Appendix F

Groundwater Management and Modelling of Inflows to Golpu Underground Mine

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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Reliance and Use

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.

The EIS shall not be used or relied upon for any purpose other than the Authorised Purpose, unless express written approval is given in advance by the WGJV Participants.

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The EIS is based in part on information not within the control of either the WGJV Participants or the Consultants. While the WGJV Participants and Consultants believe that the information contained in the EIS should be reliable under the conditions and subject to the limitations set forth in the EIS, they do not guarantee the accuracy of that information.

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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.

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WAFI-GOLPU MINE
GROUNDWATER MANAGEMENT
MODELLING OF INFLOWS TO GOLPU UNDERGROUND MINING USING FEFLOW

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PROJECT 3839-R1-2017 **January 2018**

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1 INTRODUCTION

1.1 BACKGROUND

Piteau Associates South Africa (Pty) Ltd (Piteau) have been retained by Wafi-Golpu Joint-Venture (WGJV) to produce a groundwater numerical model for the evaluation of inflows to the underground workings and for the implementation of a dewatering strategy. The following report provides the results of the construction and application of a 3D numerical groundwater flow model that simulates inflows in the various underground excavations using the FEFLOW software.

WGJV is developing the Wafi-Golpu (Golpu) underground gold and copper mine project in Papua New Guinea. Block cave mining is the method currently considered to extract minerals. The exposure to groundwater related risks will increase with the development of the project, since the tunnels and extraction zones will intersect regional geological structures, and as the block caves progress, they will intercept groundwater and surface water flow. In this context, the control of groundwater and surface water ingress into the twin declines and extraction levels is fundamental to ensure a safe and productive operation.

Following the completion of the Pre-Feasibility Optimization Study in 2016, WGJV presented in Q3 2017 a new mine plan. The geometry of underground facilities has been significantly revised, particularly in terms of the development of three extraction levels. A new groundwater numerical model is required to study the interaction between the underground infrastructure and the groundwater system. As part of the model construction phase, special attention is given to technical issues and limitations identified in previous numerical models in order to significantly improve the predictive value of the new model.

1.2 SCOPE

As part of the development of the project, WGJV have initiated the second stage of a 4-stage work plan. The Pre-Feasibility, Pre-Feasibility Optimization Study and the Environmental Impact Study (EIS) have been completed following the preliminary investigations of Stage 1. The objective was to obtain a conceptual understanding of the climatic, hydrological, hydrogeological and geotechnical characteristics of the project area, and to assess the overall site-wide water management requirements for the project to guide water management system design.

In Stage 2, WGJV is currently undertaking the improvement of site characterization. The objective is to focus investigations on specific aspects of the project to reduce uncertainties identified at the end of Stage 1 and listed in the Forward-Work Plan (FWP). The final design and the construction of mine infrastructure and mitigation measures will be part of Stages 3 and 4.

1.3 FOCUS OF THE REPORT

This report details the construction and results of 3D numerical modelling undertaken by Piteau during the period of August to October 2017, in relation to hydrogeological investigations carried out in 2017 (and ongoing) to improve the characterization of the area. The numerical model update and predictive scenarios include the conclusions of the operational water balance developed by Piteau, as well as the hydrogeological information obtained during drilling of characterization boreholes.

1.4 ANTECEDENTS

1.4.1 Existing studies

In the Pre-Feasibility Optimization Study and the Environmental Impact Study (EIS), a significant amount of data has been collected and compiled to form a consolidated hydrogeological conceptual model. The hydrogeological model encompasses information on climate, hydrology, geology and hydrogeology. To date, the most recent relevant documents are listed below:

- Datamine - Wafi-Golpu Rock Mass Model Update Method Statement Updated with recalculated GSI
- DHI - Wafi-Golpu Pre-Feasibility, Dewatering Volume Assessment
- Hydrologic Consulting (Pty) Ltd - Hydrology Assessment for the Golpu Project
- Piteau - 3695TM01V1, Wafi-Golpu Site-wide Water and Mass Balance Model

- Piteau - 3748, Spring Survey and Hydraulic Tests on Artesian Wells
- Piteau - 3695TM01V1, Wafi-Golpu Site-wide Water and Mass Balance Model
- SRK - Hydraulic Testing and Data Evaluation in Shaft Investigation and Resources Boreholes
- SWS - 56072.R, Data Collation, Review, Gap Analysis and Comparative Review of Existing Groundwater Models of the Wafi-Golpu Underground Mine
- TBC - TechMemo - Bore Dewatering Model, Rev.0
- WGJV - 532-0469-PF-REP-0006-6.2.1 PFS, Volume 6 - Section 2.1 Deposit Hydrology and Hydrogeology, Rev.0
- WGJV - 532-1002-FS-REP-0015-6.2.4 FS, Volume 6 – Section 2.4 Geotechnical Groundwater, Rev.0
- WGJV - 532-1002-FS-REP-0015-6.1, Volume 6 – Technical – Geology, Rev.0
- WGJV - 532-1002-FS-REP-0028, Numerical Groundwater Flow Model Development, Rev.5
- WGJV - 532-1002-FS-REP-0051, Hydrology Assessment – Highlands Hydrology, Rev.0
- WSP|PB - 56072TM04v1, Rainfall and Evaporation Analysis
- WSP|PB - 56072TM07v0, Modelling of Inflows to Golpu Underground using Seep/W

1.4.2 Existing mine inflow estimates

During the development of the project, the evaluation of groundwater inflows into the mine workings has been carried out by various consultants (Table 1). Initial calculations were based on a limited amount of data. Investigations carried out in the field as part of the Stage 1 development enabled refinement of the parameters used to determine the magnitude of inflows into the mine workings. Since 2011 and the first evaluation, the design of underground workings and mine schedule has changed several times, limiting the comparison between the different analytical or numerical models. However, significant discrepancies between the models have been noted, with inflow varying between 10 and 345 l/s for the decline, and between 80 and 2700 l/s for the block caves.

The lower-most estimate for mine inflow (80 l/s) is obtained in the most recent study carried out by WSP|PB in 2016. Despite uncertainties associated with the hydraulic behavior of geological faults, the study indicates that water flowing in the fresh bedrock is likely to be minimal, and most of the water which could flow towards the underground workings is stored in the weathered bedrock, or entering from the surface.

Table 1: Summary of decline and mine inflow estimates

Reference	Recharge from Rainfall	Feature	Inflow (l/s)	Comments
SRK February 2011	20% ±10%, 80% for block cave	Mine	200	Minimum of 100l/s
SKM August 2011	Only qualitative	Decline	60 - 100	From Babwaf Conglomerate only
SKM December 2011	-	Mine	1000	Includes 200l/s ROM
SKM February 2012	-	Mine	250 - 1000	Pers comm WGJV, various dates
SRK March 2012	15% for model,	Lift 2	310	5km x 5km FEFLOW model, excludes storm water ingress
	20% in conceptual description	Lift 3	900	
	0.0694444	Lift 2	450 - 590	Expected with storm water ingress along fractures
		Lift 3	1,800 - 2,700	
	-	Watut Decline (year 1-4)	30 - 122 (SEEPW) 84 - 345 (analytical)	Add 30 – 100l/s for intersection of high yielding fractures
	-	Wafi Decline (year 1-4)	46 - 73 (SEEPW) 47 - 234 (analytical)	
SKM March 2012	-	Mine	1000	As instructed, SKM suggested 200 - 4,000l/s
RPS Aquaterra May 2013	-	Watut decline	16 - 131	
		Single decline	10 - 48	
		Shaft	9 - 23	
DHI September 2014	10%	Decline	188.4 - 202.8	Unsaturated model, max in year 5.75
			197.1 - 210.7	Saturated model, max in year 5.75
		SLC1+2	416.1 - 443.0	Unsaturated model, max in year 14.25
			721.1 - 746.5	Saturated model, max in year 14.25
		SLC2	800 – 2,000 (plus 60 - 150 l/s for storage depletion)	Monte- Carlo Simulations, 27% and 95% percentiles (75%: 1,300l/s)
MMJV & WorleyParsons September 2014	0.1	Decline	195.6	Average of unsaturated DHI models
		SLC1+2	429.5	
	0.0694444	Decline + SLC1+2	884	Combined plus storm water
WSP│PB, September 2016	16%	Decline	120	Analytical calculation
		SLC1+2	40 (peak: 80)	2D seep model

Source: Adapted from Morobe Mining JV Services (Australia) Pty Limited, Review of Golpu Inflows estimates,532-1002-FS-REP-0012

2 GENERAL SETTING

The general setting and conceptual model are traced from the Worley Parson, SWS, WSP|PB and latest Piteau investigations. Additional information collected in the field and made available to Piteau for the present study corresponds to updated meteorological, hydrological, and hydrogeological monitoring records, as well as results from the spring survey, updated GoldSim water balance, Nuclear Magnetic Resonance (NMR) and Acoustic Televiewer (ATV) borehole geophysics and the drilling campaign of characterization boreholes between the quarry and Mount Golpu.

2.1 LOCATION AND PHYSIOGRAPHY

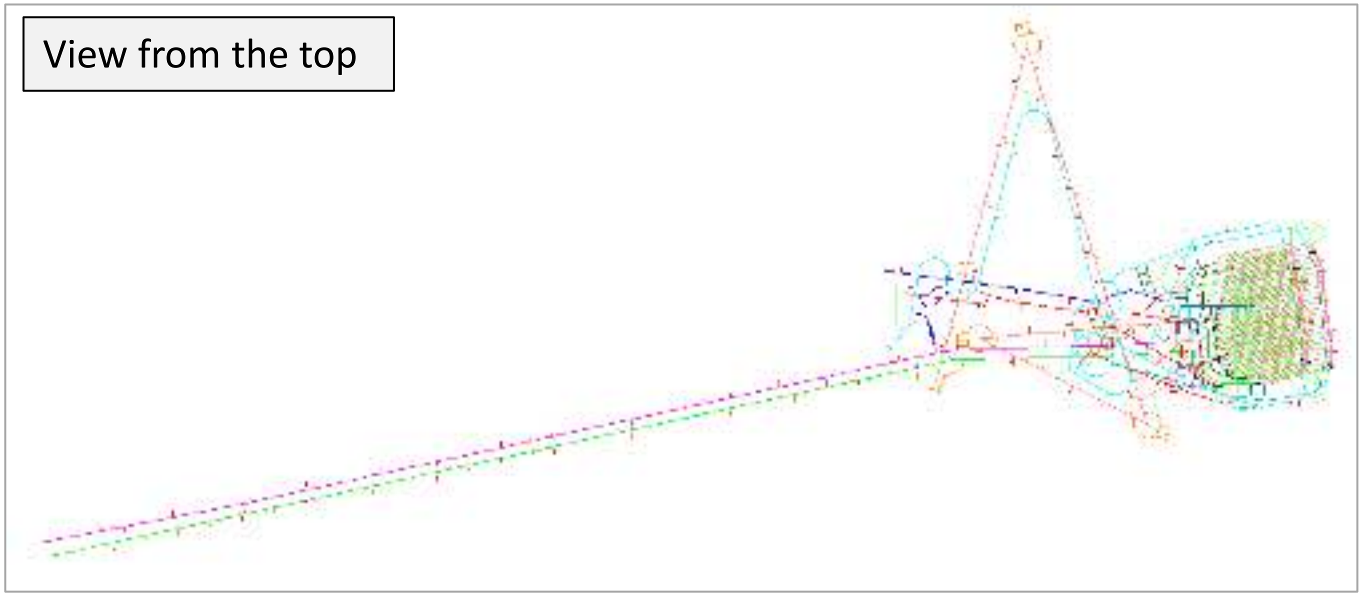
2.1.1 Location and project settings

The project location is Papua New Guinea (PNG), approximately 300 km N-NE of Port Moresby and 65 km SW of Lae in the Morobe Province. The deposit of interest is located below Mount Golpu. Given the depth and form of the porphyry deposit, the proposed technique of ore extraction is block-caving. Over the life of mine, several extraction levels will be in operation, and ore will be collected from the undercut level and transported to surface. Over time, the development of the cave will form a zone of subsidence at the surface.

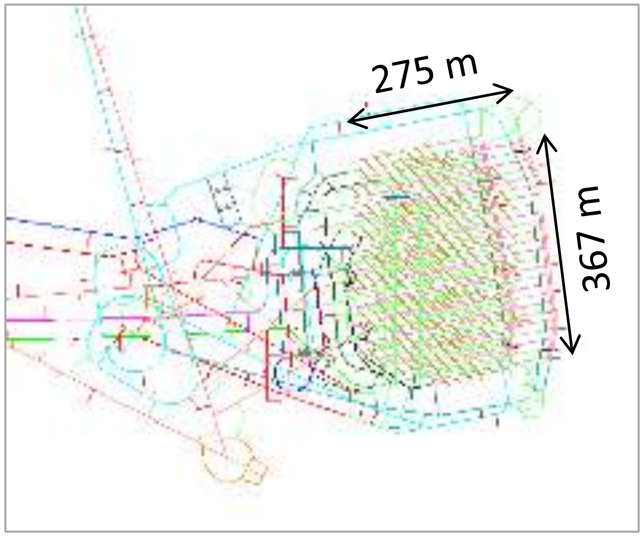
Underground workings will be connected to the surface by twin declines, with the portal access located in the vicinity of the Watut River valley. The twin declines denominated Watut Declines will have a NW-SE orientation and will be more than 3km long. A further decline, the Nambonga Decline, will be constructed from a portal entrance on the Western side of Mount Golpu in the Nambonga catchment. The process plant and other main surface infrastructure will be located at the portal access, where crushed ore will be delivered by conveyors, and concentrate and tailings will be transported via pipeline to Lae.

The Golpu mine design involves extraction of ore from three block caves (BC44, BC42 and BC40), connected to the surface by the Watut Declines, the Nambonga Decline and a ventilation shaft (See Figure 01). BC44, BC42 and BC40 are superimposed vertically and located at approximately 1300, 1500, and 1700 m respectively below Mount Golpu. The proposed design involves the construction of a ramp connecting the block caves on the northern side of the long Watut Declines. In addition, the platform RL4825 at a depth of 900 m may potentially be used for predevelopment resource definition activities.

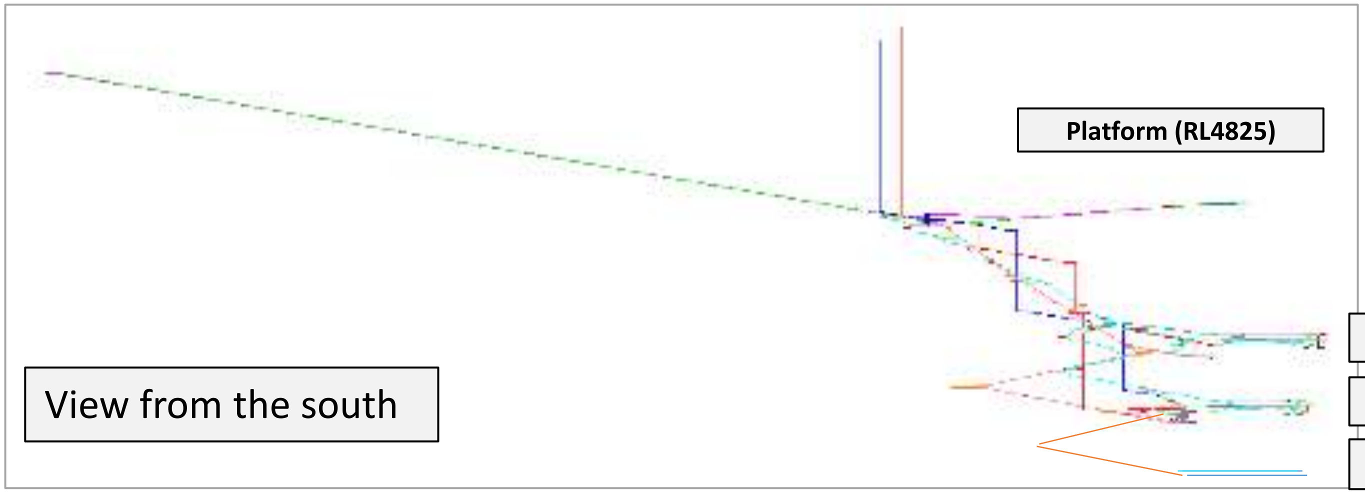
View from the top



View from the top



View from the south



REF : 532-2000-MN-MOD-30001 Golpu_BC44_BC42_10-07-17, WGJV

Wafi-Golpu, 3D Groundwater

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GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

Design of the Watut Declines and extraction levels

By	FB	Date	Oct 2017
Approved	AR	Fig	01

2.1.2 Topography

Two zones characterize the study area. The first one is the Watut River plain, a floodplain with an elevation of approximately 100 masl. Topographic gradient towards the Watut River is negligible and enhances the stagnation of water and the development of a swamp forest.

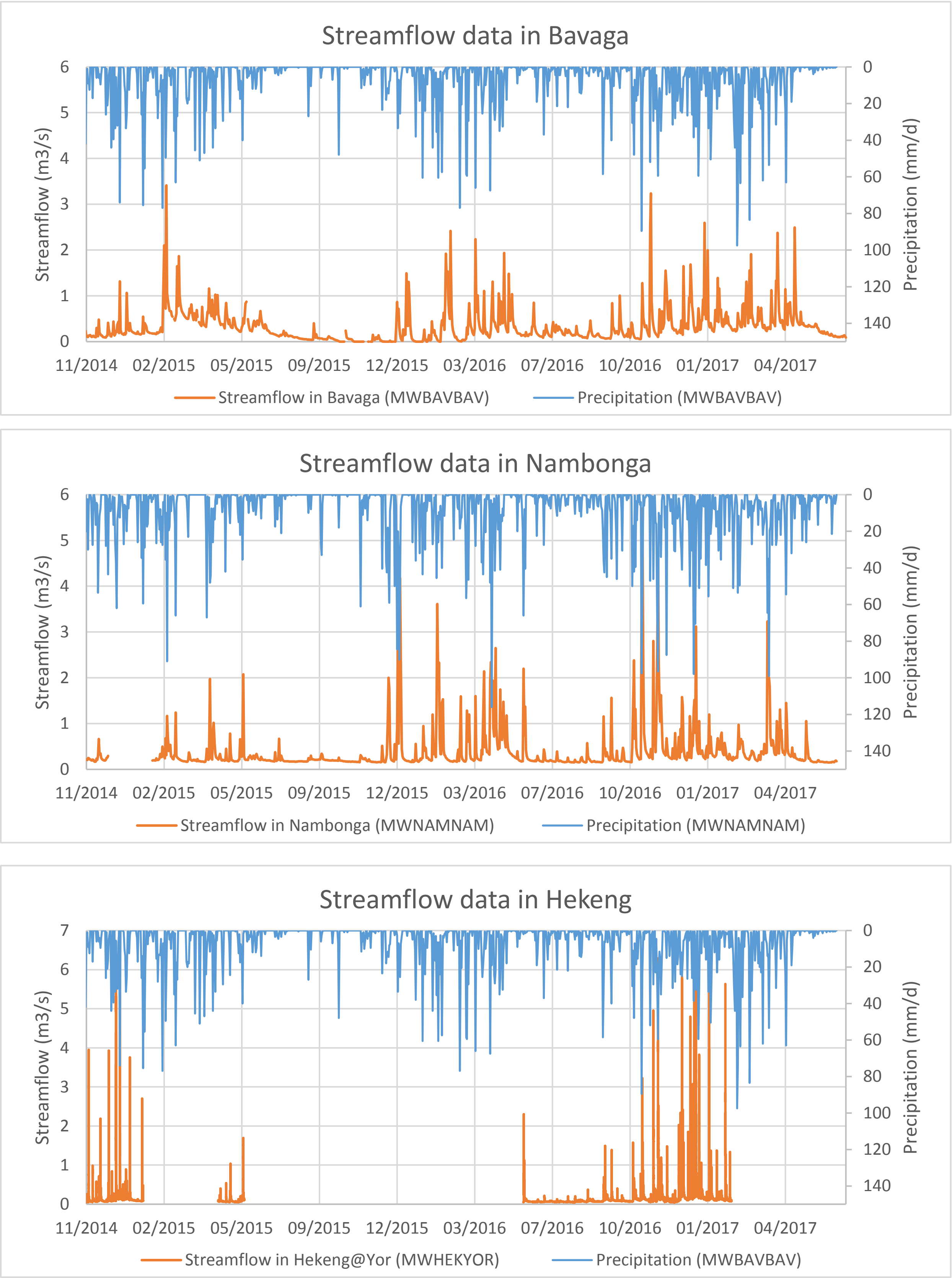
The second zone is a range of hills on the edge of the floodplain. Further to the east, relief is more pronounced and reaches an elevation of 756 masl at Mount Golpu. The area is characterized by a medium-crowned forest on steep slopes. Sediment cover is variable and subject to landslides and strong erosion especially during the wet season.

2.1.3 Hydrology

The footprint of the subsidence zone is located on the edge of the Hekeng and Nambonga catchments. Underground Watut Declines are located partially below the Nambonga catchment, and the portal access on the edge of the Watut floodplain. Streamflow stations are installed in the Wafi, Nambonga, Hekeng and Bavaga catchments, which are all tributaries of the Watut river. The Watut is a sub-catchment of the Markham River which flows to the Huon Gulf at the town of Lae.

A first assessment of hydrological conditions has been done by Hydrologic Consulting (Pty) Ltd (2015)[1]. The study revealed a strong seasonality associated with rainfall events. The maximum river flow rates for the Bavaga, Hekeng and Nambonga Rivers were found to be 2.2, 0.85 and 4.5 m^3/s respectively.

The latest hydrological data have been used in the GoldSim Site-wide Water and Mass Balance Model developed by Piteau (see Figure 02). More than two and a half years of records are available for the Bavaga, Hekeng and Nambonga catchments. Average flow at the Bavaga station is 0.31 m^3/s. The Bavaga river flow rate exceeded 3 m^3/s twice over the recording period.



Wafi-Golpu, 3D Groundwater

PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

Streamflow data in the catchments in of the study area

By	FB	Date	Oct 2017
Approved	AR	Fig	02

For Nambonga, the average flow is equivalent to 0.39 m^3/s. A peak flow rate of 5.7 m^3/s was recorded in October 2016. At Hekeng, the average flow rate is 0.12 m^3/s, and the maximum streamflow of 6.3 m^3/s was recorded in November 2016. Due to technical issues, the monitoring at the Hekeng station is only partially complete and most of the year 2015 is missing from the records.

2.2 CLIMATE

2.2.1 Climate regime

Climate data recorded at the rain gauge ‘Wafi Camp’ have been analyzed by WSP|PB in 2016. The rain gauge is located at the top of Mount Golpu and has recorded 26 years of data over the period 1990 - 2016. Numerous gaps exist in the rainfall record, and the time series have been infilled using the upscaled monthly data from Climate Forecast System Reanalysis (CFSR). The average annual rainfall is 2871 mm, equivalent to an average daily rainfall of 7.8 mm. It rains throughout the year, with the months of December to April being the wettest. During the year 1995, the area received 3440 mm making it the wettest year on record. It included in February 1995 the maximum daily rainfall event recorded to date (134.5 mm).

As Evaporation (A-Pan) is not measured on site, a compilation and analysis of evaporation data from the meteorological stations Bulolo and Erap, located respectively at 37 km and 44 km from site, has been carried out to estimate a reasonable value of evaporation for the project area. The average annual evaporation is estimated at 2082 mm. Average monthly rainfall and evaporation values are presented in Table 2 and Figure 03.

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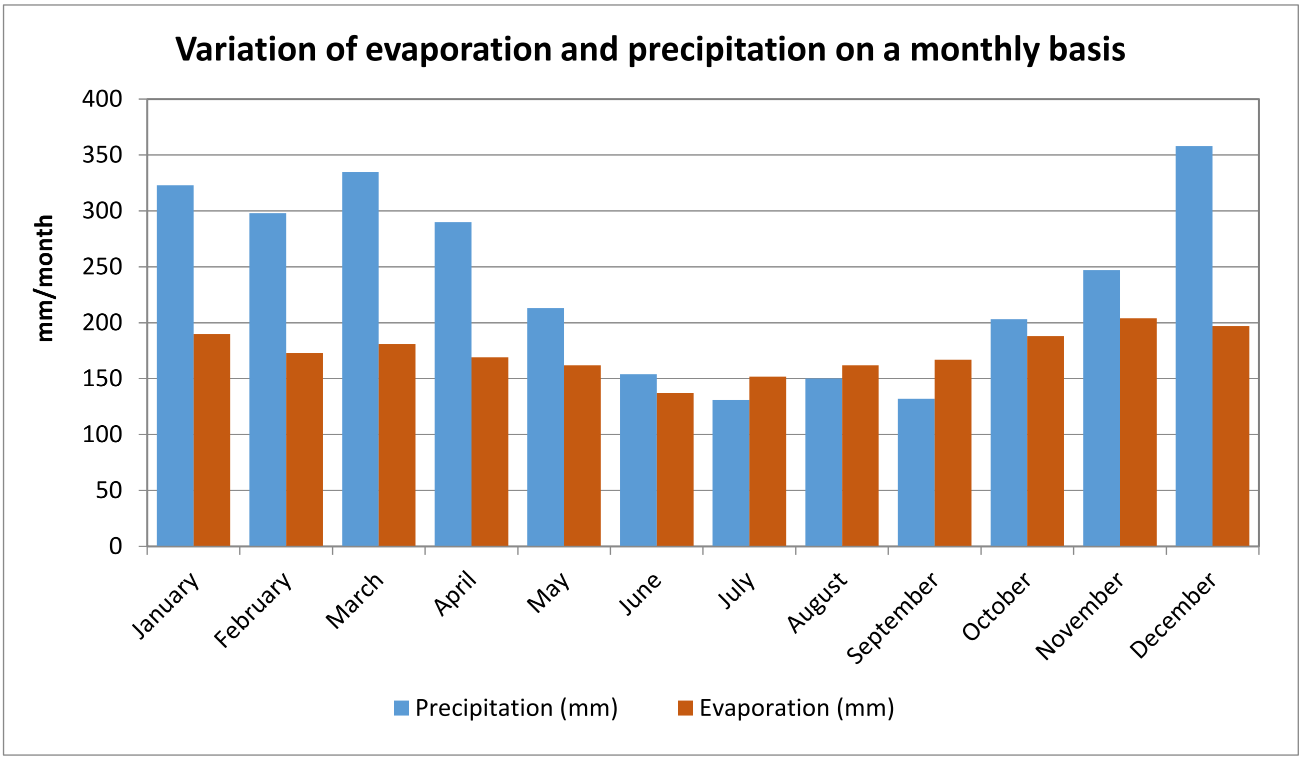
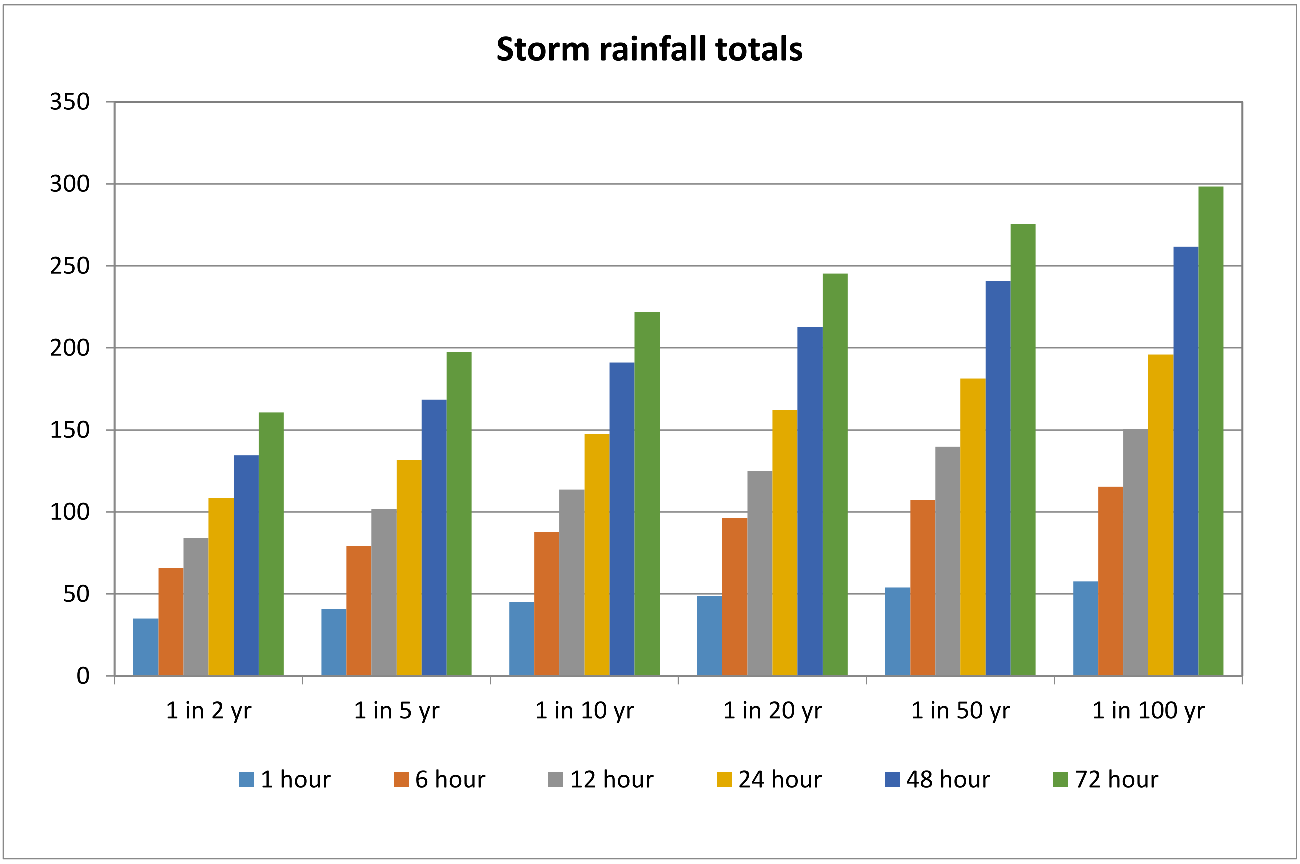
[1] Hydrologic Consulting (Pty) Ltd, Hydrology assessment for the Golpu project



Variation of evaporation and precipitation on a monthly basis



Storm rainfall totals

Source:WSP 2016

Wafi-Golpu, 3D Groundwater

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GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

Climatic data

By	FB	Date	Oct 2017
Approved	AR	Fig	03

Table 2: Average monthly rainfall for Wafi Camp and Pan Evaporation

	Precipitation (mm)	Evaporation (mm)
January	296	190
February	296	173
March	321	181
April	284	169
May	186	162
June	151	137
July	132	152
August	152	162
September	193	167
October	236	188
November	249	204
December	375	197
Total	2871	2082

2.2.2 Update of peak rainfall analysis

The peak rainfall analysis was initially conducted by Hydrologic Consulting (Pty) Ltd in October 2015, and was re-evaluated by WSP|PB in September 2016 with the Gumbel analysis. Annual Maximum Series (AMS) are consistent across the different studies. The detailed assessment of rainfall and peak flood analysis conducted by WSP|PB considers the data set covering the period from the beginning of 1990 to the middle of 2016. This study has been retained for the present review of antecedents and results are presented in Table 3.

Table 3: Rainfall intensity (mm)

	Annual Exceedance Probability (AEP, 1 in XX years)					
Hours	**2**	**5**	**10**	**20**	**50**	**100**
0.25	21	25	27	29	32	34
0.5	27	32	35	38	41	44
1	35	41	45	49	54	58
6	66	79	88	96	107	115
12	84	102	114	125	140	151
24 (R^2=0.98)	108	132	147	162	181	196
48 (R^2=0.97)	134	169	191	213	241	262
72 (R^2=0.96)	161	198	222	245	276	298

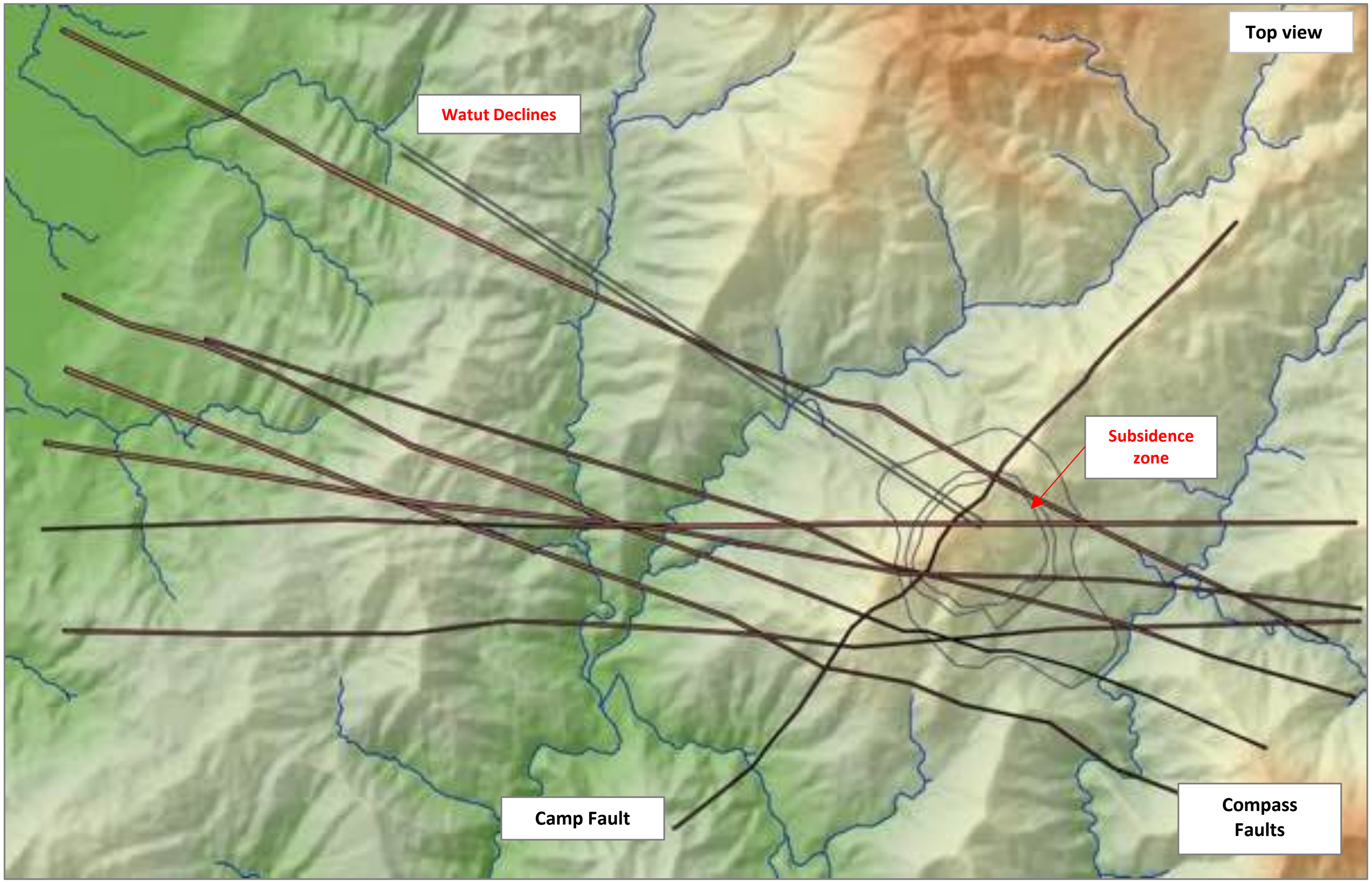
*Gumbel analysis. Red = extrapolated. 24hr upscaled by 1.13, 48hr by 1.05 and 72hr by 1.04

2.3 GEOLOGY

The main geological unit in the study area is the Lower Cretaceous aged Owen Stanley Metamorphics, predominantly comprising metasedimentary and metavolcanic rocks. The rocks have been subjected to ductile deformation and local greenschist facies metamorphism due to folding during the Papuan orogeny (60 – 30 Ma). The Owen Stanley Metamorphics are overlain by the early Miocene Langimar Beds, which represent a volcanogenic sedimentary detritus unit. To the west of the project area, the Langimar Beds are unconformably overlain by the Babwaf Conglomerate. This unit comprises poorly sorted conglomerates, with interbedded 10 – 100 m thick sandstone layers and occasional intercalated tuffs. The Babwaf Conglomerate unit is less competent than other geological units in the study area, and because of preferential erosion, it forms a flat, low-lying area coinciding with the Watut floodplain.

Magmatic activity associated with regional deep-crustal movements resulted in the intrusion of various calc-alkaline intrusions. The Golpu deposit consists of multiple hornblende-bearing diorite porphyries, with a high-sulphidation epithermal overprint. Mineralization is both disseminated and controlled by microfractures and veins, while in the epithermal system, mineralization is bedding-parallel. There are also breccias and volcaniclastics representing the Wafi diatreme, which post-date the porphyry mineralization event.

A series of different structural episodes (subduction, rifting and subsidence) took place in this region located at the edge of the Australian and Pacific plates. It contributed to the development of a complex network of thrusts and transfer faults. Post-intrusion faults have divided the original porphyries into different parts. The regional Buvu Fault coincides with an unconformity between the Langimar volcanics and the relatively unaltered Owen Stanley Metamorphics, and separates the strongly altered and mineralized rocks above from the un-mineralized host rock below the fault. A series of faults with the same dip (60 - 70° E) is identified below Mount Golpu in the Owen Stanley Metamorphics. From west to east, these faults are the Reid, Overprint and Hekeng Faults. In addition, different episodes of strain and deformation produced prominent sub-vertical faults through the metasediments. The main sub-vertical faults are the Rafferty’s, Camp, and Compass (See Figure 04). These vertical faults have been mapped near the subsidence zone and are likely to influence the propagation of the caved and fractured zone developed by the block-caving.



REF: WGJV, July 2017, GM_Faults_Fault_Volume_Camp.dxf, GM_Faults_Fault_Volume_Compass1-7.dxf

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Horizontal Faults

By	FB	Date	Oct 2017
Approved	AR	Fig	04

The Compass Fault is not a singular fault, but rather is comprised of several discontinuous and commonly disconnected structures of 10 - 100m long. These are transfer structures that have been developed to accommodate the strain in the rocks caused by thrusting. The fact that they are stepped and most likely disconnected at depth indicates a reduced potential to convey water.

Quaternary deposits in the study area comprise colluvial and alluvial material. The colluvium on the flanks of Mount Golpu is a mixture of clay, silt, sand and gravel (SRK Consulting, 2011). Alluvial deposits are present in small river systems with a thickness inferior to 5 m. In the Watut floodplain, alluvial material may exceed a thickness of over 30 m.

A regional geological model has been developed by WGJV using the Leapfrog software. The source of information used in the model is the database of exploration drilling programs. The main geological units and faults are included in the model (See Figures 05 and 06), and this indicates that two sets of faults will interact with the underground infrastructure. The Buvu Fault system with a N-S orientation will be intersected by the Watut Declines between 350 m and 400 m depth. The Reid, Overprint and Hekeng faults, dipping at approximately 60° E will intersect the extraction levels and block caves below Mount Golpu.

An update of the Leapfrog model was released to Piteau in July 2017, and it corresponds to the information of reference for the hydrogeological model.

