-6) comprises the following flows:

- water pumped from the declines;
- water pumped the cave mine (including cave infiltration and subsidence zone catchment water);
- runoff and seepage from the stockpile (construction phase only);
- runoff and seepage from the waste rock dumps; and
- runoff and geotube consolidation water from the geotube storage area.

Total treatment requirement peaks at around 890 m³/hr in 2029 becoming slightly seasonally variable with time (predominantly due to the subsidence zone catchment water) with inflows ranging between 730 and 780 m³/hr at the 90th percentile.

Water requirements for service cooler water are fixed over time and presented in Figure 8-7. Total demand for water is typically around 1,600 m³/hr during operations as shown in Figure 8-8. Reductions in demand occur from 2031 to 2033 and 2041 to 2041 as mining transitions from BC44 to 42 and BC42 to 40, respectively. Treated water and runoff water in the plant/stockpile areas are used, where possible, to supply the water demands. However, makeup water from the Watut River is required to supplement the supply. Typically providing around 5 to 15% of total demand during the construction phase and around 50% in operations.

12,400 tonnes of sludge solids are predicted to produced by the HDS. Following consolidation of the geotubes, the volume of water remaining within the pore space is predicted to be 2,500 m³.

8.2.4. Site discharges

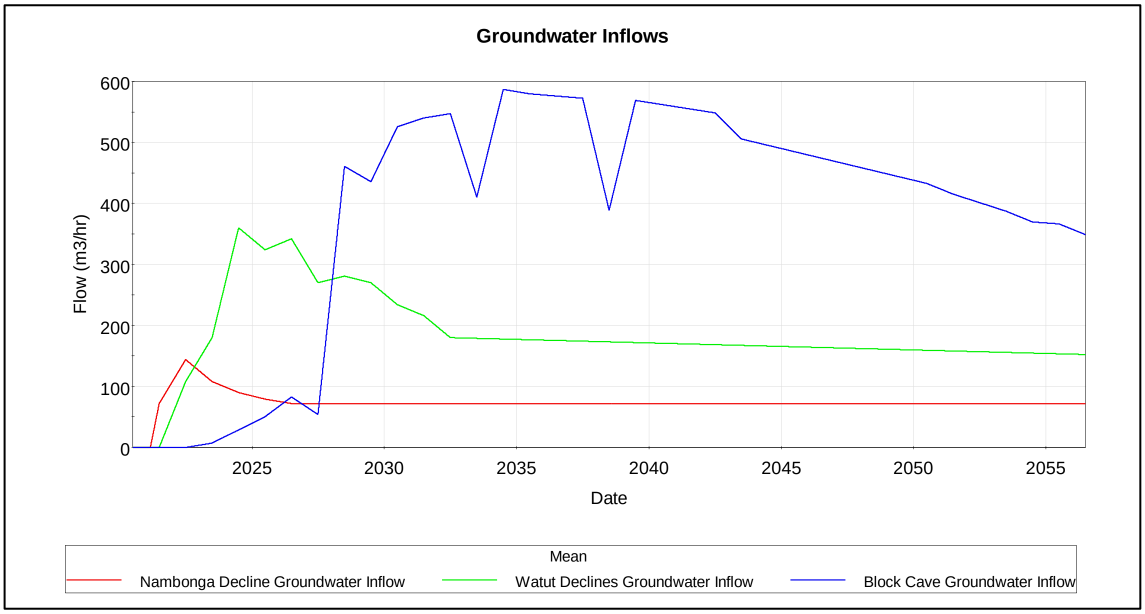
Figure 8-10, Figure 8-11 and Figure 8-12 shows the discharges to the environment from the pipeline, sediment pond and storm water pond respectively.

Flows from the pipeline (Figure 8-10) are dominated by excess treated water being discharged when they are not required in the process plant. Most notably during the construction phase but also during financial years 32, 41 and 56 when mill feed is reduced (equating to transitions from BC44 to 42, BC42 to 40 and closure, respectively).

Flows from the sediment pond (Figure 8-11) are typically low (less than 0.1 m³/hr at the 50th percentile) but following storm events during the construction phase may be as high as 60 m³/hr due to water reporting from the plant construction site. During the operations period, these flows are captured for use in the plant so flows from the sediment pond are minimal.

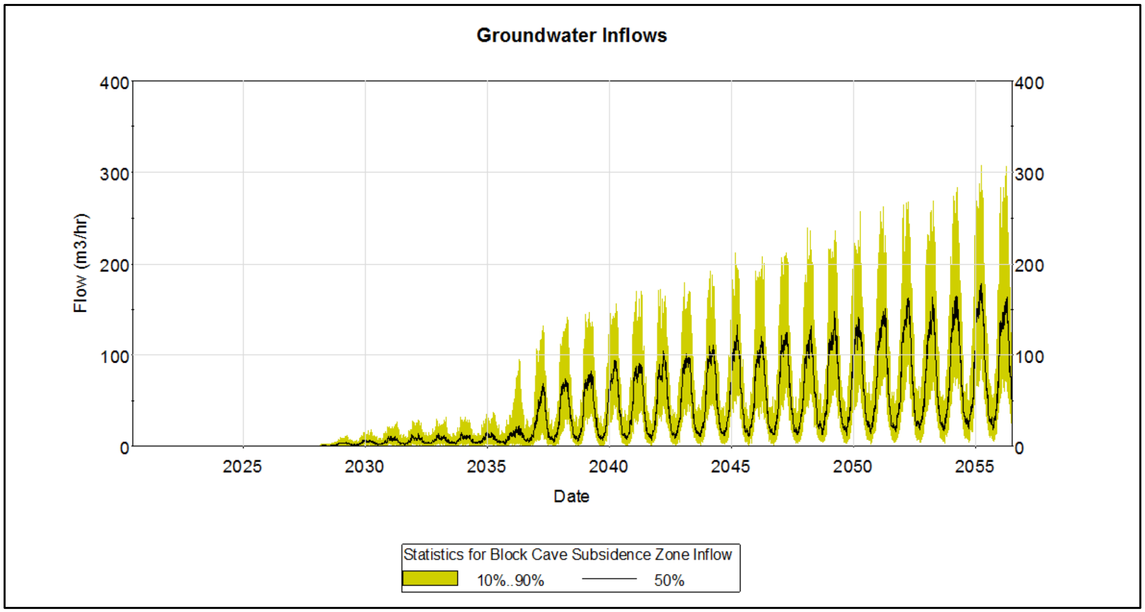
Runoff from the camp reports to the storm water pond throughout the construction and operational periods. Peak flows at the 90th percentile are around 20 m³/hr with typical daily flows of less than 0.1 m³/hr at the 50th percentile.

