

Mokolo Crocodile Water Augmentation Project Phase 2 (MCWAP-2): Desktop and Field-based Risk Assessment of the Mooivallei Bat Cave



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Table of Contents

1. PROJECT INTRODUCTION.....	5
2. ASSESSMENT TEAM	5
2.1 KATE MACEWAN	6
2.2 DR CAROLINE LÖTTER	6
2.3 TREVOR MORGAN	6
2.4 JULIO BALONA	6
2.5 STUART MORGAN	6
3. ENVIRONMENTAL SETTING.....	7
3.1 GEOLOGY & CAVES.....	7
3.2 HYDROLOGY.....	7
3.3 VEGETATION & LAND-USE	7
4. IMPORTANT LEGISLATION AND CONSERVATION CONSIDERATIONS.....	9
4.1 INTERNATIONAL AGREEMENTS	9
4.1.1 CONVENTION ON BIOLOGICAL DIVERSITY (CBD)	9
4.1.2 (BONN) CONVENTION ON THE CONSERVATION OF MIGRATORY SPECIES (CMS) OF WILD ANIMALS	9
4.2 NATIONAL LEGISLATION.....	9
4.2.1 NATIONAL ENVIRONMENTAL MANAGEMENT: BIODIVERSITY ACT (NEM:BA)	9
4.3 PROVINCIAL LEGISLATION.....	9
4.3.1 LIMPOPO ENVIRONMENTAL MANAGEMENT ACT (LEMA)	9
4.4 PROTECTED AREAS	9
4.5 LIMPOPO CONSERVATION PLAN (C-PLAN)	9
5. METHODOLOGY	12
5.1 SOURCES OF INFORMATION	12
5.2 BAT SPECIES LIKELIHOOD OF OCCURRENCE.....	12
5.3 FIELDWORK	12
5.4 DATA ANALYSIS	13
5.5 SENSITIVITY MAPPING.....	13
5.6 DETERMINATION OF RISKS AND RECOMMENDED MITIGATION.....	13
5.7 LIMITATIONS	13
6. RESULTS AND DISCUSSION	16
6.1 POTENTIALLY OCCURRING BAT SPECIES	16
6.2 MOOIVALLEI CAVE.....	16
6.3 CROCODILE (WEST) RIVER	21
6.4 SURROUNDING LANDSCAPE	22
6.5 SUMMARY	23
7. KEY PROJECT CONCERNS	24
7.1 DIRECT CONCERN	24
7.2 ASSOCIATED CONCERNS	24
7.2.1 WEIR CONSTRUCTION AND ABSTRACTION	24
7.2.2 CROP-LAND IRRIGATION	25
8. CONCLUSIONS	25
9. RECOMMENDATIONS AND WAY FORWARD	25
10. REFERENCES	29



11. APPENDIX 1: GRAVITY SURVEY IMAGE OF MOOIVALLEI BAT CAVE AND ITS IMMEDIATE SURROUNDS (FROM GEOFOCUS, 2020)	31
12. APPENDIX 2: SONOGRAMS OF THE CALLS OF 12 BAT SPECIES RECORDED AT MOOIVALLEI	32
13. APPENDIX 3: GEOTECHNICAL ASSESSMENT OF MOOIVALLEI BAT CAVE BY GEOID (2020)	46