2.4 GEOTECHNICAL CHARACTERIZATION

A geotechnical block model was developed with the Datamine[2] software in 2015. The objective was to provide inputs for the block cave propagation model. Spatial interpretation and statistics on the information collected from the logs highlighted some trends for each geological unit. The Rock Quality Designation (RQD) is equivalent to 40% for the weathered unit. Despite the fracturing associated with fault zones, an RQD between 55 and 69% is observed, indicating a relatively high rock integrity. Geological units intercepted by the Watut Declines and the extraction zone shows a RQD between 74% and 89%, indicating that the rock mass is very competent and with very limited fractures. The Geological Strength Index (GSI) follows the same trend of the RQD and RMR with mean values between 37 and 62% (Table 4). The GSI of the rock mass is

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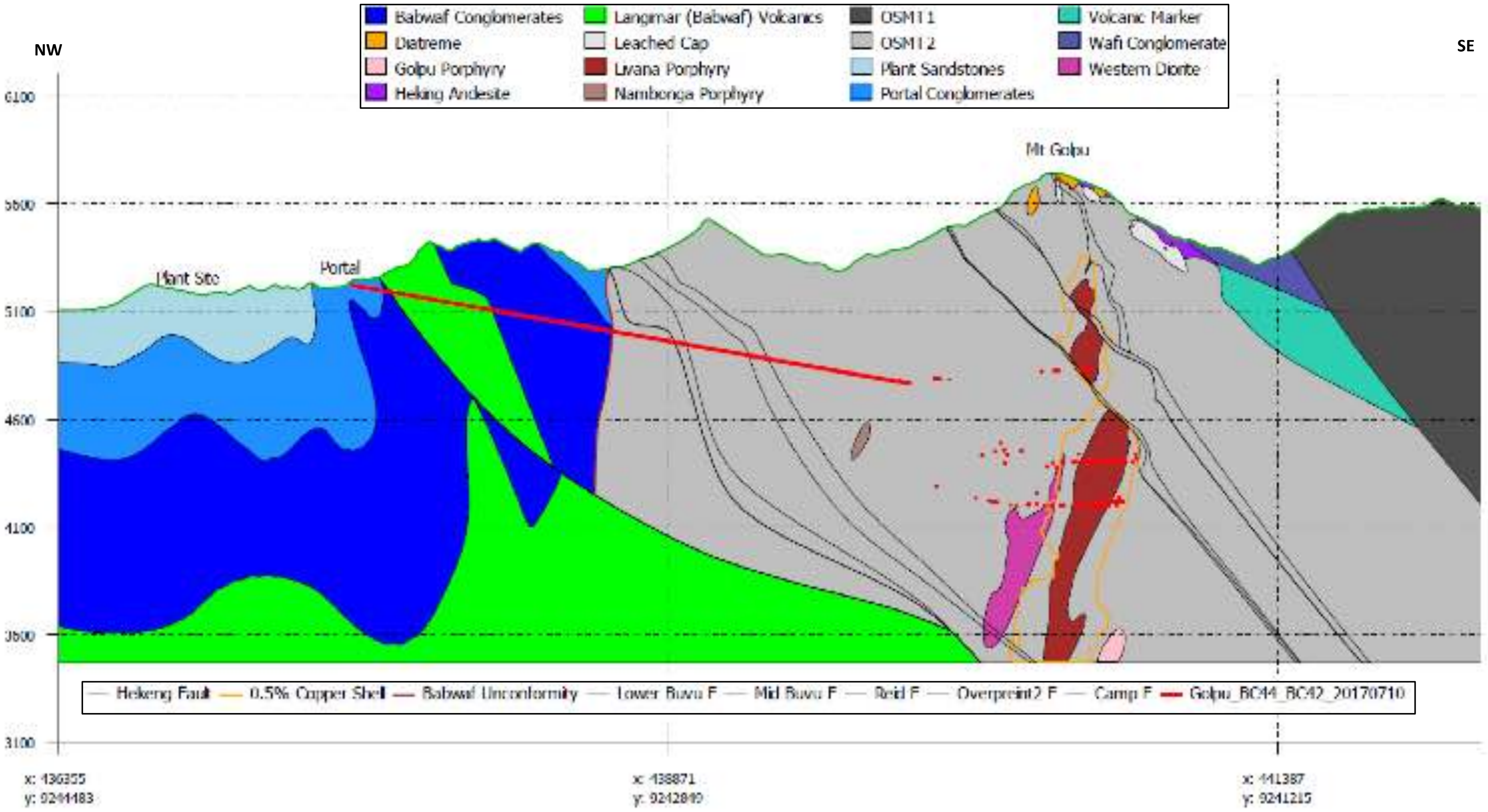
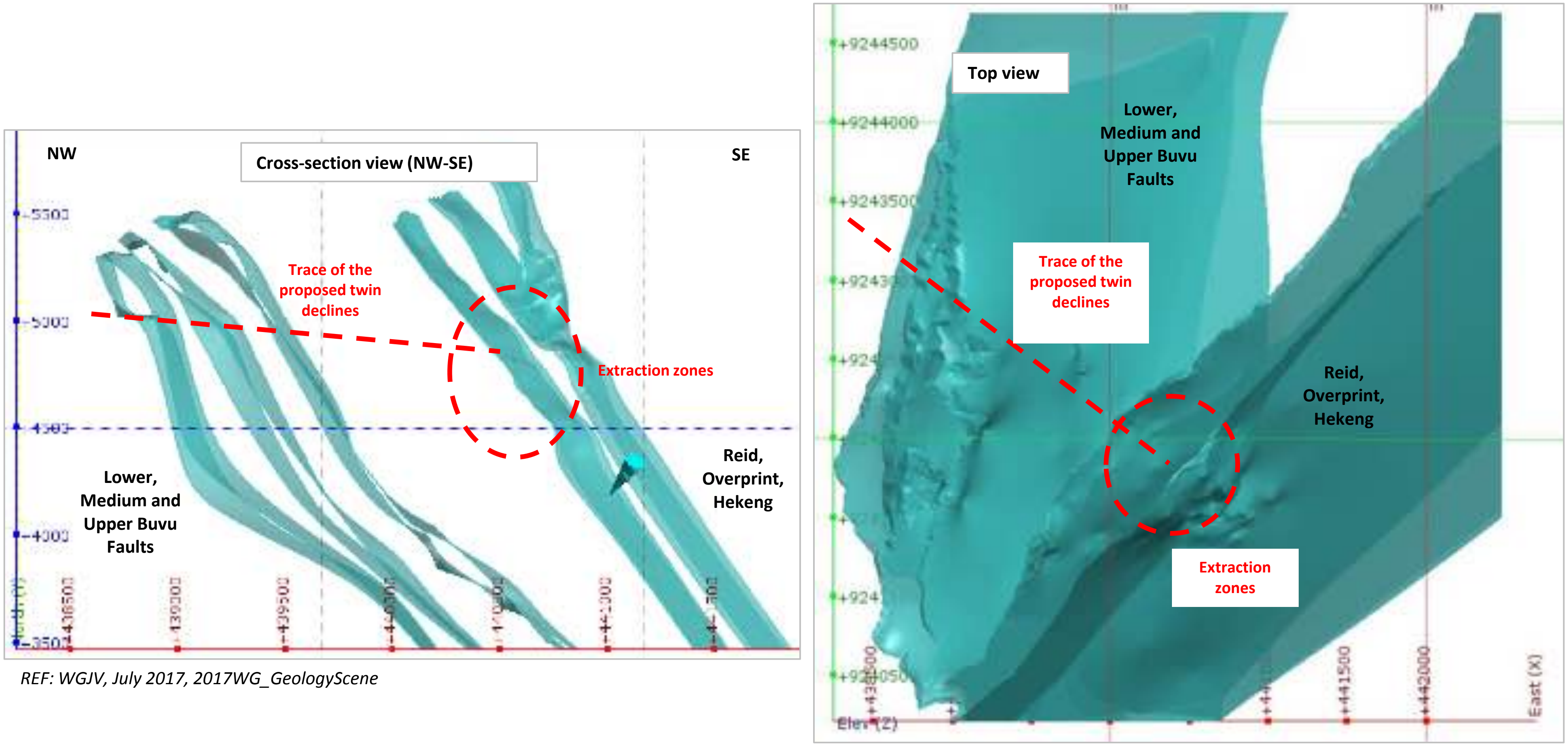
[2] Datamine, Wafi-Golpu Rock Mass Model Update Method Statement Updated with recalculated GSI



REF: WGJV, July 2017, 2017WG_GeologyScene

Wafi-Golpu, 3D Groundwater	PITEAU ASSOCIATES GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS			
Regional geological model (Leapfrog)	By	FB	Date	Oct 2017
	Approved	AR	Fig	05



REF: WGJV, July 2017, 2017WG_GeologyScene

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Regional Structural model (Leapfrog)

By	FB	Date	Oct 2017
Approved	AR	Fig	06

notably better below the Reid Upper Fault, implying that most of the underground facilities are taking place in very competent rocks (See Figure 07).

Table 4: Geotechnical domains and descriptive statistics

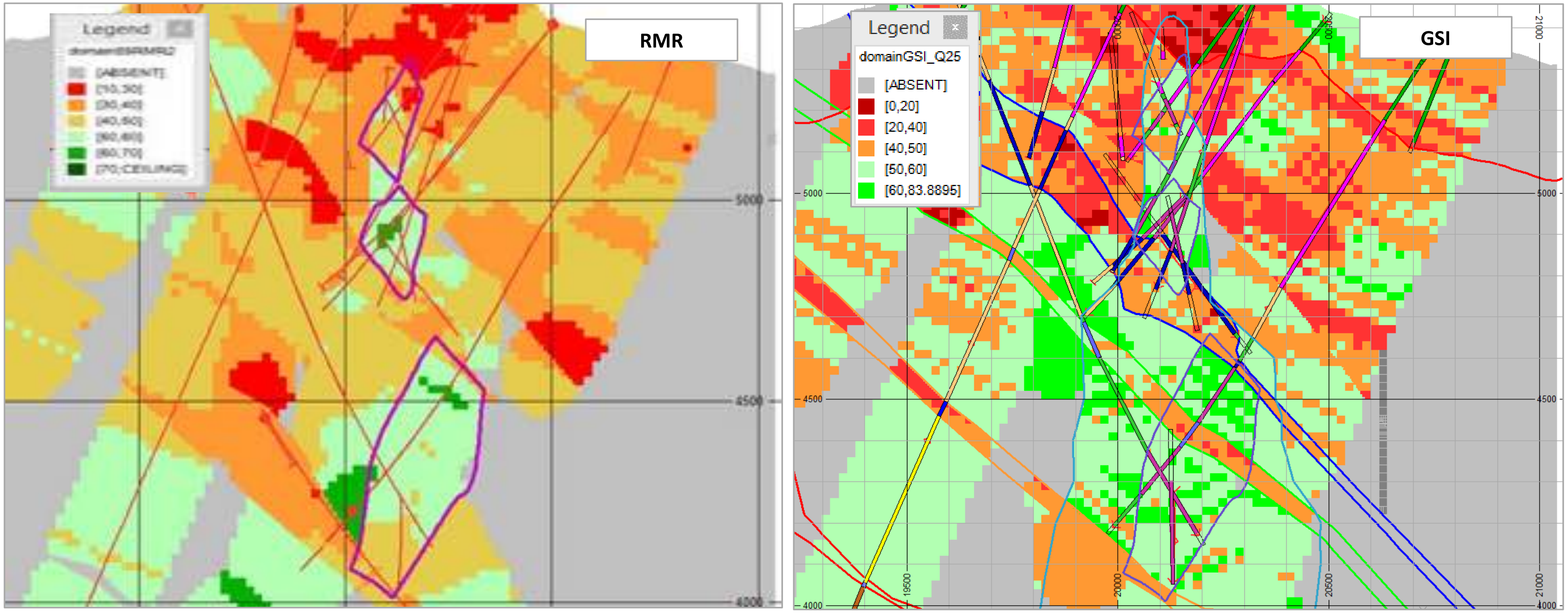
Lithology	**GSI_Q25**					**RQD (%)**		**FF**	
Geotech Zone	**Samples**	**25th**	**Median**	**75th**	**Mean**	**Samples**	**Mean**	**Samples**	**Mean**
Weathered	7184	21.8	37.7	50.4	36.7	13155	39.9	13155	15.2
Lower & Mid Buvu	1818	34.2	41.6	50.4	41.6	2099	55.9	2099	10.9
Reid Lower	1438	34.3	44.7	50.4	42.4	1732	61.0	1732	6.1
Reid Upper	4203	33.7	45.3	53.3	42.4	5193	55.0	5193	9.7
Upper Buvu	749	35.9	44.5	53.3	43.2	772	64.8	772	10.7
Overprint Fzone	11734	37.4	48.8	54.2	45.6	13766	63.4	13766	8.7
DLT Fzone	656	40.8	47.0	52.3	46.1	838	69.1	838	4.8
Babwaf Conglomerate	4632	42.9	50.4	60.0	50.4	5899	74.6	5899	2.4
OSM	6181	49.7	53.6	57.3	52.1	6286	76.4	6286	4.8
Langimar Seds	2658	50.4	53.6	57.3	54.1	2838	88.7	2838	3.1
Langimar Volc	1890	50.4	55.8	57.3	54.6	1827	87.4	1827	4.3
Actinolite	4090	50.4	54.2	60.0	55.2	4890	86.1	4890	4.2
Porphyry	2902	53.9	56.3	62.3	57.2	3020	88.6	3020	4.3

Recent geotechnical investigations have been carried out on WR519, WR520 and WR522 (See Figure 08). The investigations show that the first 400 m of rock from the surface have a variable competence, ranging from fresh to strongly fractured. Below 400 m, it is rare to observe low RQD in the cores.

2.5 HYDROGEOLOGICAL CHARACTERIZATION

2.5.1 Hydrogeological properties

From 2005 to present, several drilling campaigns have been run with different objectives (mineral exploration, geotechnical characterization, hydrogeological characterization). Field investigations enabled the identification of different units characterized by different hydraulic properties. The hydraulic conductivity and storativity were determined by hydraulic tests and geophysical well logging completed in the investigation drill holes. The sub-sections below summarize the results of the different characterization campaigns.



REF : Wafi-Golpu Rock Mass Model Update Method Statement Updated with recalculated GSI, Datamine

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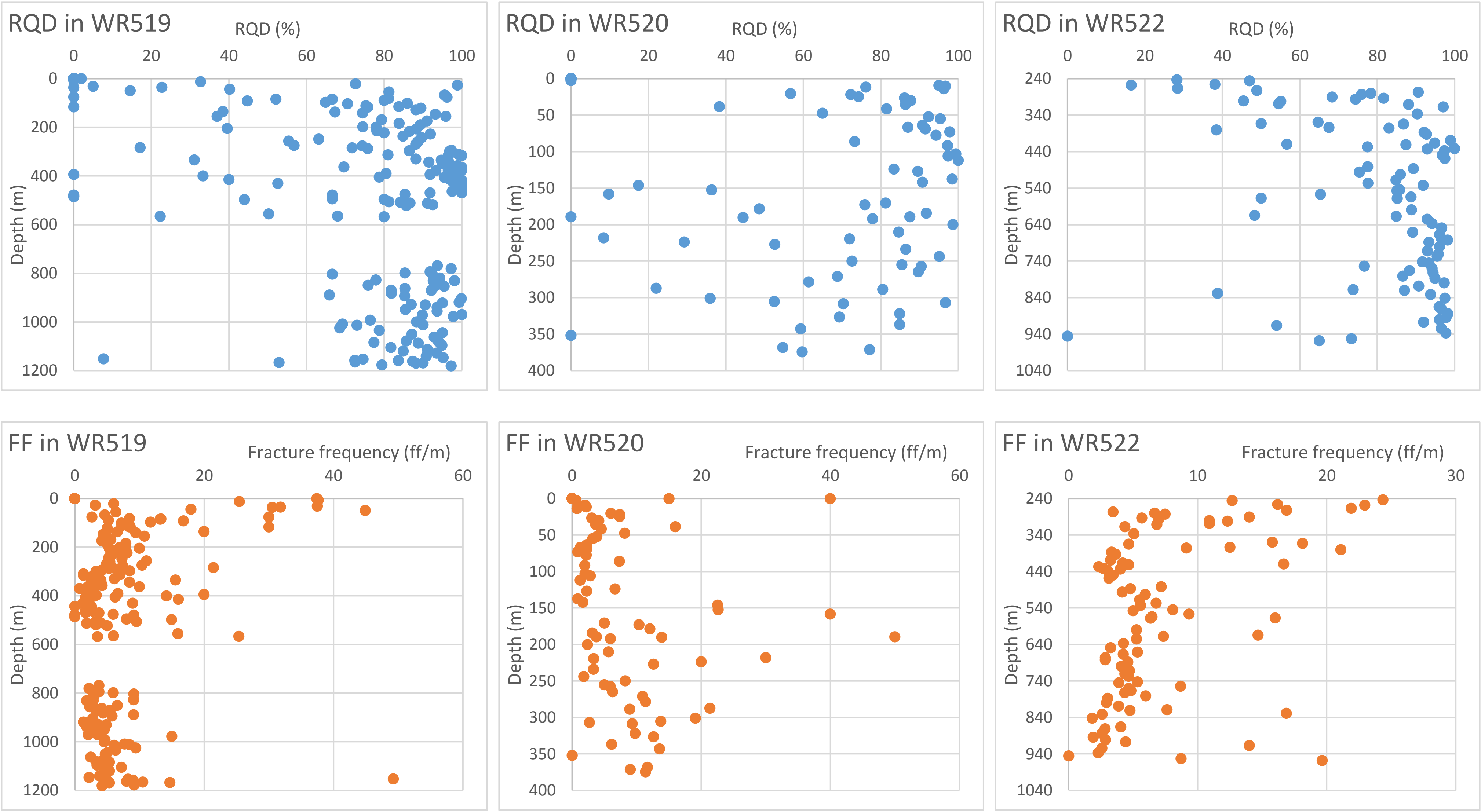
Geotechnical model

By	FB	Date	Oct 2017
Approved	AR	Fig	07



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RQD and Fracture Frequency collected in recent geotechnical holes

By	FB	Date	Oct 2017
Approved	AR	Fig	08

Packer tests (2005-2013)

WGJV carried out a total of 90 packer-tests in core-diamond exploration and geotechnical holes between 2005 and 2013 and in different sectors of the project area. Analysis of the packer test data underlined a clear depth-dependence of in-situ hydraulic conductivity at the Golpu site. Hydraulic properties derived from the hydraulic tests suggest an exponential decrease in hydraulic conductivity with depth (see Table 5 and Figure 09).

Table 5: Change in hydraulic conductivity with the depth

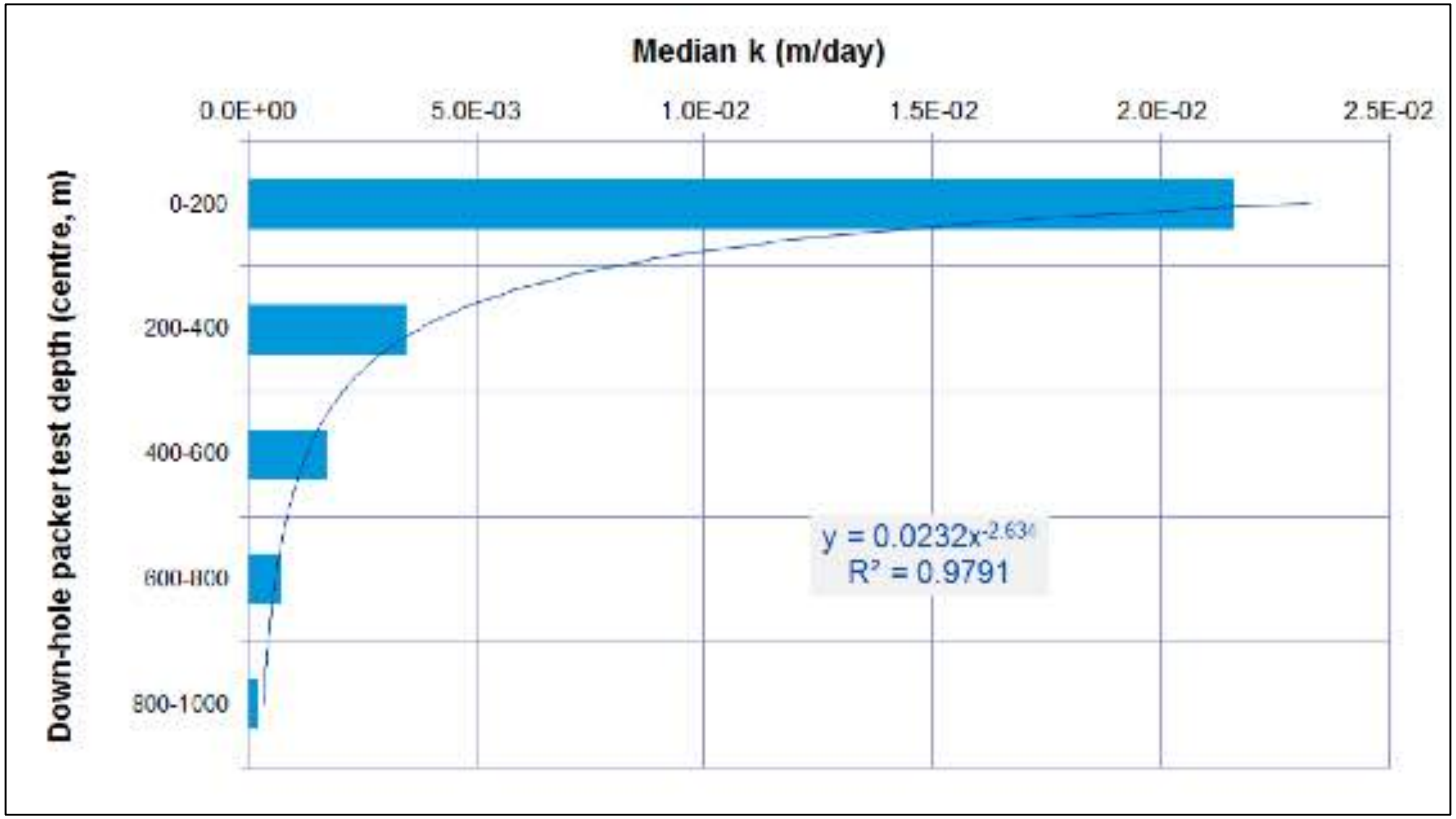
	Depth	**Average K**	**Median K**
	m	**m/d**	
Weathered and Partially weathered	0-200	2.02×10^{-2}	2.16×10^{-2}
Metasediments	200-400	6.47×10^{-3}	3.46×10^{-3}
	400-600	5.85×10^{-3}	1.73×10^{-3}
	600-800	1.72×10^{-3}	7.26×10^{-4}
	800-1000	2.10×10^{-4}	2.42×10^{-4}

Packer tests were the main technique used to evaluate hydraulic conductivity of the units exceeding 400 m of depth. The tests provided valuable information for the deeper units in which the Watut declines and the extraction levels will be situated.

For the Buvu, Hekeng and Reid faults, the packer-tests in WR494, WR498, WR499 and WR502 did not indicate a strong contrast of permeability with the surrounding units (SRK, 2013).

Pumping-tests in hydro-bores (2014)

To determine the storage capacity of the rock units, the packer test investigations needed to be accompanied by pumping tests in completed wells. The drilling of pumping and observation wells on different hydro-pads enabled the completion of step discharge, constant discharge and recovery tests. Three deep pump tests in WHDB10d, WHDB11d and WHDB13d and 2 shallow tests in WHDB12s and WHDB14s have been assessed (Table 6). Each pumping well has at least one observation borehole within 20 – 50 m from the pumping borehole.



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Hydraulic Conductivity vs depth (Packer-test 2005-2013)

By	FB	Date	Oct 2017
Approved	AR	Fig	09

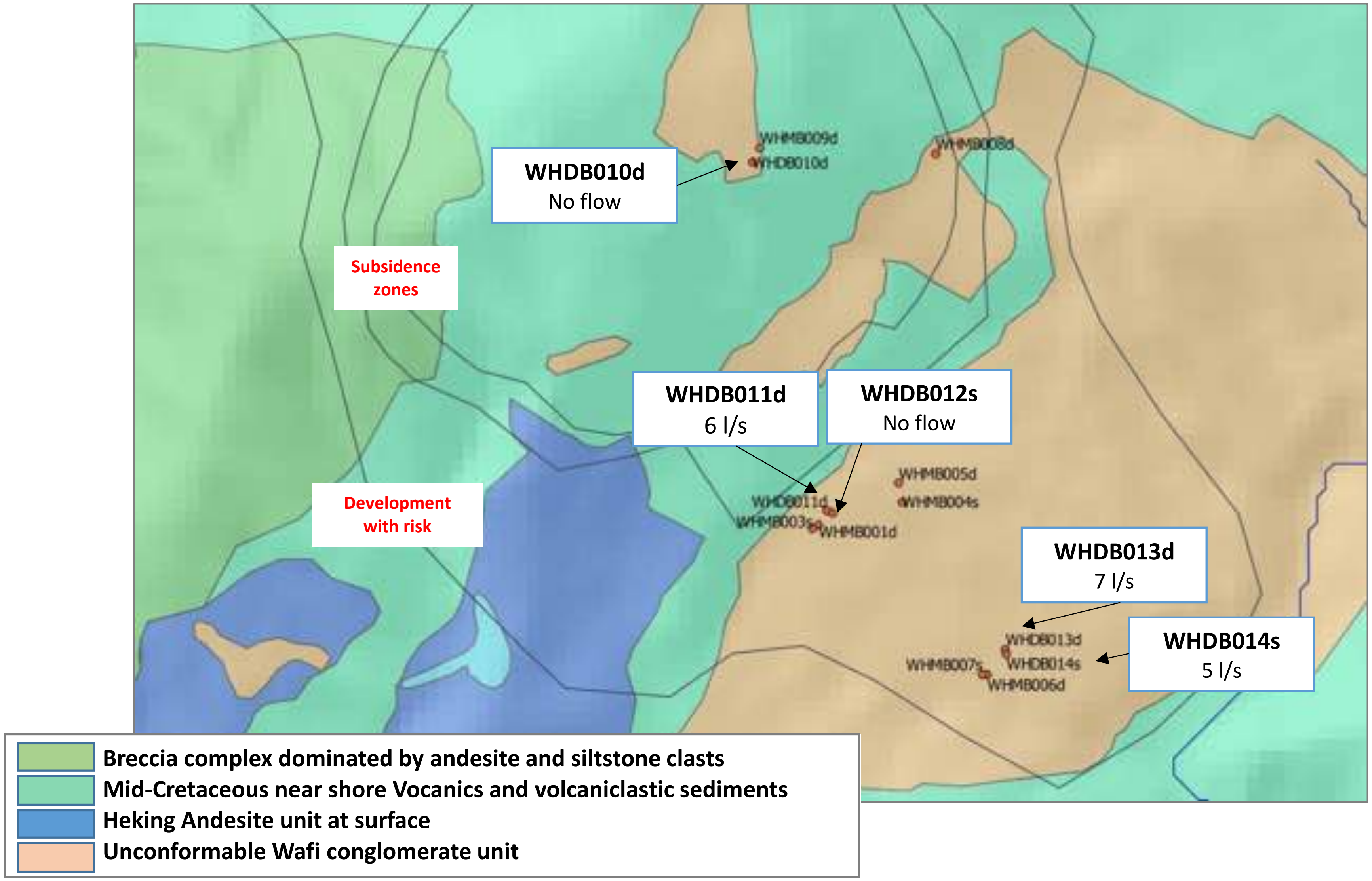
Table 6: Summary of pumping tests results

Pumping Bore	Monitoring Bores	T (m^2/d)	k (m/d)	S (-)
WHDB010d	-	0.204	7.5 x 10^{-4}	-
	WHMB09d	-	-	-
WHDB011d	-	-	-	-
	WHMB001d	9.73	4.2 x 10^{-2}	5.8 x 10^{-4}
	WHMB001d	42.16	1.8 x 10^{-1}	-
	WHMB005d	19.09	8.2 x 10^{-2}	3.8 x 10^{-4}
	WHMB003s	-	-	-
WHDB012s	-	0.545	9.4 x 10^{-3}	-
	WHMB003s	-	-	-
WHDB013d	-	-	-	-
	WHMB006d	0.545	3.0 x 10^{-2}	1.4 x 10^{-3}
	WHMB005d	90.1	8.6 x 10^{-1}	5.5 x 10-3
	WHDB014s	3.3	3.3 x 10^{-2}	3.3 x 10^{-2}
WHDB014s	-	0.85	1.6 x 10^{-2}	-
	-	7.32	1.5 x 10^{-1}	-

Source: Adapted from Morobe Mining JV Services (Australia) Pty Limited Technical Geotechnical - Deposit Hydrology Hydrogeology, 532-0469-PF-REP-0006-6.2.1_Rev0, November 2014

Based on geological logs, the screen sections have been located over the weathered and un-weathered metasediments, with wire screen protection over the faulted zones. Results of the pumping tests are highly variable (see Figure 10) and summarized as follows:

- WHDB010d is the located within the subsidence zone, near the summit of Mount Golpu. One minor fault has been intersected below the groundwater level. The lack of response from both observation wells (located 20 - 30m away) during the pumping tests and the slow recovery in the pumping well suggests that the sandstone is very tight. Besides the fact that this well is in the subsidence zone, the deep groundwater surface and the negligible production rate make this well a poor option to use for future dewatering.
- Pumping-tests on deep boreholes WHDB011d & WHDB013d indicated a potential for these holes to be used as dewatering boreholes. The constant discharge test indicates that pumping rates of 6.5 and 8l/s are possible in the long-term. Multiple faults have been intersected by these artesian boreholes located at mid-slope of Mount Golpu. As the screen section is only within the metasedimentary units, it does not allow for ingress of water from the overlying Wafi conglomerates or weathered bedrock, and it suggests that multiple faults act as conduit for groundwater.



REF : Wafi Golpu (AEFSA) - FS

Wafi-Golpu, 3D Groundwater

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Flow rates during constant discharge tests in the Hydro-bores

By	FB	Date	Oct 2017
Approved	AR	Fig	10

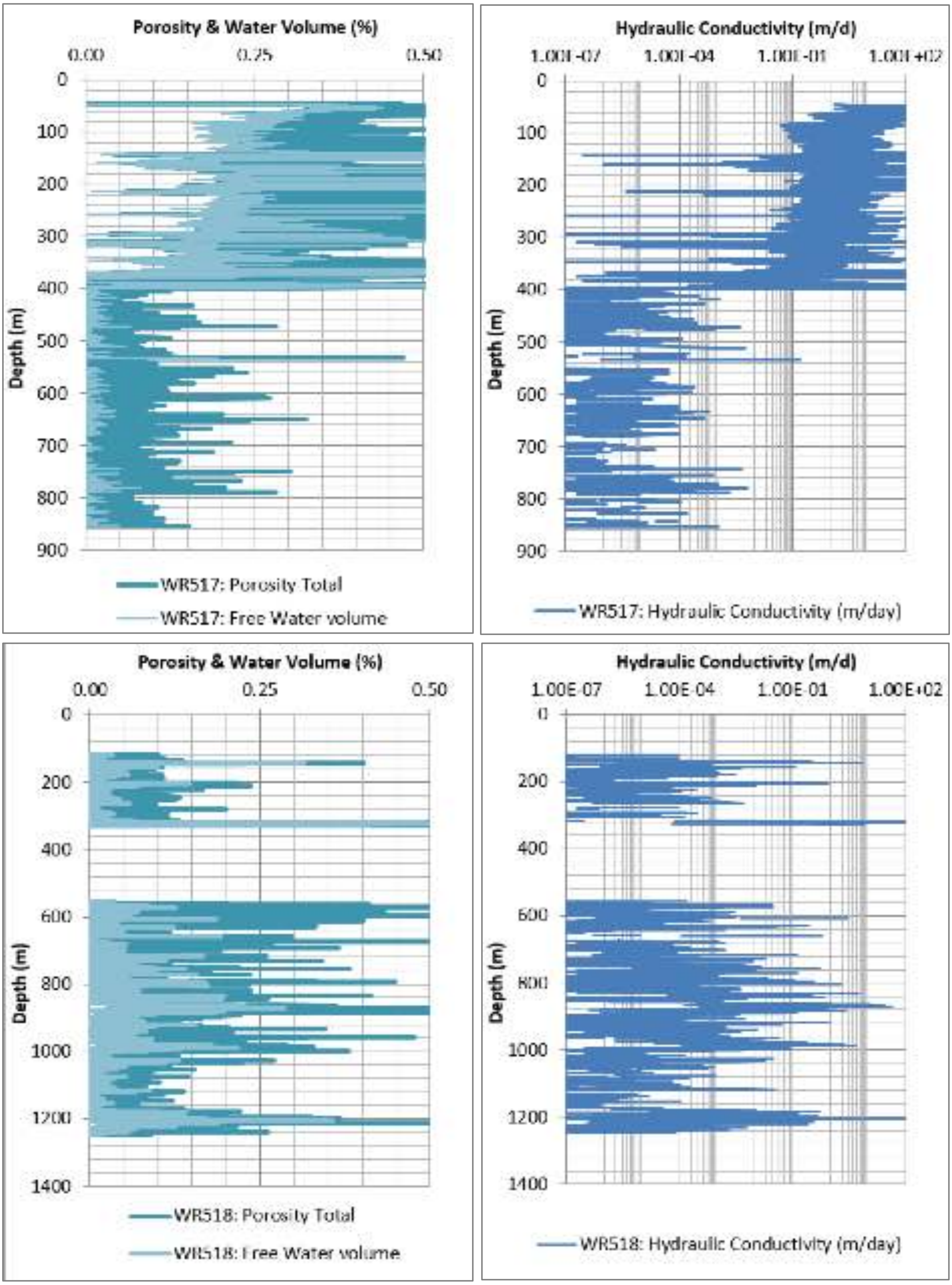
- WHDB12s is a shallow well that intersects a large faulted sequence. The oxide layer comprises some andesite intrusions and non-water bearing siltstone units. which are likely to be partially confining the limited extent to which the sandstone/fault block can yield water.
- WHDB14s is a shallow borehole emplaced in the Wafi conglomerate (or weathered bedrock) which is likely to be contributing the most to flow into the wellbore. Although some reduction in head is recorded at the observation well (approximately 2 m away), a limited lateral extent is inferred based on maximum drawdown being reached during step 3 of the test.

It is probable that faults logged in the core samples are the primary fluid flow conduits with the andesite intrusions acting as flow barriers partially confining the units beneath. Pumping tests in WHDB10d and WHDB12s were unsuccessful due to the lack of inflow from the surrounding units, even at low flow rates. Most of the volume of water pumped during the test was coming from the volume of the borehole.

NMR and ATV wireline survey (2016)

Wireline data provide valuable information from the exploration boreholes. Unlike hydraulic tests, wireline provides a high resolution and continuous stream of data. The tools used by WGJV are the caliper, Nuclear Magnetic Resonance (NMR), Gamma ray and Acoustic Tele-Viewer (ATV). Information obtained from the interpretation of data include diameter of boreholes, porosity of the surrounding formation (and related parameters such as permeability), natural gamma radiation, and image of the borehole walls. Results of the NMR campaign on WR517 to WR523 are shown in Figure 11a to 11c. Observations are listed below:

- In WR512 and WR514, ATV logging is used to evaluate the rock quality along the Watut Declines. In WR512, a fractured zone is identified between 98 and 117 mbgl, and between 229 and 279 mbgl. In WR514, the unit is visibly fractured around 217, 226 and between 375 to 402 mbgl.
- In WR517, the weathered bedrock is observed to a depth of 46 to 120 mgbl. This presents as a highly-fractured zone with an average porosity of 30%. Various peaks with a porosity equivalent to 50% are observed, and free water represents 50% to 100% of the water volume. Hydraulic conductivity is equivalent to 1 m/d in most of the unit. Caliper results are highly variable and indicate weak material with poor competency. Partially weathered bedrock is observed between 120 and 400 m. After 400 mbgl, the rock is very competent and only small-scale fractures are detected. The porosity and permeability in the deep bedrock is negligible.



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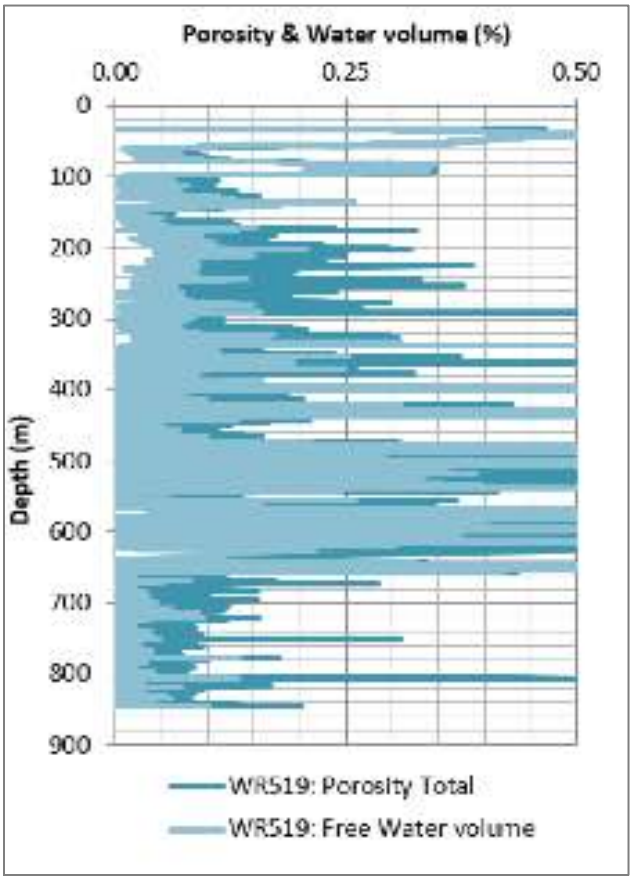
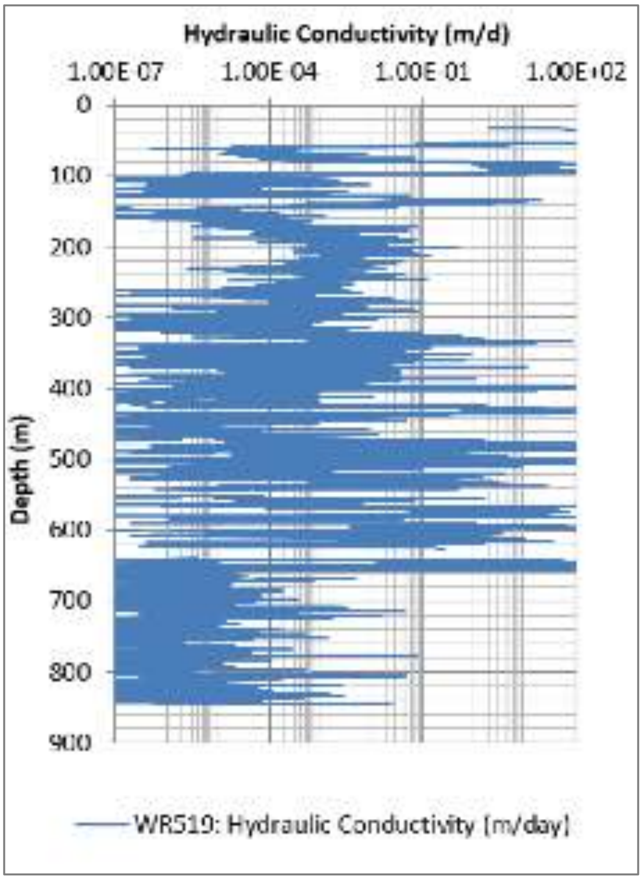
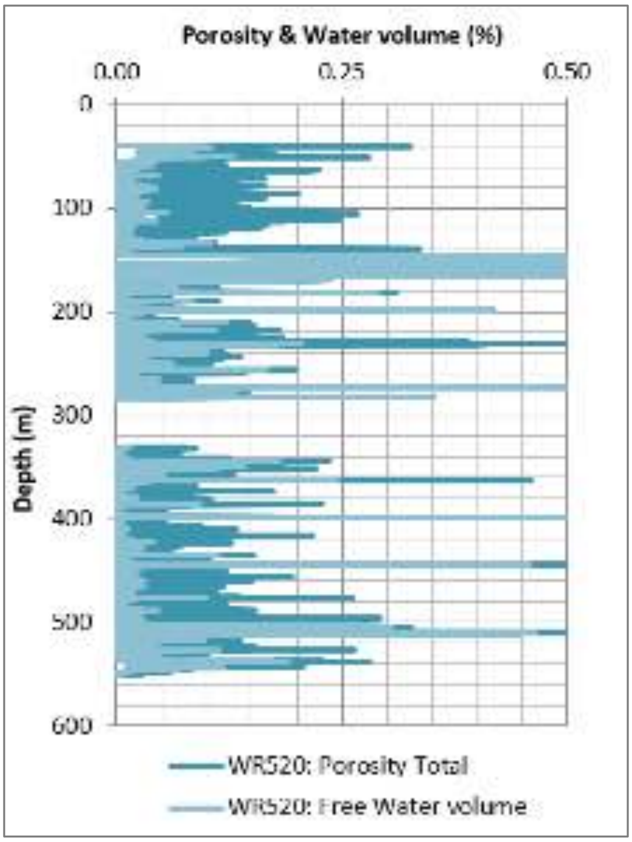
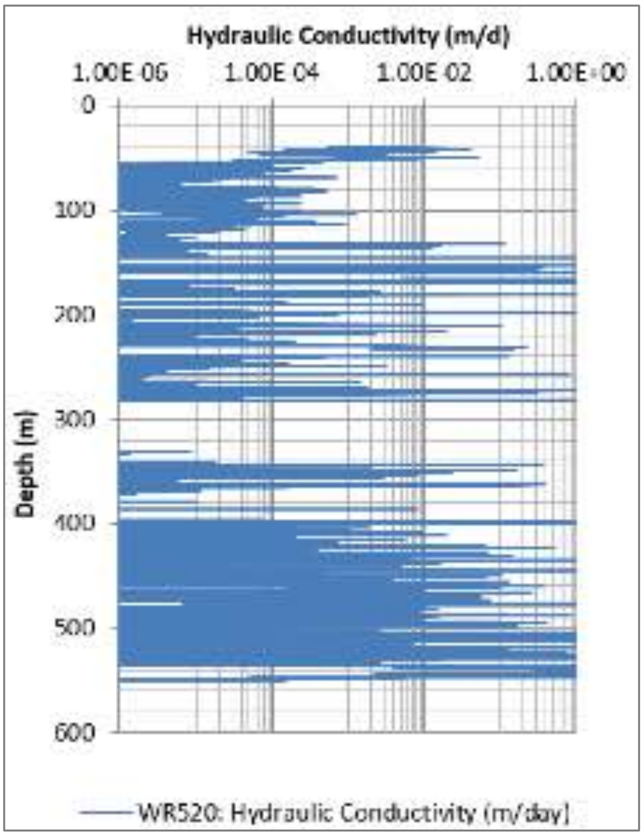
NMR data for WR517 and 518