Figure 8-1: Groundwater inflows to the declines and mine



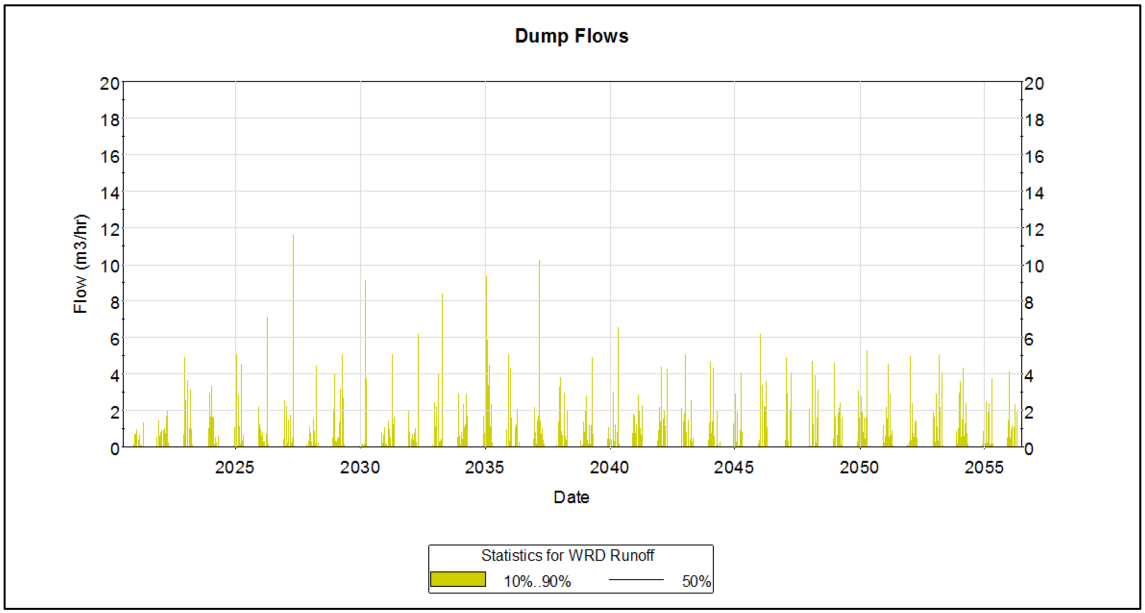
Note: These are assumed dates for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction

Figure 8-2: Subsidence zone catchment water inflow to the mine



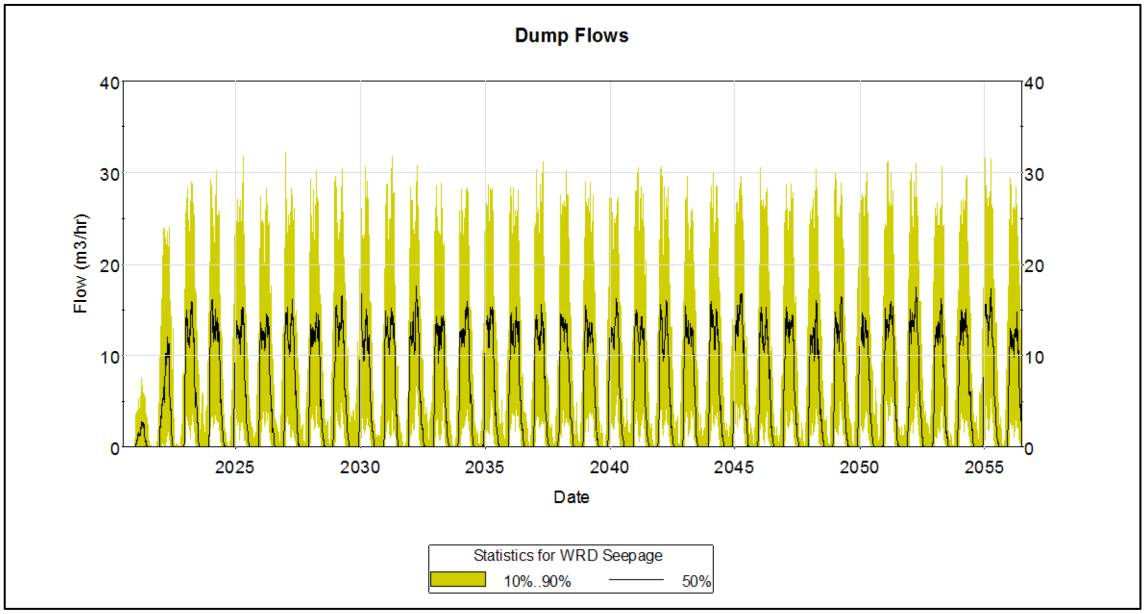
Note: These are assumed dates for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction

Figure 8-3: Runoff from waste rock dump



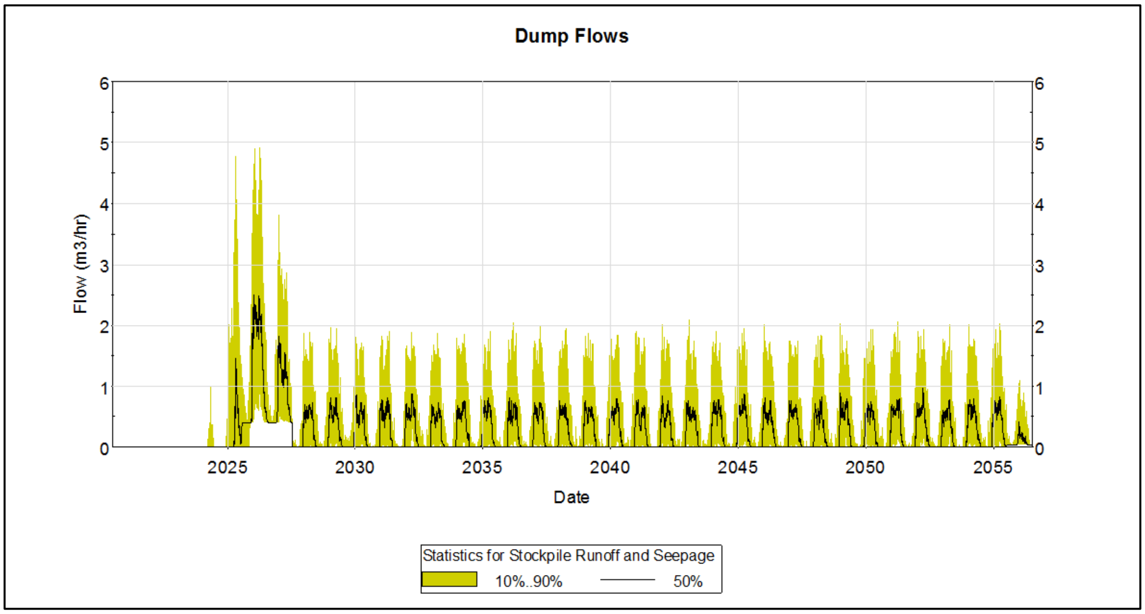
Note: These are assumed dates for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction

Figure 8-4: Seepage from waste rock dump



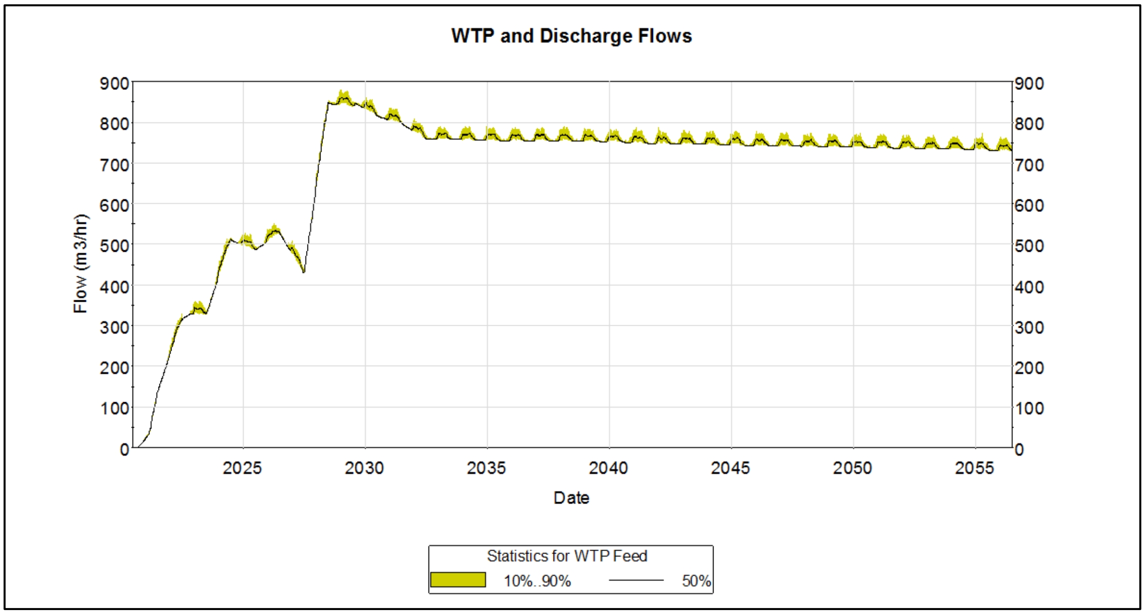
Note: These are assumed dates for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction

Figure 8-5: Runoff and seepage from the stockpile



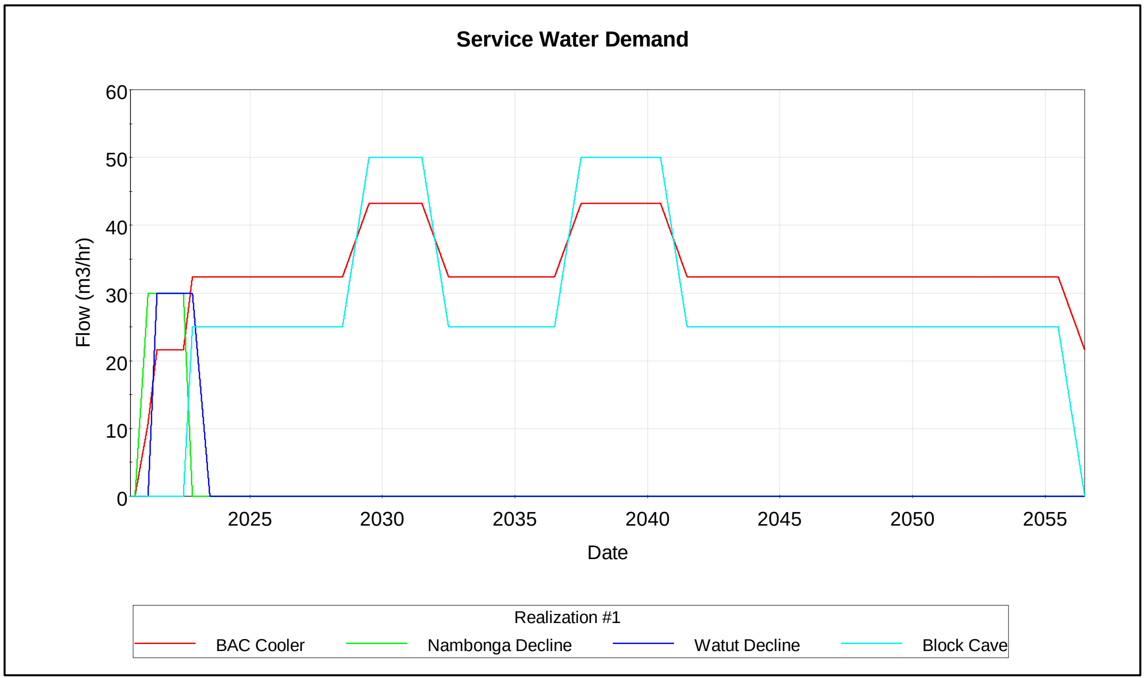
Note: These are assumed dates for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction

Figure 8-6: Total water treatment feed from underground and surface runoff sources



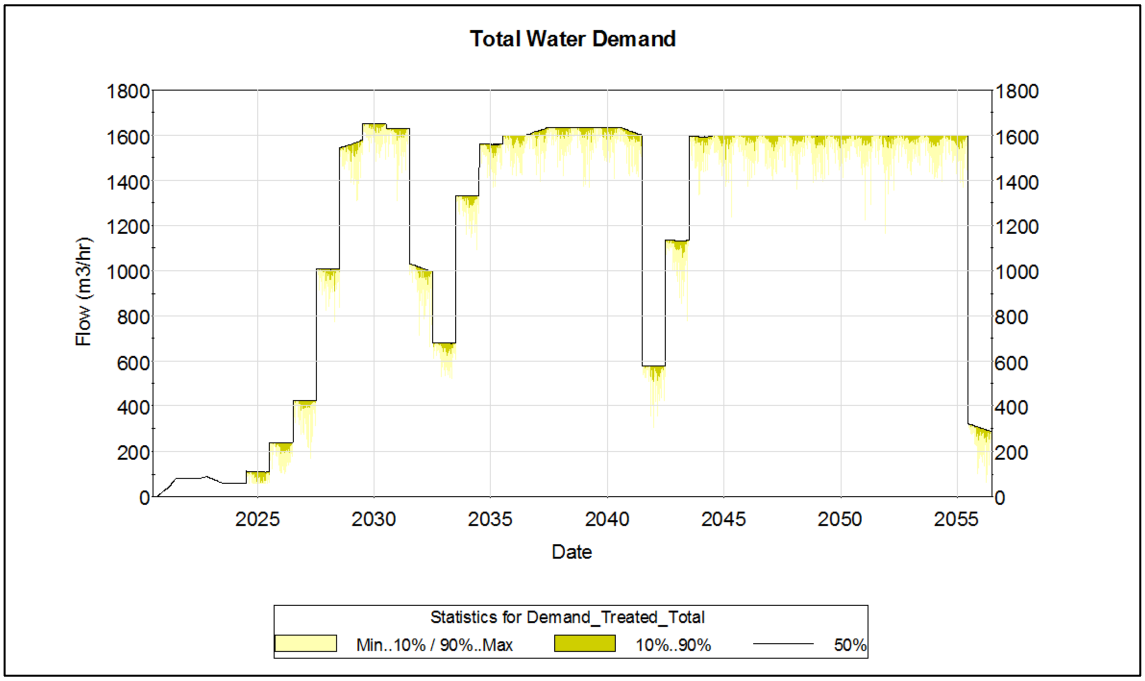
Note: These are assumed dates for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction

Figure 8-7: Water demand for service and cooler water



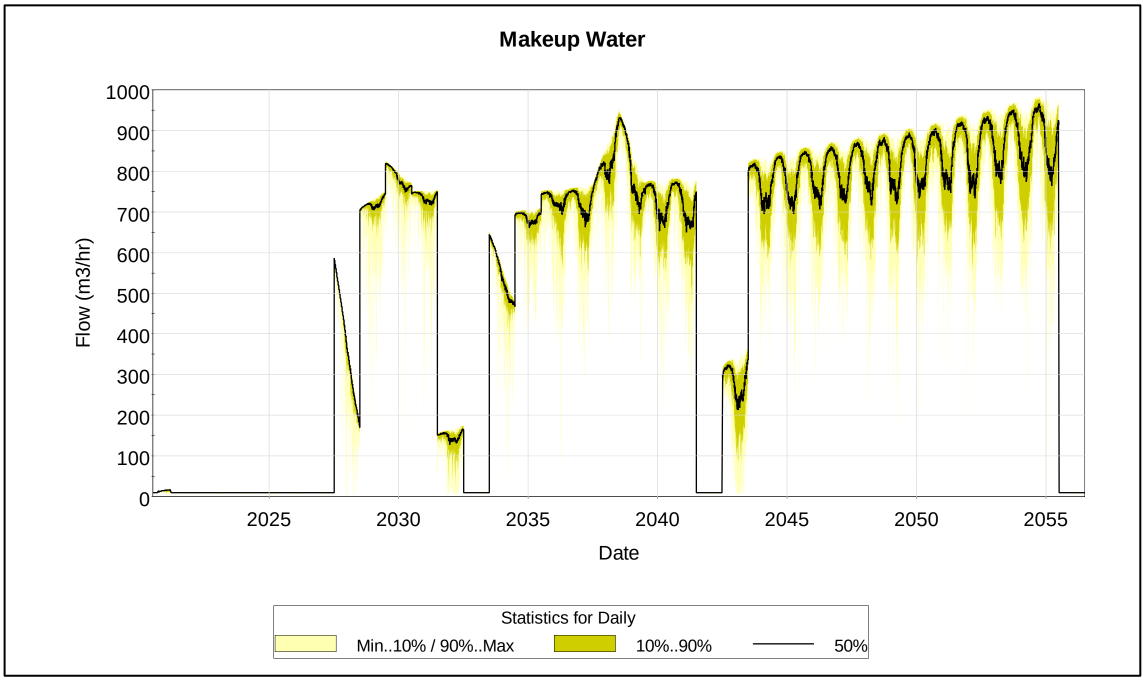
Note: These are assumed dates for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction

Figure 8-8: Total demand for water



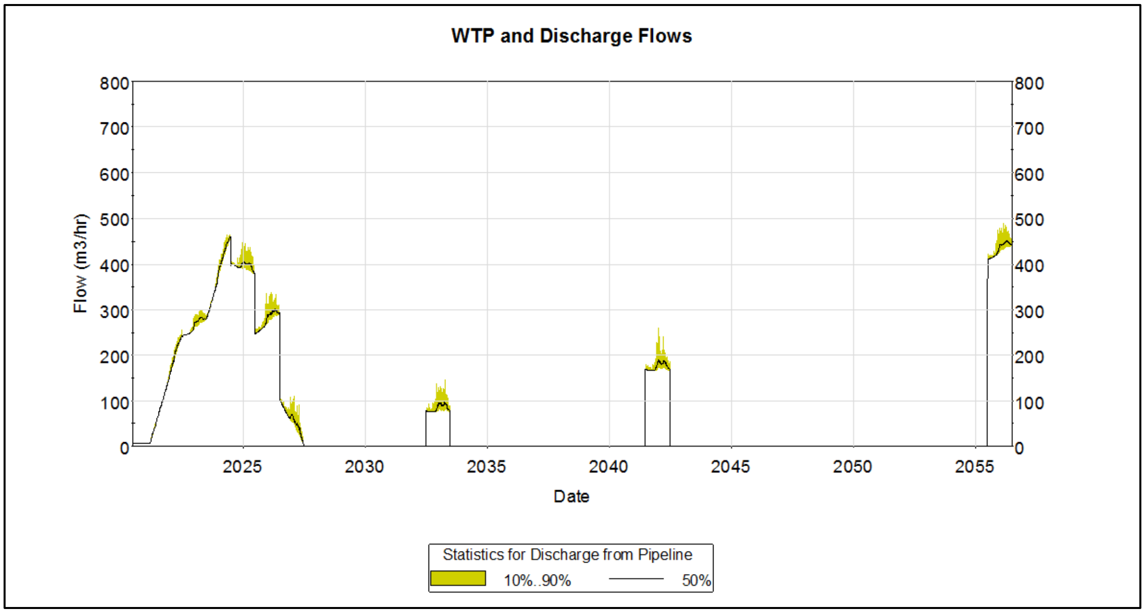
Note: These are assumed dates for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction

Figure 8-9: Total makeup requirement



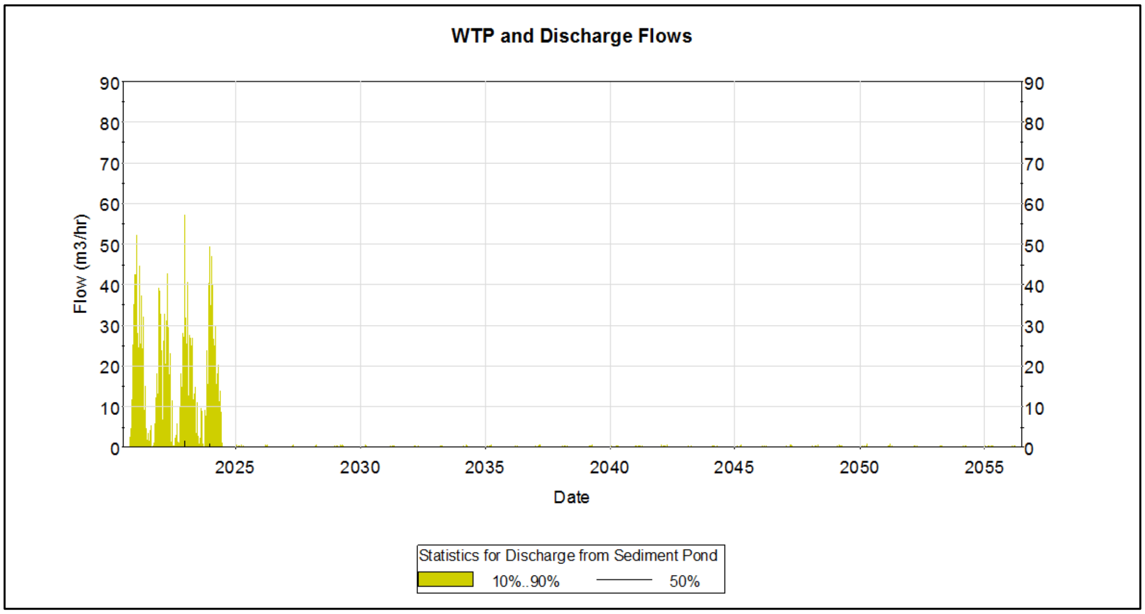
Note: These are assumed dates for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction

Figure 8-10: Discharge to the environment from pipeline (comprising excess STP and treatment plant discharge)



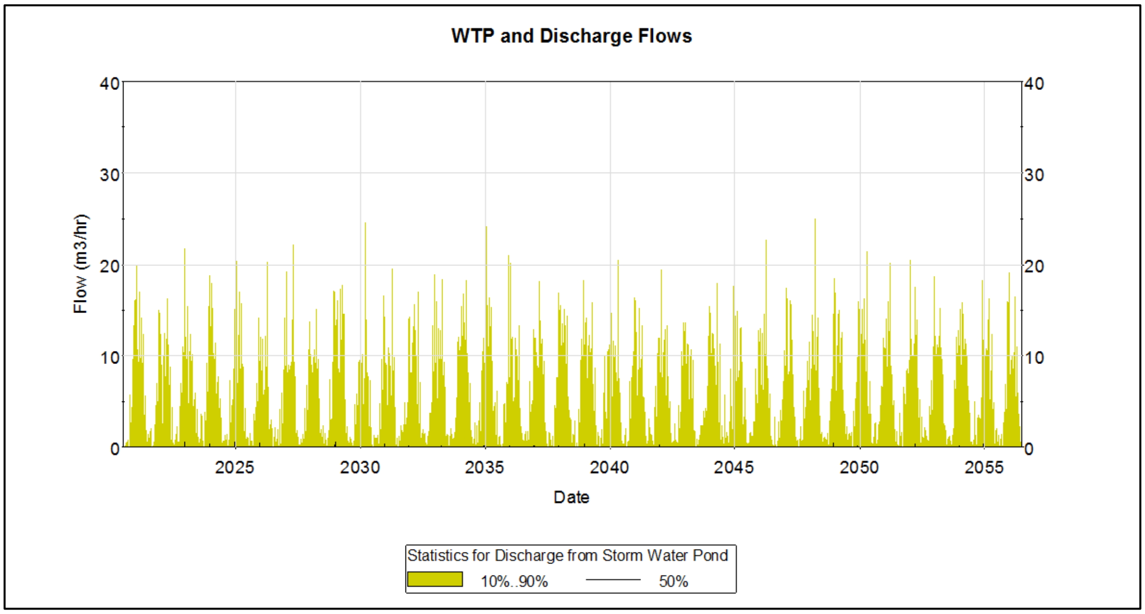
Note: These are assumed dates for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction

Figure 8-11: Discharge to the environment from the sediment pond



Note: These are assumed dates for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction

Figure 8-12: Discharge to the environment from the storm water pond



Note: These are assumed dates for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction

8.3. Chemical mass balance

As with the predicted physical water balance presented in Section 8.2,the following discussion on chemical mass balance, and the accompanying figures (Figure 8-13 to Figure 8-20) are based on the assumed dates adopted for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction.

All of the dissolved water quality results presented below are annual average concentration as required by the EIS team. It should be noted that the daily variations in some flows, such as the WRDs, can be one or two orders of magnitude different to the annual average.

Figure 8-13 and Figure 8-15 show annual average predicted dissolved sulphate and copper concentrations in groundwater inflow to the declines and the mine. Sulphate and copper have been chosen because they provide good examples of the degree to which water has come into contact with sulphide rock and the effects of water treatment. These flows are not directly impacted by variations in precipitation and, therefore, the results are not probabilistic. Once stabilised, groundwater in the declines is typically around 1,400 mg/L sulphate and 7 mg/L copper. In the mine, sulphate values are slightly higher at around 2,000 mg/L and copper is much higher at 40 mg/L.

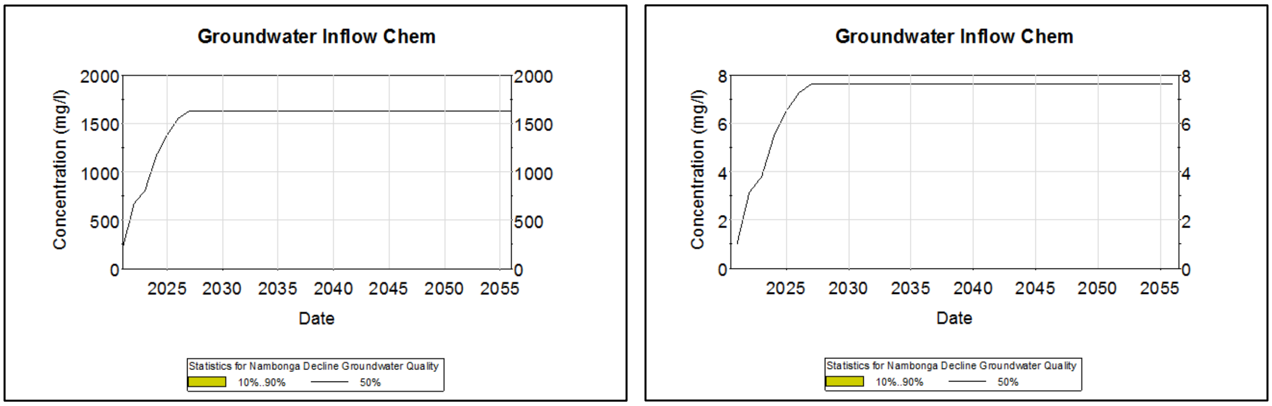
Figure 8-16 shows the annual average dissolved sulphate and copper concentration of the subsidence zone catchment water inflow. Concentrations peak in 2035 and 2036 when the block cave volume is large but the subsidence zone is still modest in size. As the subsidence zone increases in size (so increasing infiltration) but the block cave volume remains relatively constant (so maintaining source term size), the average concentrations reduce.