By	FB	Date	Oct 2017
Approved	AR	Fig	11a









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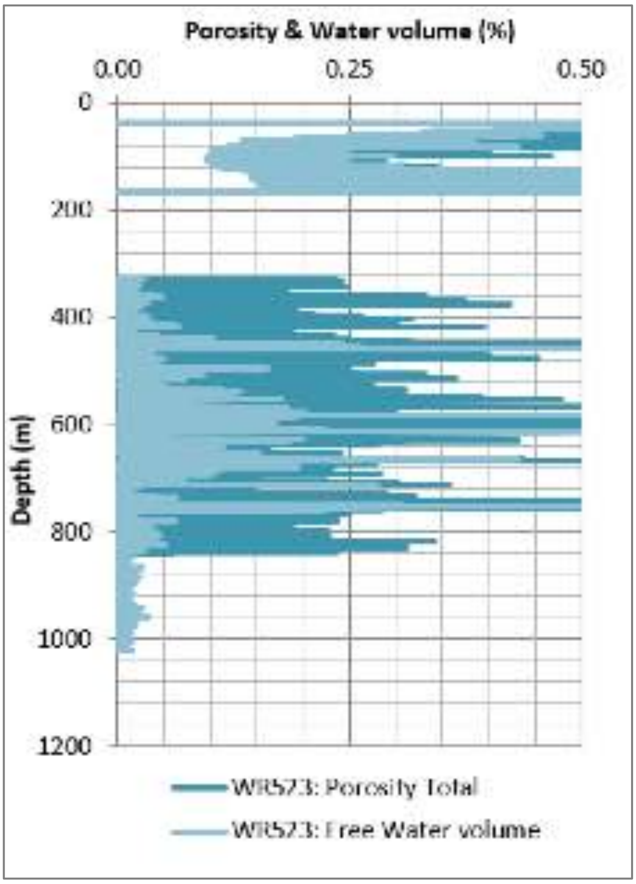
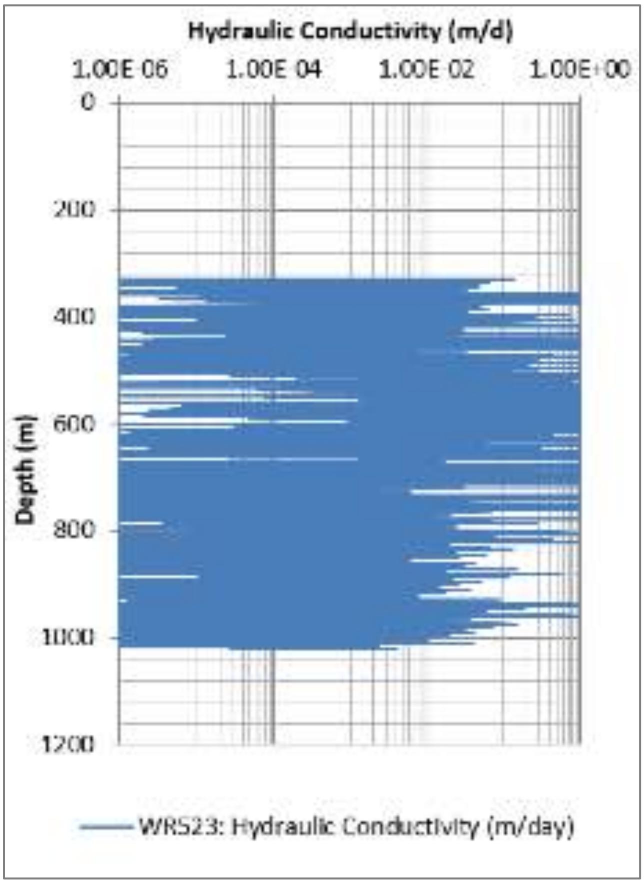
NMR data for WR519 and 520

By	FB	Date	Oct 2017
Approved	AR	Fig	11b





Wafi-Golpu, 3D Groundwater

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NMR data for WR523

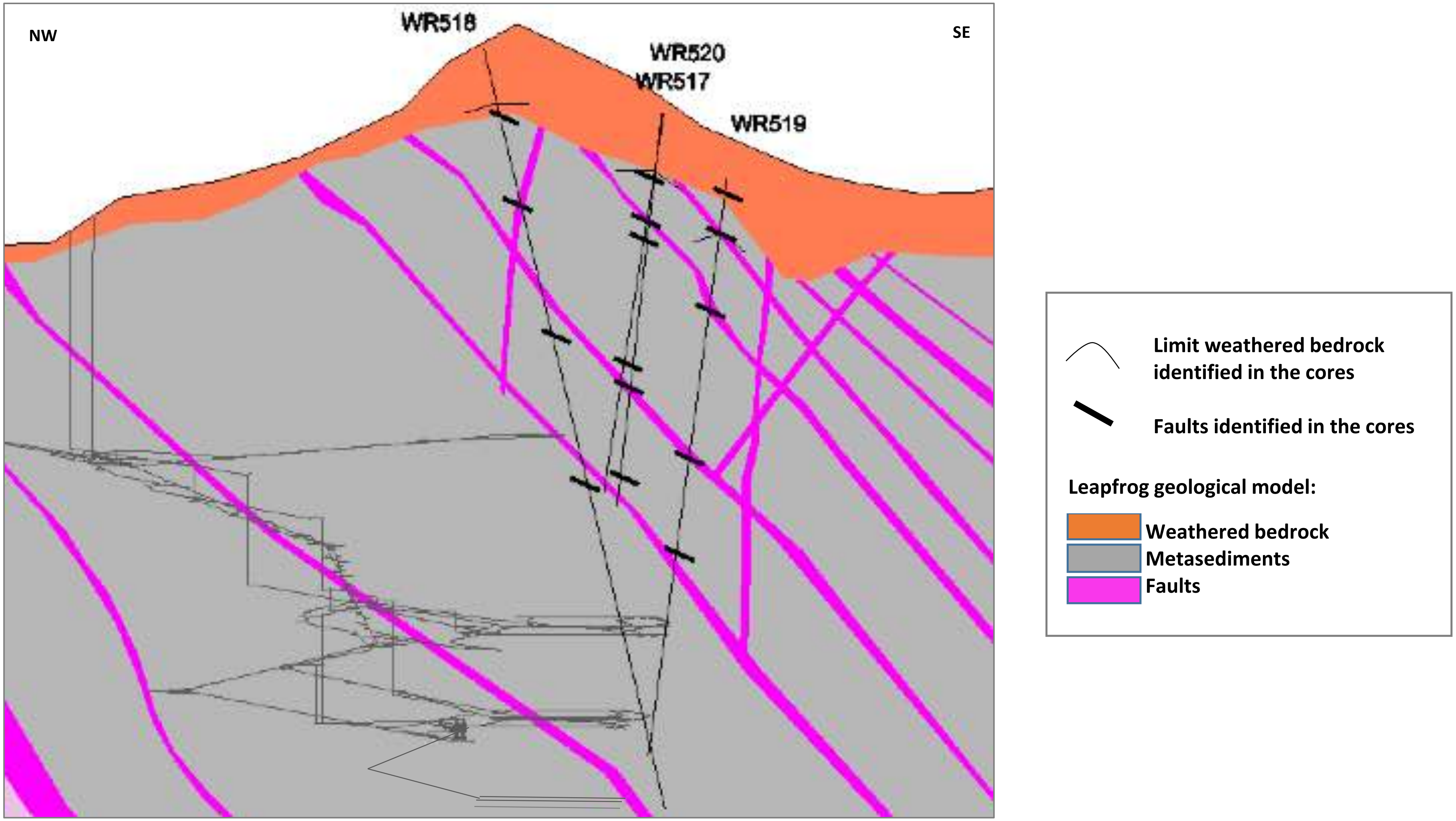
By	FB	Date	Oct 2017
Approved	AR	Fig	11c

- In WR518, the mean porosity of metasediments is inferior to 5%, and there is nearly no free water. Hydraulic conductivity is equal or inferior to 1 x 10^{-5} m/d. The NMR relaxation time is short and suggests that it correspond to a non-producing zone. For the minor faults (~15 minor faults over the 161 m of logs in the range of 118 to 279 mbgl depth), the hydraulic conductivity increases from 1 x 10^{-5} to 1 x 10^{-3} m/d. The thickness of these features is approximately 1 m. These zones are generally associated with longer but reasonable relaxation time in the NMR. There is a large faulted zone at 315 to 330 mbgl characterized by a hydraulic conductivity of between 1 x 10^{-4} to 1 m/d. Peaks with 30% of free water associated with zones of high porosity (equivalent to 40%) are observed in this zone. Peaks in the caliper coincide with the fractured zones. Below 350 mbgl, the rock is very competent, with reduced fracturing and negligible porosity.
- In WR519, a section with very competent rock is observed from 120 to 190 mbgl. Below that, variably fractured rock is intersected with some large-scale features (at depths (mbgl) of 396, 401, 430, 554 to 620, 652 and 808). Measured pore size is sufficiently large that the water may be considered as free. Connected pores exhibit a hydraulic conductivity of up to 1 m/d. Unlike other logs, WR519 identifies fractures at greater depth. Given its position on the Eastern flank of Mount Golpu, WR519 should intersect most of the Overprint faults, and also some of the alteration and deformation induced by the porphyry intrusion and associated contact metamorphism.
- In WR520, the weathered bedrock is observed in the section from 40 to 54 mbgl. The unit presents a porosity of 10 to 30%. The water volume shows approximately 10% of free and capillary water. Hydraulic conductivity in this unit varies between 1 x 10^{-4} and 1 x 10^{-1}m/d. in the partially weathered bedrock characterized by a porosity in the range of 5 to 20%, the water volume is essentially composed of capillary and bound water. Hydraulic conductivity is in the range of 1 x 10^{-6} and 1 x 10^{-3} m/d. A significant faulted zone is detected at 146152 mbgl. In the metasediments, hydraulic conductivity is equal or inferior to (but not measured) 1 x 10^{-6} m/d. The unit presents a very low porosity at a depth of 300 to 390 mbgl.
- In WR523 which is located over the Nambonga deposit a reduction in fracturing, porosity and permeability is observed between 34 mbgl and 48 mbgl. Partially weathered bedrock is then observed between 48 mbgl and 166 mbgl, with two major faults at 128 and 166 mbgl (possibly the DLT fault). The section 350 to 1018 mbgl exhibits very reduced porosity and permeability. Disparate small-scale features are identified, but the likelihood of these being connected to major faults is low.

Through the geotechnical drilling supervised by Pitt & Sherry, it was possible to detect the different regional faults (Reid, Overprint, Hekeng and Camp) in the Boreholes WR517, WR518, WR519, WR520, WR522 and WR523 (See Figure 12). The location of the faults developed in the geological model coincides with the fault locations indicated during geotechnical drilling. Based on the faults identified in the geotechnical boreholes, the different logs have been reviewed:

- The Overprint shell has been formally detected with the NMR and ATV (251-269 m in WR517, 39-45 m in WR518, 287-292 m in WR519, 222-233 m in WR520). It corresponds to a series of small open fractures, and the NMR detects a potential to convey water with the presence of free water and a permeability of 0.1 m/d.
- The Overprint2 fault is located deeper below the surface of Mount Golpu in very fresh rock. In WR517, some fractures are visible but the NMR indicates a low porosity and permeability. In WR518, at 637-647 m, there is no porosity and no permeability detected.
- The Reid fault is the deepest fault below Mount Golpu. In WR517, at 787-789 m depth, nearly no free water is detected and the permeability is indicated as negligible. Similarly, at 999-1002 m depth in WR518, the NMR does not show a high permeability. On the contrary, in WR522 at 957-961 m depth, the NMR indicates that there are two zones with more water.
- Some faults such as Overprint2 are overprinted by large zones of high permeability which are likely to be correlated with actinolite alteration. In WR520, the section 280-580 m coincides with the actinolite zone, a medium RQD and an intermediate permeability.

WSP Australia developed in 2017 a summary table of NMR/ATV data and interpretation (See Table 7. NMR information confirms that groundwater movement through the deep and fresh metasediments is expected to be negligible given that it shows a very low permeability and effective porosity.



Wafi-Golpu, 3D Groundwater	PITEAU ASSOCIATES GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS		
Leapfrog geological model and data collected in the recent geotechnical holes	By FB	Date Oct 2017	
	Approved AR	Fig 12	

Table 7: NMR/ATV Log Data and Interpretation of Overprint and Reid Fault Structures (Modified from WSP, 2017)

Fault	Hole	Interval (Downhole m)	NMR/ATV Features	Interpretation of ability to transmit water
Overprint Shell	WR517	251.1 to 251.6 & 268.7 to 269.5	Chloritic and sericitic rich fault rock, presence of free water; NMR indicates possibly water bearing but so is rock either side of structures. The ATV data shows cluster of partial open fracture between 250.8 – 251.6 and 259.2 – 267.2 m. Open fracture at 251.6, 260 and 268.2m.	Likely yes, also surrounding rock has relatively high porosity with high component of free water and typical permeability characteristics > 0.1 and commonly > 1 m/d.
	WR519	287 to 292	NMR show some free water & moderate K of 0.1 m/d at 280 - 291m. ATV shows cluster of partially open fractures from 286.5 – 294.0m. Two open fractures at 287.2 – 287.3 m and one open fracture at 289.4 m.	Possibly some water movement, but not high.
	WR520	222 to 230.7	NMR: Free water and high K in fracture zones above and below modelled fault zone, however, the modelled fault zone has minor free water and K < 0.01 m/d.; The zones of high free water and K are between 210 – 210.4; 215.5 - 219 m and at 233.5m. ATV shows 2 open fractures at 210.3 – 210.4m; cluster of partial open fractures between 215.2 – 219.3 m.	Yes, within water bearing fracture zones either side of modelled fault location.
Overprint 2	WR517	587	NMR: No free water, some bound water, low K. The ATV shows cluster partially open fractures from 587 to 589.2 m.	No
	WR518	637 to 647	NMR: Very low porosity, miniscule free water, low K. ATV shows cluster of partially open fractures between 640.4 – 642m and 646.8 - 648m. Two open fractures at 647.4 to 647.6m.	No
	WR520	546.75 to 546.85	NMR: Miniscule free water at 546.75 - 546.85m and very low K. ATV shows cemented joints in modelled zone and at least 5 m either side.	No
	WR522	614.4 to 617.4	calliper deviation indicating fracturing although NMR shows variable porosity content, high free water presence and high K - similar to surrounding rock. ATV shows some small fractures but not indication if fractures are open. Common cemented joints.	Potentially yes, and extends outside modelled fault zone, although calliper log and ATV do not show large fractures. Possibly NMR response associated with rock type properties.
Reid Fault	WR517	787.6	NMR: Minor free water and low K. ATV shows 5 open fractures between 788.4 – 789.5m.	Likely No
	WR518	999.2 to 1002.7	NMR: free water and low to very low K. ATV shows 3 open fractures at 1002.8 – 1003.2m.	No
	WR519	803.4 to 810.3	Caliper and geology log indicates crushed zone between 804 - 807m, NMR shows some free water and low to moderate K between 0.01 and 0.1 m/d. ATV shows cluster of open fractures between 802.3 – 805 m and 811 – 812.3 m.	Possibly some minor water movement.
	WR522	957.6 to 961.5	NMR shows no free water and low K at 957.6 - 961.5. The ATV shows no fracturing. Calliper indicates fracturing (higher RQD) above and below modelled fault area at 946 - 948 m, at 963 and 966m. The NMR indicates free water presence and high K in these fractures. The ATV shows some partial open fractures between 963 and 966 m.	Yes, within water bearing fracture zones either side of modelled fault location.

Some values of permeability in the NMR exceed 100 m/d and are unrealistic. The permeability is not measured directly with the NMR, but results from the derivation of other NMR measurements. These derivations are fundamentally based on algorithms developed by the oil & gas industry for the evaluation of homogenous porous media and thus are not specifically designed for the evaluation of fractured hard rock formations. However, the results exhibit significant value as they are indicative of local fracture conditions on the bore wall. While this does not imply that groundwater can flow along entire fault planes in a material with those characteristics, it provides an otherwise unobtainable semi-quantitative measure of the relative permeability of different areas in the borehole. Free water and permeability should be considered as qualitative parameters.

The review of NMR and ATV data does not highlight specific characteristics for the regional faults. Overprint shell has been formally identified in the core logging while the Reid fault shows high variability in parameters across different drill holes. This highlights the variability in the properties of the regional faults. The faults may host a large amount of water and produce peaks of inflows in the future underground works. However, it is very unlikely that the faults will provide a continuous pathway for water from the surface to depths greater than 400 m.

Tests on artesian wells (2017)

As part of a series of field work investigations carried out by Piteau in 2017, hydraulic-tests on artesian wells at Mount Golpu and the portal were undertaken in March 2017. The objective of this fieldwork was to refine the characterization of the hydrogeological conditions of the Golpu site. ‘Shut-in tests’, using the valves of artesian wells enabled the completion of pseudo-constant discharge and recovery tests, in order to deduce the hydraulic properties in different sectors with minimum material mobilization. The highest flow rate was observed at the portal in WR516 with 2 l/s at equilibrium. The flow rate decreased to less than 1 l/s at equilibrium in other artesian holes.

Table 8 shows the hydraulic properties calculated from the artesian tests on the hydro-bores. The results appear to be in the same ranges of the those obtained during the first pumping tests conducted in 2014.

Table 8: Results of hydraulic tests on artesian wells, and comparison with pumping-tests on hydro-bores in 2014 (WGJV, 532-0469-PF-0006-6.2.1)

		Artesian test (2017)		Pumping Test (2014)	
		T (m^2/d)	S (-)	T (m^2/d)	S (-)
Test 01: WHDB013d	**WHDB013d**	2.6	-	-	-
	WHMB006d (Observation)	3.8	8.40×10^{-4}	3.15	1.4×10^{-3}
	WHMB007s (Observation)	1.3	5.50×10^{-3}	90.1	5.5×10^{-3}
Test 02: WR451	**WR451**	2.9	-	-	-
Test 03: WR516 (Portal)	**WR516**	17.2	-	-	-
	WG046-20m	4.36	1.36×10^{-3}	-	-
	WG046-40m	2.29	2.91×10^{-4}	-	-
	WG046-60m	4.88	2.58×10^{-3}	-	-
	DB13	9.12	2.34×10^{-3}	-	-
Test 04: WR206	**WR206**	10.1	-	-	-
Test 05: WHDB014s	**WHDB014s**	3.4	-	0.85	-
	WHDB013d (Observation)	6.04	2.68×10^{-2}	-	-
	WHMB006d (Observation)	7.18	8.43×10^{-3}	-	-
	WHMB007s (Observation)	5.48	1.27×10^{-2}	-	-
Test 06: WHDB011d	**WHDB011d**	8.53	-	9.73	5.8×10^{-4}

Hydraulic tests on artesian boreholes provided valuable information on the storage value for different sectors of the study area. The first 200 m of weathered metasediments have been tested with the shallow and deep hydro-bores. The storage capacity is relatively low for a shallow unit, and it is reasonable to expect even lower values for the deep and fresh bedrock.

In addition, long term flow rates observed in the hydro-bores indicates that they have not been affected by any clogging or obstruction. Thus, WHDB011d and WHDB013d eventually completed by their shallow wells (WHDB012s and WHDB014s respectively) are still relevant for the installation of pumping wells for the dewatering of the block cave.

At the portal, the opening of valves in WR516 and WR510 enabled detection of an immediate response in Vibrating-Wire Piezometers located at the top of the high wall. The rapid level decrease produced by horizontal drains indicated a strong potential to dewater the portal high wall and improve the geotechnical design with horizontal drains.

Pumping-tests on new hydro-bores (2017)

Aquifer testing of holes recently drilled are currently in progress and results were not available at the time of model construction. It is recommended that should the results indicate any significant variation from previous results, that the model is updated accordingly.

The preliminary results from the ongoing drilling program, as well as a number of *ad hoc* injection and slug tests do corroborate in the current conceptual understanding of the site. This especially in terms of the fact that yields encountered in the completed boreholes have generally been low, and have decreased with depth unless associated with a specific structure. Furthermore, preliminary injection test results, although not sufficiently definitive to be included in this report, do provide semi-quantitative confirmation of the range of permeability values expected for the area.

2.5.2 Hydrogeological units

Results derived from the packer-tests showed a strong dependency of hydraulic conductivity on the depth and associated degree of weathering. The different lithologies (Langimar Beds, Babwaf Conglomerate and Owen Stanley Metamorphics) are associated with varied degrees of weathering. As described in the WSP|PB study, the hydrogeological units in the project area correspond to the superposition detailed below:

- **Alluvium and colluvium (HU1)**: The alluvial aquifer is developed predominantly in the Watut floodplain where the thickness of alluvial material can reach 80 m, and as low as 30 m on the floodplain margins. In minor valleys and elevated floodplain margins near Mount Golpu, the alluvium is a thin unit of silt, clay and gravel with a thickness of approximately 2-5 m (SRK, 2007).

  On the flank of Mount Golpu, the uppermost unit corresponds to colluvium and is characterized by a mixture of clay, silt, sand and gravel. This material has not been tested hydraulically, and it is expected that it will be essentially unsaturated and play a fundamental role in the control of the recharge and runoff. On outcrops on the road cuttings, some seepages have been repeatedly observed at the contact of the colluvial material and the weathered bedrock, indicating that a portion of the infiltrated water in the sediment is flowing laterally as interflow. In terms of hydraulic properties, it is likely to exhibit a hydraulic conductivity of 0.01 to 1 m/d, i.e. the classical range of values for hydraulic conductivity for a soil or an overlying unconsolidated sediment.

- **Weathered bedrock (HU2)**: In the early development of Wafi-Golpu project, this shallow unit was described as the oxidized unit because it is a weak and oxidized rock unit with some clasts and argillic material. Weathering occurs across the project area with different depths above each different lithology (Wafi Conglomerate, Babwaf Conglomerate, Langimar and OSM units). Analysis of the weathered surface from geological block models indicates that the depth is highly irregular and varies between 20 and 150 mbgl. In addition, some intercalation of unweathered and weathered bedrock in the first 50 m is frequently observed in the core logs. Outcrops on road cuttings also exhibit evidence of this irregular weathering, with weak and altered zones surrounded by stronger beds. Outside of the exploration area, the geometry of this unit is not defined with precision. Results of the pumping-test campaigns suggest that the drainable water is inferior to 5% of the rock volume.

  The leapfrog model proposes a limit of weathering around Mount Golpu. Based on the database of drilling logs, it shows that the average thickness is 85 m. The weathered horizon tends to extend to greater depths on the eastern side of Mount Golpu (See Figure 13).

- **Partially weathered bedrock (HU3)**: This is a transition unit between the weathered bedrock and the metasediments. This unit is characterized by a rubbly texture, with less clay content and consequently more integrity than the weathered material. In terms of geometry, it appears to be highly irregular with a depth varying between 10 and 300 mbgl. Hydraulic tests did not show a clear contrast of hydraulic conductivity between the partially weathered bedrock and weathered bedrock. Both weathered and unweathered bedrock display a significant heterogeneity with hydraulic conductivity ranging over four orders of magnitude. Storage is expected to be lower than the overlying unit.

- **Metasediments (HU4)**: At greater depth, metasediments corresponds to fresh competent rock with in-filled micro-fracturing. There is a strong alteration associated with schistose metamorphism and a reduction in the level of brecciation, pervasive fracturing and weak zones. Packer-tests carried out in the metasediments indicate a strong correlation of hydraulic conductivity with depth. Packer-test results show hydraulic conductivity equivalent to 2.1×10^{-4} m/d at the depth of the underground platform (900 m). NMR data at depths greater

REF: WGJV, July 2017, 2017WG_GeologyScene

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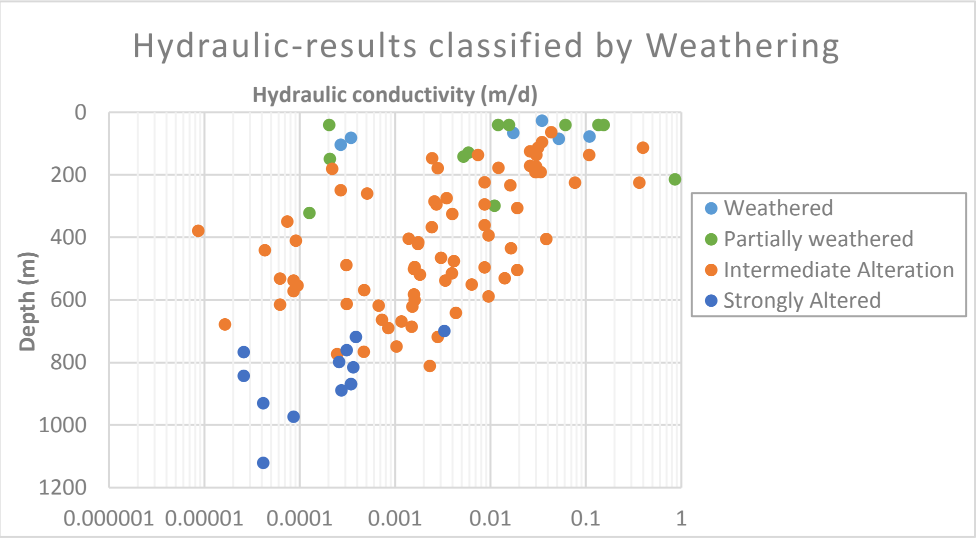
Geometry of the weathered horizon

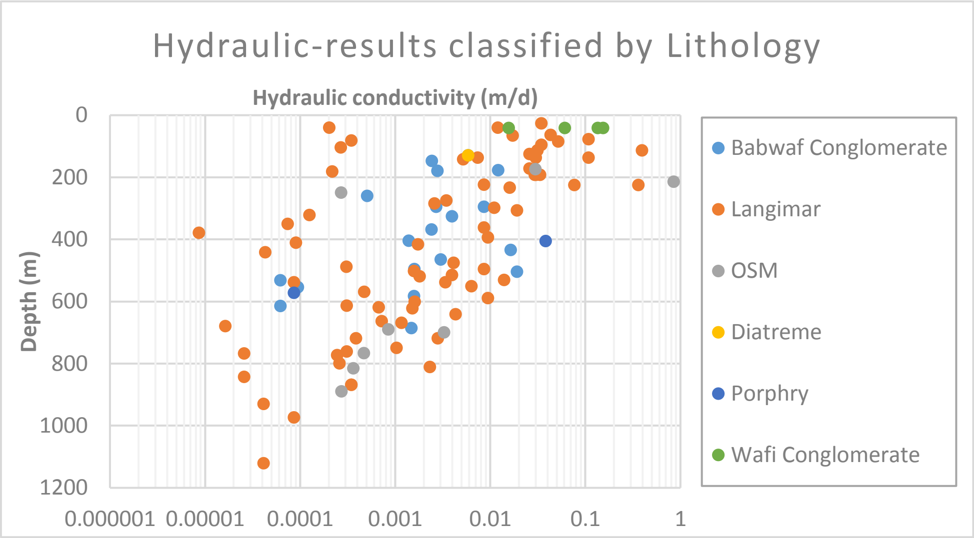
By	FB	Date	Oct 2017
Approved	AR	Fig	13

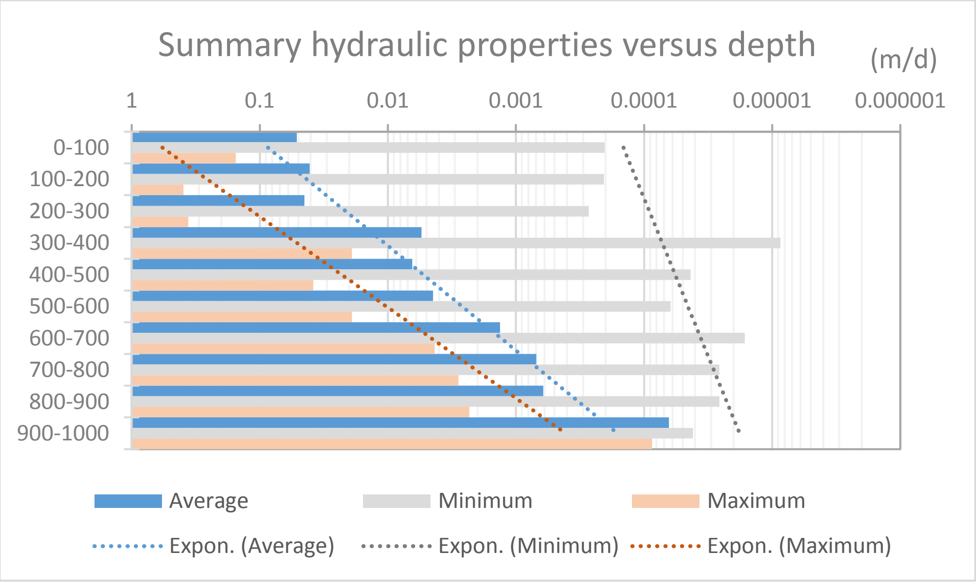
than 400 m exhibit very low to negligible storage capacity and thus support the packer test results.

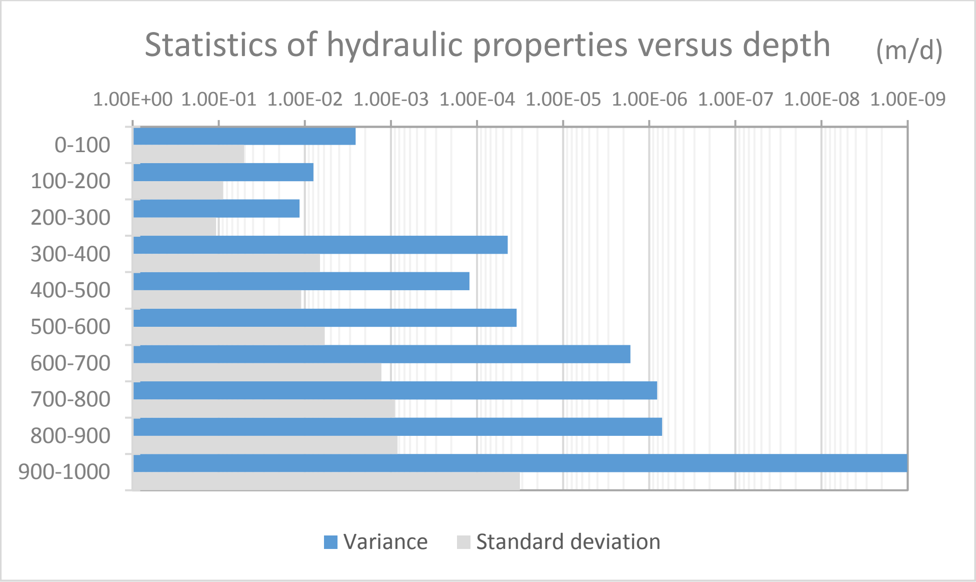
- **Faults (HU5)**: The fault zones have been tested with six packer tests, all exhibiting a wide range of hydraulic properties from 2.0 x 10^{-5} to 5.0 x 10^{-2} m/d. Faults are characterized by a deterioration in the rock competency to the point of brecciation. In some cases, increased weathering is observed on either side of the crushed, sheared and fractured zones.
  Regional faults correspond to large scale fractured zones in the bedrock with heterogeneous hydraulic properties. The maximum thickness of fractured material is observed in the Buvu Fault which is intersected by the exploration borehole WR436. The Buvu Fault corresponds to a fracture zone of 50 m wide. As observed in the interpretation of NMR and ATV data, the thickness of the other faults ranges from 1 to 10 m.

Given the very low hydraulic conductivity of the metasediments, water movement occurs essentially through the secondary porosity (fractures). This is particularly relevant for the subsidence zone which will be intersected by the thrust faults, dipping at approximately 60° to the east (Reid, Overprint and Hekeng), but not by the Buvu Fault which only intersects the Watut Declines. It is noted that parameters such as the width of the fault, size of clasts, clay content, aperture and sealing material are highly heterogeneous, mainly at the small scale of observation of the NMR and ATV data. While some very high hydraulic conductivities are measured with the NMR tool, there is no guarantee that structures exhibit continuously the same property from the point of measurement to the block caves. The geotechnical block model confirms this assumption with GSI and RQD being predominantly low but highly variable along the main faults. It is therefore considered relatively unlikely that such structures will transmit significant amounts of water to depths greater than 400 m. Table 9 and Figure 14 summarize the hydraulic properties of the different hydrogeological units.


Hydraulic-results classified by Weathering


Hydraulic-results classified by Lithology


Summary hydraulic properties versus depth


Statistics of hydraulic properties versus depth

Wafi-Golpu, 3D Groundwater

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Statistics of the different campaigns of hydraulic tests

By	FB	Date	Oct 2017
Approved	AR	Fig	14

Table 9: Summary of hydraulic conductivity and storativity for hydrogeological units

Hydrogeological Unit		Approx. depth range (mbgl)	Hydraulic Conductivity (m.day-1)				Storativity (-)
			Minimum	Maximum	Geomean	Number of measurements	
HU1: Alluvial		0-50m	3.46x10^{-2}	4.32x10^{-1}	1.57x10^{-1}	3	-
HU2: Weathered bedrock		20-100m	2.68x10^{-4}	1.09x10^{-1}	8.23x10^{-3}	6	-
HU3: Partially weathered bedrock		10-300m	1.26x10^{-4}	8.54x10^{-1}	7.68x10^{-3}	8	3.30x10^{-2}
HU4: Metasediments	**Intermediate Alteration**	60-900m	8.64x10^{-6}	4.32x10^{-2}	1.89x10^{-3}	69	6.32x10^{-4}
	Strongly Altered	500-1200+m	2.00x10^{-5}	3.28x10^{-3}	1.73x10^{-4}	13	-
HU5: Faults		Variable	2.00x10^{-5}	5.18x10^{-2}	8.71x10^{-3}	6	-

Source: Adapted from Morobe Mining JV Services (Australia) Pty Limited, Numerical Groundwater Flow Model Development, 532-1002-FS-REP-0028, April 2016

2.5.3 Fractured material

As mentioned in the WSP|PB study, the block-caving extraction method involves the removal of material from the extraction zone and the upward development of a cave. The controlled caving of a block of ore requires breakdown into sizes that permit discharge through cones at the base of the block. Itasca Australia Pty Ltd (Itasca) developed a predictive scenario of the block cave operation with FLAC3D to evaluate the development of the caved and fractured zone in the metasediments and weathered horizons. The two respective zones are distinguished in the numerical model by differences in plastic strain. A strain greater than 0.5% defines the fractured zone. Displacements greater than 1-2 m are grouped in the caved zone. The rock mass damage will increase from the edge of the fractured zone to the center of the caved zone. Propagation of the fractured and caved zone above the extraction levels is influenced by the thrust faults and the Camp fault.

In the context of a greenfield project, it is difficult to forecast the hydraulic properties of fractured and caved materials within the block cave and the subsidence zone. In addition, studies of hydraulic property modification over a subsidence zone from other projects are limited. However, it is possible to forecast the following effects:

- Stress has a great effect on the permeability of the rock mass. Many investigations have been undertaken to find empirical relationship between permeability and effective pressure (difference between the exterior confining pressure and the pore-fluid pressure). Most of the empirical relationships have been developed to answer the problems associated with the loading of intact rock. In the present study, the reduction of stress is the principal factor driving the change of permeability. Some relationships for coupled hydro-mechanical models have been developed to link hydraulic conductivity and rock mass damage. The plastic strain (proportional to stress according to Young's Modulus) is an output of the FLAC3D model, and could be used as a variable of hydraulic conductivity.

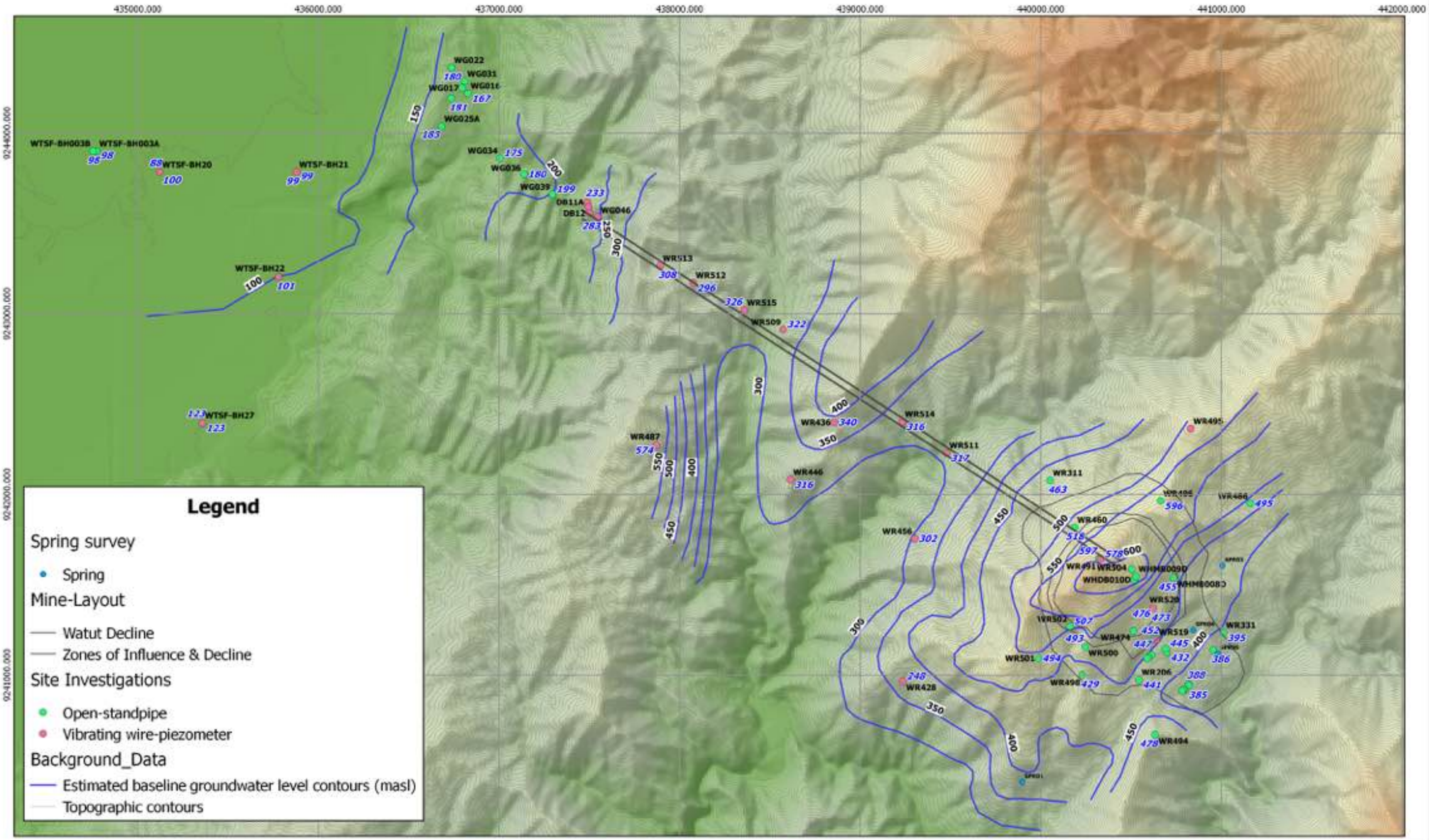
- The increase in hydraulic conductivity is capped with a maximum value of up to 3 or 4 orders of magnitude higher than initial value. This relationship may be of significant interest for the development of a fully coupled model. It requires further investigation, and the constants will need to be further calibrated as the block-caving operation commences.
- A bulking factor of 110-115% has been used in the geomechanical modelling. A reduction of in-situ stress causes increased storativity of the caved zone due to the dilation of the competent metasediments.
- Dilation of faults due to a reduction of stress should enhance the role of faults as preferential pathways for inflow to the Watut Declines and caved material emplaced in the metasediments. It is very likely that the inward dipping structures will dilate more because of loss of shear strength and sliding along the fault surface.

Given the expected increase of hydraulic conductivity in the caved zone, there will be increased interaction between the surface and the underground mine. The high permeability pathway between the surface and the deepest extraction level will be equivalent to 1700 m.

2.5.4 Groundwater levels

The existing monitoring network used to define the piezometric surface across the site is localized around Mount Golpu, along the proposed Watut Declines alignment and the portal area in the Watut floodplain (see Figure 15 and Table 10). Including the recent piezometers installed in the Watut plain, the current active monitoring network is composed of:

- 41 vibrating wire sensors which are installed in 25 different exploration holes to record the pore-pressure distribution along the Watut Declines and subsidence zone.
- 37 exploration boreholes have been integrated to the monitoring network. Some artesian bores have been fitted with a tap and a grout platform to control the water outflow.
- 13 monitoring boreholes designed with slotted pipes and gravel in the annulus space. These piezometers have been constructed as observation boreholes to deduce the specific yield from pumping tests. In addition, discrete shallow and deep wells are present allowing the



Datum:AGD66 / AMG zone 55
EPSG: 20255

Wafi-Golpu, 3D Grounwater Model

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Available baseline groundwater level data and inferred approximate groundwater level contours

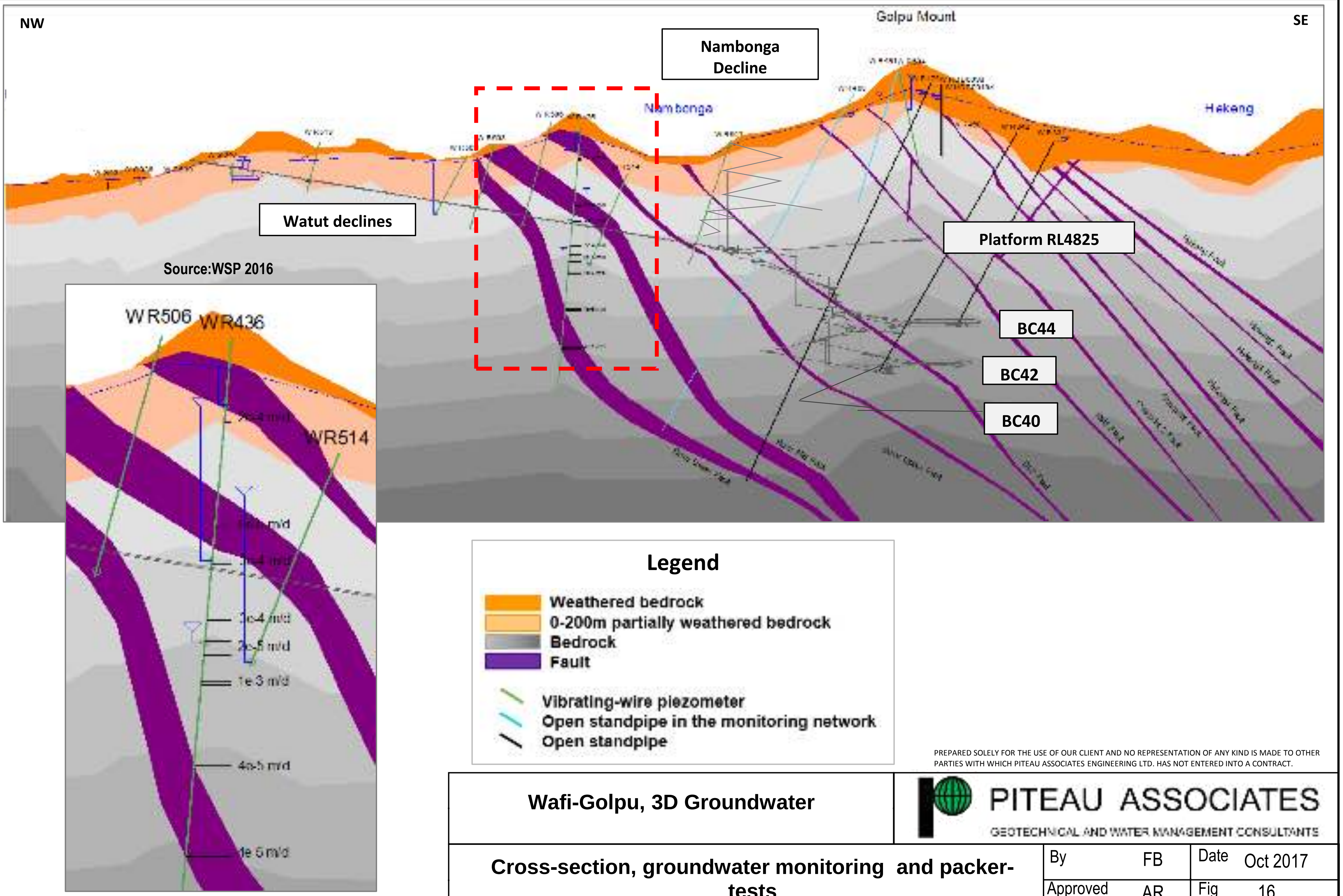
By FB	Date Oct 2017
Approved AR	FIG 15

characterization of the hydraulic connection between the shallow weathered aquifer and deeper fractured aquifer.

- 5 springs identified on the Eastern side of Mount Golpu, and considered as representative of shallow groundwater levels interacting with the ground surface.

Given the spatial distribution of the monitoring points, regional piezometric contours have been drawn where the density of monitoring boreholes is sufficient (see Figure 15). In Figure 16, the cross-section along the Watut Declines possesses enough monitoring data to estimate the piezometric surface. The general trend that emerges from the monitoring results is:

- In the Watut Floodplain, groundwater levels are very shallow (1 to 2 mbgl). The alluvial material is totally saturated and hydraulically connected to the Watut river.
- Along the decline and subsidence zone, the groundwater levels follow the topographic pattern. It indicates that recharge through the colluvial material and the weathered bedrock occurs over the entire area.
- Downward gradients are observed in most of the multi-level Vibrating Wire Piezometers (VWPs). This condition is not specific to Mount Golpu (WR495 and WR504) because WG046 at the Portal and WR436 along the decline are also showing a downward gradient. The combination of a pronounced relief and a high natural recharge from precipitation produces highly negative gradients towards the location of discharge coinciding with the natural drainage system.
- Seasonal variations are observed in WR487 and WR491 but some doubts exist as to the significance of these level variations, which may correspond to recharge via the borehole annulus. To a lesser extent, some variations are observed in WR496 and WR460 (see Figure 17). For the other monitoring points located in the partially weathered bedrock or the metasediments, hydraulic heads are stable over the year. Oscillations observed on a bi-daily basis in the levels registered by the dataloggers during the tests on the artesian wells correspond to “Earth tides”.
- In WR478, WHDB10d and WHMB09d located at approximately 150 m to the east of the top of Mount Golpu, groundwater levels are higher than those registered at the top of Mount Golpu (WR491 and WR504). The discrepancy between the hydrological and hydrogeological catchment is certainly due to a combination of structural and lithological control. A series of Faults (Hekeng and Overprint) dipping at 60-70° to the east may enhance groundwater movements towards the east of mount Golpu. The occurrence of Wafi Conglomerates in the valley and the andesite at mid-slope may disturb the general groundwater flow pattern.



Source:WSP 2016

Legend

- 🟧 Weathered bedrock
- 🟧 0-200m partially weathered bedrock
- ▨ Bedrock
- 🟪 Fault
- ╲ Vibrating-wire piezometer
- ╲ Open standpipe in the monitoring network
- ╲ Open standpipe

Wafi-Golpu, 3D Groundwater

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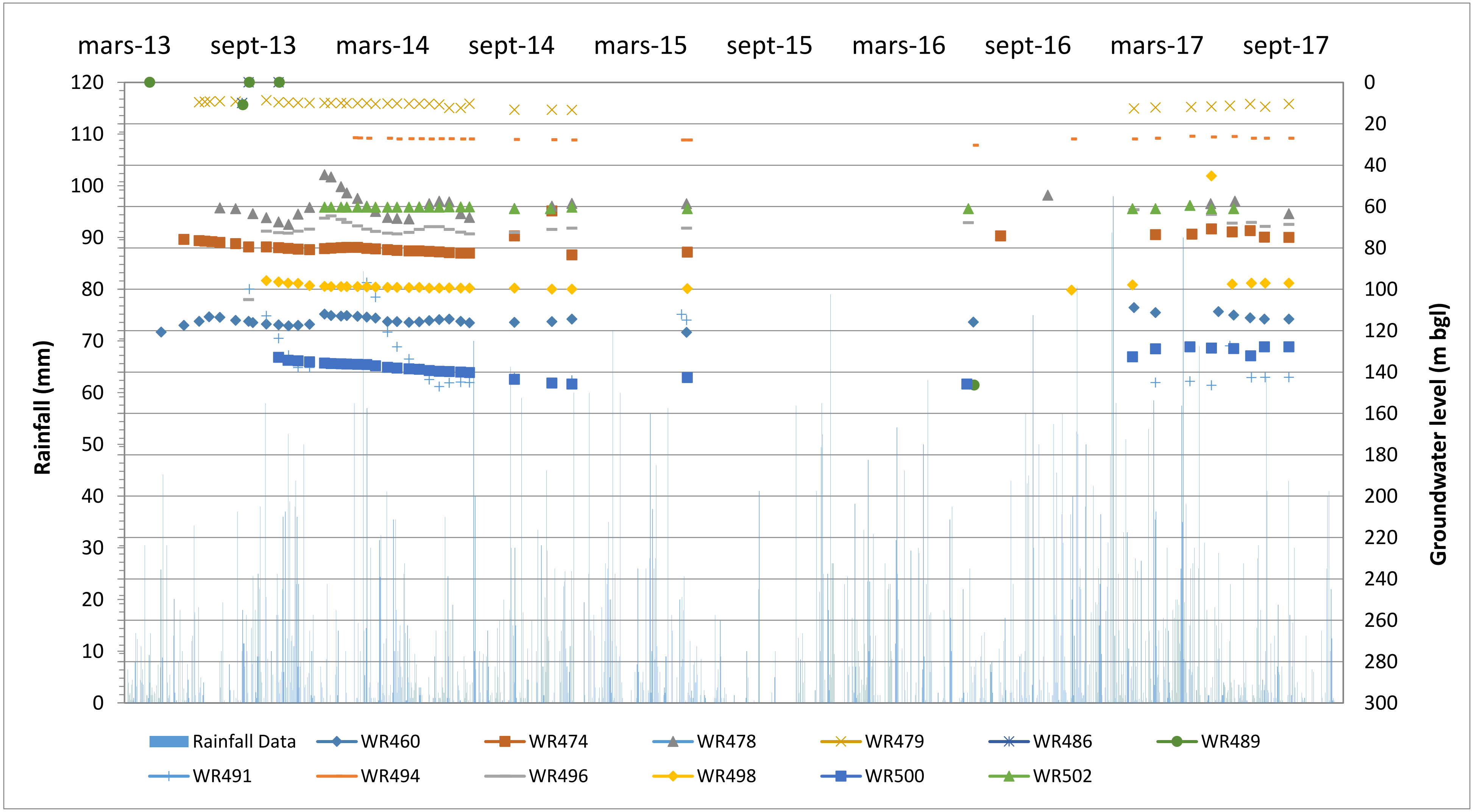
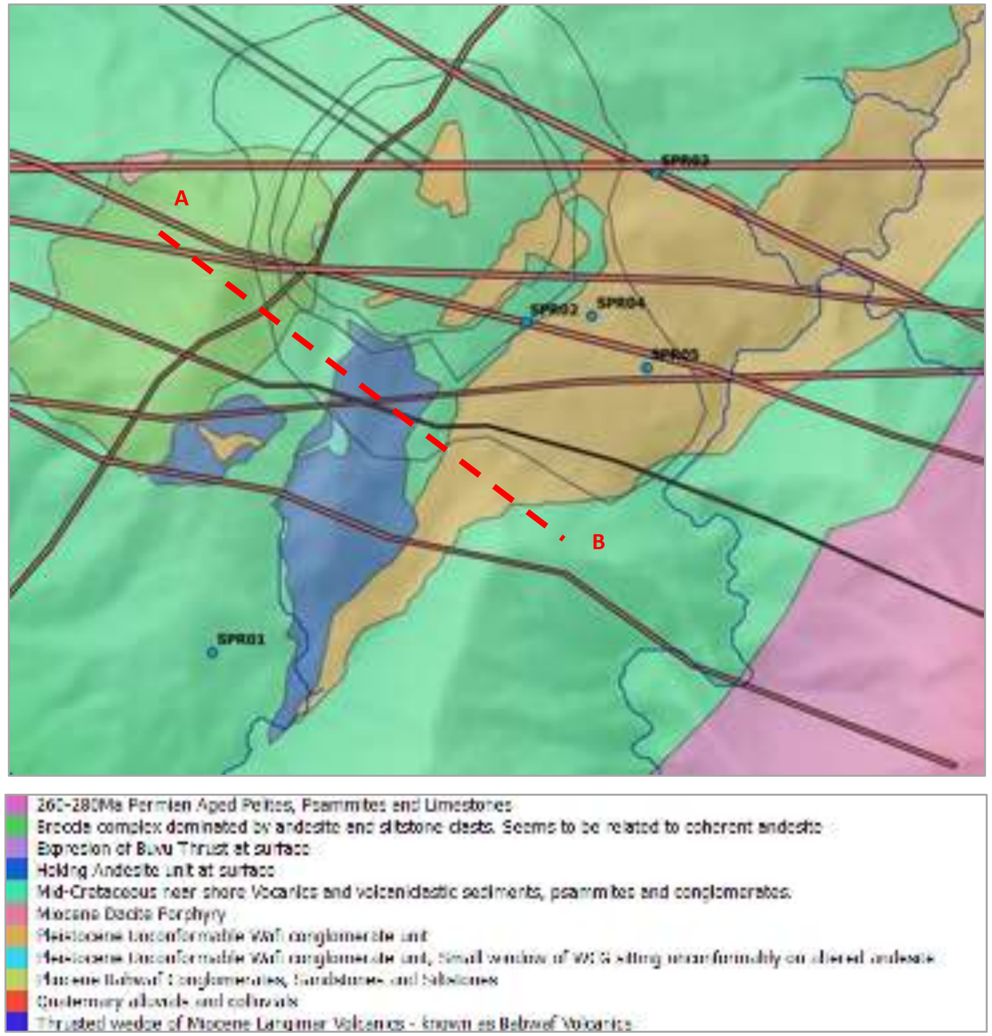
Cross-section, groundwater monitoring and packer-tests

By	FB	Date	Oct 2017
Approved	AR	Fig	16



Wafi-Golpu, 3D Groundwater	PITEAU ASSOCIATES GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS			
Groundwater level measurement in the standpipes	By	FB	Date	Oct 2017
	Approved	AR	Fig	17

- Along the decline, it has been noted that groundwater levels between WR513 and WR515 are flat. The monitoring point WR512 has a lower groundwater level while it has the higher collar elevation. There is limited monitoring information to interpret precisely the groundwater flow direction, but the information available suggests an aquifer with a significant lateral connection over the twin declines. Flow reduction in the twin declines is unlikely to be significant in the sector below WR513 to WR515.
- Some artesian conditions are observed at mid-slope of Mount Golpu, on the eastern side. The spring survey carried out by Piteau in 2017 highlighted the coincidence of some springs with regional geological contacts. Most of the thrust faults (Overprint and Hekeng) are intersected by exploration holes on the eastern side of Mount Golpu. Where the exploration boreholes are intersected by the faults, the hydraulic head is directly related to recharge along the fault pathway. This highlights the hydraulic connection between the recharge zone and the deeper rock units by the network of faults. Artesian conditions are indicated in or below the andesite and Wafi Conglomerates. Those two units may confine the deeper groundwater system. (See Figure 18).



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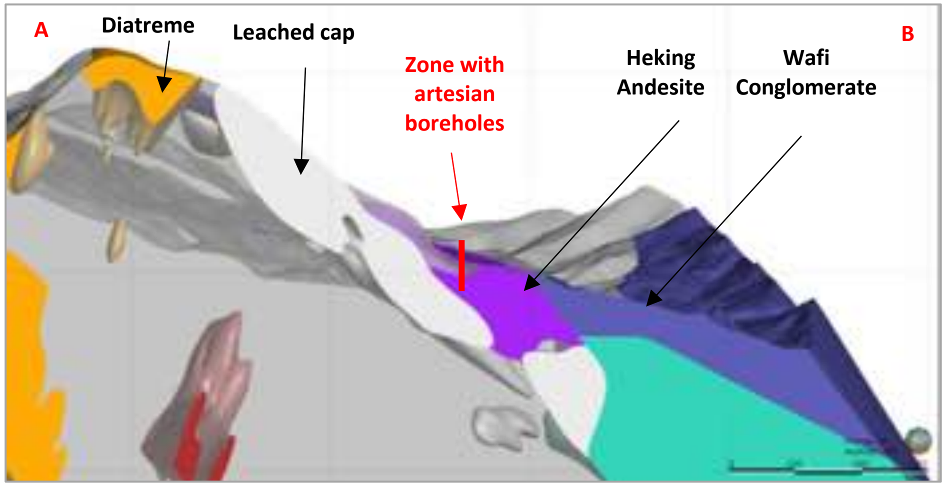

REF: WGJV, July 2017, 2017WG_GeologyScene

Wafi-Golpu, 3D Groundwater

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Correlation of springs and artesian wells with the geology

By	FB	Date	Oct 2017
Approved	AR	Fig	18

Table 10: Summary of groundwater elevation monitoring data (July 2017)

	General information						Design				Monitoring		
ID	Easting (AMG66)	Northing (AMG66)	Elevation AMG66 (mRL)	Type of Monitoring	Location		Max_depth	Inclination at collar (deg)	AMG_Azimuth (deg)		Monitoring data from	Monitoring data to	Relative level at last reading
WG016	436828	9244220	198.1	OSP	Infrastructure		30	-90	0		14/11/2014	23/06/2017	168.3
WG017	436796	9244249	206.7	OSP	Infrastructure		31	-90	0		14/11/2014	23/04/2017	181.1
WG022	436736	9244362	211.1	OSP	Infrastructure		30	-90	0		14/11/2014	20/02/2017	180.3
WG025A	436682	9244038	209.5	OSP	Infrastructure		30	-90	0		17/01/2015	23/06/2017	183.2
WG026	436734	9244192	214.5	OSP	Infrastructure		30	-90	0		14/11/2014	23/04/2017	182.5
WG031	436809	9244287	205.6	OSP	Infrastructure		30	-90	0		14/11/2014	23/06/2017	173.2
WG034	437006	9243861	193.7	OSP	Infrastructure		30	-90	0		14/11/2014	17/01/2015	175.3
WG036	437139	9243772	210.2	OSP	Infrastructure		30	-90	0		14/11/2014	27/05/2017	198.9
WG039	437296	9243661	220.1	OSP	Infrastructure		30	-90	0		17/02/2017	23/06/2017	199.1
WG049	439352	9251491	125.8	OSP	Infrastructure		71	-90	0		27/06/2016	21/06/2017	80.9
WG050	439379	9251572	123.5	OSP	Infrastructure		100	-70	124		27/06/2016	21/06/2017	78.5
WG054	441549	9250116	164.8	OSP	Bavaga		30	-90	0		27/06/2016	02/03/2017	150.8
WG056	441589	9249922	158.0	OSP	Bavaga		50	-81	287		03/03/2017	21/06/2017	140.4
WG058	441187	9250793	149.8	OSP	Bavaga		50	-90	0		29/06/2016	23/06/2017	136.0
WG061	440367	9250643	189.9	OSP	Bavaga		75	-69	307		07/09/2013	21/06/2017	164.4
WG063	441578	9249732	166.2	OSP	Bavaga		40	-90	0		27/06/2016	23/04/2017	155.0
WG065	440337	9250519	217.3	OSP	Bavaga		75	-80	42		29/06/2016	21/06/2017	162.5
WHDB010D	440518	9241527	674.6	OSP	Golpu		359	-90	0		12/05/2014	21/05/2017	621.5
WHDB011D	440607	9241113	450.0	OSP	Golpu		358	-90	0		02/09/2014	17/01/2015	450.5
WHDB012S	440613	9241111	450.1	OSP	Golpu		74	-90	0		02/09/2014	17/01/2015	443.8
WHDB013D	440819	9240949	388.3	OSP	Golpu		194	-90	0		02/09/2014	13/11/2014	388.3
WHDB014S	440820	9240943	387.9	OSP	Golpu		70	-90	0		02/09/2014	13/11/2014	387.9
WHMB001D	440597	9241097	449.7	OSP	Golpu		325	-90	0		14/02/2014	17/01/2015	447.4
WHMB003S	440590	9241092	449.7	OSP	Golpu		53	-90	0		18/02/2014	21/05/2017	440.0
WHMB004S	440696	9241124	447.4	OSP	Golpu		96	-90	0		14/02/2014	21/05/2017	432.7
WHMB005D	440692	9241146	447.7	OSP	Golpu		350	-90	0		14/02/2014	21/05/2017	447.7
WHMB006D	440797	9240918	387.3	OSP	Golpu		160	-90	0		18/02/2014	02/02/2017	385.8
WHMB007S	440792	9240919	387.3	OSP	Golpu		70	-90	0		14/02/2014	02/02/2017	384.9
WHMB008D	440736	9241538	536.3	OSP	Golpu		175	-90	0		28/02/2014	21/05/2017	467.4
WHMB009D	440527	9241545	674.9	OSP	Golpu		355	-90	0		18/03/2014	21/05/2017	623.3
WR206	440544	9240974	441.5	OSP	Golpu		772	-65	316		22/03/2017	21-Jun-17	441.5
WR311	440052	9242077	463.8	OSP	Golpu		502	-	-		21/03/2017	21/03/2017	463.8
WR331	441011	9241234	395.8	OSP	Golpu		1059	-59	274		21/03/2017	21/03/2017	395.8
WR451	440784	9240913	386.4	OSP	Golpu		639	-68	314		21/03/2017	21/03/2017	386.4
WR460	440187	9241817	630.5	OSP	Golpu		1932	-60	311		17/05/2013	21/06/2017	503.5
WR474	440514	9241243	538.5	OSP	Golpu		1167	-72	299		18/06/2013	19/06/2017	463.1
WR478	440504	9241586	689.3	OSP	Golpu		2181	-65	310		07/08/2013	05/10/2016	633.2
WR479	440629	9241201	462.9	OSP	Golpu		1536	-70	294		09/07/2013	21/06/2017	450.5
WR486	441161	9241950	497.8	OSP	Golpu		1003	-59	311		07/09/2013	21/05/2015	495.7
WR489	440955	9241138	386.9	OSP	Golpu		1601	-69	314		07/09/2013	21/05/2015	386.9
WR491	440320	9241642	743.8	OSP	Golpu		680	-73	315		07/09/2013	19/06/2017	598.8
WR494	440633	9240670	505.4	OSP	Golpu		341	-90	0		09/02/2014	19/06/2017	477.4
WR496	440664	9241964	658.8	OSP	Golpu		156	-88	0		07/09/2013	19/06/2017	589.7
WR498	440231	9240999	555.4	OSP	Golpu		306	-69	341		11/10/2013	19/06/2017	429.4
WR500	440246	9241157	622.2	OSP	Golpu		302	-57	318		28/10/2013	19/06/2017	492.7
WR501	439988	9241092	637.5	OSP	Golpu		164	-63	99		11/11/2013	21/06/2017	494.0

	General information						Design				Monitoring		
ID	Easting (AMG66)	Northing (AMG66)	Elevation AMG66 (mRL)	Type of Monitoring	Location		Max_depth	Inclination at collar (deg)	AMG_Azimuth (deg)		Monitoring data from	Monitoring data to	Relative level at last reading
WR502	440161	9241269	567.1	OSP	Golpu		599	-51	315		31/12/2013	19/06/2017	505.8
WTSF-BH003A	434772	9243899	97.8	OSP	Watut TSF		-	-90	0		18/06/2016	03/03/2017	97.1
WTSF-BH003B	434752	9243900	97.8	OSP	Watut TSF		-	-90	0		23/06/2016	29/07/2016	98.6
WTSF-BH008A	434858	9245439	95.6	OSP	Watut TSF		-	-90	0		19/06/2016	27/06/2017	96.1
WTSF-BH008B	434851	9245443	95.7	OSP	Watut TSF		-	-90	0		19/06/2016	27/06/2017	95.8
WTSF-BH01	435554	9245573	120.9	OSP	Watut TSF		-	-90	0		18/06/2016	03/03/2017	103.1
WTSF-BH028A	433539	9243776	99.3	OSP	Watut TSF			-90	0		18/06/2016	08/03/2017	99.1
WTSF-BH04	434868	9242619	102.2	OSP	Watut TSF		-	-90	0		18/06/2016	05/02/2017	102.0
WTSF-BH06	435507	9243781	99.2	OSP	Watut TSF		-	-90	0		17/06/2016	08/03/2017	98.7
WTSF-BH11	435471	9245179	96.3	OSP	Watut TSF		-	-90	0		18/06/2016	03/03/2017	94.6
WTSF-BH12A	434619	9244716	96.3	OSP	Watut TSF		-	-90	0		17/06/2016	23/07/2016	95.9
WTSF-BH12B	434626	9244703	96.4	OSP	Watut TSF		-	-90	0		20/06/2016	23/07/2016	96.1
WTSF-BH14A	435419	9244752	96.5	OSP	Watut TSF		-	-90	0		17/06/2016	03/03/2017	96.4
WTSF-BH14B	435422	9244743	96.7	OSP	Watut TSF		-	-90	0		17/06/2016	04/02/2017	97.2
WTSF-BH23A	434347	9243247	99.4	OSP	Watut TSF		-	-90	0		02/07/2016	23/07/2016	98.9
WTSF-BH23B	434340	9243254	99.6	OSP	Watut TSF		-	-90	0		02/07/2016	23/07/2016	99.0
WTSF-BH24A	435107	9243212	101.0	OSP	Watut TSF		-	-90	0		19/06/2016	23/07/2016	99.0
WTSF-BH24B	435115	9243213	101.1	OSP	Watut TSF		-	-90	0		19/06/2016	23/07/2016	98.7
WTSF-BH28	433534	9243784	99.9	OSP	Watut TSF		-	-90	0		18/06/2016	08/03/2017	99.1
DB11A	437488	9243618	281	VWP	Underground Access		60	-80	165		20/06/2016	22/06/2017	276.4
DB12	437496	9243591	281	VWP	Underground Access		60	-80	165		20/06/2016	22/06/2017	249.4
DB13	437500	9243558	281	VWP	Underground Access		60	-80	360		20/06/2016	23/06/2017	241.1
WG046-20	437545	9243537	285.7	VWP	Underground Access		100	-80	-		25/11/2014	22/06/2017	301.6
WG046-40	437545	9243537	285.7	VWP	Underground Access		100	-80	-		25/11/2014	22/06/2017	282.8
WG046-60	437545	9243537	285.7	VWP	Underground Access		100	-80	-		25/11/2014	22/06/2017	238.1
WG046-80	437545	9243537	285.7	VWP	Underground Access		100	-80	-		25/11/2014	22/06/2017	212.8
WR428-100	439237	9240966	400.3	VWP	Old Portal		1050	-85	246		17/02/2013	18/06/2017	383.1
WR428-450	439237	9240966	400.3	VWP	Old Portal		1050	-85	246		17/02/2013	18/06/2017	249.0
WR436-146	438856	9242398	484.9	VWP	Golpu		1300	-85	224		18/02/2013	17/06/2017	421.3
WR436-485	438856	9242398	484.9	VWP	Golpu		1300	-85	224		18/02/2013	17/06/2017	340.0
WR446-500	438615	9242082	391.7	VWP	Old Portal		914	-50	291		05/12/2012	22/06/2017	319.2
WR456	439302	9241754	387.0	VWP	Golpu		1022	-54	300		29/01/2013	24/06/2017	300.3
WR495-138	440831	9242364	661.7	VWP	Underground Access		1659	-89	255		17/02/2013	19/06/2017	638.7
WR495-486	440831	9242364	661.7	VWP	Underground Access		1659	-89	255		17/02/2013	19/06/2017	508.2
WR495-780	440831	9242364	661.7	VWP	Underground Access		1659	-89	255		17/02/2013	19/06/2017	434.1
WR504-194	440331	9241641	744.2	VWP	Underground Access		528	-78	126		17/02/2013	19/06/2017	571.3
WR504-978	440331	9241641	744.2	VWP	Underground Access		528	-78	126		17/02/2013	19/06/2017	521.9
WR509	438574	9242912	327.8	VWP	Underground Access		344	-62	302		24/11/2014	22/06/2017	324.1
WR512	438076	9243172	426.1	VWP	Underground Access		340	-75	297		24/11/2014	22/06/2017	295.8
WR513	437892	9243266	395.6	VWP	Underground Access		269	-76	303		24/11/2014	22/06/2017	308.7
WR514	439234	9242403	371.6	VWP	Underground Access		500	-67	312		24/11/2014	18/06/2017	316.3
WR515	438358	9243020	338.2	VWP	Underground Access		310	-65	303		24/11/2014	06/06/2016	326.9
WR519-264	440640	9241196	453.0	VWP	Golpu		1187	-71	331		04/10/2016	21/06/2017	424.3
WR519-400	440640	9241196	453.0	VWP	Golpu		1187	-71	331		04/10/2016	21/06/2017	422.2
WR520-347	440623	9241369	536.0	VWP	Golpu		740	-72	306		22/10/2016	19/06/2017	452.5
WR520-392	440623	9241369	536.0	VWP	Golpu		740	-72	306		22/10/2016	19/06/2017	449.8
WR520-518	440623	9241369	536.0	VWP	Golpu		740	-72	306		22/10/2016	19/06/2017	418.0
WTSF-BH09	435877	9245657	135.1	VWP	Watut TSF		35	-80	-		20/06/2016	22/06/2017	115.6

	General information						Design				Monitoring		
ID	**Easting (AMG66)**	**Northing (AMG66)**	**Elevation AMG66 (mRL)**	**Type of Monitoring**	**Location**		**Max_depth**	**Inclination at collar (deg)**	**AMG_Azimuth (deg)**		**Monitoring data from**	**Monitoring data to**	**Relative level at last reading**
WTSF-BH12-24.5	434628	9244731	96.3	VWP	Watut TSF		100.5	-89.8	0		20/06/2016	22/06/2017	99.0
WTSF-BH12-48	434628	9244731	96.3	VWP	Watut TSF		100.5	-89.8	0		20/06/2016	22/06/2017	97.6
WTSF-BH14-8	435428	9244750	96.6	VWP	Watut TSF		60.7	-89.8	0		20/06/2016	27/06/2016	100.7
WTSF-BH14-34.5	435428	9244750	96.6	VWP	Watut TSF		60.7	-89.8	0		20/06/2016	27/06/2016	98.7
WTSF-BH15-8	435904	9244780	100.0	VWP	Watut TSF		29.7	-89.8	0		20/06/2016	27/06/2017	97.9
WTSF-BH15-18	435904	9244780	100.0	VWP	Watut TSF		29.7	-89.8	0		20/06/2016	27/06/2017	97.6
WTSF-BH20-15	435121	9243784	99.4	VWP	Watut TSF		60	-89.8	0		20/06/2016	27/06/2016	100.6
WTSF-BH20-25	435121	9243784	99.4	VWP	Watut TSF		60	-89.8	0		20/06/2016	27/06/2016	88.7
WTSF-BH21-9.45	435879	9243785	102.5	VWP	Watut TSF		40.2	-89.8	0		20/06/2016	27/06/2016	99.9
WTSF-BH21-29.85	435879	9243785	102.5	VWP	Watut TSF		40.2	-89.8	0		20/06/2016	27/06/2016	99.2
WTSF-BH22	435778	9243204	102.3	VWP	Watut TSF		30	-89.8	0		27/06/2016	27/06/2017	101.8

2.5.5 Recharge and discharge

Natural recharge

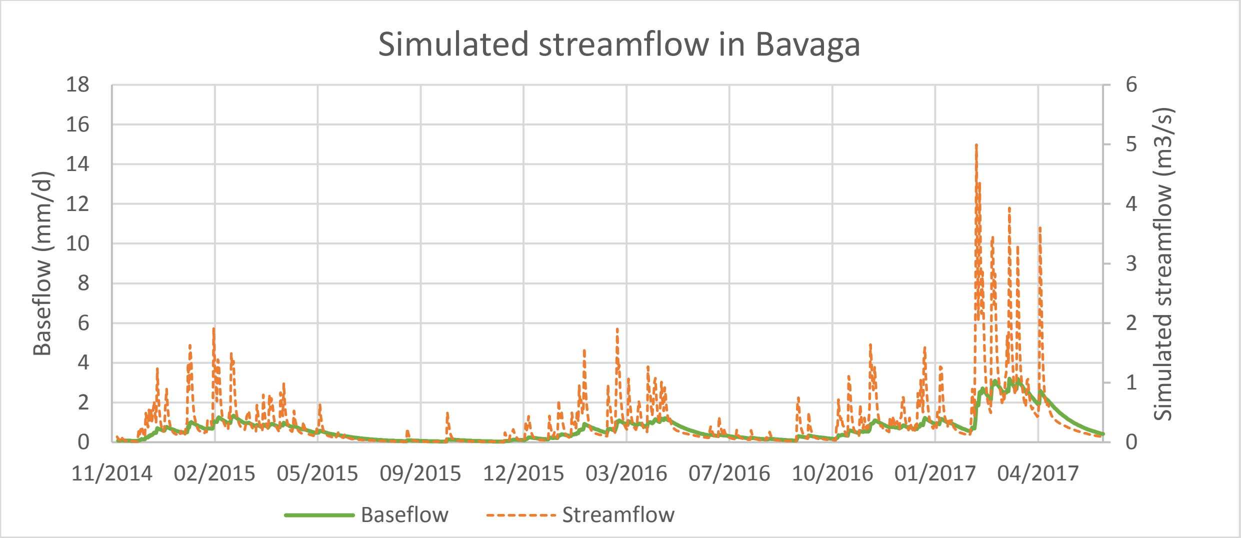
Aquastat data from the Food and Agriculture Organization of the United Nations (FAO, 2014) indicate an annual recharge rate of 457 mm for Papua New Guinea. This equates to a recharge rate of 16% of the annual precipitation. This recharge value was estimated for the whole of PNG and it is very likely that there are some local or regional variations. In the study area, the recharge could vary spatially as a function of the slope, vegetation cover, and the shallower geological units. It is expected that most of the recharge will flow laterally in the shallow colluvium and weathered bedrock to discharge in the adjacent alluvium and river systems. A portion of the recharge will flow in the deeper system via a network of conductive faults which will act as preferential pathway for recharge.

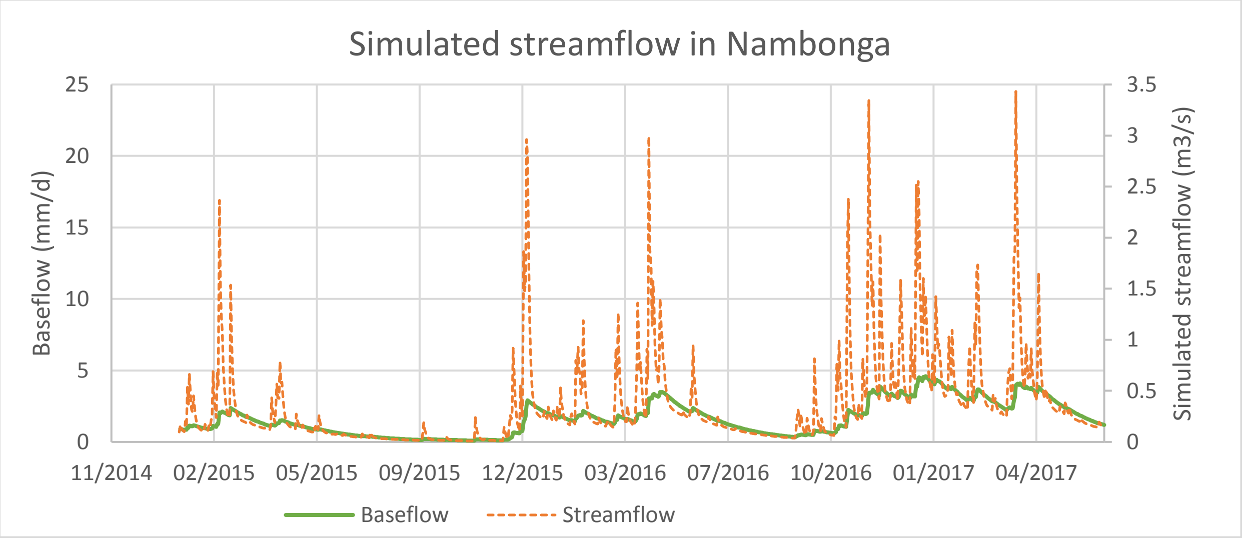
Evaluation of the river flow by Hydrologic Consulting (Pty) Ltd (2015) enabled a determination of effective recharge. In the catchments located near the Watut Declines and subsidence zone, effective recharge ranges from 8 to 24% of rainfall. Given the occurrence of rainfall throughout the year, recharge to the groundwater system should occur over the entire year. The baseflow, which is the groundwater component of streamflow, has been deduced with the Soil Water Assessment Tool (SWAT) method, and the average baseflow values for the Wafi, Bavaga, Hekeng and Nambonga Rivers are 2.5, 0.15, 0.07, and 0.18 m^3/s respectively.

As part of additional analysis done in the Water and Mass Balance Model developed by Piteau, the Australian Water Balance Model (AWBM) has been used in GoldSim to simulate runoff over the project area. It attempted to reproduce streamflow data measured at the flow gauge stations. To achieve a correct calibration of total outflow, the runoff and baseflow component have been separated from the latest streamflow records. Results of the baseflow separation are presented in Figure 19. Current evaluation with AWBM indicates that recharge varies between 9 and 11% for Bavaga, and between 14 and 19% for Nambonga. The partial dataset over the period 2014 to 2016 for Hekeng does not enable an evaluation of the recharge for this sector.

Recharge over the subsidence zone

Considering the high Mean Annual Precipitation (MAP) in the mine area, variations in the recharge rate will have critical incidence on the total volume of water reaching underground works. A major concern lies in the occurrence of storm events over the caved area, which will





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Separation of baseflow with the AWBM Model	By	FB	Date	Oct 2017
	Approved	AR	Fig	19

result in significant inflows within a short timeframe. Such inflows have the potential to impact underground facilities once construction and mining activities commence. This component is fundamental as the volume of rainfall during a storm event can easily exceed the long-term groundwater inflow.

Modifications of the topographic surface in the subsidence zone will locally modify the hydrological water balance by disrupting natural runoff and recharge. The main change will be the modification of the recharge rate. Direct infiltration at the surface of the cave zone could be as high as 90% of rainfall. Higher permeability material below the subsidence zone will enhance the infiltration of water. The concave surface will form a trap for water, and the component of runoff inside the subsidence zone will be systematically converted to recharge to the underlying fractured unit.

Given the location of the subsidence zone on the upper part of Mount Golpu, the size of the catchment reporting to the subsidence zone is relatively small and will decrease with the development of the cave zone. Runoff as well as natural recharge over the catchment reporting to the subsidence zone will be negligible.

Based on hydrological data and parameters calibrated in the GoldSim model, the portion of rainfall potentially reaching the extraction levels is presented in Table 11. Over the subsidence zone, it is assumed that 10% of direct rainfall flows preferentially through the cave zone to the upper extraction level with a mean travel time of 2 days in order to simulate large-scale surface fractures which produce preferential pathways. The remaining 90% of direct rainfall on the subsidence zone is subject to the AWBM runoff model so is subject to evaporation and soil moisture controls. In addition, the cave zone is assumed to be producing residual porosity at 1% the rate of cave volume growth, and infiltrating water is thus ‘removed’ at this rate and only once this is exceeded will it report to the upper extraction level.

The above method results in a mean annual recharge over the subsidence zone of approximately 25 l/at the end of the life of Mine. This is significantly higher than the pre-mining recharge in this area as a direct result of the presence of the subsidence crater. The recharge value of 25 l/s is indicative of the average conditions, and provides a conservative average volume for rainfall recharge (in addition to inflows from groundwater) which needs to be pumped over the life of mine. However, it does not consider the variability and discrete distribution inherent to storm events. The magnitude of rainfall during storm events is critical because it will produce peaks of recharge to the underground operation which can be significantly higher than the average recharge. Significant water volumes over short time periods will infiltrate through the fractured and caved material, although it is difficult to predict the exact factors which may influence the rate of this infiltration as a result of the unique nature of the Golpu block cave as a greenfields operation which does not exist under or adjacent to an open pit.

Table 11: Evolution of the total recharge over the cave zone

Years	Precipitation	Subsidence zone area	Inflow at extraction level
	mm/yr	ha	l/s
2021	2485	0	0
2022	3060	0	0
2023	2512	0	0
2024	2806	0	0
2025	3125	0	0
2026	2950	0	0
2027	2552	0	0
2028	2567	1.6	0.12
2029	2755	9.7	0.86
2030	2614	16.2	1.4
2031	2840	22.7	2
2032	2859	26.9	2.5
2033	2769	28.9	2.5
2034	3116	30.8	3.1
2035	2537	32.8	2.6
2036	3528	34.8	8.2
2037	2581	36.8	10
2038	3084	38.8	13
2039	2799	40.7	13
2040	3269	42.7	19
2041	2797	44.7	15
2042	2573	46.8	11
2043	2614	49.1	14
2044	2602	51.3	13
2045	2493	53.5	12
2046	3007	55.8	21
2047	2195	58	10
2048	3129	60.3	24
2049	2959	62.5	23
2050	2583	64.7	18
2051	2820	67	23
2052	2431	69.2	14
2053	2655	71.5	20
2054	2837	73.7	25
2055	3258	75.9	36
2056	2701	78.2	24

The potential volume of water in cubic meters that could enter the underground workings through the final subsidence zone (equivalent to 792,980 m² in 2056) during large storms events is given in the

Table 12. The total volume considers the duration, the intensity of the rainfall events evaluated in the rainfall intensity analysis, and a very conservative recharge rate of 90%.