Figure 8-17 shows the annual average dissolved sulphate and copper in the WRD discharge (runoff and seepage combined). Both show a peak during the construction phase due to exposed PAF material from the declines. Once this is encapsulated by a clay layer and non-acid forming (NAF) material, the values are considerably reduced and remain consistent for the reminder of mine life.

Figure 8-18 shows the annual average discharge (dissolved) quality from the pipeline. This is dominated by outflow from the water treatment plant (see Section 8.2.4) and are therefore a 50:50 blend of HDS and DeSALx outflows.

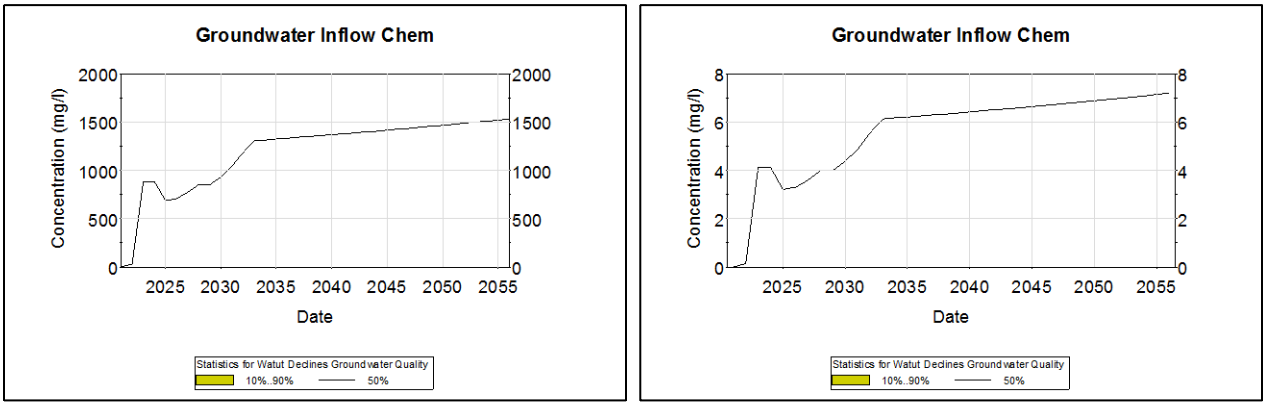
Figure 8-19 and Figure 8-20 show the annual average dissolved sulphate and copper concentrations for discharge from the sediment and storm water ponds respectively. Both show very low values because the chemistry is dominated by runoff from semi-natural catchments.

Figure 8-13: Dissolved sulphate (left) and copper (right) concentration in Nambonga decline groundwater



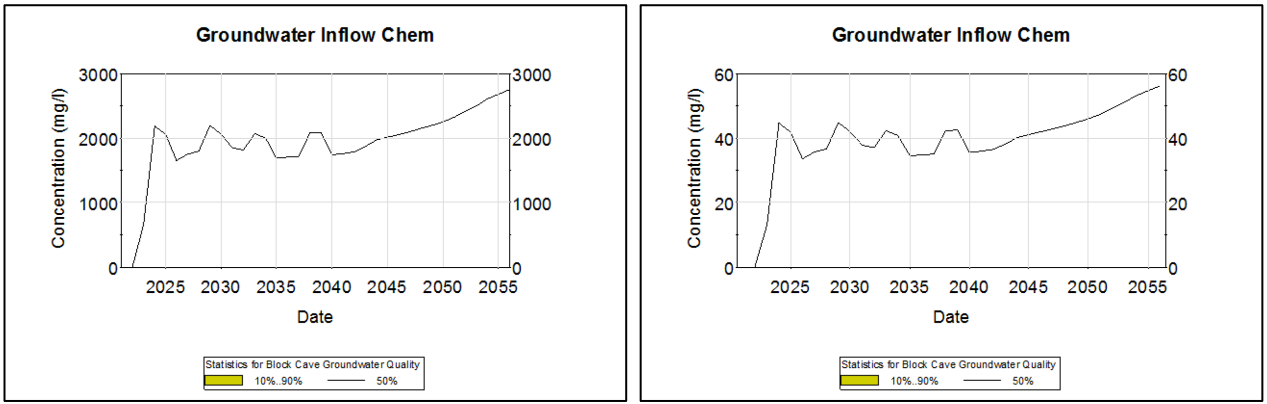
Note: These are assumed dates for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction

Figure 8-14: Dissolved sulphate (left) and copper (right) concentration in Watut decline groundwater



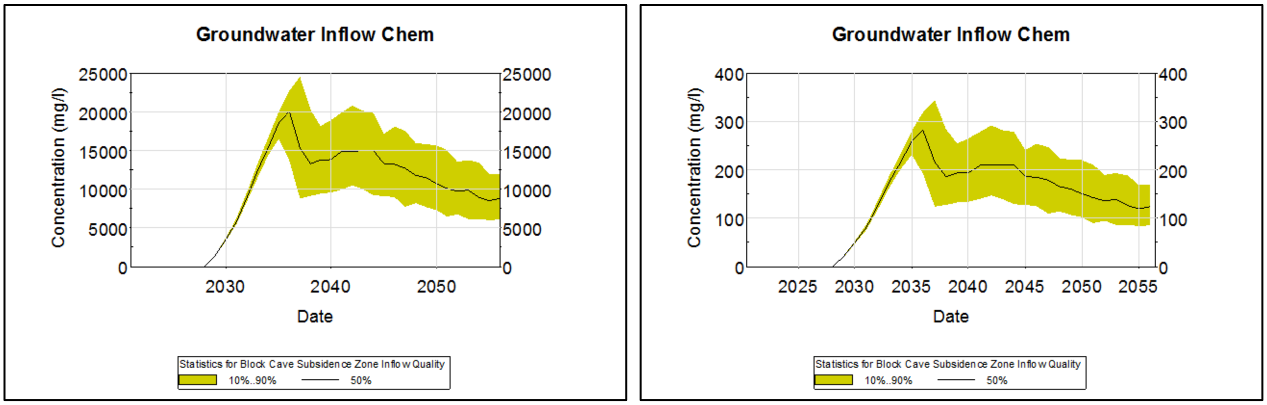
Note: These are assumed dates for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction

Figure 8-15: Dissolved sulphate (left) and copper (right) concentration in mine groundwater