Table 12: Equivalent volume of recharge (in cubic meter) over the subsidence zone for rainfall events with different return periods and durations

		Hours						
		0.5	**1**	**6**	**12**	**24**	**48**	**72**
Annual Exceedance Probability (AEP, 1 in XX years)	**2**	20 566	26 292	49 570	63 357	81 588	101 250	121 063
	5	23 881	30 812	59 515	76 766	99 216	126 939	148 787
	10	26 141	33 825	66 144	85 656	110 968	143 965	167 168
	20	28 326	36 763	72 472	94 169	122 193	160 238	184 797
	50	31 113	40 606	80 684	105 243	136 658	181 331	207 623
	100	33 223	43 468	86 861	113 530	147 581	197 152	224 724

Volumes considered in Table 12 will recharge the caved zone over less than 72 hours. Given the distance of approximately 1700 m between the subsidence zone and the extraction zone BC40, a buffer effect is expected to be produced by the caved and fractured material. Following a high rainfall event, inflows to the extraction zone will increase gradually. The time taken for the water to reach the extraction zone, as well as the duration and the magnitude of the peak in the recharge level, are difficult to constrain.

Owing to the unique nature of the proposed Golpu block cave operation, it is challenging to confirm the order of magnitude of the predicted inflow values from peak flow and storm events. This is especially since the majority of block cave operations lie beneath open pits which have significantly higher runoff coefficients and thus results in a very high proportion of rainfall reporting to the extraction levels. However, anecdotal evidence indicates that inflows at existing block cave operations from peak storm or typhoon events in Australia can be as high as 1,200 l/sec. Block cave operations in the Andes can see inflows from snow melt of between 450 and 800 l/sec in addition to inflows from groundwater.

3 CONCEPTUAL HYDROGEOLOGICAL MODEL

3.1 OVERVIEW

As a precursor to the construction of a numerical model for the evaluation of long-term groundwater flow to the excavation zone, a conceptualization of the hydrogeological system and the principal controls on recharge, flow and discharge was produced. This conceptual model was used to develop a representative section ultimately adopted in the 3D numerical model.

3.2 HYDROGEOLOGICAL UNITS

The conceptual groundwater model for the Mount Golpu area adopted for purposes of numerical model construction incorporates identical hydrogeological units (HU) as those recognized in borehole logs as discussed in Section 2. Thus, the main units are included in the model:

- Alluvium and colluvium (HU1): The alluvial unit is developed predominantly in the Watut floodplain. This unit plays a minor role in the present study focused on groundwater inflows in the extraction zone. The colluvial unit covers the uplands, and is the unit offering the most significant storage capacity. The colluvium is generally not fully saturated, and provides recharge downward to the weathered bedrock, or water for root uptake and evaporation by matrix suction. The topography around the extraction zone is characterized by steep slopes. This results in highly differential erosion and weathering. As a result, the colluvium material is highly heterogeneous in terms of grain size distribution and cementation. Consequently, hydraulic conductivity and porosity of this unit are subject to marked variations.
- Weathered bedrock (HU2): This unit exhibits relatively low primary hydraulic conductivity. The degree of weathering as well as the thickness of this unit are regular, but the depth varies between 20 and 100 mbgl. Most of the groundwater movement is by fracture flow. The fractures in the upper weathered zones are variably interconnected, and the hydraulic conductivity is consequently expected to be highly variable. However, hydraulic conductivity most likely approximates 1×10^{-2} m/d and the storage capacity is estimated to range between 1% and 5%.
- Partially weathered bedrock (HU3): This transition unit has lower hydraulic conductivity than the weathered bedrock. The degree of oxidation is negligible, but the rock unit is not classified as fresh. The hydraulic conductivity is estimated at about 8×10^{-3} m/d. The storage capacity is

likely to be lower than 1% based on experience from comparable operations, and is expected to decrease progressively with depth.

- Metasediments (HU4): The entire un-weathered bedrock (composed of Langimar Volcanics, Babwaf Conglomerate and Owen Stanley Metamorphics) may be conceptualized as forming a single hydro-stratigraphic-unit. The main parameter determining the hydraulic conductivity in the metasediments is depth. The bedrock is characterized by a very low permeability and low storativity. Most of the groundwater movements in this unit occur through the secondary porosity (fractures). The hydraulic conductivity of the unit is 1 x 10^{-4} m/d, and decreases with depth. The storage capacity of this unit should be in the range of 0.1-0.5% outside of the fractured zone.
- Fractured and caved material: The fractured material forming as a result of cave development will have a higher permeability than the metasediments. There will be enhanced connectivity with the thrust faults, which will also dilate due to the loss of shear strength. The connectivity between the extraction zone and the groundwater and fault system will be enhanced with the development of the caved zone. Hydraulic conductivity of the caved zone is expected to vary between 1 and 10 m/d, however, hydraulic properties are likely to be very heterogeneous as a function of lithology and depth.

3.3 GROUNDWATER LEVELS AND FLOW PATHS

3.3.1 Pre-mining observations

The observed trend is that the piezometric surface follows the expression of the natural topography. Groundwater levels are very shallow beneath the floodplain and highly variable in the uplands. Colluvium in the uplands is not necessarily saturated as groundwater levels can be encountered at significant depth (of up to 142 m) on the slopes of Mount Golpu.

In the uplands, groundwater within the shallow weathered bedrock and metasediments groundwater levels is de-coupled due to the low permeability of the competent bedrock. Most of the groundwater will flow laterally in the first 100 m of weathered bedrock and discharge locally in areas of lower topography. However, groundwater from recharge occurring at shallow depth will continuously act as a ‘leaky’ groundwater unit, recharging the metasediments at depth along preferential pathways formed by non-mineralized fractures. In lower lying areas, local artesian conditions occur in some fracture zones because of the downslope groundwater flow. Certain lithologies (e.g. quartzite) are very broken and permeable, particularly where associated with known or unknown faults. In addition, the weathered horizon is likely to extend to deeper levels in the faults zones due to deeper oxidation and weathering.

The underlying fractured bedrock has very low hydraulic conductivity with very little storage capacity (0.1-0.5%). The transition between the upper weathered zone and the fresh bedrock is variable and controlled by active weathering. Any flow is controlled by faults in the fresh metasediments. Fracture zones may or may not be continuous. It is unlikely that any continuity of flow occurs for more than about 400 m. It is expected that the number of potential fractures decreases with depth and that there is no active groundwater circulation in the deep fresh bedrock.

Faults zones in the fresh rock may be highly fractured and locally permeable, with a drainable porosity ranging between 0.2 and 2%. The faults are unlikely to be continuous over dip and strike for more than about 100 m.

3.3.2 Groundwater levels and flow paths during operation

The first 200-500 m of the Watut Declines will be driven through the weathered zone. Monitoring data near the portal show similar groundwater levels. It is likely that the groundwater system in this area is well connected, and may provide a significant amount of water to the tunnels. The first section of the decline will pass through variable ground with many low-pressure water strikes. The first 500 m may receive a steady inflow of 50-70 l/s, with short term peak of up to 100-120 l/s as the decline is driven down.

As the decline progresses, it should encounter progressively more competent ground. The total sustained inflow from base of the weathered zone to extraction level is likely to be in the range of 10 to 30 l/s. Some short-term peaks with high pressure inflows of up to 7 bars and up to 100 l/s are likely to occur within known or unknown fault zones. The flows are unlikely to be sustained for more than 7 days. The use of cover holes may enable the identification of these zones.

With the construction of the extraction levels and the development of the caved zone, water will flow towards the underground mine workings along the thrust faults. The caved and fractured material will exhibit a hydraulic conductivity higher than the surrounding material. Thus, the water in faults cross-cutting the fractured zone will discharge into the caved zone and subsequently the extraction zone. Once the cave reaches the surface, the zone of highly fractured rock mass will form a preferential pathway for direct infiltration from the surface.

3.4 RECHARGE

3.4.1 Natural recharge

The tropical climate is characterized in the study area by significant rainfall over the entire year. Groundwater recharge is considered in the conceptual model to be a direct function of rainfall. Some variations of recharge between the different sectors are expected as a result of different altitudes, soil cover and topography. According to baseflow analysis on river flow gauges in the project area, the effective recharge is in the range of 8 to 24%. The recharge rate of 16% proposed by the FAO for the regional natural recharge is considered as a reference value, but is subject to local variation as a function of the slope steepness, soil cover and vegetation type.

3.4.2 Recharge over the subsidence zone

Subsidence is an inevitable consequence of the block-caving method. It modifies the overlying strata over the caved zone and the resulting ground movements form a concave surface. The fractured and collapsed rock mass forms a highly transmissive zone which enhances the hydraulic connection between aquifers and facilitates the infiltration of surface water. Direct infiltration at the surface of the cave zone could be as high as 80-95%.

The block cave will take approximately 4 years to reach the surface. Extraction of material in the undercut will generate a subsidence zone. Rainwater entering the mine will increase with the establishment and expansion of a subsidence zone. As a result, subsidence issues and increased hydraulic connection with the surface will be especially critical for the last 10 years of operation. Infiltrated water will seep vertically through to unsaturated material layers to reach the extraction zone. Migration time to the undercut will decrease with the development of the cave zone. The runoff reaching the subsidence zone will be negligible due to the reduced size of the sub-catchment., Thus, it is the direct recharge over the subsidence zone which will be the most important component of recharge.

3.5 DISCHARGE

The conceptual model assumes natural discharge to be confined to the drainages located around Mount Golpu. The main natural drainage systems are the Hekeng and Nambonga rivers. During the LOM, the Watut Declines and the extraction zone will potentially form a component of artificial discharge. The development of a cone of depression will modify locally the groundwater flow direction and disturb the pre-mining water balance of each sub-catchment.

3.6 CONCEPTUAL WATER BALANCE

According to the characterization of the recharge and discharge mechanisms described above, an underground water balance was obtained for pre-mining conditions, the results of which are summarized in Table 13. These calculations represent aggregate inflows and outflows for the entire model domain (covering 153 km² and extending across the Bavaga, Nambonga and Hekeng catchments). The hydrogeological balance for pre-mining conditions assumes the main inflow to be derived from natural recharge, with a recharge value of 16%, equivalent to 457 mm per annum. Using this value yields a total recharge over the model domain of 2230 l/s. Discharge from the entire domain is assumed for the pre-mining condition to equate to river base flow. Values of base flow were distributed across the model domain on a pro-rata basis in accordance with catchment size and slope distribution.

Table 13: Groundwater balance conceptualization for pre-mining conditions

Inflow (l/s)		**Outflow (l/s)**	
Effective rainfall (Recharge 16%)	2230	**Contribution to Bavaga**	278
		Contribution to Nambonga	136
		Contribution to Hekeng	64
		Contribution to other catchments	1752
Total	2230	**Total**	2230

4 MODEL DEVELOPMENT

4.1 MODEL APPROACH AND CODE

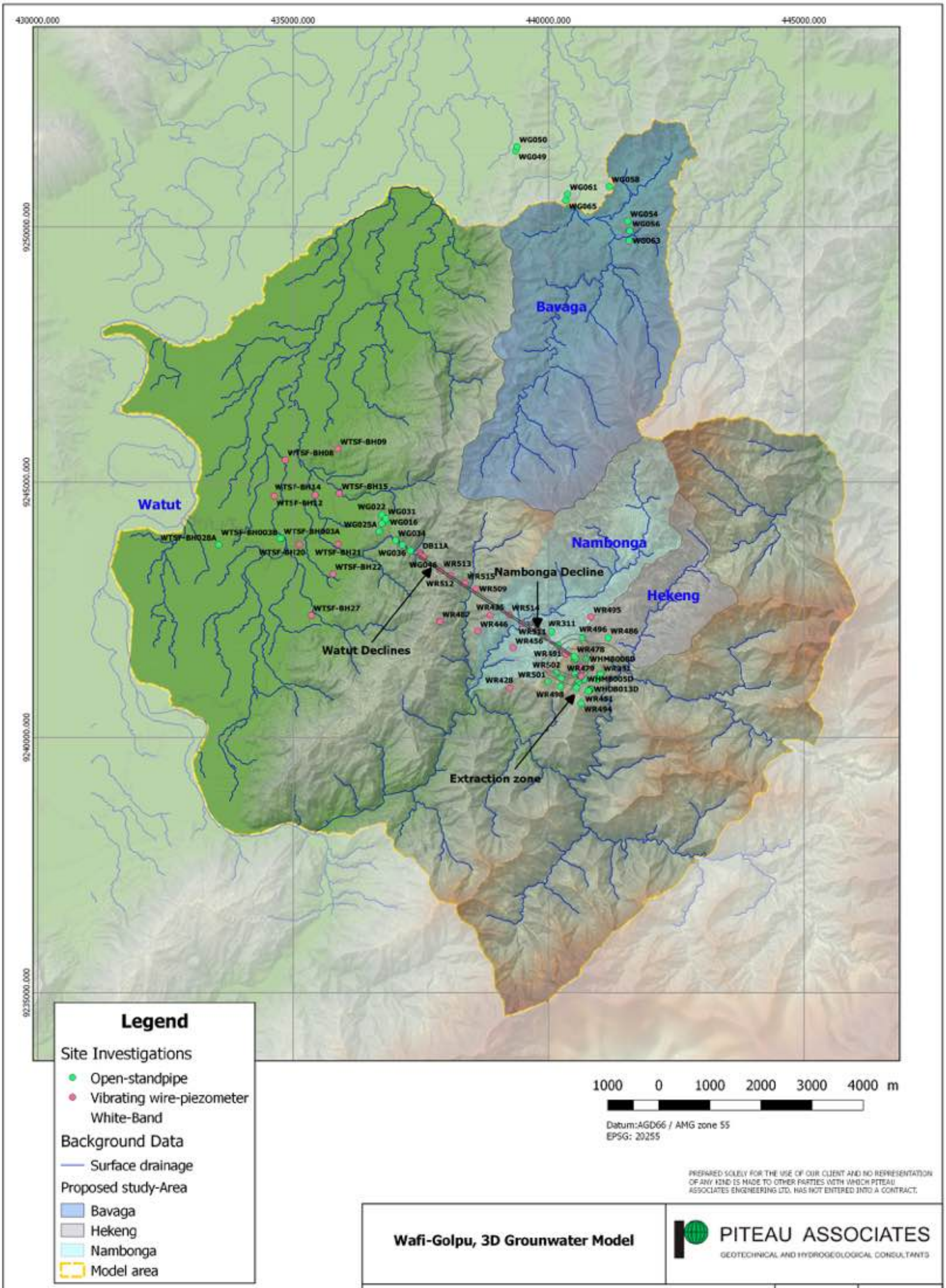
The FEFLOW model described in this report was developed with the central objective of simulating groundwater elevations and flow orientations at the proposed Wafi-Golpu mine. The model is configured such that it may be of utility for simulation of any alternative mine plans. The site-wide groundwater flow model was constructed using the commercially available software FEFLOW (Version 7), developed by DHI-WASY GmbH. FEFLOW is an industry-standard code for modelling both flow and solute transport under saturated conditions. It is a 'finite element' model which may be regarded as of particular utility for simulation of groundwater systems influenced by non-matrix flow (dominated by fractures or structural features). The flexibility provided by the FEFLOW finite element mesh, with a network of nodes and vertices to form triangular cells, enables detailed representation of complex geological features. At Wafi-Golpu, this is particularly critical as regional structures follow variable orientations across the model domain. FEFLOW offers the following additional attributes:

- Integration of 1D and 2D discrete features to model high-conductivity structures, underground voids (tunnels) or drains.
- A fully integrated graphical user interface, Version 6 offers enhanced mesh algorithms and provides direct access to the numerical solver 'SAMG'.
- Full integration of a module for hydraulic parameter estimation, PEST (Doherty, 2015) via a graphic interface (FE-PEST).
- The Version 7 of FEFLOW offers the possibility to build a fully unstructured mesh which enables the construction of a 3D model with superimposed hydrogeological units, faults and underground infrastructures.

4.2 MODEL DOMAIN

The domain, or area of coverage, of the numerical groundwater model, as shown in Figure 20, is populated within FEFLOW by a finite element mesh which defines all stratigraphic and structural features plus mine voids which are likely to exert control on groundwater flow.

The spatial limits of the model were determined primarily on a natural catchment boundary basis. However, in some instances catchment areas were truncated to avoid unwarranted extrapolation



Wafi-Golpu, 3D Grounwater Model	PITEAU ASSOCIATES GEOTECHNICAL AND HYDROGEOLOGICAL CONSULTANTS			
Model domain	By	FB	Date	Oct 2017
	Approved	AR	FIG	20

of groundwater flow simulation into areas for which no sufficient data exist for calibration. The domain shown in Figure 20 is essentially delimited as follows:

- The coordinate system for the numerical model and all associated Figures is AGD66/AMG zone 55 (EPSG 20,255).
- The northern limit is defined by the Bavaga River, the northernmost point of which is at N9,252,107.
- The eastern limit is fixed at 4 km from the subsidence zone and follows the ridge of high mountains and the limit of sub-catchments.
- The western limit is demarked by the Watut River. Thus, the model includes the eastern side of the Watut Plain. The E-W extent of the model extends from E431,259 to E446,035.
- The southern model limit coincides with a limit of catchment (N9,234,532) and the Wafi River turning to the west towards the Watut floodplain.

The overall area of coverage of the model domain is 153 km². This encompasses all major mine facilities in the center of model area. The size of the model domain was selected to provide a balance between the need to avoid any potential boundary effects, while effectively accounting for the limited spatial distribution of the available hydrogeological data. This domain size is considered to provide the optimum compromise which enables relatively high-confidence modelling of the proposed mining infrastructure while adequately accounting for limitations in the data. A larger area would not have sufficient data coverage to promote high-confidence in the results and a smaller area would likely be such that the close proximity of the model boundaries to the proposed infrastructure may numerically influence the results of the assessment.

4.3 MODEL STRESS PERIODS AND TIME STEPS

Development of the FELOW model was undertaken using discrete time-steps, within which either the physical conditions prevailing within the model domain or the ‘operational rules’ applicable to variables such as mine dewatering, were considered likely to differ. The dates used in the FEFLOW model and discussed here are assumed dates for the purpose of modelling only and may change as the Project mine plan is refined. In the execution of LOM simulations for Wafi-Golpu mine plan, a large number of time-steps was incorporated to reflect changes of recharge, flow and discharge likely to arise in response to progressive underground mine development. The principal time-steps (referred to as ‘stress periods’) comprised:

- 2017: Steady-state calibration time-step: This time-step was included to represent hydrogeological conditions prior to the operation of the construction of the mine. Pre-mining conditions are considered to be the earliest point in time for which any meaningful data could be sourced for use in calibration.

- 2018-2048: Transient predictive simulation: the period from 2018 to 2044 is represented in the FEFLOW model as one in which all progressive adjustments of surface mine infrastructure and underground mine development as envisaged in the mine plan are incorporated. Modifications to recharge and discharge dynamics are simulated at monthly resolution throughout this period.

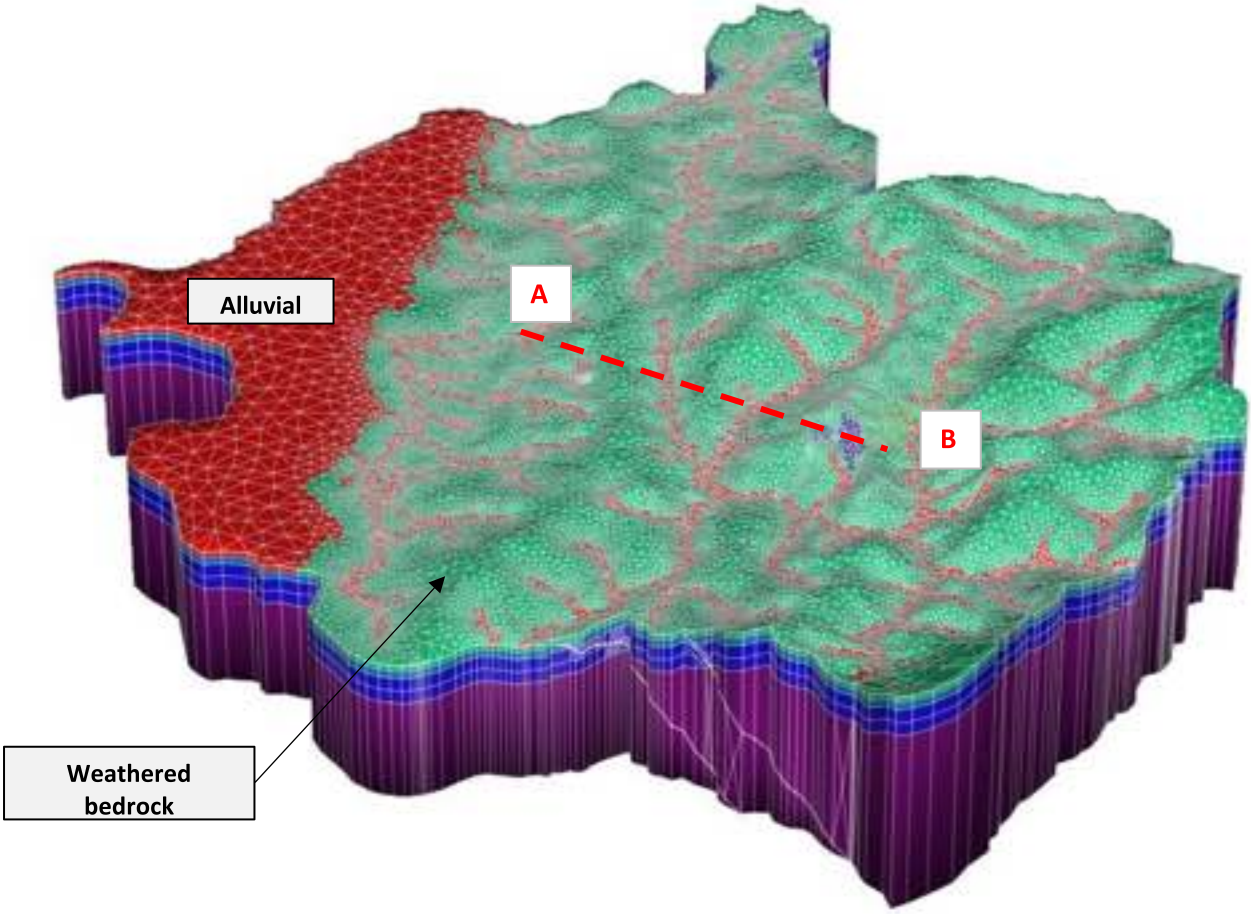
The transient calibration has not been developed in the initial version of the model, because the dataset does not show sufficient seasonality or a physical stress implying groundwater level variations. In the absence of time-dependent variations, the transient calibration cannot bring additional confidence in the parameters used in the model. As a result, it is proposed that the model be recalibrated at a later date once a sufficiently detailed and complete hydrogeological dataset exists to allow for the assessment of multiple hydrological seasonal cycles. However, for the purposes of the feasibility study update the steady state calibration conducted is considered robust and complete.

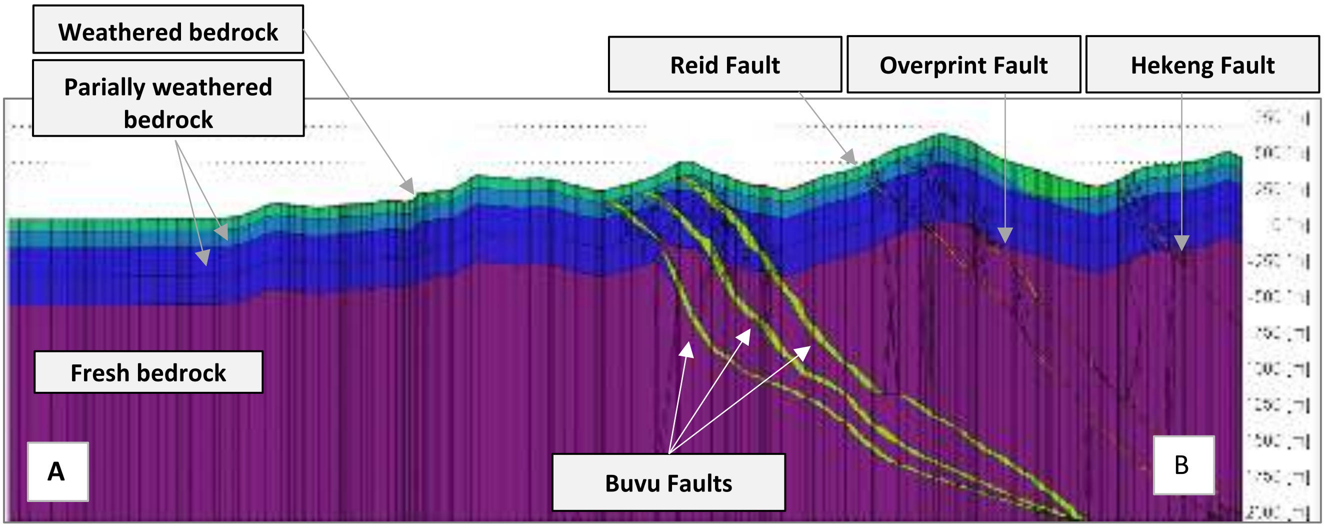
4.4 VERTICAL MODEL DISCRETIZATION

The vertical discretization of the numerical model incorporates multiple layers of variable thickness at discrete locations across the model domain (Figure 21). Due to the introduction of the unstructured mesh, layers do not have necessarily a horizontal extension over the entire model area. In all cases, the elevation of the uppermost layer corresponds to the topographic surface. This topography and its associated elevation was derived from a Digital Elevation Model (DEM) generated from on Lidar data with a horizontal definition of 15x15 m and a vertical resolution of 10 m. The maximum elevation in the model area is 1360 masl. This corresponds to the summit of a mountain located at the southern limit of the model area. The minimum elevation coincides with the Watut floodplain at an elevation of 87 masl.

The base of the model domain was set at a constant elevation of minus 2000 masl. This permits the capture of the deepest levels of the underground mine to be developed during the implementation of Wafi-Golpu's level mine plan (minus 1000 masl).

The characteristics and average thicknesses of each hydro-stratigraphic unit identified in the conceptual model for Wafi-Golpu were defined based on analysis of logs from boreholes completed by WGJV during the exploration, and also on the results of hydraulic tests carried out





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Model discretization

By	FB	Date	Oct 2017
Approved	AR	Fig	21

at different depths in the boreholes. Hydro-stratigraphic boundary definition within the FEFLOW model involved the assignment of:

- A shallow weathered bedrock layer thickness averaging 85 m, based on the average thickness of the weathered horizon in the Leapfrog model. Punctual information from the Leapfrog model was then used to vary the thickness of these units laterally to correspond exactly with the logged thicknesses at known coordinates around Mount Golpu. The first layer is sub-divided to contain an alluvial unit of 10 m in the eastern sector, and 85 m in the Watut plain.
- Two Layers with thicknesses of 200 and 400 m to introduce the partially weathered bedrock and the progressive improving ground with the increasing depth.
- A deep fresh bedrock layer below 600 m. Information from previous investigations on hydraulic properties are relatively limited and restricted to packer-tests.
- Faults are crossing the partially weathered horizons and are connected to the weathered bedrock which is the unit receiving the recharge by rainfall. The unstructured mesh enabled to represent precisely the geometry of the Lower, Middle and Upper Buvu faults, and also the Reid, Overprint and Hekeng faults (Figure 22).

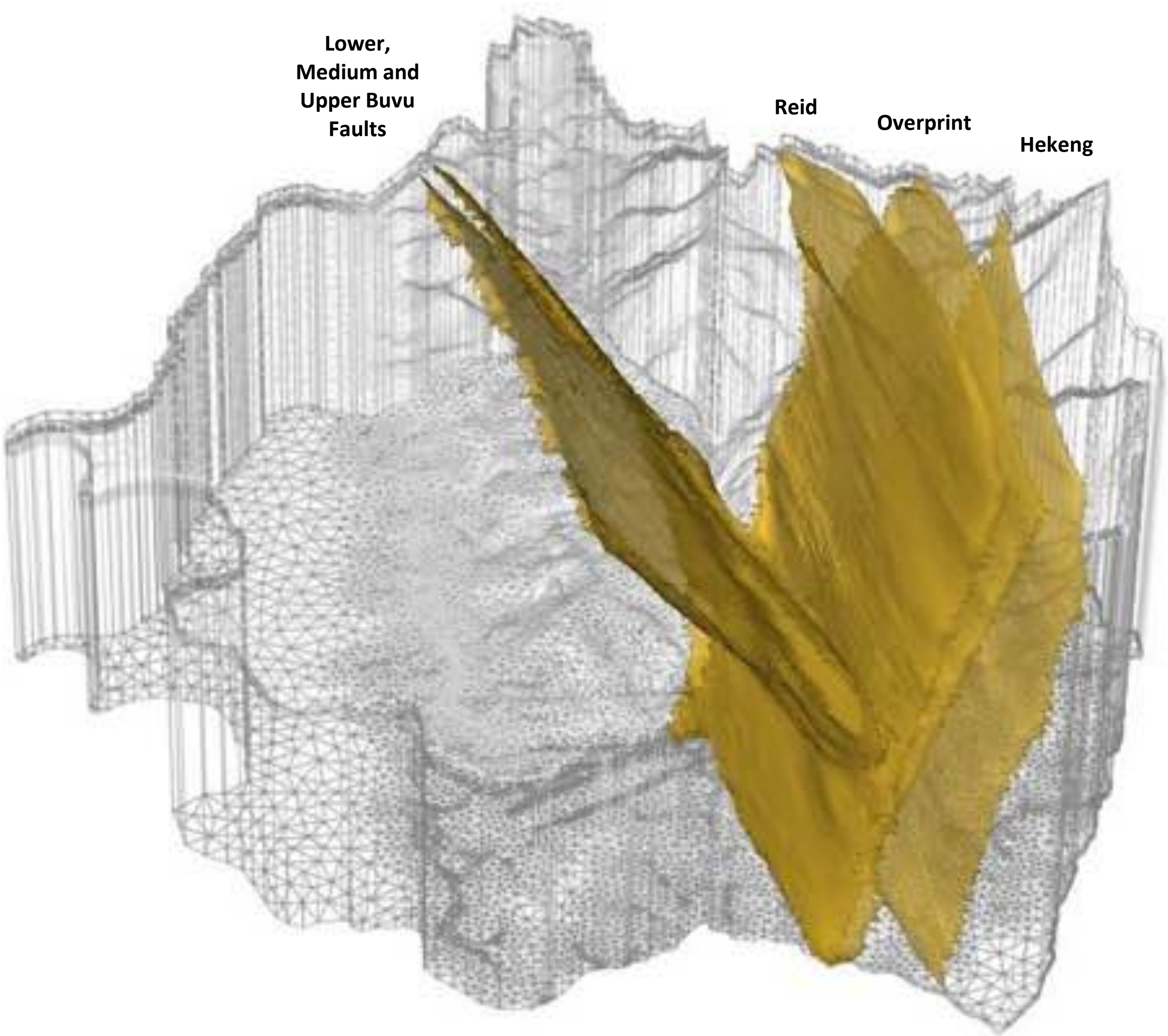
The characteristics of the different layers are summarized in the Table 14.

Table 14: Geometry of FEFLOW layers

Layers	Hydro stratigraphic Unit	Elevation of the Upper slice (masl)	Elevation of the lower slice (masl)	Thickness (m)
1	HU 1: Alluvial/Colluvial	Topographic surface	Topographic surface - 10m	10
	HU 2: Weathered bedrock			
2	HU 1: Alluvial in the Watut River	Top of layer 1	Top of layer 1 -75m	75m on average, variable near Mount Golpu
	HU 2: Weathered bedrock			
3	HU 3: Partially weathered bedrock 0-200m	Top of Layer 2	Top of Layer 2 - 200m	200
4	HU 3: Transition in the bedrock 200-600m	Top of Layer 3	Top of Layer 3 - 400m	200
5	HU 4: Bedrock	Top of Layer 4	Variable	Variable
3,4,5	HU 5: Faults	Going through the different layers		

4.5 MODEL MESH

The FEFLOW domain is populated with triangular cells to which hydraulic properties are assigned uniquely to every element. The resolution of triangulation is variable across the domain, with a higher density of nodes (thus producing better numerical accuracy) present in the central area of



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Regional faults

By	FB	Date	Oct 2017
Approved	AR	Fig	22

the domain. In the establishment of this model mesh or grid, the following considerations were accounted for:

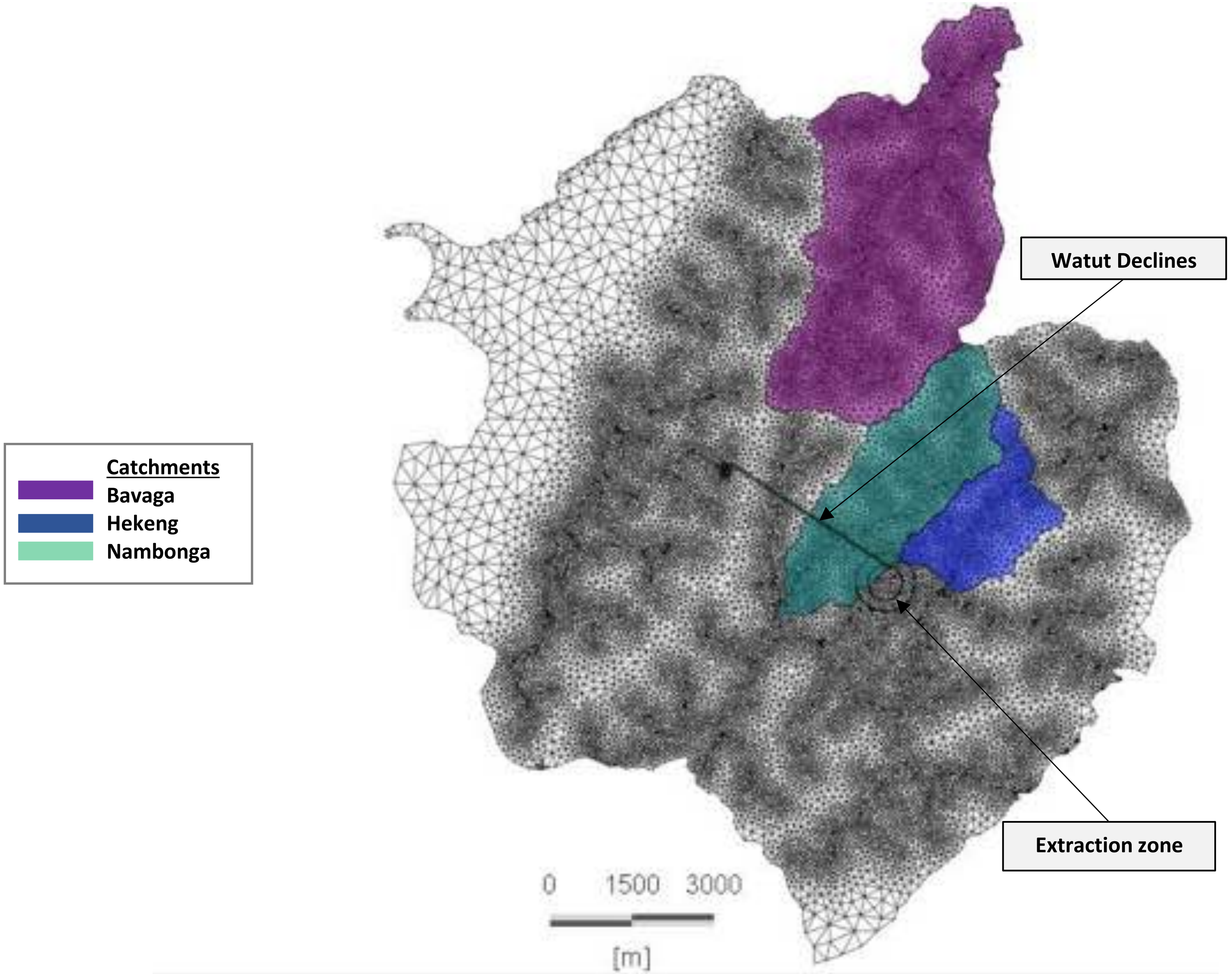
- The phreatic surface follows the topographic trend and produces locally a sharp hydraulic gradient which requires a refined mesh resolution. On the contrary, refinement in the Watut plain is coarse due to a very low gradient and the absence of future installations.
- The underground mine is likely to produce a high contrast of pressure/head relative to the surrounding groundwater system. Mesh refinement in the underground mine was therefore considered to be required in order to effectively model the gradient of pressure and ensure numerical stability.
- The mesh was necessarily adapted to the geometry of the model with triangular elements having normal angles. Elements with large angles generate instability. The Delaunay criterion was applied to design a suitable mesh geometry.

The mesh ultimately adopted for construction of the groundwater model is shown in Figure 23. The introduction of the unstructured mesh implies that triangles in 3D are converted either in prisms, pyramids or tetrahedra. The total number of elements in the pre-mining calibration model is 490,740. In the predictive model, the model is re-meshed (with 651,279 elements) with the mesh editor TetGen to adapt the position of nodes along the underground installations with the correct node-spacing.

4.6 PROBLEM SETTINGS AND INITIAL CONDITIONS

In order to effectively model the groundwater system in accordance with its conceptualization as a series of inter-connected aquifers, the model was assigned within FEFLOW as variably saturated and unconfined. This option is routinely applied to allow an unconfined aquifer layer to be modelled using Richard’s equation. Previous model development showed that variably saturated models are more conservative model in term of mine inflows (DHI, 2014). In addition, the unconfined model guarantees a good consideration of the storage released by the development of the underground mine.

Initial distribution of piezometric heads in the steady-state calibration model is not considered of major significance for the resolution of a numerical problem independent of the time variable. Initial conditions of groundwater elevation for the predictive scenarios were established within FEFLOW for use at the initiation of the transient model with the distribution of piezometric heads calculated in the steady-state model.



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Model Mesh

By	FB	Date	Oct 2017
Approved	AR	Fig	23

4.7 BOUNDARY CONDITIONS

Appropriate model boundary conditions were assigned to allow simulation of processes related to (a) the interaction of the groundwater system with the surface, (b) the ingress and/or discharge of water across the model domain boundary, and (c) the effect of artificial introduction or abstraction of water from the system. The model includes specific boundary conditions to represent:

- Natural recharge at the surface as a climatic boundary.
- Enhanced recharge over the subsidence zone.
- Discharge from the groundwater system as baseflow to surface drainage.
- Flow associated with depressurization within the underground mine.

4.8 NATURAL RECHARGE

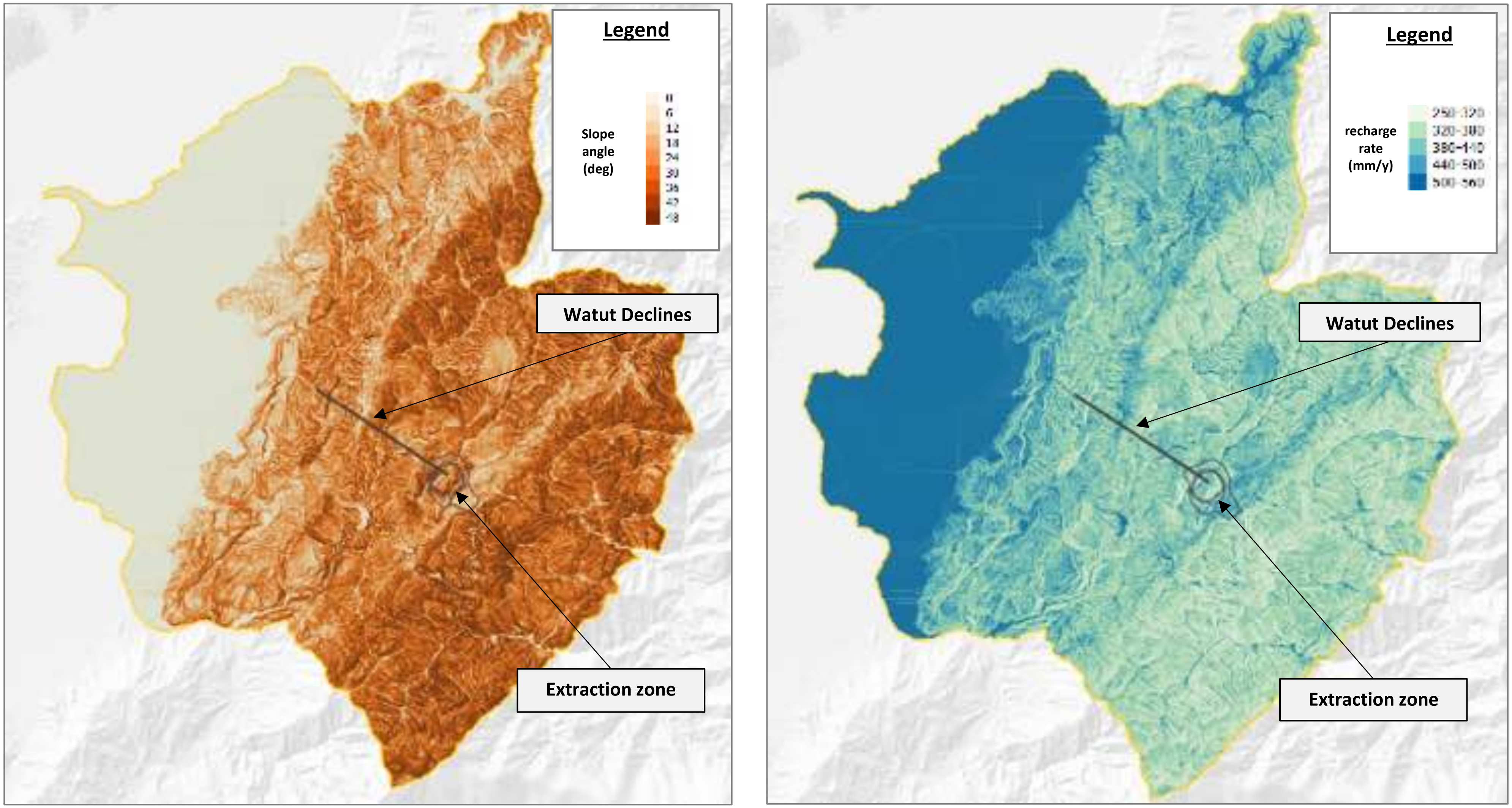
A spatial distribution of the natural recharge has been developed based on the regional recharge, equivalent to 16% of the rainfall and the slope (Figure 24 and 25). The runoff is promoted in areas with a steep slope and implies a subsequent reduction of the recharge. The overall recharge rate is equivalent to the 16% of natural recharge provided by the FAO.

Recharge was applied in the steady-state model across Layer 1 using the FEFLOW parameter ‘In/Outflow on Top/Bottom’. The main application of this parameter is the definition of groundwater recharge on the top layer, with areal inflow into the model from underlying aquifers.

In the transient predictive scenario, given the occurrence of rainfall year-round, seasonal variations are unlikely to have a secondary effect on groundwater levels and discharges. Thus, a constant rate for the natural recharge has been applied in the transient predictive model.

4.9 DISCHARGE IN NATURAL STREAMS

Flow discharge to streams is represented in the FEFLOW model by seepage nodes which correspond to a ‘hydraulic-head’ boundary condition with a flow constraint. Seepage nodes are distributed along the axes of streams in the model domain (Figure 26). The applied boundary condition generates a stream by the combination of conductance of the surrounding elements and the difference between the groundwater level and the ground level. Seepage nodes are established in the FEFLOW model such that only discharge may occur, with reverse flow precluded.



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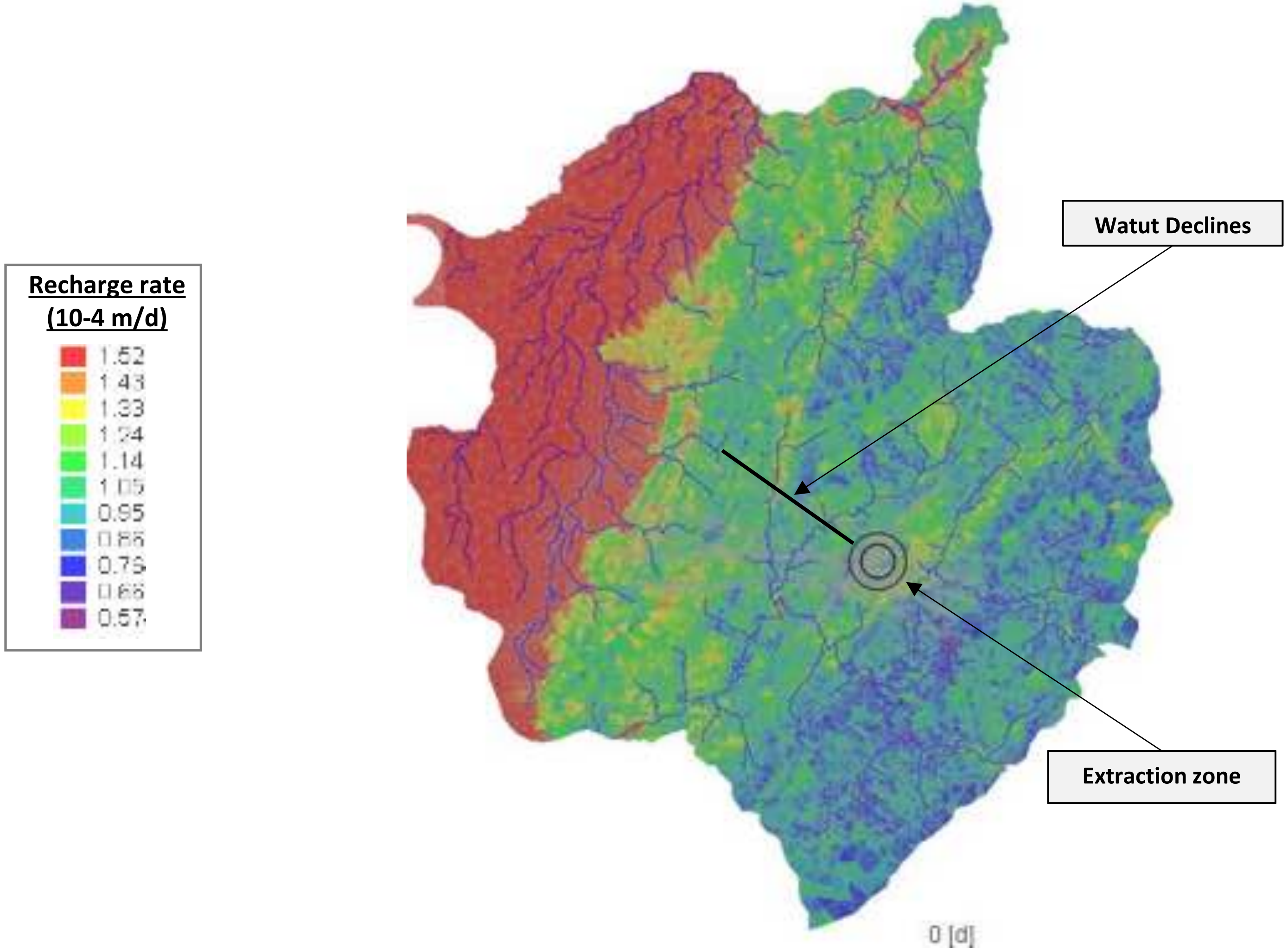
Model of groundwater recharge distribution

By	FB	Date	Oct 2017
Approved	AR	Fig	24



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Modelled recharge in Feflow

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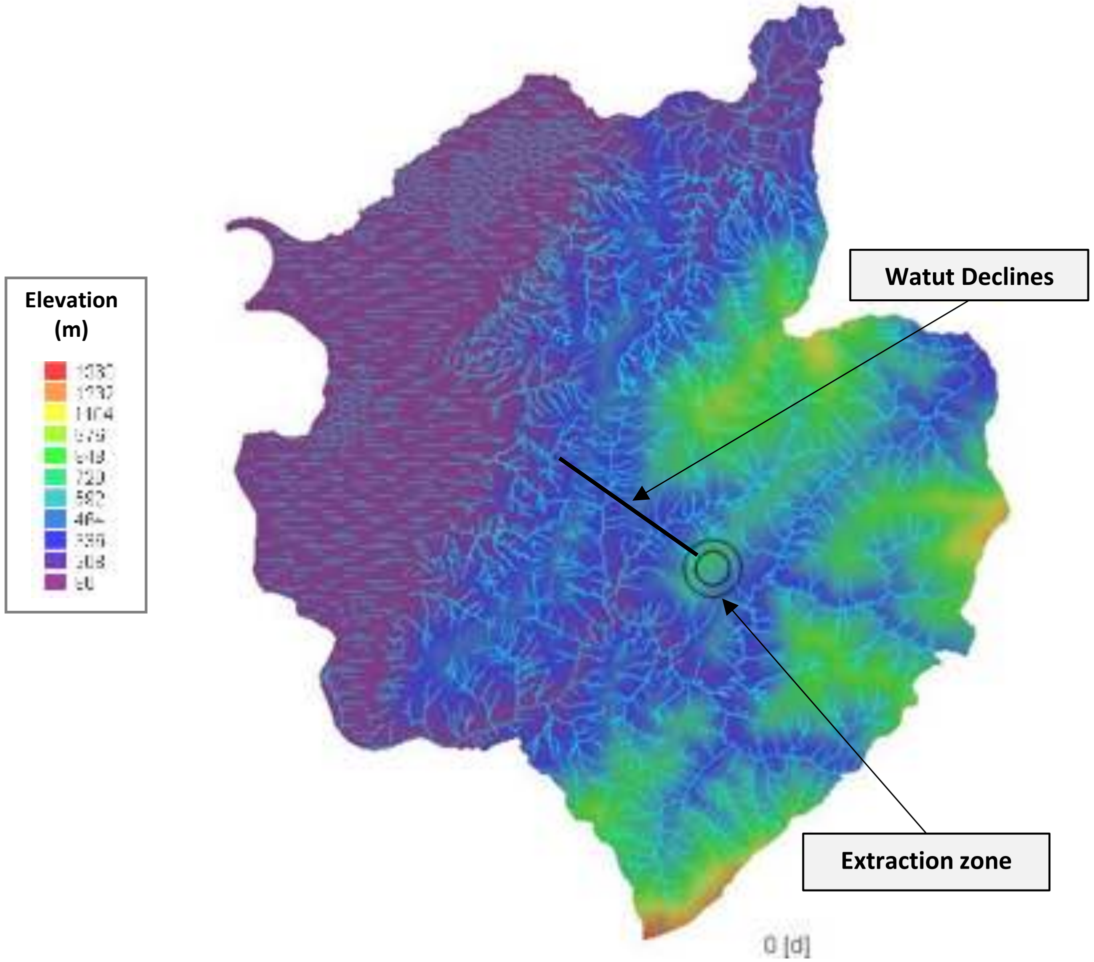
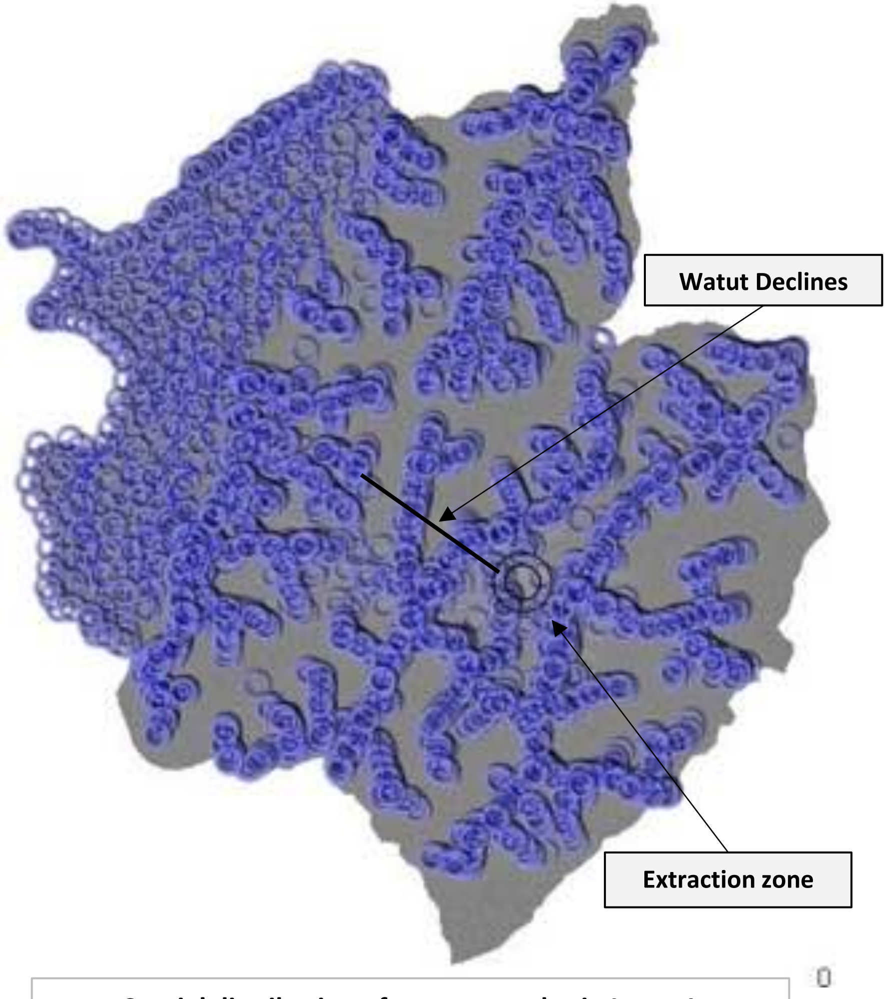
Approved	AR	Fig	25



Topography and network of natural drainages



Spatial distribution of seepage nodes in Layer 1

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Natural streams modelled with seepage node in Layer 1

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It is assumed for simplicity that the flows reported in these nodes correspond to the effective baseflow discharges along with evapotranspiration flows, after any re-infiltration from the waters of the channel to the groundwater system. In any case, the boundary condition was considered the most appropriate to represent the base flow, which occurs in most of the streams located in the modeling area.

For perennial streams in the main valleys around the project area, the hydraulic-head boundary condition is selected to simulate the recharge to the aquifer. With the development of a cone of depression associated with the development of the mine, groundwater levels may decrease below the level of the main rivers. Under those circumstances, the surface water may recharge the weathered bedrock and other underlying units, and seepage nodes would not be appropriate in this case.

4.10 HYDRAULIC PROPERTIES

Hydrogeological units within each layer of the FEFLOW model are assigned values of hydraulic conductivity (K, m/s), specific yield (Sy, %) and specific storage (Ss, 1/m) on an element by element basis. These parameters were defined and distributed both horizontally and vertically. The following provides a summary of the parameters adopted:

4.10.1 Hydraulic conductivity

Hydraulic conductivity values for all major units of the stratigraphy were defined based on results of hydrogeological investigations carried out by WGJV from 2005 to 2017 (see Section 2) and the subsequent interpretation of hydraulic tests. The hydraulic properties of the different units were initially entered based directly on the ‘average’ values for each lithology derived from pump tests. They were then iteratively adjusted within the limits of the minimum and maximum values derived from the tests until optimum model convergence was achieved. The values ultimately used in the calibrated numerical model are summarized in Table 15. A generic value of 0.01 m/s has been used for the faults, which is about the order of magnitude of the higher measured hydraulic conductivity for a geological structure. Given the thickness assigned to the Buvu faults (50 m), it will lead to conservative results in term of groundwater inflows in the mine.

4.10.2 Specific yield and specific storage

Specific porosity (Sy) and specific storage (Ss) control changes in the saturated volume of rock, and therefore variations of head, groundwater level and flow over time. The steady-state FEFLOW model does not require values for these parameters. For the model in transient mode, they are however essential. Most of the drainable porosity corresponds to generic values. A value of 4% has been used for the weathered bedrock, which is a conservatively high value considering results obtained for artesian wells.

Table 15: Hydraulic properties of main hydrogeological units

HU	Hydro stratigraphic Unit	Hydraulic conductivity (m/d)	Drainable porosity (%)	Specific storage (1/m)
1	Alluvial/Colluvial	4.5×10^{-1}	25	0.0001
2	Weathered bedrock	$2. \times 10^{-3}$ to 1.4×10^{-2}	4	0.0001
3a	Partially weathered bedrock 85-200m	2.5×10^{-3}	1	0.0001
3b	Transition in the bedrock 200-600m	9.0×10^{-4}	0.4	0.0001
4	Bedrock	2.0×10^{-5}	0.1	0.0001
5	Faults	1.0×10^{-2}	0.5	0.0001

Given the problem settings, flow is simulated via Richard' Equation (variably saturated) under unconfined conditions. With development of a large-scale drawdown cone in the deep bedrock, it is expected that water will come first from the release of water stored in the pore-space. As it is generally the case for unconfined conditions, water comes from gravity drainage because aquifer compression generally yield relatively little water from storage. The value chosen for the specific storage is consequently secondary for the total value of storativity. The generic value of 1×10^{-4} 1/m used in the model is in the range of classical values of specific storage, and certainly very conservative for units HU 3 and 4.

5 MODEL CALIBRATION

5.1 OVERVIEW

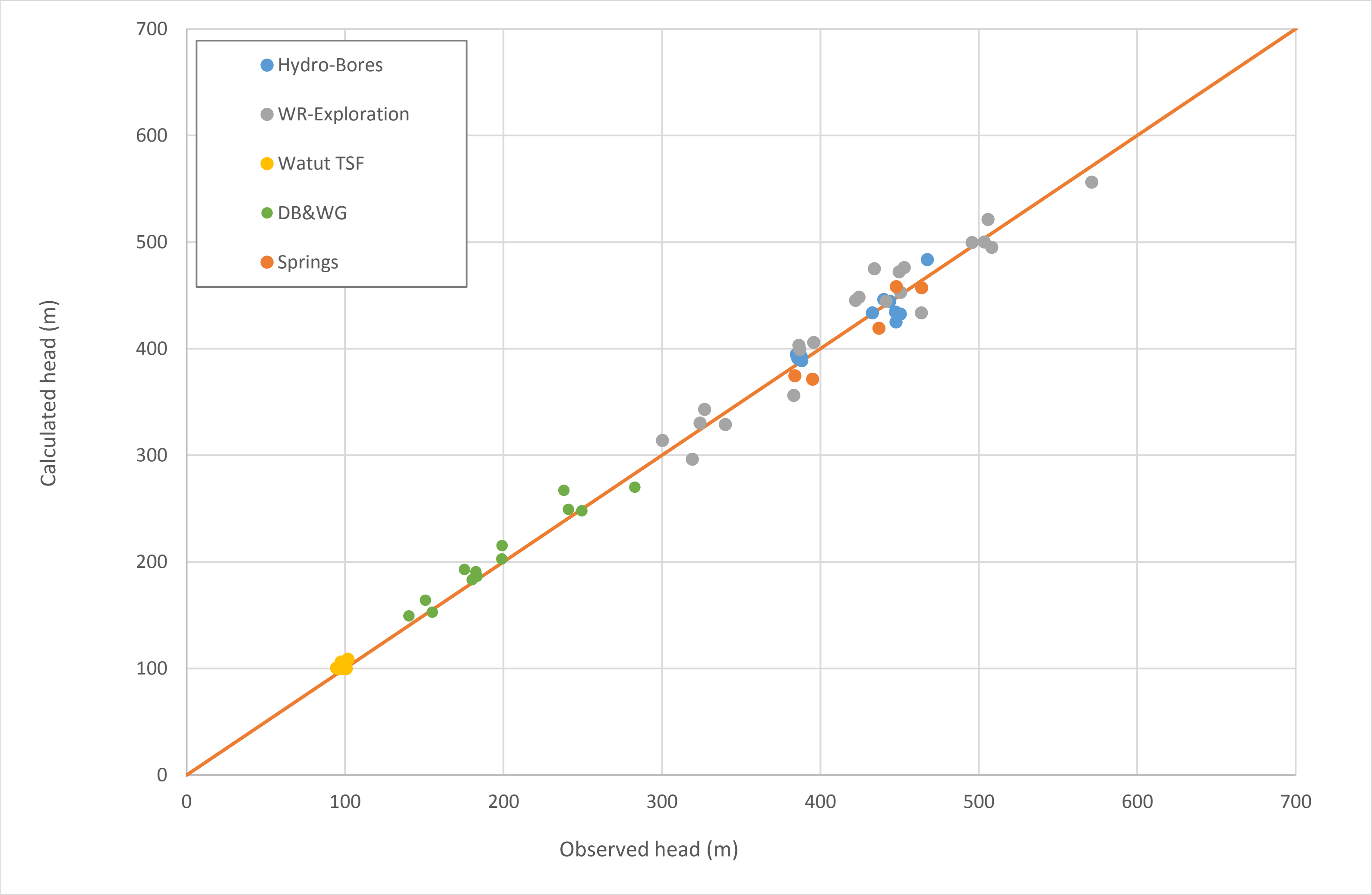
Following initial construction of the FEFLOW model for pre-mining conditions in Wafi-Golpu as outlined in Section 4, a rigorous process of calibration against observed groundwater elevation conditions was performed to ensure that the model may subsequently be applied with confidence in the prediction of future conditions. Calibration of the model involved comparison of model outputs for elevation against measured trends at a series of defined monitoring points across the model domain. A total of 77 points within Wafi-Golpu’s empirical database were considered to provide reliable groundwater level measurements for use in calibration. These were specifically used for the calibration of groundwater levels. In general, monitoring boreholes applied for purposes of model calibration are completed within a defined hydrogeological unit. In some instances, however, the depth or precise mode of completion of boreholes is unknown. It is the case of exploration boreholes with the nomenclature WR, and an unknown depth for the plugs and pipes in place. In such instances, the importance of attaining optimum model convergence is considered secondary to that applicable to boreholes representing established stratigraphic units.

5.2 CALIBRATION OF GROUNDWATER LEVEL

Calibration of the FEFLOW model with respect to groundwater level elevation was primarily performed at the 2017 time-step with the most recent monitoring data. The hydrogeological parameters subject to adjustment during calibration included hydraulic conductivity in each hydrogeological unit of the model, plus effective recharge. These parameters were optimized using an auto-calibration process in Pest, via the interface FePEST. Groundwater level calibration data were subject to evaluation using two main forms of output:

- The simulated piezometric surface at the 2017 time-step in model calibration can be evaluated qualitatively in terms of proximity to measured/inferred piezometric surface at the same time-step.
- Statistics calculated to express the residual differences between observed and simulated values for the last time-step of the transient simulation. This permits quantitative assessment of the precision of the calibration on a location specific basis (Figure 27).

The hydraulic-head condition in layer 1 for 2017 is shown in Figure 28. The comparability of modeled versus measured elevations is generally good. Modelled trends over time also replicate variations of observed levels closely between time-steps.



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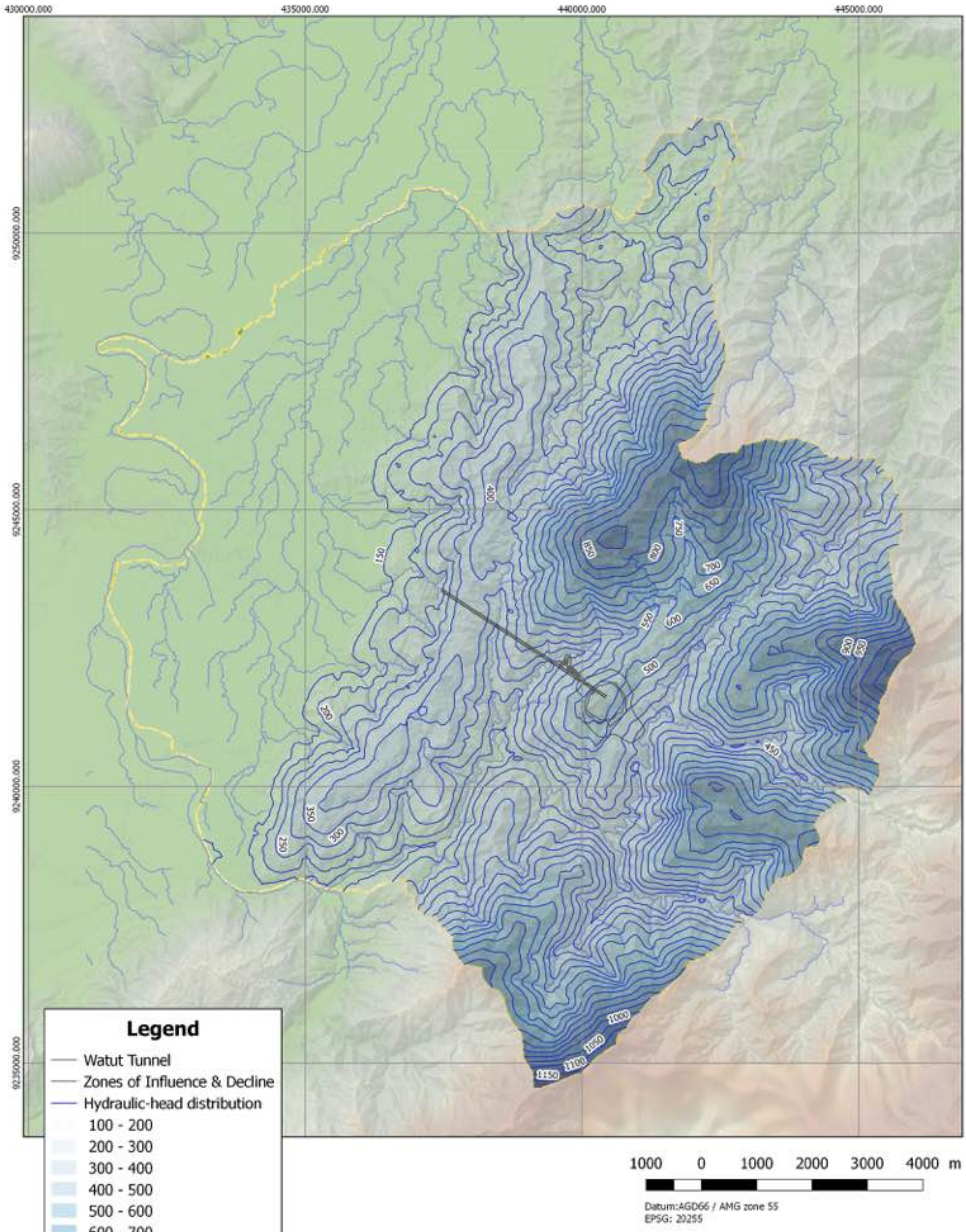
Statistics of calibration

By	FB	Date	Oct 2017
Approved	AR	Fig	27



Datum:AGD66 / AMG zone 55
EPSG: 20255

Legend

- Watut Tunnel
- Zones of Influence & Decline
- Hydraulic-head distribution
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 500
- 500 - 600
- 600 - 700
- 700 - 800
- 800 - 900
- 900 - 1000
- 1000 - 1100
- 1100 - 1200
- Surface drainage
- Topographic contours
- Model area

Wafi-Golpu, 3D Grounwater Model

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Simulated groundwater levels for pre-mining conditions

By FB	Date Oct 2017
Approved AR	FIG 28

Table 16 shows groundwater levels observed in 2017 in conjunction with simulated levels from the FEFLOW model at the end of the pre-mining simulation period. Computed residuals are provided for all locations to indicate the degree of error of the model. Observed and simulated levels are presented graphically in Figure 27. The straight line in Figure 27 represents an ideal condition of 100% model convergence. Statistical indicators of the quality of calibrations which are routinely applied in groundwater modelling include:

- Mean error, calculated as the average difference between observed and modelled water levels.
- Absolute average error, calculated as the average of the absolute difference between the levels of observed and modelled values.
- Normalized root mean square, representing the standard deviation of the difference between simulated and observed values.

Table 16: Groundwater level results of the steady-state calibration

	Observed	Calculated	Residual			Observed	Calculated	Residual
DB12	249.5	*247.8*	*1.7*		**WR504-194**	571.3	*556.2*	*15.2*
DB13	241.0	*249.3*	*-8.3*		**WR509**	324.1	*330.1*	*-6.0*
WG022	180.3	*183.2*	*-3.0*		**WR515**	326.9	*343.1*	*-16.2*
WG025A	183.2	*186.4*	*-3.1*		**WR519-264**	424.3	*448.4*	*-24.1*
WG026	182.5	*190.7*	*-8.3*		**WR519-400**	422.3	*445.4*	*-23.2*
WG034	175.3	*192.8*	*-17.5*		**WR520-347**	452.9	*476.2*	*-23.2*
WG036	198.9	*202.7*	*-3.9*		**WR520-392**	449.8	*472.1*	*-22.3*
WG039	199.1	*215.4*	*-16.4*		**WTSF-BH003A**	97.1	*100.0*	*-2.9*
WG046-40	282.8	*270.0*	*12.8*		**WTSF-BH003B**	98.6	*100.0*	*-1.4*
WG046-60	238.1	*267.3*	*-29.1*		**WTSF-BH008A**	96.1	*100.0*	*-4.0*
WG054	150.8	*164.0*	*-13.2*		**WTSF-BH008B**	95.8	*100.0*	*-4.2*
WG056	140.4	*149.3*	*-8.9*		**WTSF-BH028A**	99.1	*100.3*	*-1.2*
WG063	155.0	*152.9*	*2.1*		**WTSF-BH06**	98.7	*100.4*	*-1.7*
WHDB011D	450.5	*432.5*	*18.0*		**WTSF-BH11**	94.6	*100.5*	*-5.9*
WHDB012S	443.8	*444.5*	*-0.7*		**WTSF-BH12-24.5**	99.0	*100.0*	*-1.1*
WHDB013D	388.3	*388.7*	*-0.5*		**WTSF-BH12-48**	97.6	*100.0*	*-2.4*
WHDB014S	387.9	*392.8*	*-4.9*		**WTSF-BH12A**	95.9	*100.0*	*-4.1*
WHMB001D	447.4	*434.4*	*13.0*		**WTSF-BH12B**	96.1	*100.0*	*-3.9*
WHMB003S	440.0	*446.1*	*-6.1*		**WTSF-BH14-34.5**	98.7	*100.0*	*-1.3*
WHMB004S	432.7	*433.5*	*-0.7*		**WTSF-BH14-8**	100.7	*100.0*	*0.7*
WHMB005D	447.7	*425.0*	*22.7*		**WTSF-BH14A**	96.4	*100.0*	*-3.6*
WHMB006D	385.8	*390.9*	*-5.2*		**WTSF-BH14B**	97.2	*100.0*	*-2.8*
WHMB007S	384.9	*394.7*	*-9.8*		**WTSF-BH15-18**	97.6	*106.1*	*-8.5*
WHMB008D	467.4	*483.6*	*-16.2*		**WTSF-BH15-8**	97.9	*106.1*	*-8.2*
WR206	441.5	*444.5*	*-3.0*		**WTSF-BH20-15**	100.6	*100.2*	*0.3*
WR311	463.8	*433.6*	*30.1*		**WTSF-BH21-29.85**	99.2	*104.7*	*-5.5*
WR331	395.8	*405.7*	*-9.9*		**WTSF-BH21-9.45**	99.9	*104.6*	*-4.7*
WR428-100	383.1	*356.1*	*27.0*		**WTSF-BH22**	101.8	*108.7*	*-6.9*
WR436-485	340.0	*328.9*	*11.1*		**WTSF-BH23A**	98.9	*100.6*	*-1.7*
WR446-500	319.2	*296.4*	*22.9*		**WTSF-BH23B**	99.0	*100.6*	*-1.6*
WR451	386.4	*403.1*	*-16.8*		**WTSF-BH24A**	99.0	*101.9*	*-2.9*
WR456	300.3	*314.0*	*-13.7*		**WTSF-BH24B**	98.7	*102.0*	*-3.3*
WR460	503.5	*500.0*	*3.5*		**WTSF-BH28**	99.1	*100.3*	*-1.2*
WR479	450.5	*452.9*	*-2.4*		**SPR01**	395.0	*371.4*	*23.6*
WR486	495.7	*499.6*	*-3.9*		**SPR02**	448.0	*458.3*	*-10.3*
WR489	386.9	*399.0*	*-12.1*		**SPR03**	464.0	*457.1*	*6.9*
WR495-486	508.2	*495.0*	*13.2*		**SPR04**	437.0	*419.3*	*17.7*
WR495-780	434.1	*475.0*	*-40.9*		**SPR05**	384.0	*374.7*	*9.3*
WR502	505.8	*521.3*	*-15.4*					

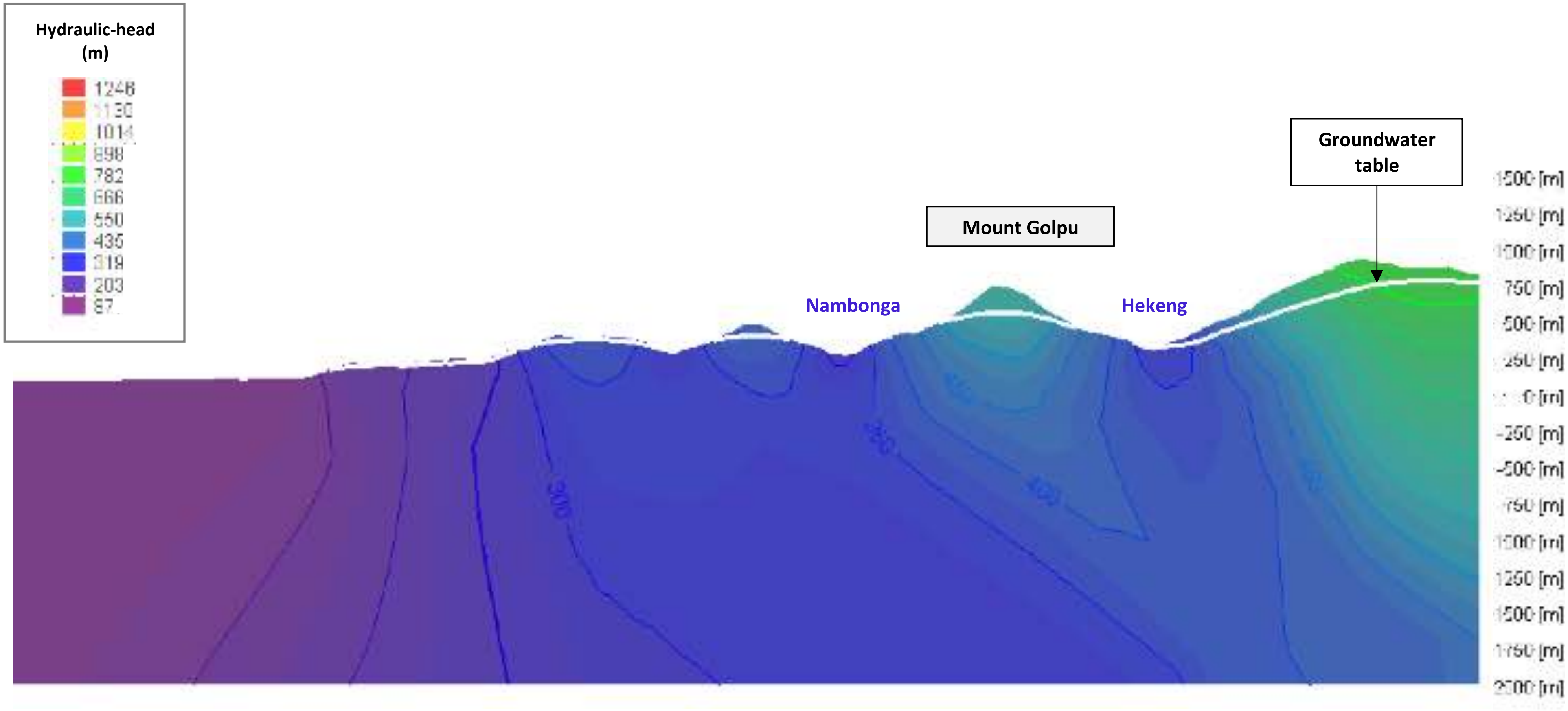
The pronounced relief and the groundwater system in the fractured bedrock are particularly challenging aspects of the model. The calibration of the pre-mining model yields a mean error of -3.0m and an absolute average error of 9.5m. Residuals indicate a successful calibration, with all but a few locations exhibiting residual errors in the +5 to -5% range (conventionally considered to signify high precision of calibration). A difference of 476 m between the maximum and minimum piezometric level is evident from empirical monitoring. Using this measured variance, the normalized root mean square of the model is 4.9%. This is considered to be very high degree of calibration to measured data and indicates that the current confidence interval of the model is sufficient for predictive modelling purposes. It is also a significant improvement over the level of calibration of previous models which is accounted for by the significantly improved dataset available for analysis.

The modelled hydraulic-head distribution for pre-mining conditions shows:

- A complex distribution of the simulated hydraulic heads in relation to the different zones of hydraulic conductivity and the network of surface drainage associated with the different streams is observed.
- Groundwater levels varying between 87 masl in the Watut Plain and 1218 masl on a mountain located at the edge of the model area. In the central zone of the future subsidence zone, the mean groundwater level elevation is equivalent to 560 masl.
- At the bottom of the valleys and streams, the depth of the groundwater level remains close to the surface, between 0 and 25 m.
- Hydraulic-head distribution respects the hydraulic gradient observed in the VWPs (Figure 29).

5.3 GROUNDWATER BALANCE

Analysis of the water balance for the FEFLOW model domain for pre-mining period suggests that all individual water balance components identified in the site conceptual model (Section 3) are correctly enumerated, with negligible errors between empirical and modelled values observed. This is exemplified in Table 17, from which the balance error is equivalent to 0.09 l/s, or with an error inferior to 0.001%. Conventionally, an error inferior to 1% indicates both a high level of model robustness and significant numerical stability of the model.



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Simulated groundwater level (Pre-mining) along the decline

By	FB	Date	Oct 2017
Approved	AR	Fig	29

Table 17: steady state water balance for initial conditions

Simulated flow		Out (l/s)	In (L/s)
Dirichlet Boundary Conditions	**Streams**	2223	45
	Underground mine	-	-
Neumann Boundary Conditions		-	-
Wells		-	-
Distributed Sink/Source		-	2178
Storage		-	-
Imbalance		-	0.09

The inflow associated with the streams indicates that the Dirichlet boundary condition works locally as a recharge to the groundwater system, and provides surface water to the groundwater system. However, given the ratio of inflow/outflow, the groundwater system works essentially as a contributor to the surface water baseflow.

An evaluation of the baseflow in the different sub-catchments evaluated in the study area have been carried out, and the results are given in Table 18. The baseflow is equivalent to the total flow measured in the gauge station with the runoff component subtracted. This allows for an estimate of the recharge over a catchment to be made.

The modelled baseflows in Nambonga and Bavaga are of the same order of magnitude, but tend to be slightly higher than the baseflow estimated with the AWBM method. This overestimation of baseflow can be explained by the fact that the recharge is derived from the mean annual precipitation. Local climatic variations may explain the differences of recharge rate between the different catchments.

Table 18: Modelled groundwater balance for pre-mining conditions

Inflow (l/s)		Outflow (l/s)	
Effective rainfall (Recharge 16%)	2178	**Contribution to Bavaga**	282
		Contribution to Nambonga	110
		Contribution to Hekeng	57
		Contribution to other catchments	1729
Total	2178	**Total**	2178

6 PREDICTIVE SIMULATIONS

6.1 OVERVIEW

Once the numerical model was calibrated, a series of predictive simulations were executed from the calibrated model to predict the potential effects of the project development in the study area. These simulations considered different options for the dewatering of the mine.

The specific objectives of the simulation scenarios are as follows:

- Simulate the development of the underground mine and proposed installations during the life of the mine.
- Simulate drainage flows associated with the development of the underground mine and caves throughout the life of mine.
- Evaluate the potential effects of mine dewatering on the hydrogeological environment of the mine sector.

6.2 MODEL CONSTRUCTION

6.2.1 Mine schedule

The simulations have been constructed from the calibrated model, which represents the current hydrogeological conditions, equivalent to pre-mining conditions. The simulations are based on assumed dates adopted for the purpose of modelling and which may change as the Project mine plan is refined. The total duration of the predictive scenario is 11,000 days to include all the major developments provided in the mine plan. It is divided into monthly and yearly stress periods to follow the mine plan provided by WGJV. Closure of the operation is currently predicted to occur in 2056 after which all pumping will cease and the underground excavation will flood. Various scenarios for this flooding are contemplated and in the process of being evaluated.

6.2.2 Underground mine

The underground mine voids are represented in the FEFLOW transient model as a dual line of seepage nodes which represent the ingress of groundwater to the tunnels. The rate of inflow is modelled at these nodes as a function of the pressure gradient between the aquifer rock and the mine void. Such nodes are distributed at the correct depth in the model. The location of the underground mine and associated boundary conditions are shown in the Figure 30.

The exact geometry of the tunnels cannot be included in the model, and the current methodology involves ensuring a flow equivalence between a real tunnel (or a cylinder) and a series of nodes (1D features) in a model. The node-spacing between the boundary conditions is the key in the equivalence between the different geometries representing the tunnels. The upscaling carried out by DHI in 2014 indicated close similarity between the mine-scale model and the smaller scale-up model with a node spacing of 7.3 m along the dual line. This proposed node spacing has been used to simulate the Nambonga Decline, Watut Declines and the various underground drives and ramps between the extraction levels in the model.