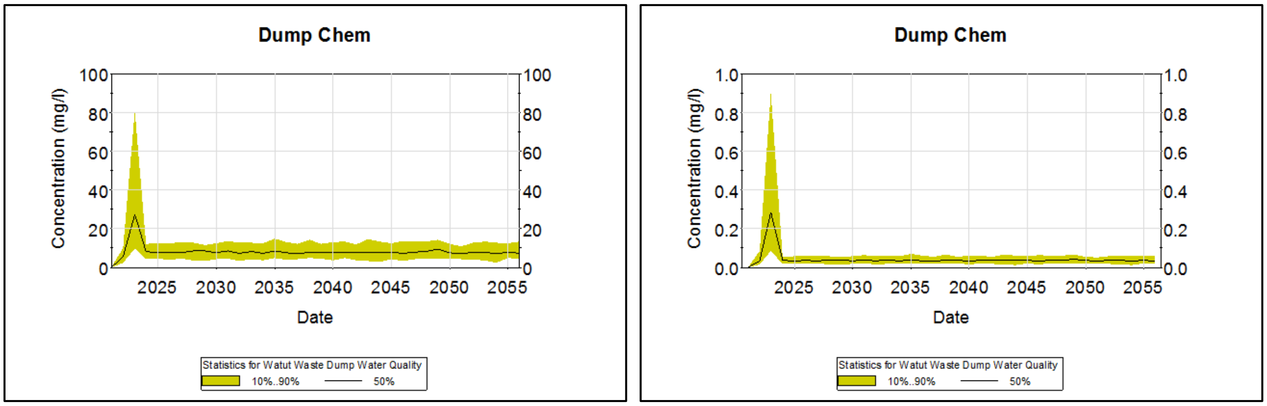
Note: These are assumed dates for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction

Figure 8-16: Dissolved sulphate (left) and copper (right) concentration in cave infiltration and subsidence zone catchment water



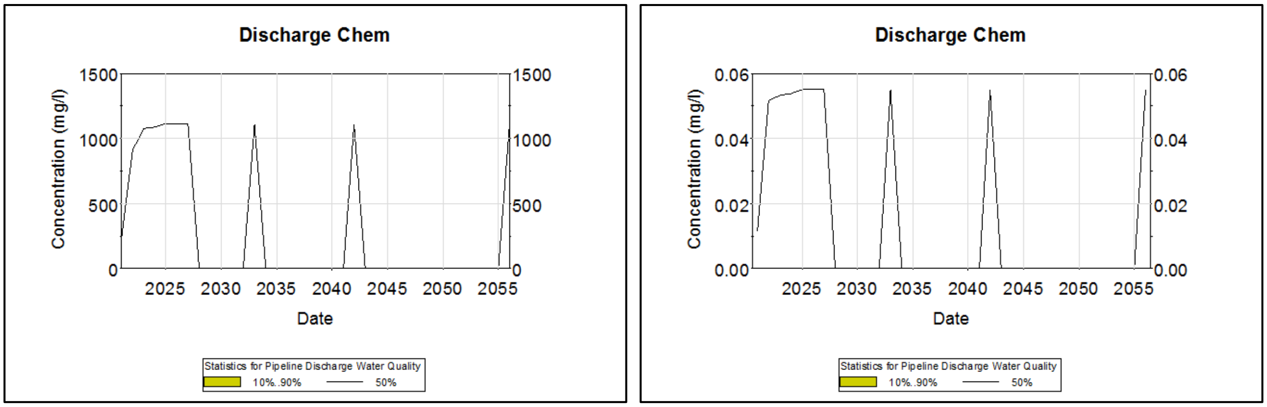
Note: These are assumed dates for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction

Figure 8-17: Dissolved sulphate (left) and copper (right) concentration in WRD runoff and seepage



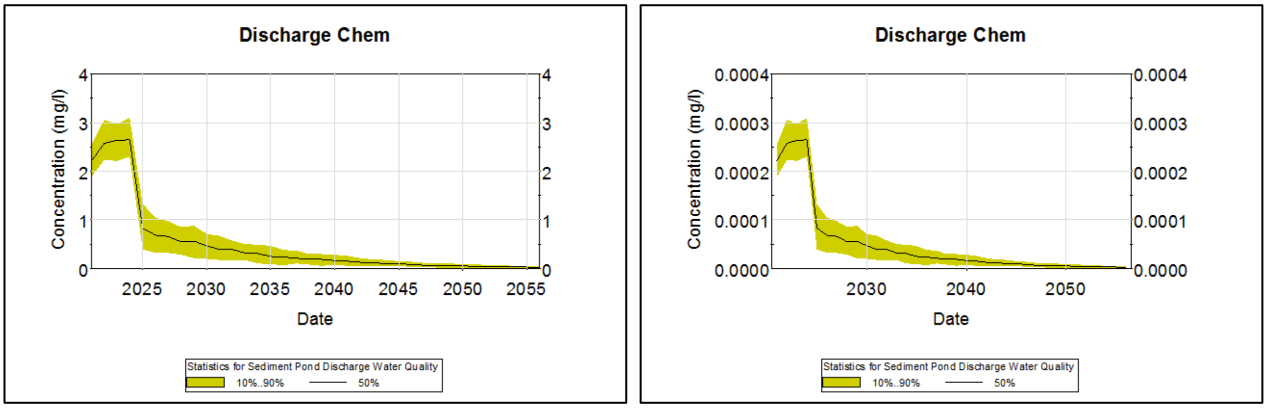
Note: These are assumed dates for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction

Figure 8-18: Dissolved sulphate (left) and copper (right) concentration in pipeline discharge



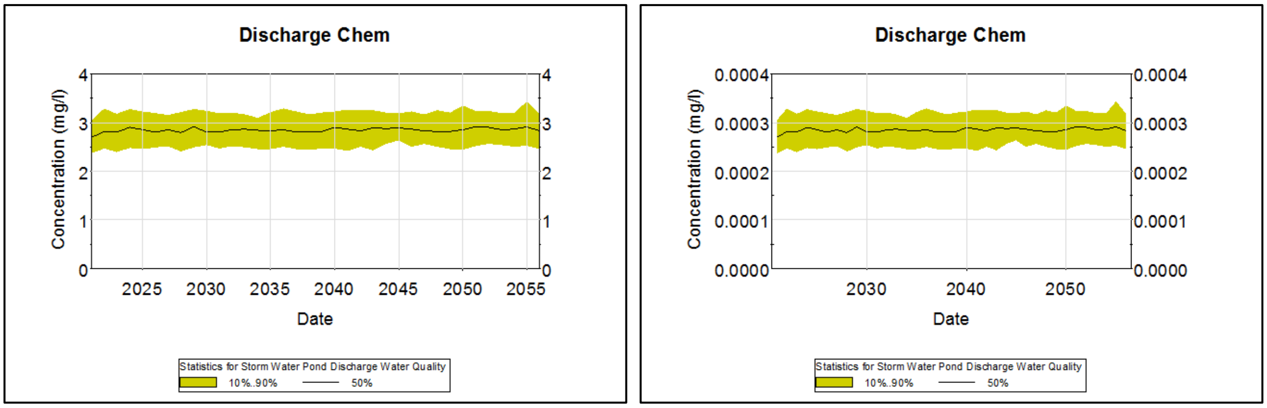
Note: These are assumed dates for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction

Figure 8-19: Dissolved sulphate (left) and copper (right) concentration in sediment pond discharge



Note: These are assumed dates for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction

Figure 8-20: Dissolved sulphate (left) and copper (right) concentration in storm water pond discharge