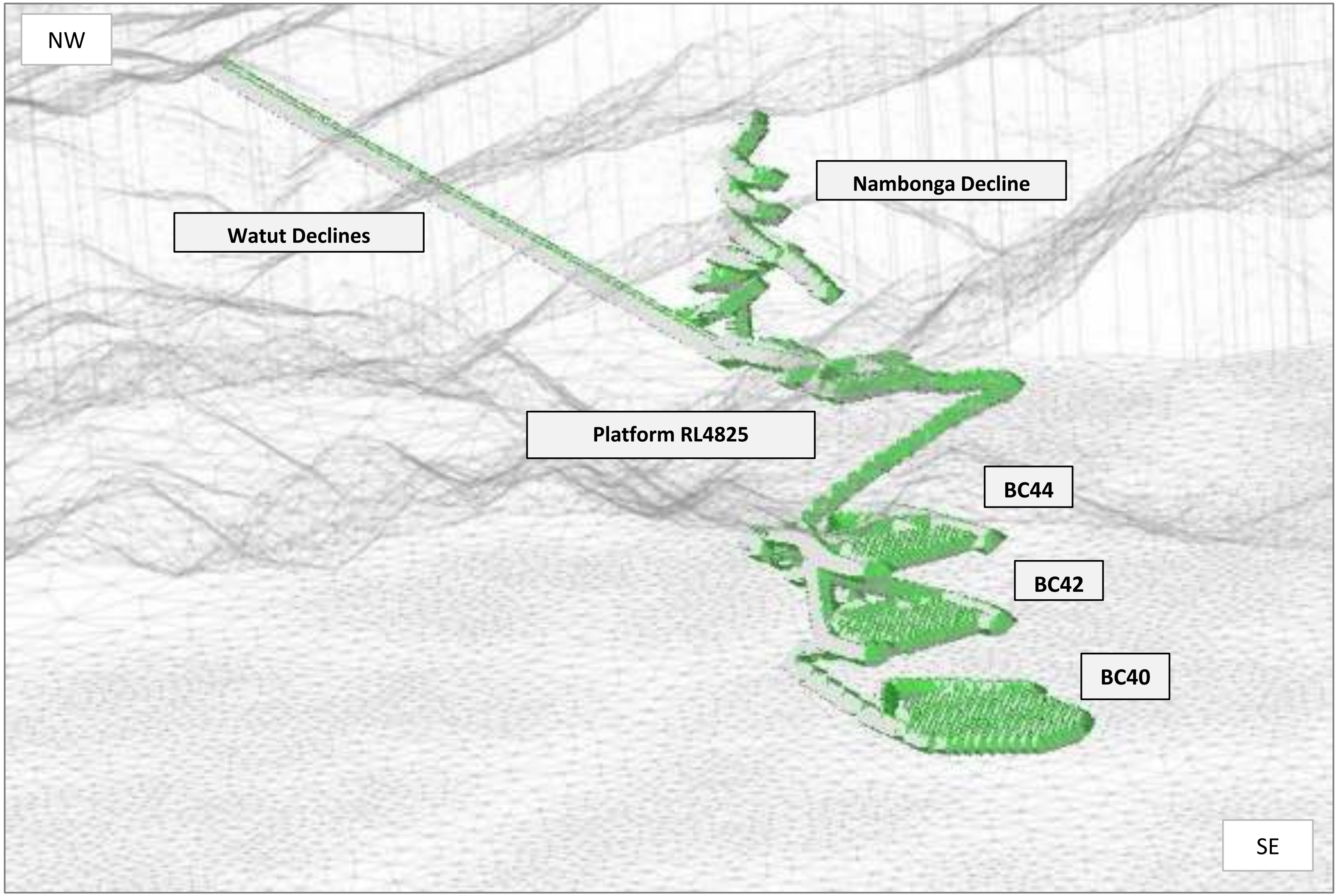
The use of modulation functions enables the progressive activation of the seepage nodes representing the underground infrastructure. The Watut Declines construction is modelled on a monthly time-step. Other underground infrastructure is activated in the model on a yearly time-step.

6.2.3 Cave propagation

Based on the information provided by the Itasca model, the propagation of the cave has been replicated in the groundwater model by the expansion of a zone of higher conductivity. The exact replication of the shape of the cave has been limited by the geometry of mesh elements that do not necessarily coincide perfectly with the cave. However, the lateral extent as well as the maximum elevation of the cave at a determined time has been respected in the assignment of model properties. A linear interpolation has been used to vary material properties of the cave and simulate the progressive development of the cave on a yearly time-step.

Given the limited information available on the hydraulic properties of the cave material, a generic value of 1 m/d has been chosen to model the fractured and caved material. For the regional hydrogeological numerical model, the objective is to have a material that rapidly conveys water to the extraction level, and thus limits the accumulation of water in the fractured and caved material.

Information provided at the time of model construction correspond to cave propagation and subsidence zone. A transition of fractured bedrock caused essentially by rock unloading should



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Assignment of the underground mine in the model

By	FB	Date	Oct 2017
Approved	AR	Fig	30

form a halo around the block-cave and could be added to the model if the cave propagation model manages to provide this level of detail. Increased fracturing should facilitate the drainage of water towards the block-cave. Influence of the fractured bedrock around the block-cave on groundwater level distribution should be observed essentially in the deep fresh bedrock. Given the very low hydraulic conductivity associated to the deep bedrock, the halo of fractured bedrock could easily move the groundwater further away of the block-cave in its deeper part, but probably with a minimal effect on the total inflow in the block-cave.

6.2.4 Recharge over the subsidence zone

Recharge on the subsidence zone is applied in Layer 1 using the FEFLOW parameter ‘In/Outflow on Top/Bottom’, when the caved zone reaches the surface and initiates the development of a subsidence zone. The recharge rate adopted over the subsidence zone is equivalent to 95% of the total rainfall.

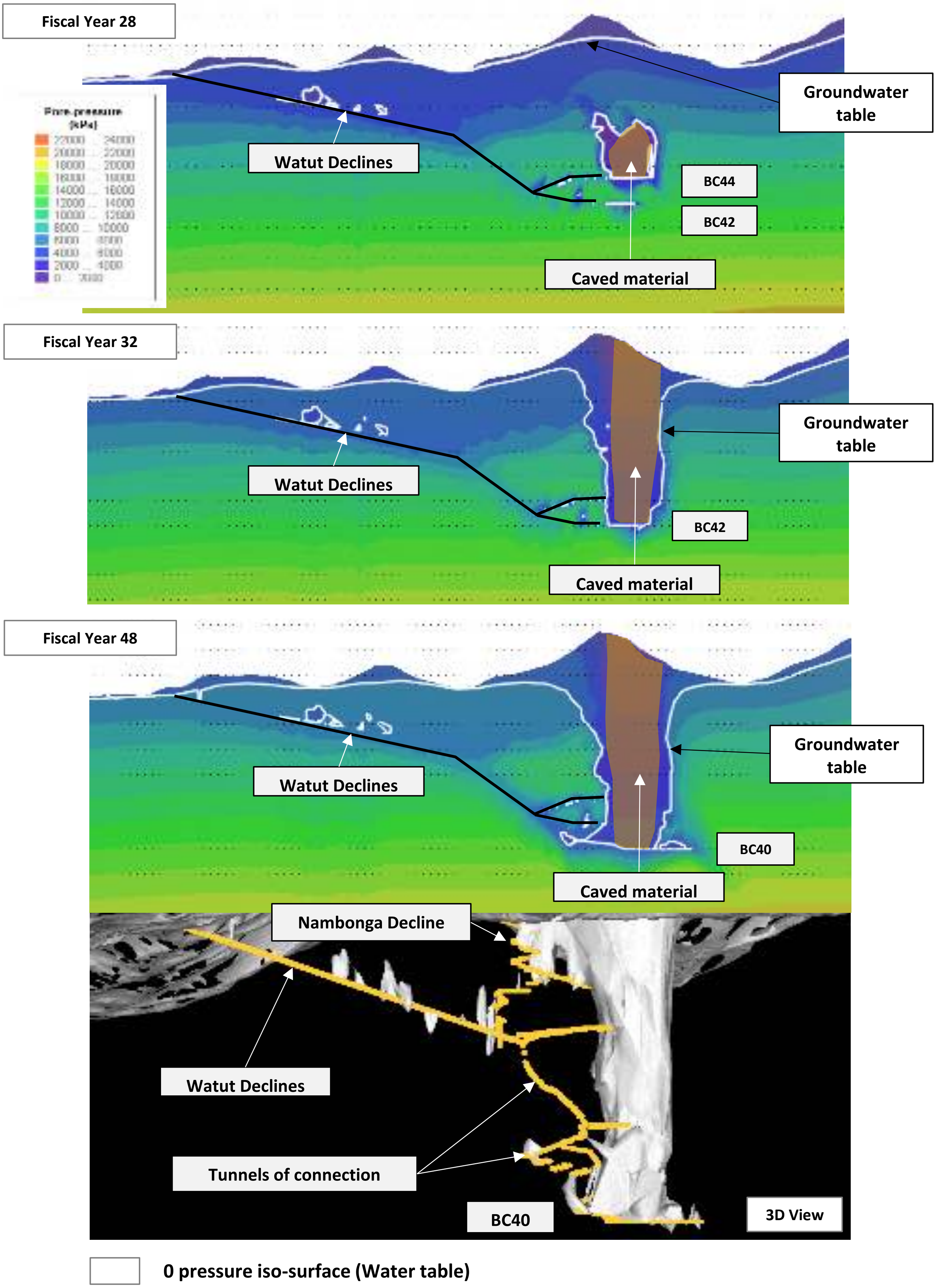
6.3 RESULTS OF THE BASE CASE MODEL

6.3.1 Groundwater levels

Effects of underground infrastructure on groundwater levels are only apparent in the long-term. On the contrary, the high hydraulic conductivity associated with the caved material immediately generates a cone of depression in close proximity around the block-cave.

In the upper hydrogeological units around the block-cave, the groundwater level tends to decrease due to the discharge in the caved zone (Figure 31 and 32). Given the very limited conductivity associated with the bedrock, groundwater remains very close to the cave in the deeper unit.

Drawdown at the end of the LOM is significant around the cave, but the lateral extension is limited to 1.2 km only (Figure 33). The main rivers recharge the weathered bedrock more effectively than the underground mine dewaters the bedrock, so it prevents the propagation of a drawdown cone. The Watut Declines also generate a drawdown that can reach 50 m in the Portal area. Results presented in Figure 33 suggest that the area of coverage of the model is sufficient, with limits that do not influence model results.



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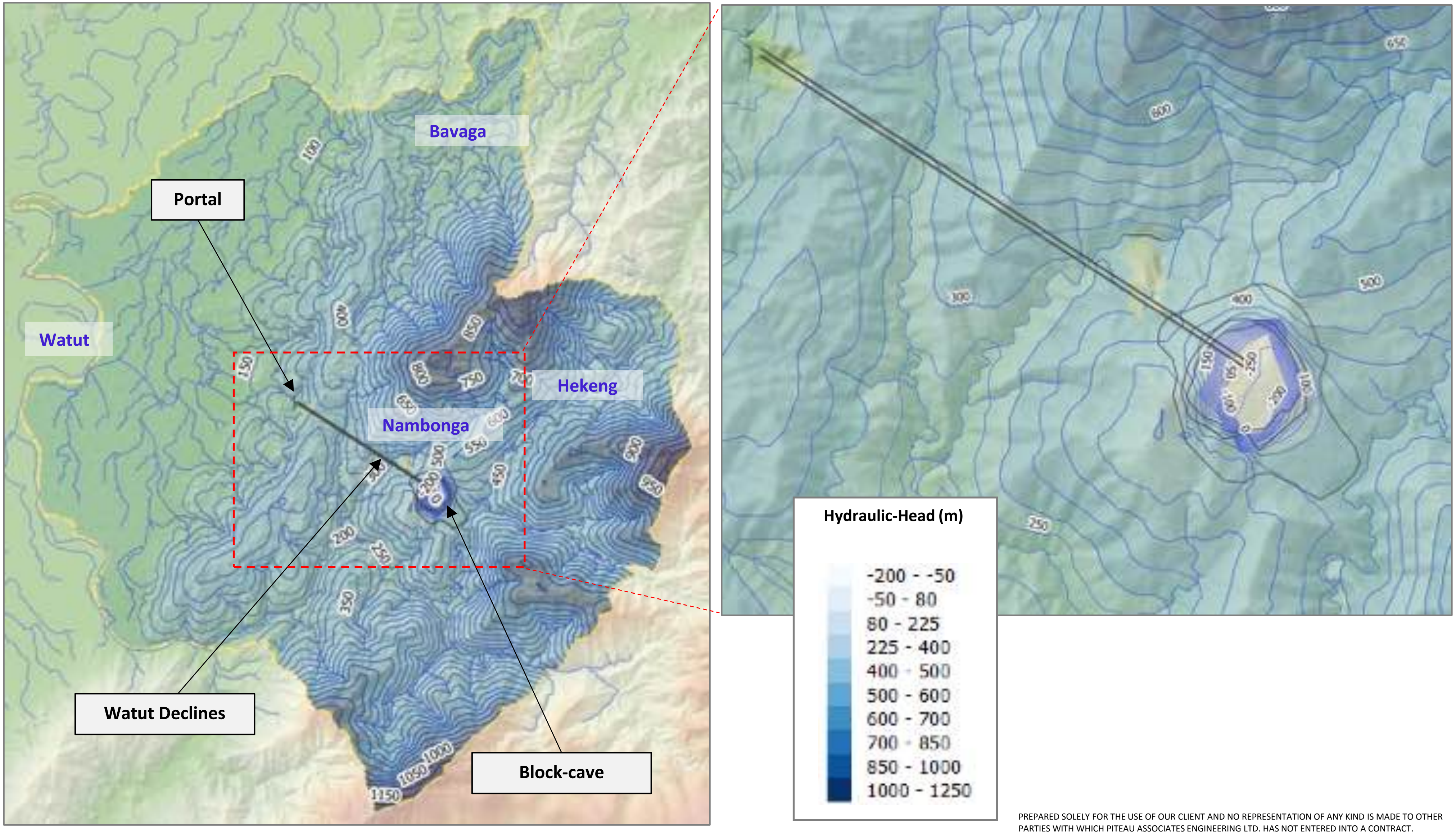
Development of the drawdown cone and pore-pressure distribution associated to the cave propagation

By	FB	Date	Oct 2017
Approved	AR	Fig	31



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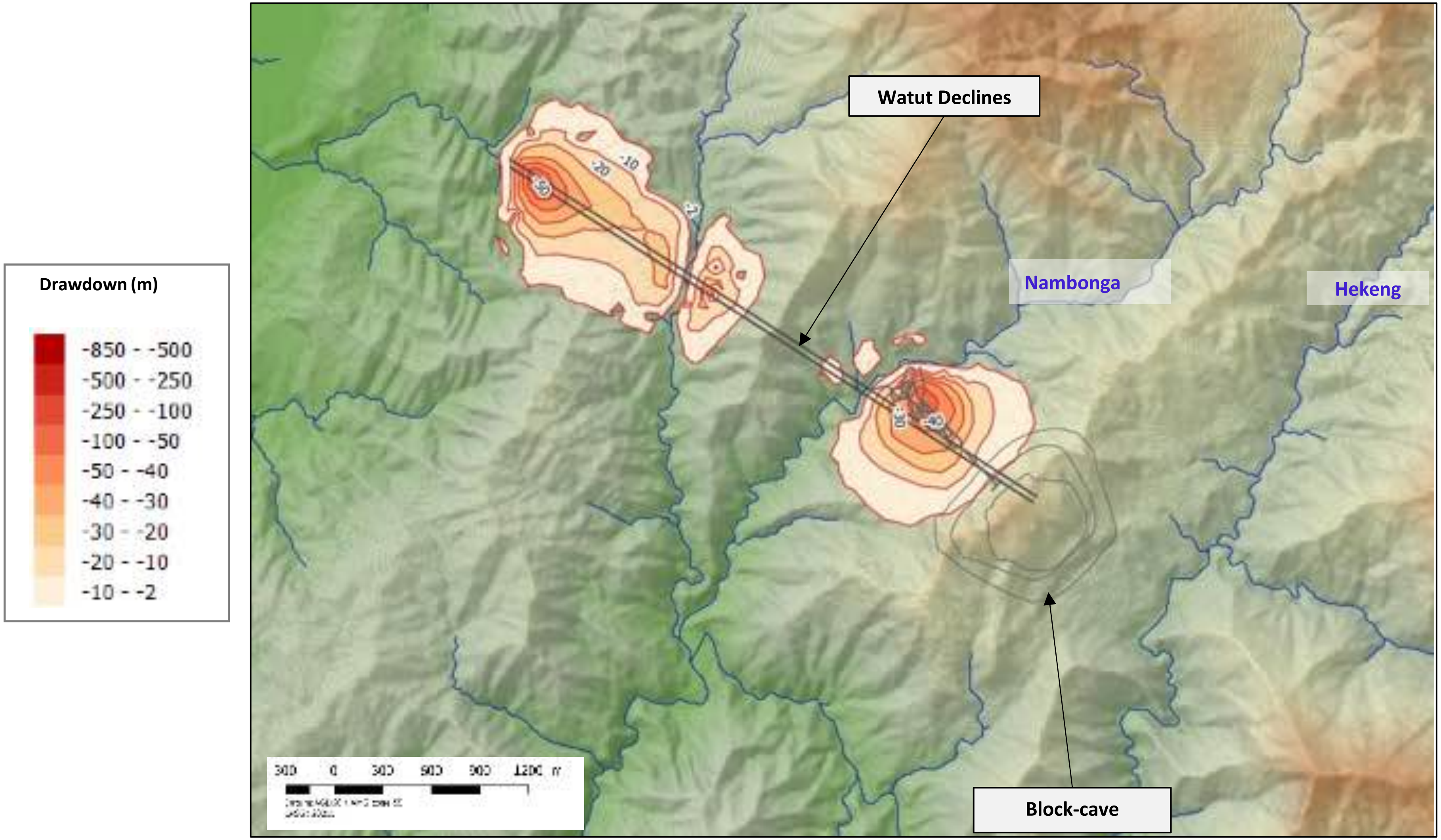
Groundwater contours at the end of the predictive simulation (FY57)

By	FB	Date	Oct 2017
Approved	AR	Fig	32



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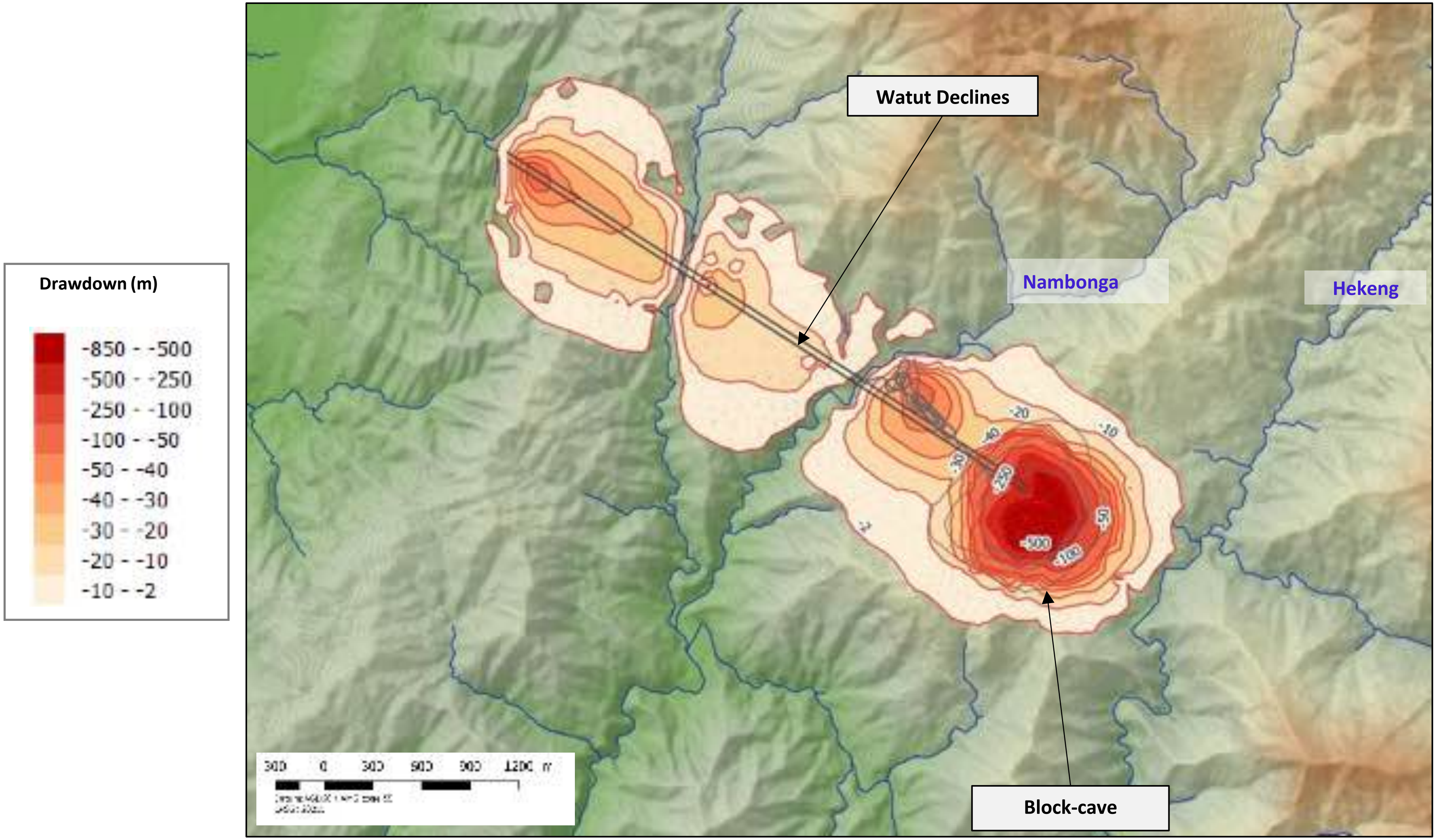
Drawdown contours at Y03 (2023)

By	FB	Date	Oct 2017
Approved	AR	Fig	33a



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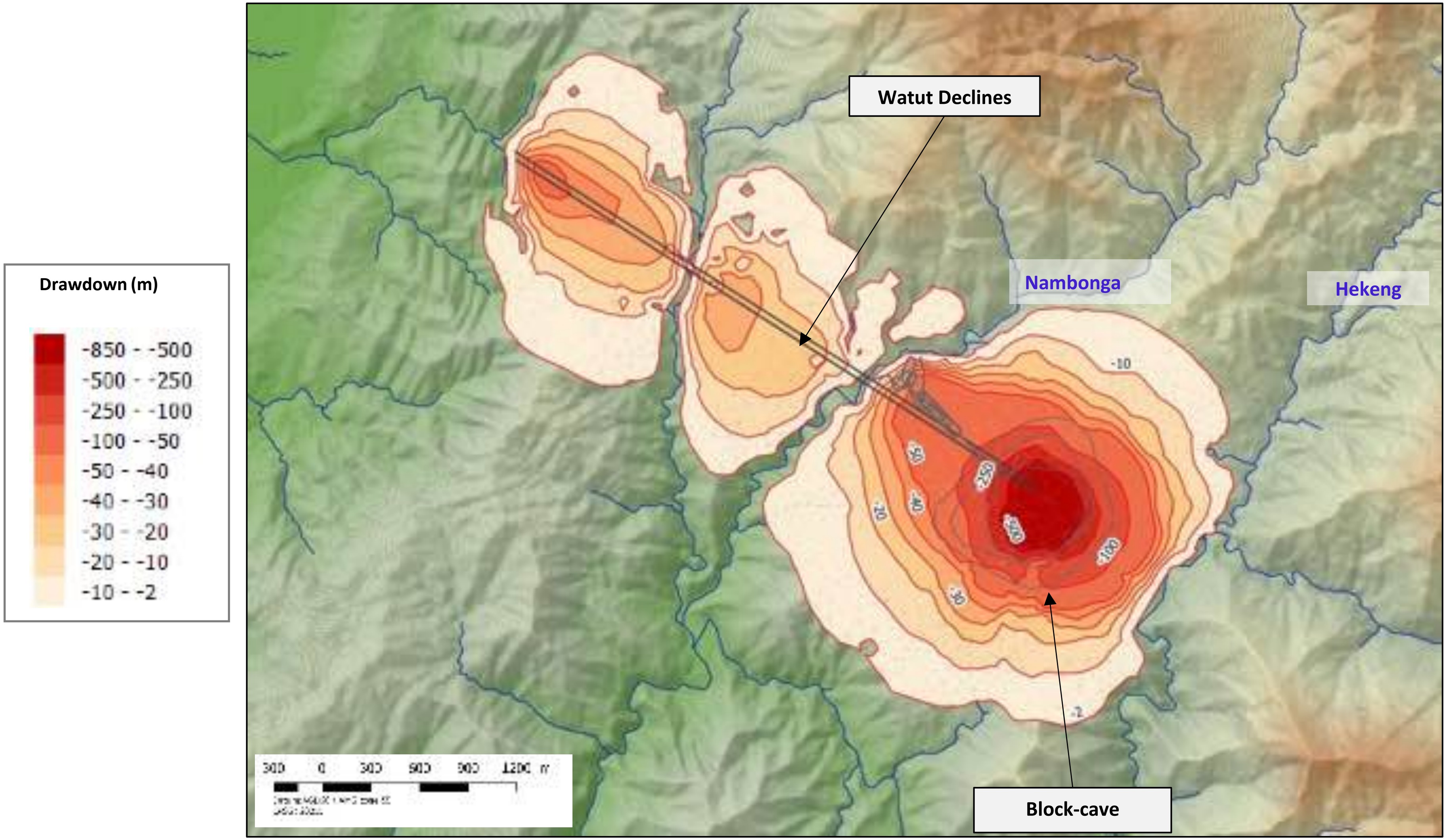
Drawdown contours at Y10 (2030)

By	FB	Date	Oct 2017
Approved	AR	Fig	33b



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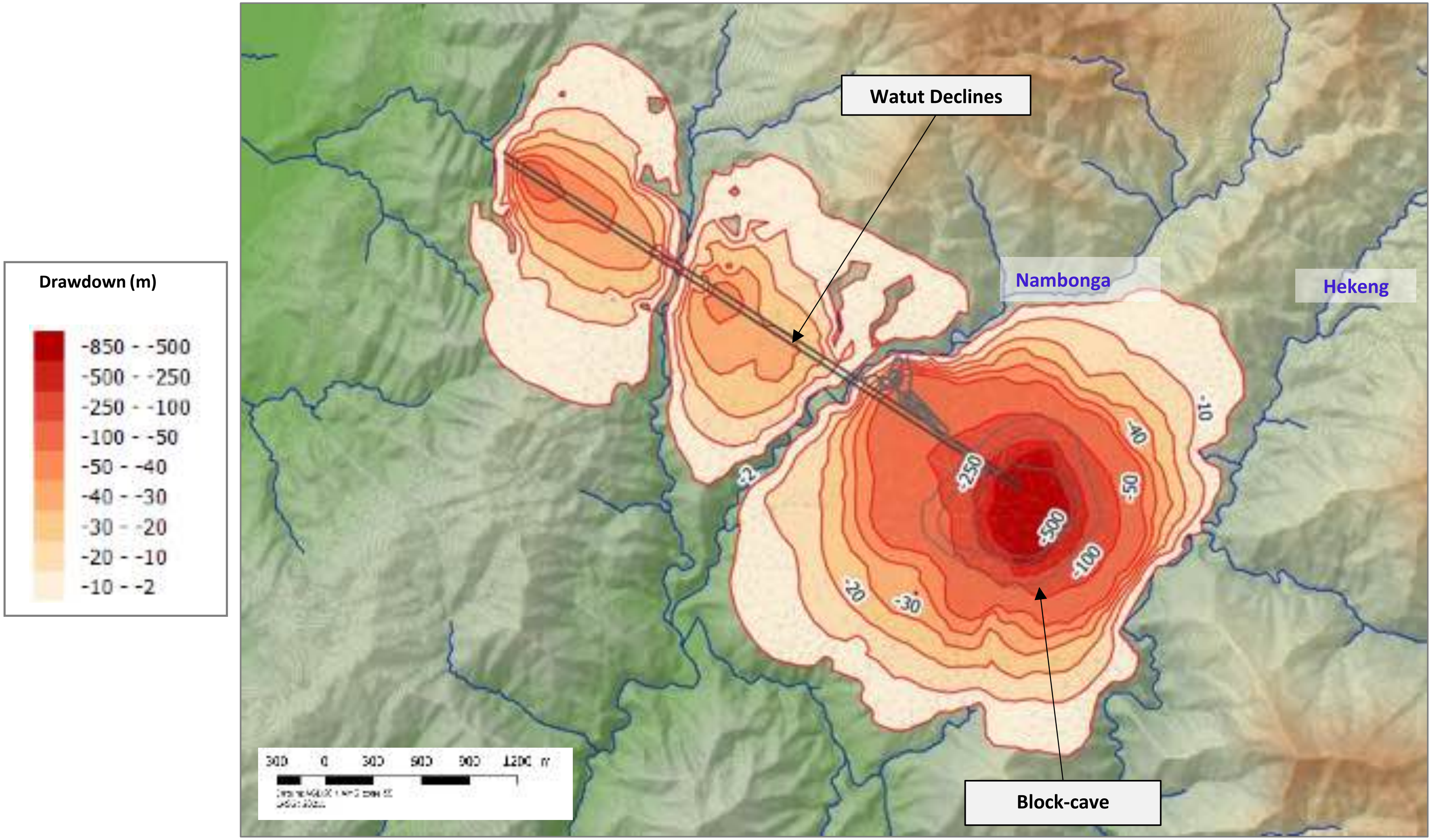
Drawdown contours at Y20 (2040)

By	FB	Date	Oct 2017
Approved	AR	Fig	33c



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Drawdown contours at the end of the predictive simulation (FY57)

By	FB	Date	Oct 2017
Approved	AR	Fig	33d

6.3.2 Inflows in the underground mine

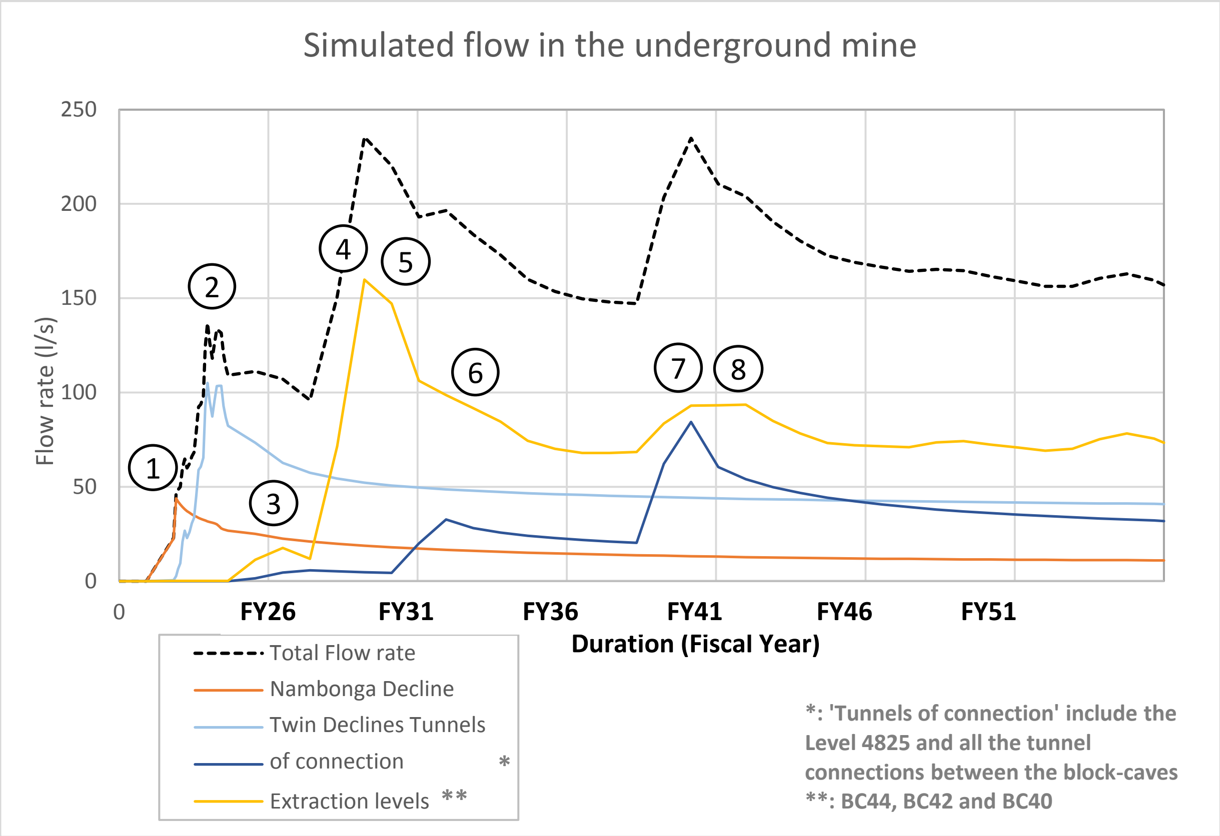
Results presented in Figure 34 are summarized as follows:

- The model calculates a peak inflow of 40 l/s and a long-term inflow of 10 l/s for the Nambonga Decline. The Nambonga Decline reduces the hydraulic head over the last section of the Watut Declines and contributes to a decrease in the total inflow in the Watut Declines.
- For the Watut Declines, the base case model indicates a peak at 100 l/s and a long-term inflow of 40 l/s.
- Total inflow in the Access decline and conveyor decline between the extraction levels (including the platform 4825) reaches 70 l/s with the construction of the last block-cave (BC40), and 30 l/s on the long-term.
- Extraction levels (BC44, BC42 and BC40) reach a peak inflow value of 150 l/s. Flow exceeding 100 l/s is always associated with the cave propagation from BC44, BC42 and BC40. The cave grows very quickly from BC44 as it reaches the surface in only 4 years.
- When the extraction starts from BC42 and BC40, the main cave has already reached the surface from BC44, but the cave expands laterally and below BC44.
- Groundwater inflows in the extraction levels account for the increased recharge over the footprint of the subsidence zone (equivalent to 15 l/s). Thus, long term inflow in the extraction levels from groundwater only is equivalent to 55 l/s.

Results are based on the current understanding of regional hydrogeological settings. It is important to emphasize that local singularities may generate unexpected short term high inflows. For instance, the near surface fractured quartzite in the Nambonga catchment and Nambonga Decline area presents a risk of initial peak inflows which may exceed 40 l/s.

6.3.3 Baseflow variation during operation

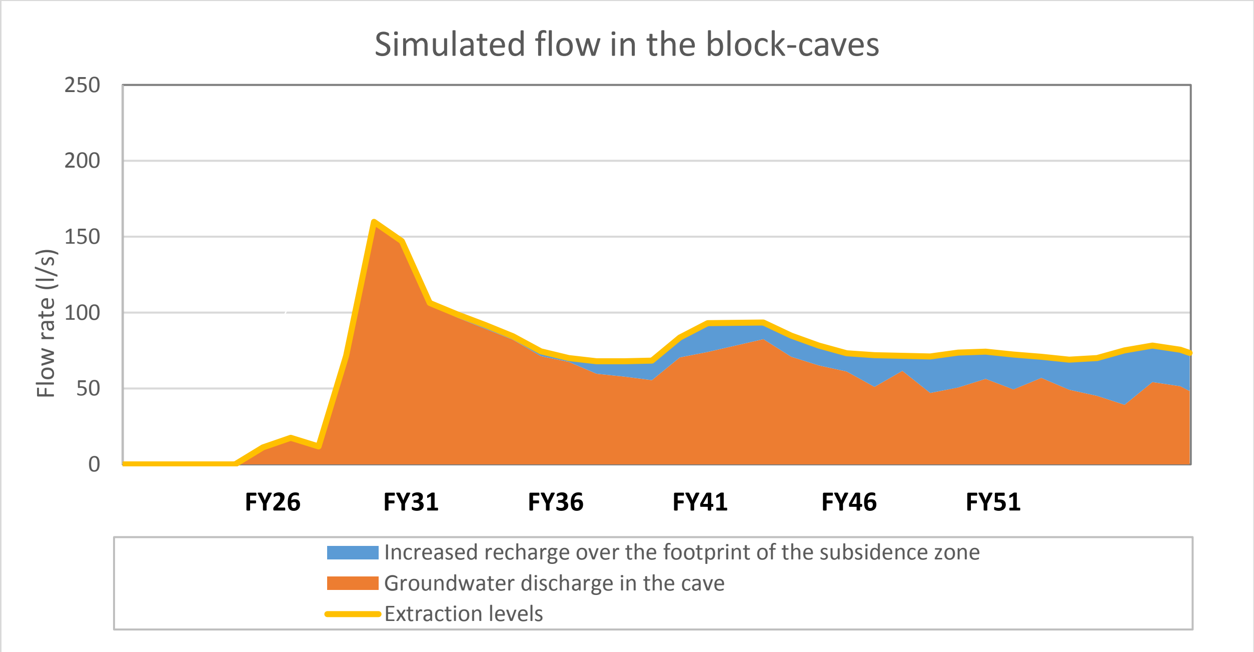
As outlined in the conceptual model and water balance, the groundwater system works essentially as a contributor to the surface water baseflow. However, operation of the mine will imply the interception and extraction of a significant amount of groundwater during the LOM. This will result in the development of a drawdown cone along and around the declines and the block-cave, and consequently decrease the hydraulic gradient towards the different streams located in the project area. A reduction of the groundwater discharge towards the different streams is expected to occur simultaneously with the development of the tunnels and the block-cave.



Simulated flow in the underground mine

*: 'Tunnels of connection' include the Level 4825 and all the tunnel connections between the block-caves
**: BC44, BC42 and BC40

1/ Construction of the Nambonga Decline
2/ Construction of the twin declines
3/ Construction of platform 4825, BC44 and all the tunnels of connection
4/ Beginning of the block-cave operation from BC40
5/ Block cave breaks through the surface and construction of BC42
6/ Block-cave operation from BC42
7/ Construction of BC40
7/ Block-cave operation from BC40



Simulated flow in the block-caves

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Simulated flow in the underground mine

By FB
Date Oct 2017
Approved AR
Fig 34

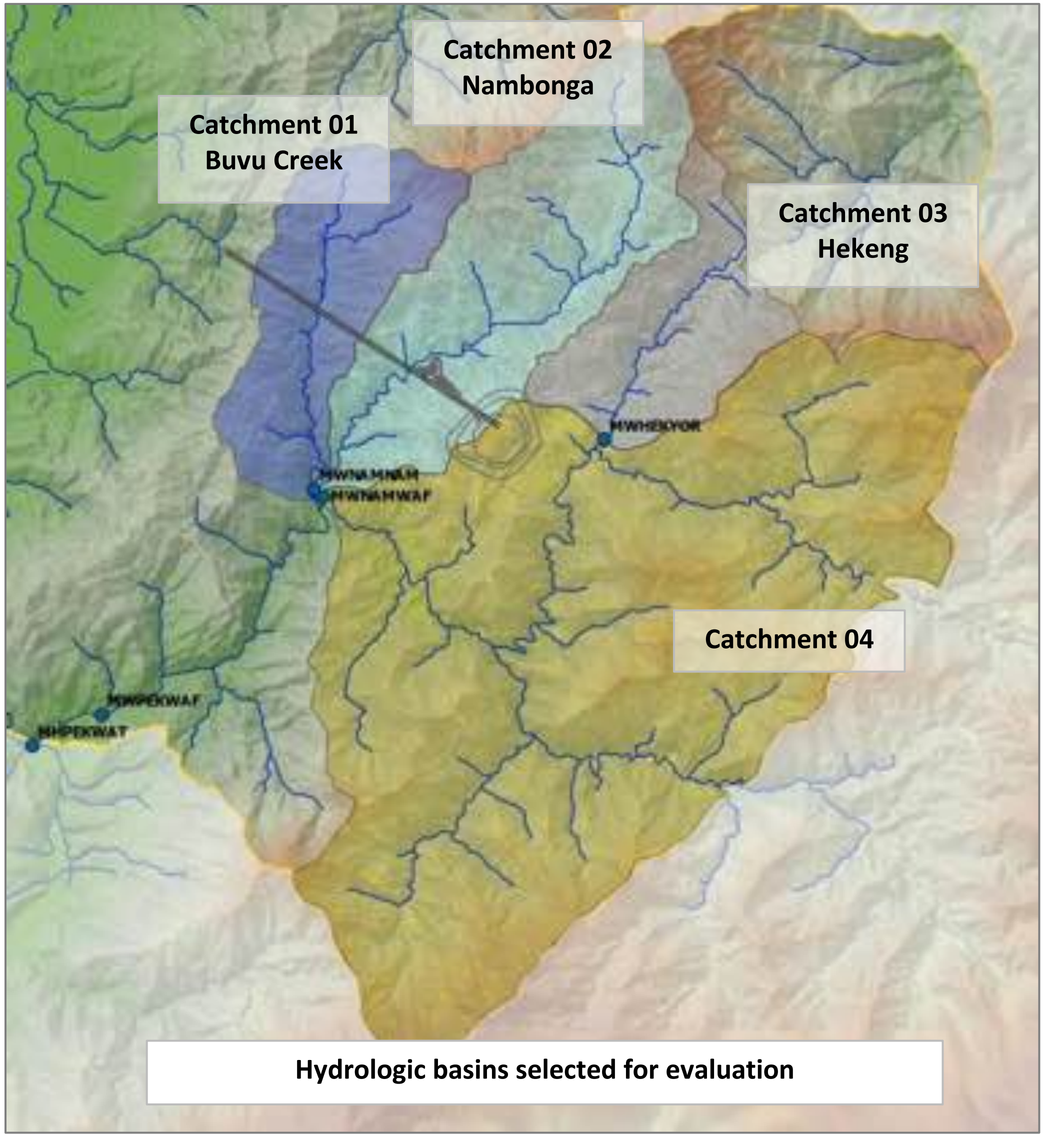
In the numerical model, flow discharge to streams is represented in the FEFLOW model by seepage nodes and hydraulic-head boundary conditions. Different surface areas encompassing specific catchments over and around the twin declines and the block-cave have been determined to evaluate the variation of groundwater contribution over the LOM (See Figure 35 and Table 20). Catchment 01 is located over the twin decline footprint and corresponds to the entire Buvu Creek catchment. Catchment 02 corresponds to the Nambonga catchment up the flow gauge station MWNAMNAM. Catchment 03 corresponds to the Hekeng catchment up the flow gauge station MWHEKYOR. The last zone of evaluation entitled Catchment 04 corresponds to the entire area of contribution to the Wafi river, up to the edge of the model domain. It is important to notice that a part of the upper catchment of the Wafi river is located to the East of the project area and is not included in the model domain, and variations of baseflow will be consequently expressed only for the sector near the block-cave.