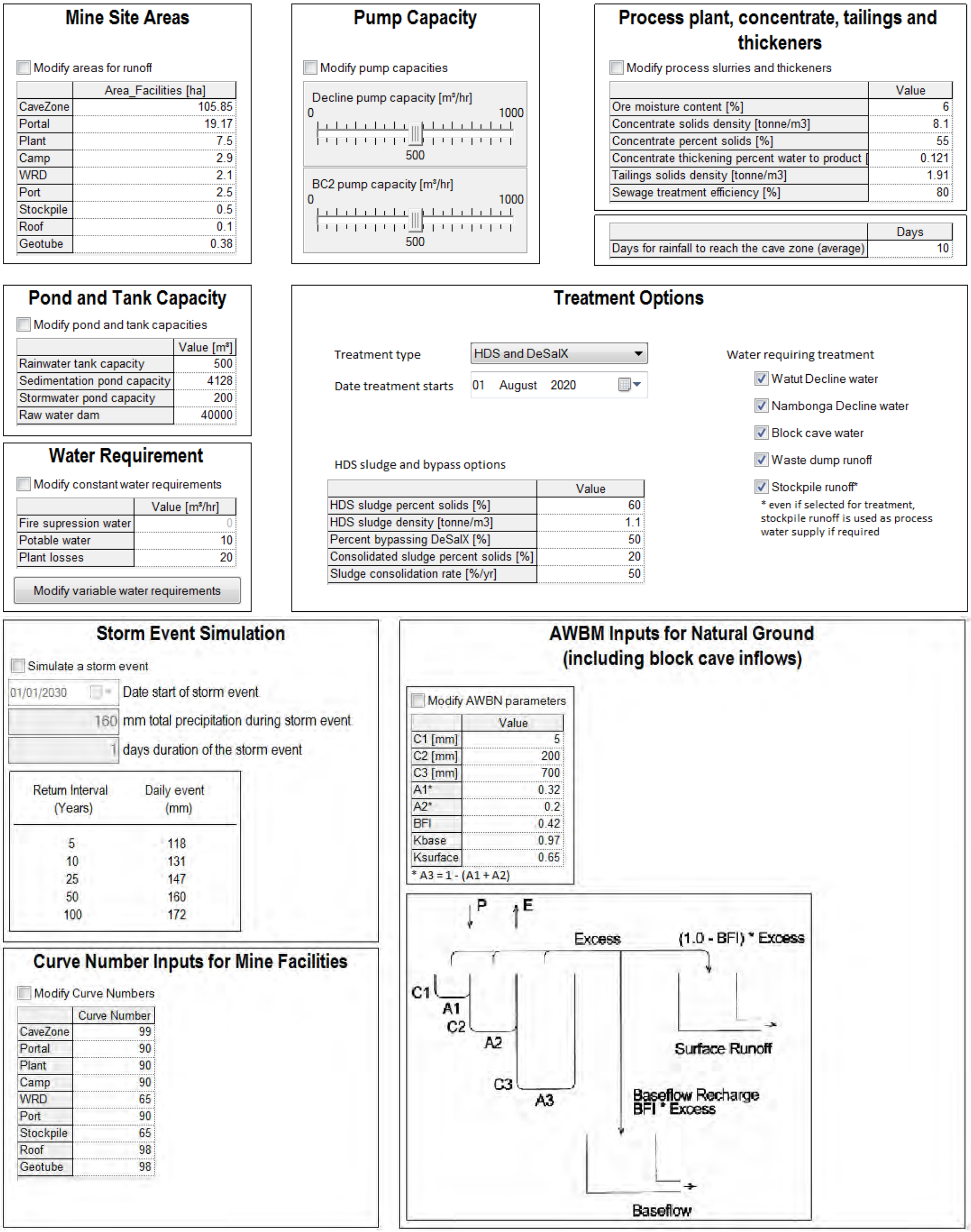
Note: These are assumed dates for the purpose of the modeling and may change as the Project mine plan is refined. The start date is nominal and should be considered to be the start of year 1 construction

Yours truly,

PITEAU ASSOCIATES SOUTH AFRICA LTD.

Simon Sholl
Senior Hydrogeologist

APPENDIX A: CONSTANT VALUE INPUTS TO GOLDSIM MODEL



Mine Site Areas

☐ Modify areas for runoff

	Area_Facilities [ha]
CaveZone	105.85
Portal	19.17
Plant	7.5
Camp	2.9
WRD	2.1
Port	2.5
Stockpile	0.5
Roof	0.1
Geotube	0.38

Pump Capacity

☐ Modify pump capacities

Decline pump capacity [m^3/hr]
0 1000
500

BC2 pump capacity [m^3/hr]
0 1000
500

Process plant, concentrate, tailings and thickeners

☐ Modify process slurries and thickeners

	Value
Ore moisture content [%]	6
Concentrate solids density [tonne/m3]	8.1
Concentrate percent solids [%]	55
Concentrate thickening percent water to product [	0.121
Tailings solids density [tonne/m3]	1.91
Sewage treatment efficiency [%]	80

	Days
Days for rainfall to reach the cave zone (average)	10

Pond and Tank Capacity

☐ Modify pond and tank capacities

	Value [m^3]
Rainwater tank capacity	500
Sedimentation pond capacity	4128
Stormwater pond capacity	200
Raw water dam	40000

Water Requirement

☐ Modify constant water requirements

	Value [m^3/hr]
Fire supression water	0
Potable water	10
Plant losses	20

Treatment Options

Treatment type: HDS and DeSalX

Date treatment starts: 01 August 2020

HDS sludge and bypass options

	Value
HDS sludge percent solids [%]	60
HDS sludge density [tonne/m3]	1.1
Percent bypassing DeSalX [%]	50
Consolidated sludge percent solids [%]	20
Sludge consolidation rate [%/yr]	50

Water requiring treatment

☑ Watut Decline water

☑ Nambonga Decline water

☑ Block cave water

☑ Waste dump runoff

☑ Stockpile runoff*

* even if selected for treatment, stockpile runoff is used as process water supply if required

Storm Event Simulation

☐ Simulate a storm event

01/01/2030 Date start of storm event

160 mm total precipitation during storm event

1 days duration of the storm event

Return Interval (Years)	Daily event (mm)
5	118
10	131
25	147
50	160
100	172

Curve Number Inputs for Mine Facilities

☐ Modify Curve Numbers

	Curve Number
CaveZone	99
Portal	90
Plant	90
Camp	90
WRD	65
Port	90
Stockpile	65
Roof	98
Geotube	98

AWBM Inputs for Natural Ground (including block cave inflows)

☐ Modify AWBN parameters

	Value
C1 [mm]	5
C2 [mm]	200
C3 [mm]	700
A1*	0.32
A2*	0.2
BFI	0.42
Kbase	0.97
Ksurface	0.65

* A3 = 1 - (A1 + A2)