Table 20: Groundwater contribution to surface water systems during operation

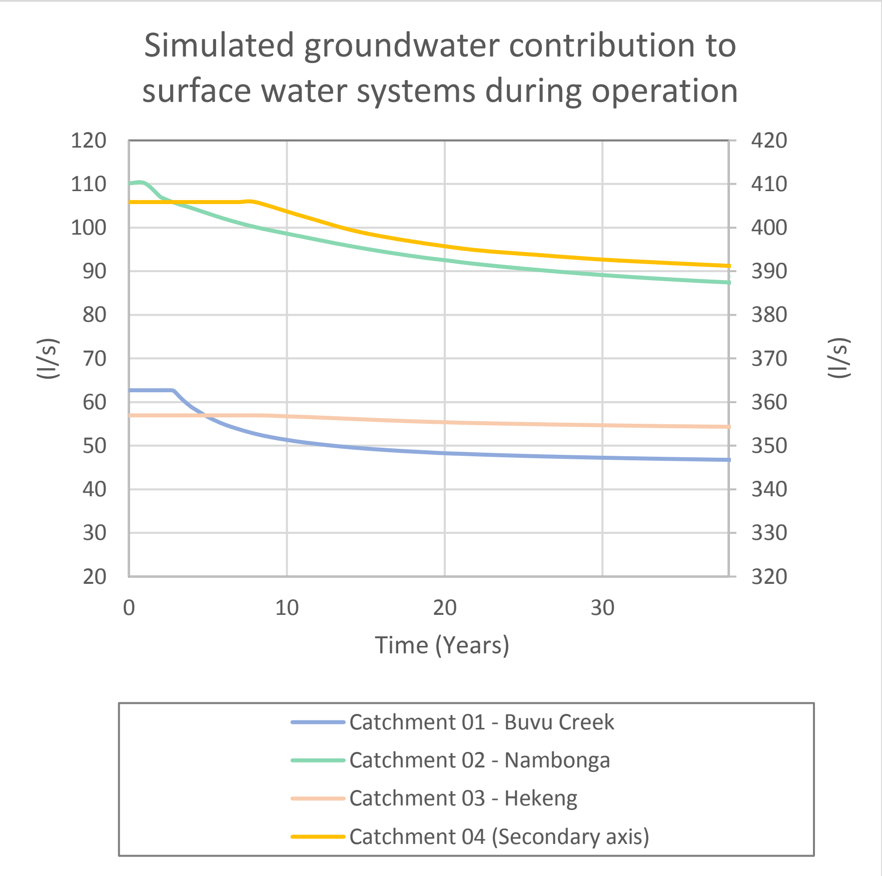
	Groundwater Contribution		
Catchment ID	**Initial Baseflow (l/s)**	**Minimum baseflow simulated (l/s)**	**Variation (%)**
1 – Buvu Creek	63	47	-34
2 - Nambonga	110	87	-26
3 - Hekeng	57	54	-5
4	406	391	-4

An evaluation of the results indicates that:

- A decrease in base flow is first observed in the Nambonga catchment, and is due to the construction of the first installation which is the Nambonga Decline.
- After 3 years of operation, effect of construction of the twin declines is identified in the Buvu Creek catchment.
- Around the block-cave, the base flow in the Hekeng Catchment is moderately affected by the block-cave because it indicates a maximum baseflow reduction of 5%.
- In catchments 01, 02 and 04 that are located directly over the footprint of some underground facilities, baseflow reduction is comprised between 15 and 23 l/s. The variation of baseflow is more pronounced when the catchment is smaller.
- After 30 years of operation, the simulated baseflow in the Buvu Creek catchment stabilizes at 47 l/s, which implies a reduction of 34% of the groundwater contribution to the surface water system. The Buvu Creek catchment is where the variation of simulated baseflow is the more pronounced.



Hydrologic basins selected for evaluation


Simulated groundwater contribution to surface water systems during operation

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Effect of the block-cave operation over the groundwater contribution to surface water systems

By	FB	Date	Oct 2017
Approved	AR	Fig	35

6.4 EVALUATION OF THE DEWATERING STRATEGY

6.4.1 Feedback on existing dewatering wells and review of dewatering options

The drilling of hydro-bores in 2014 was partially successful, and only a part of the pumping well drilled can be used as such.

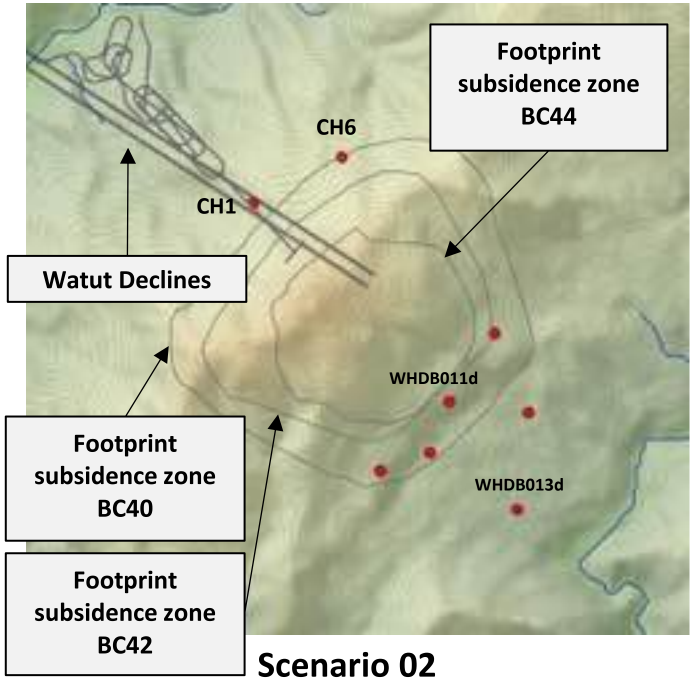
Additional drilling of characterization holes would provide valuable information:

- Hydraulic tests on borehole CH3 will indicate the existence or not of a boundary condition corresponding to the Nambonga river. The high yield equivalent to 14 l/s detected in the long-term airlift tests suggests that the fractured quartzite has the ability to convey water.
- Drilling of boreholes CH1, CH6 and CH5 will provide more information on the hydrogeological conditions of the western side of Mount Golpu. The western side of Mount Golpu, characterized by a breccia diatreme and fractured quartzite, has been poorly constrained in terms of hydraulic conductivity until now.

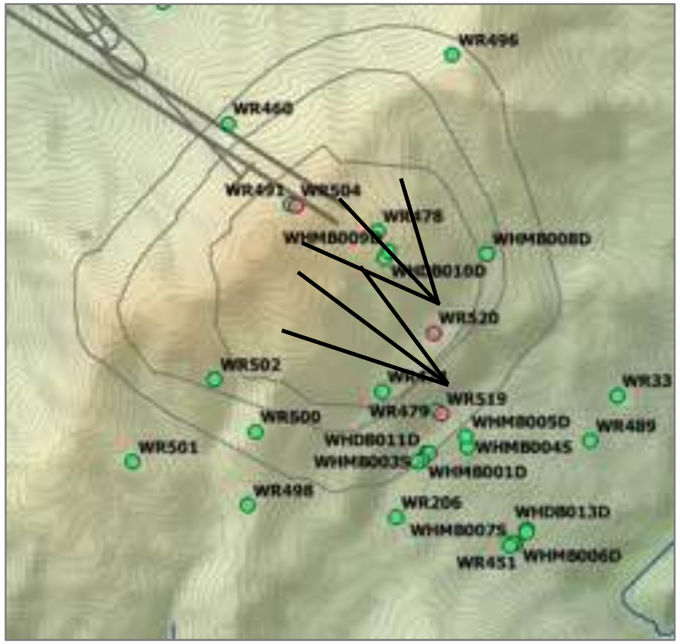
The dewatering should focus on the reduction of groundwater levels in the weathered bedrock above the subsidence zone, as it is the only drainable unit. The fresh metasediments yield negligible amounts of water, and dewatering this unit would have little effect on groundwater levels due to the very low conductivity and storage capacity. Thus, in the eventual use of vertical pumping wells, the maximum depth should not exceed 200 m, unless a specific objective or target justifies it. Two different scenarios have been developed in order to evaluate the beneficial effect of each dewatering method on the reduction of inflows in the extraction levels (Figure 36):

- CH1 and CH6 will be located on Mount Golpu, and outside of the subsidence zone. Depending on the results of the pumping tests, they could be used as dewatering wells to reduce the groundwater head in the upper part of Mount Golpu. Those wells should be added to the existing dewatering capacity on the Eastern side of Mount Golpu (approximately 15 l/s in total with WHDB011d, WHDB013d and WHDB014s).
- As a cost-effective alternative, horizontal drains drilled from the platforms WR519 and WR520 could be considered. The trace of the drains would go essentially through the weathered unit which is holding the largest amount of water. In addition, groundwater levels are high on this side of Mount Golpu, so the groundwater system will be intersected rapidly. From a practical perspective, if the first drain is successful, the same platform can be used to drill several drains at different directions and inclinations.

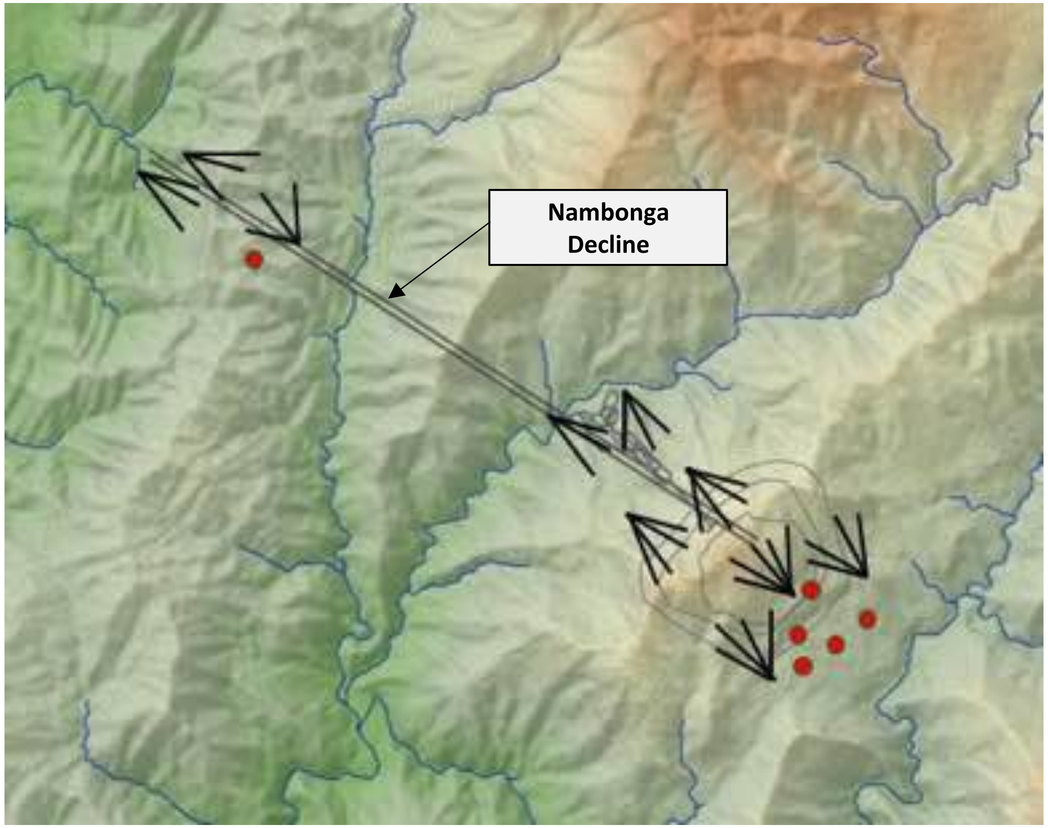
Scenario 01



Scenario 02



Scenario 03



—	**Horizontal drain**
●	**Pumping well**

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Scenario developed to evaluate different dewatering strategies

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Approved	AR	Fig	36

6.4.2 Development of scenarios to simulate different dewatering strategies

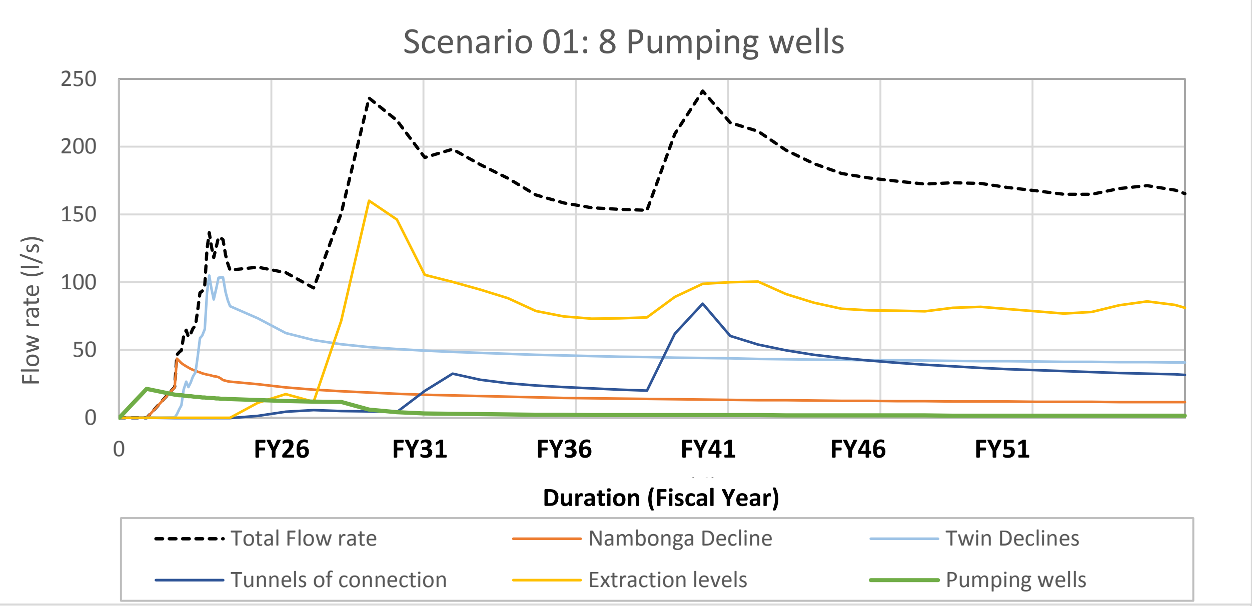
Based on the available information, the following scenarios have been developed (see Figure 36):

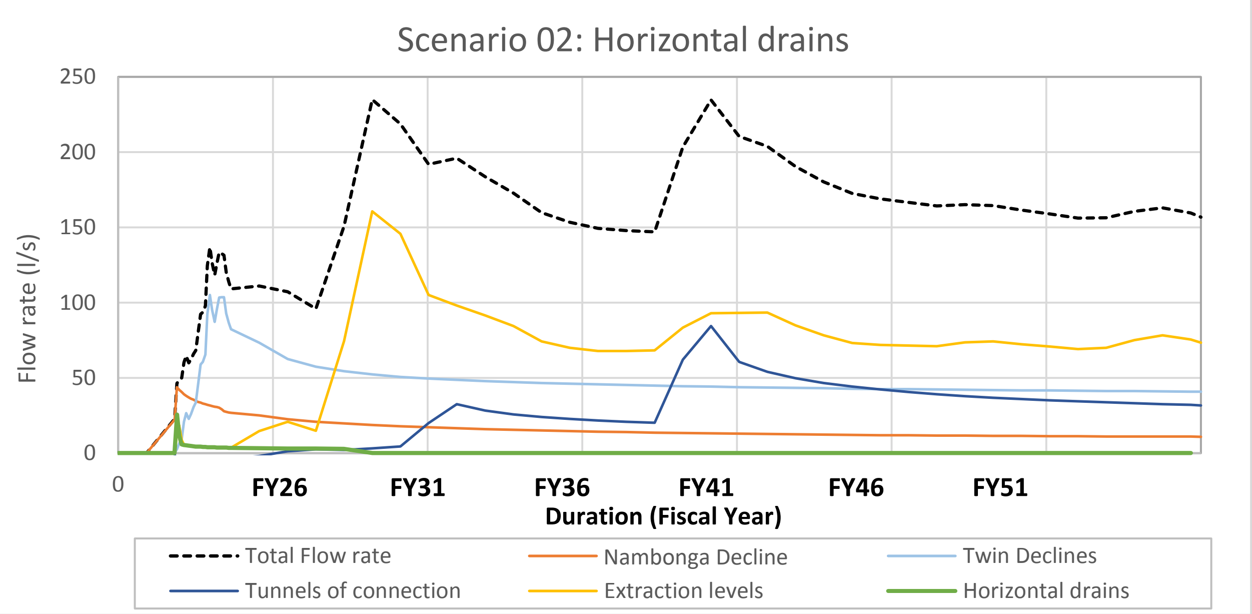
- **Scenario 01, Vertical wells**: A first scenario with 8 vertical wells immediately around the subsidence zone is implemented. This scenario assumes that WHDB013d, WHDB011d, CH1 and CH6 can be used for the dewatering. Thus, this scenario considers the construction of 4 dewatering wells only.

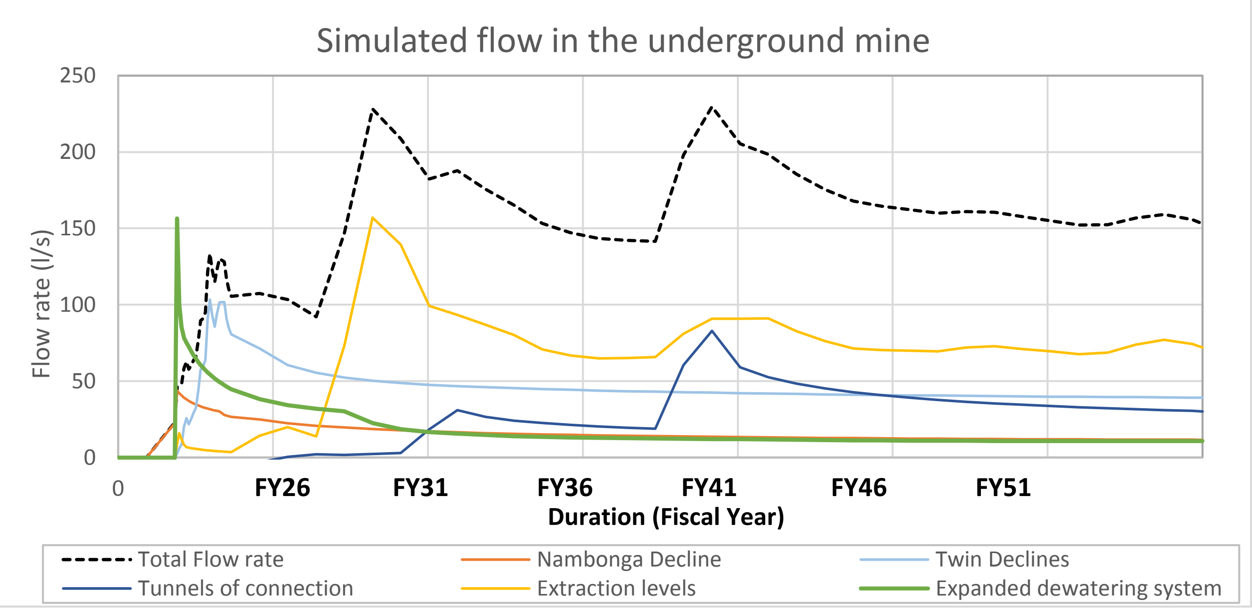
  The base case scenario is used to develop an alternative model, with the inclusion of dewatering wells. The dewatering wells are added to the model with the boundary condition ‘Well’. A maximum flow rate of 5 l/s is assigned to each well. In addition, a hydraulic-head constraint is applied to the boundary condition to deactivate the boundary condition if the hydraulic-head is below the well (or conceptually the pump). To finish, the boundary condition is activated at FY20. It provides a period of 10 years before the cave reaches the surface.
- **Scenario 02, Horizontal drains**: The second scenario considers horizontal drains drilled from the WR519 and WR520 drill pads. It considers the construction of horizontal drains by the installation of seepage nodes at the contact between the weathered bedrock and partially weathered bedrock to an elevation varying between 440 and 520 masl and at a distance of 200-300 m of the drill pads. As well as scenario 01, the boundary condition is activated at FY20. It provides a period of 10 years before the cave reaches the surface.
- **Scenario 03, Expanded vertical wells**: This scenario considers the implementation of 36 horizontal drains and 6 pumping wells around the footprint of the subsidence zone, the Nambonga Decline and the Portal. A special focus is given to pumping around the Nambonga Decline to evaluate the effect of pumping wells.

6.4.3 Interpretation of model results

Dewatering scenarios indicates that in terms of volume, dewatering boreholes manage to remove a larger amount of water than the horizontal drains (Figure 37). The column of water above the horizontal drains is inferior to the total volume pumpable by the vertical wells. Nevertheless, horizontal drains do remove water and reduce the hydraulic head above the cave, and the dewatering boreholes remove water at the side of the future subsidence zone on the slopes of Mount Golpu.







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Simulated flow in the underground mine with the pumping wells and horizontal drains

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Effects of different scenarios are very similar in terms of inflow reduction in the extraction level. It has no effect on the first peak of inflow in the extraction levels, which coincides with the development of the cave from BC44 in the bedrock and partially weathered bedrock. The second peak associated with the development of the cave from BC42 and BC40 are not influenced by any of the dewatering systems. Only scenario 03 achieves an overall inflow reduction of 10l/s, equivalent to an inflow reduction of only 7%.

Analysis of groundwater levels and extracted volumes of water by the dewatering systems indicate that a dewatering strategy from the surface is only beneficial in the first ten years of operation. Once the cave reaches the surface, groundwater levels around the cave drop and all the pumping wells and horizontal drains installed at the surface become dry and inoperable.

Dewatering strategies implemented in the shallower weathered bedrock have a limited effect on the total reduction of inflows in the deeper units. It appears technically difficult to extract water in deep units with low conductivity and storage capacity, but a large surface of contact with the caved zone.

Calculated inflows, including the peak flow rate, are reasonable given the scale and the depth of the underground mine. More importantly, magnitude of groundwater inflows obtained in the model are manageable by conventional pumping systems with or without considering the dewatering system. Consequently, the consideration a dewatering system can be questioned given the limited beneficial effect.

7 SENSITIVITY AND UNCERTAINTY ANALYSIS

7.1 SENSITIVITY ANALYSIS

Sensitivity analysis was performed to assess the influence of variations introduced for key model parameters. This sensitivity analysis process typically assists in the provision of fundamental understanding of principal controls within the groundwater flow system.

The parameters subject to testing during the sensitivity analysis included the K values assigned to each of the hydrogeological units. Table 21 summarizes the sensitivity of calibrated hydraulic-head to each parameter assessed. This represents a quantitative index of model sensitivity. Relative Composite Sensitivity (RCS) is calculated by multiplying composite sensitivity (which is an output of the FePEST software) by the log of parameter variance. It corresponds to the changes in model outputs that are incurred by a fractional change in the value of any input parameter.

Table 21: Results of PEST sensitivity analysis to model calibration

		Calibrated value	**Relative Composite Sensitivity**
HU1	**Alluvial**	4.5×10^{-1}	0.82
HU2	**Weathered bedrock**	$2. \times 10^{-3}$ to 1.4×10^{-2}	10.44
HU3a	**Weathered bedrock (85-200m)**	2.5×10^{-3}	3.81
HU3b	**Partially weathered bedrock (200-600m)**	9.0×10^{-4}	4.57
HU4	**Bedrock**	2.0×10^{-5}	0.28
HU5a	**Golpu faults**	1.0×10^{-2}	0.57
HU5b	**Buvu faults**	4.5×10^{-1}	0.48

Based on the data presented in Table 20, the calibration of groundwater levels in the FEFLOW model appears highly sensitive to the weathered bedrock (HU2) value entered into the model. A lesser, though significant level of sensitivity is also displayed with respect to the hydraulic conductivity assigned to the partially weathered units (HU3).

The fact that monitoring data are located essentially in the weathered and partially weathered bedrock supports the quantitative observation presented in Table 20. In addition, it appears logical that the hydraulic head in relatively shallow observation points located on Mount Golpu, and following accurately the steep topographic pattern, are primarily determined by units having a very reduced hydraulic conductivity.

A similar sensitivity analysis was carried out on a steady-state model with the underground mine to evaluate sensitivity of underground flow to parameters. Results are presented in Table 22.

Table 22: Results of PEST sensitivity analysis to underground mine inflow

		Calibrated value	**Relative Composite Sensitivity**
HU1	**Alluvial**	4.5×10^{-1}	211
HU2	**Weathered bedrock**	$2. \times 10^{-3}$ to 1.4×10^{-2}	5791
HU3a	**Weathered bedrock (85-200m)**	2.5×10^{-3}	52662
HU3b	**Partially weathered bedrock (200-600m)**	9.0×10^{-4}	182275
HU4	**Bedrock**	2.0×10^{-5}	695386
HU5a	**Golpu faults**	1.0×10^{-2}	7320
HU5b	**Buvu faults**	4.5×10^{-1}	22071

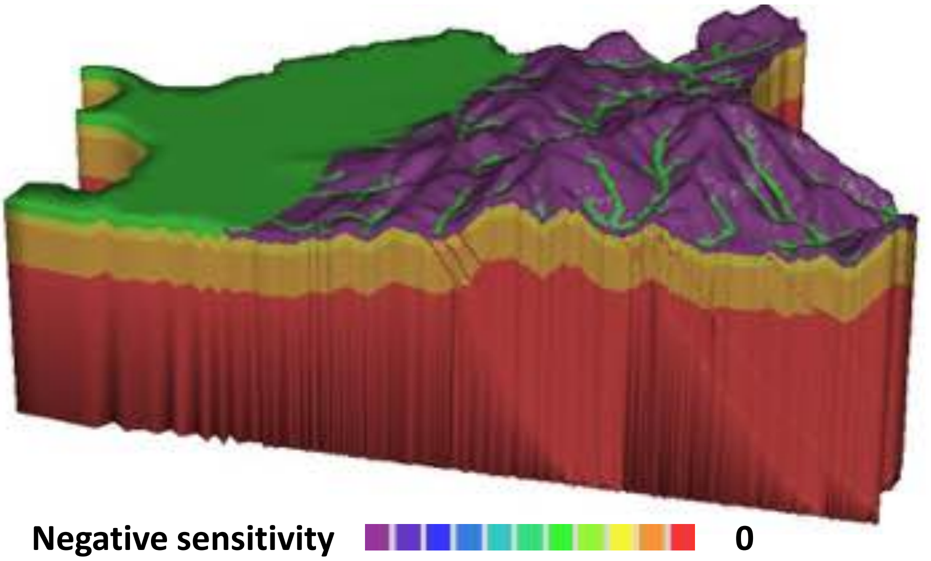
The normalization by the number of observations explains why composite sensitivity is much higher than in the previous sensitivity analysis. According to the RCS presented in Table 21, it appears that underground inflow is highly sensitive to the bedrock value (HU4), and to a lesser extent to the partially weathered bedrock (HU3). The higher sensitivity associated with the Buvu faults compared to the Golpu faults (Reid, Overprint and Hekeng) can be explained by the greater thickness of these features crossing the Watut Declines.

Figure 38 shows the variation of model sensitivity across the domain with respect to (a) the hydraulic conductivity assigned for calibration points, (b) the hydraulic conductivity assigned for underground mine inflows, and (c) a multiplication of the initial parameter value with fixed constant values. In the first figure, negative sensitivity values reflect a tendency for decreasing hydraulic-head with increasing value of the input parameter. Figure 38 therefore indicates that:

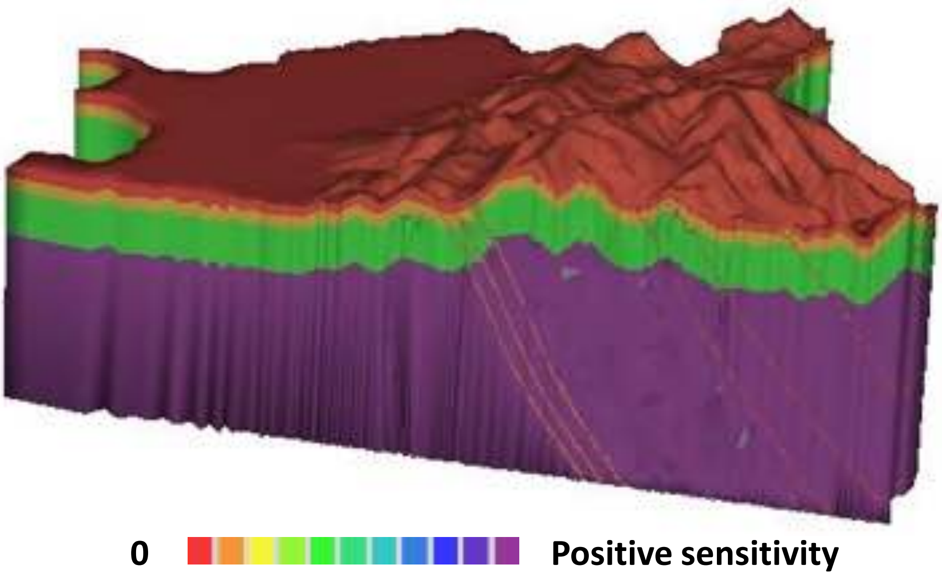
a) For the hydraulic head, there is a strong negative sensitivity to hydraulic conductivity values assigned to the weathered bedrock (HU2). Thus, any increase in the calibrated hydraulic conductivity value would be expected to negatively impact simulated groundwater levels.

b) For the underground inflow, there is a strong sensitivity to bedrock (HU4) followed by the partially weathered bedrock (HU3). The Watut Declines and the Nambonga Decline cross the partially weathered bedrock (HU3) and increase the sensitivity on this parameter,

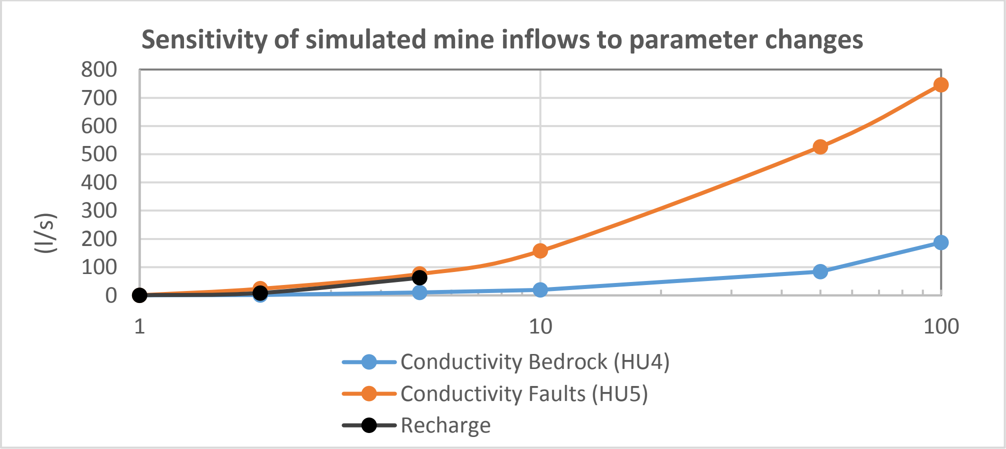
a) **Distribution of sensistivity for hydraulic-head calibration**



b) **Distribution of sensistivity for underground mine inflows**



c)


Sensitivity of simulated mine inflows to parameter changes

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Results of the sensitivity analysis

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while most of the extraction levels are emplaced in the bedrock (HU4) and explain the high sensitivity to the parameter assigned for this unit.

c) Multiplying the initial parameter by fixed constant values indicates that mine inflows are most sensitive to the hydraulic conductivity of the fault. It is expected that faults with a high conductivity may play a critical role in the low conductivity bedrock, especially where they intersect the block cave. However, presenting the results of the sensitivity analysis in this way can be misleading and contradictory with previous observations. This is because the results presented in the graph and increments of 10 and 100 are highly dependent on the initial value of each parameter, and the fact is that the initial hydraulic conductivity of faults is higher than the hydraulic conductivity of the bedrock by various orders of magnitude.

7.2 UNCERTAINTY ANALYSIS

The base case model evaluated in Section 6 is a deterministic model based on the judgement of the modeler and the information available. The base case model is one combination of parameters that enables a good match with calibration variables. Range of values associated to parameters used in the calibration involves a non-uniqueness associated with the inverse solution. Thus, it is possible to find more than one calibrated model with different parameter sets and predictions varying at different levels, making difficult the use of a single model for decision making.

One of the objectives of the uncertainty analysis is to identify best cases and worst cases, and the probability of occurrence of a given prediction. A Monte-Carlo analysis has been undertaken on the pre-mining model. Two hundred simulations have been modeled with random values for each hydrogeological unit. The bounds identified in Table 9 have been used to define ranges of parameter values to be used in the Monte-Carlo analysis. Maximum hydraulic conductivity of faults has been set to 1 m/d to encompass potential high values associated with discrete features that have very high permeability. A log uniform distribution over the parameter range has been chosen to not concentrate parameters around the calibrated parameter in the deterministic model.

The random parameter sets give variable results in term of hydraulic head calibration. A screening among the Monte-Carlo simulations has been applied to select the 20 best calibrations, which are equivalent to parameter sets giving a NRMS inferior to 15%. It is worth noting that none of the calibration-constrained Monte Carlo simulations give a calibration better than that obtained in the deterministic model.

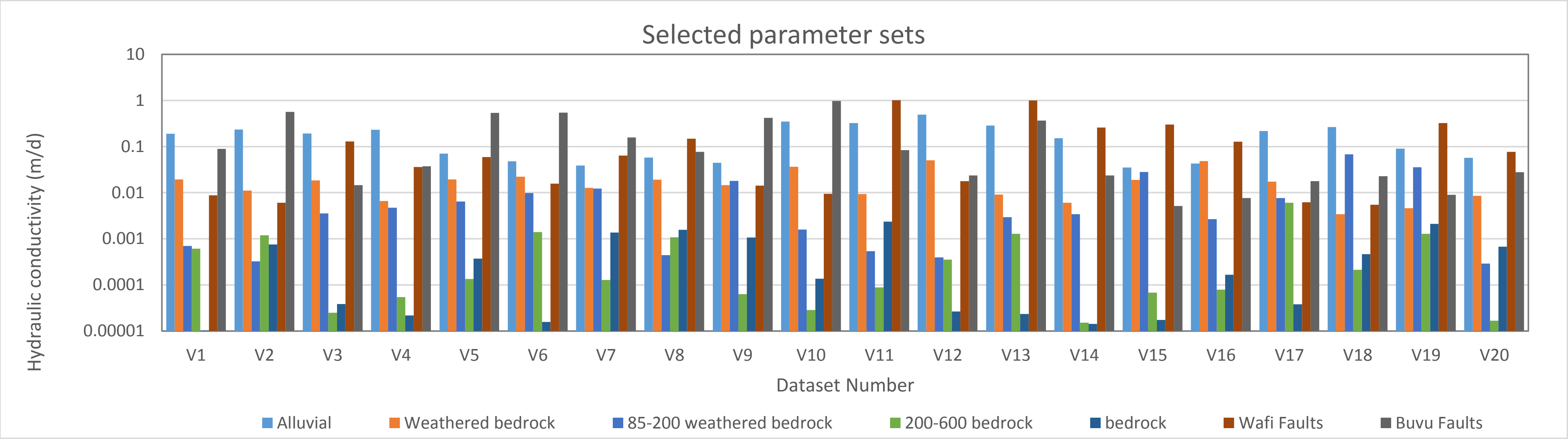
The models have been run to evaluate the inflow of water to the underground mine. Results are presented in Figure 39. The results show that:

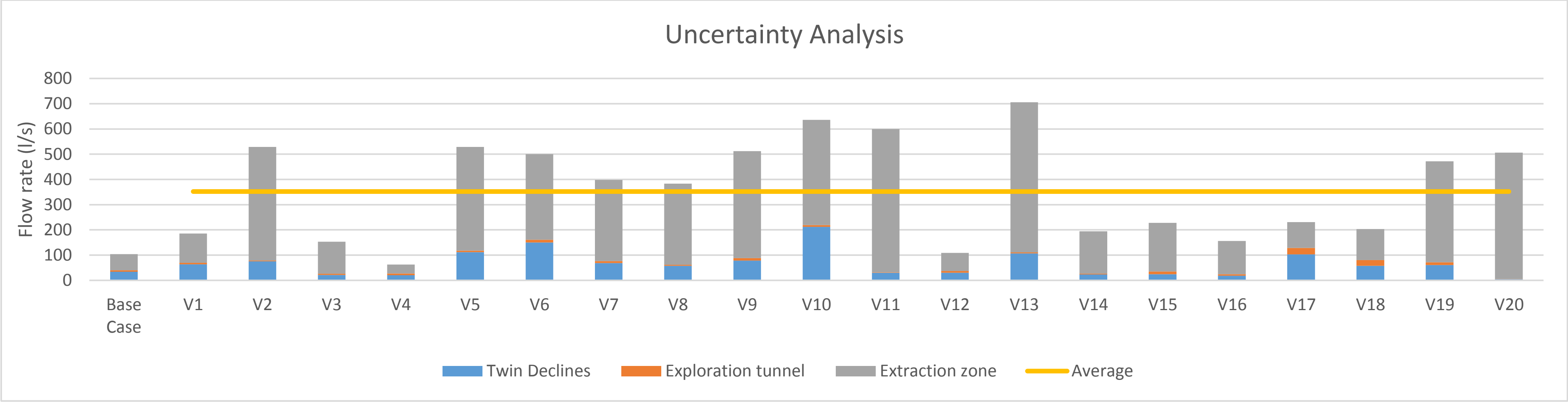
- Underground mine inflows range from 60 to 700 l/s, with an average value of 350 l/s.
- Monte-Carlo models give generally higher mine inflow values than the base case model which suggests a long-term mine inflow of 110 l/s. The base case model uses a hydraulic conductivity of 2 x 10^{-5} m/d for the bedrock (HU4), which coincides with the lower value in the parameter range. In contrast, the models obtained in the Monte-Carlo analysis always have a hydraulic conductivity higher than the base case model for the parameter the most sensitive for the prediction. Thus, Predictions in uncertainty analyses will always be greater than that used in the base case model, so mine inflows simulated from other parameter sets are likely to be higher. Higher mine inflows are obtained with parameter sets combining high hydraulic conductivity for the fresh bedrock and faults.

7.3 CONCLUSION

The sensitivity analysis and uncertainty analysis underlines parameter uncertainties associated with the fresh bedrock (HU4). The calibrated model constrains values for the weathered bedrock (HU2) and partially weathered bedrock (HU3), upon which model predictions are relatively sensitive. However, the model has a very limited influence on the constraints of the bedrock (HU4), which is the most important unit for model predictions.

Given the range of hydraulic conductivity obtained from field measurements, the K value for the fresh bedrock (HU4) in the base case model coincides with the lower bound of this unit. In consequence, as it is suggested by the uncertainty analysis, the deterministic model may appear unconservative. However, given the depth of the proposed facilities (up to 1700 mgbl), and the absence of hydrogeological information below 1121 mbgl, the value of 2 x 10^{-5} m/d considered for the bedrock (HU4) is realistic and not unconservative for very fresh bedrock.





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Results of the uncertainty analysis

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8 LIMITATIONS

Piteau Associates has exercised reasonable skill, care and diligence in obtaining, reviewing, analyzing and interpreting the information acquired during this study, but makes no guarantees or warranties, expressed or implied, as to the completeness of the information contained in this report. Conclusions and recommendations provided in this report are based on the information available at the time of this assessment.

In preparing the recommendations contained herein, Piteau has relied on information and interpretations provided by others. Piteau is not responsible for any errors or omissions in this information. This report is comprised of text, tables, figures, photos and appendices, and all components must be read and interpreted in the context of the whole report. The report has been prepared for the sole use of Morobe Mining Services (Australia) Pty Ltd, and no representation of any kind is made to any other party.

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