List of Figures

FIGURE 1	PHOTOGRAPHS OF MOOIVALLEI BAT CAVE AND THE NEARBY CROCODILE (WEST) RIVER	8
FIGURE 2	HYDROLOGICAL FEATURES AND VEGETATION TYPES AROUND MOOIVALLEI BAT CAVE	10
FIGURE 3	MINES, PROTECTED AREAS, AND PROVINCIAL CRITICAL BIODIVERSITY AREAS AROUND MOOIVALLEI BAT CAVE	11
FIGURE 4	EXAMPLES OF SAMPLING METHODS USED DURING THE IWS FIELD SURVEY FROM 30 SEPTEMBER TO 2 OCTOBER 2020	14
FIGURE 5	IWS' SAMPLING EFFORT AT AND AROUND MOOIVALLEI BAT CAVE, INCLUDING WHERE THE CALLS OF DIFFERENT BAT SPECIES WERE RECORDED ALONG DRIVEN TRANSECTS, AND WHERE BAT GUANO WAS FOUND DURING ACTIVE SEARCHING FOR BAT ROOSTS	15
FIGURE 6	AGGREGATIONS OF <i>R. SIMULATOR</i> , BAT GUANO, AND ONE OF SEVERAL DEAD BATS IN THE MOOIVALLEI BAT CAVE	18
FIGURE 7	BAT SPECIES THAT WERE CAPTURED IN A HARP TRAP AT THE ENTRANCE OF MOOIVALLEI BAT CAVE	19
FIGURE 8	DIVERSITY OF BAT SPECIES RECORDED BY EM3 AND SM2 ULTRASONIC BAT DETECTORS PLACED INSIDE OR OUTSIDE THE CAVE OR AT THE NEARBY CROCODILE (WEST) RIVER	20
FIGURE 9	BUILDINGS THAT WERE SEARCHED FOR EVIDENCE OF BAT ROOSTING	22
FIGURE 10	PHOTOGRAPHS TAKEN BY GARY BAUER AT MOOIVALLEI OF BATS	23
FIGURE 11	PROPOSED BUFFERS FOR THE MOOIVALLEI BAT CAVE AND NEARBY CROCODILE (WEST) RIVER AND ITS SUBTROPICAL ALLUVIAL VEGETATION	28

List of Tables

TABLE 1	LIST OF CONFIRMED AND POTENTIALLY OCCURRING BAT SPECIES	17
TABLE 2	NUMBER OF CALLS RECORDED BY DIFFERENT BAT SPECIES AT MOOIVALLEI BAT CAVE AND THE CROCODILE (WEST) RIVER	21



Declaration of Independence

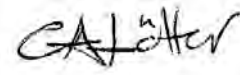
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Signed for Inkululeko Wildlife Services (Pty) Ltd by:



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1. Project Introduction

GBN Joint Venture (GBN-JV) is assisting the Department of Water and Sanitation (DWS) with the environmental approval process for the Mokolo Crocodile (West) River Water Augmentation Project Phase 2 (MCWAP-2) - the transfer of water from the Crocodile (West) River near Thabazimbi, to the Steenbokpan and Lephalale areas, including the implementation of the River Management System in the Crocodile (West) River and its tributaries.

The proposed MCWAP-2 Water Transfer Infrastructure (WTI) initiates its route in the Vlieëpoort Mountains at the proposed weir site in the Crocodile (West) River, in the south-western point of the project area. From there, it continues in a predominantly northerly direction along existing roads, farm boundaries and a railway line, until it reaches its destination near the Medupi Power Station between Steenbokpan and Lephalale.

Various baseline and impact assessments have been performed for this project, including at least one on mammals (Galago Environmental, 2010), terrestrial ecology (Nemai Consulting, 2018a), wildlife / the regional game farming industry (NABRO Ecological Analysts, 2018), environmental impact assessment (Nemai Consulting, 2018b), dolomite stability (GBN-JV, 2020a), and geohydrology and geotechnical considerations (GBN-JV, 2020b). In a number of these reports, a cave on (Portion 10 of) the Farm Mooivallei 342 KQ (hereafter referred to as Mooivallei Bat Cave) and/or the local or regional presence of cave-roosting bat species, is mentioned. Although in certain reports Galago Environmental (2010) is cited as having found the Cave, there is no mention in their report of any cave. It was instead highlighted by a farmer during a 2009 public participation process, and was already in 1996 mapped by the South African Speleological Association and Council for Geoscience (Martini and Moen, 1996). A Gravity Survey of Mooivallei Bat Cave was performed more recently by GeoFocus (2020).

Mooivallei Bat Cave occurs over an area underlain by extensive dolomite. Therefore, in terms of the Limpopo Environmental Management Act (LEMA; Act 7 of 2003) concerning the preservation of caves, and with regard to the rules of engagement for structures on / traversing dolomite in the national code of practice SANS 1936:2012, and in terms of the pre-construction monitoring requirements of the Environmental Authorisation (EA) issued for the project by the Department of Environmental Affairs, Forestry and Fisheries (DEFF) on 18 March 2019, the GBN-JV approached Inkululeko Wildlife Services (IWS) to request the present assessment of Mooivallei Bat Cave from a zoological and geotechnical perspective. Provisional findings and recommendations from a desktop investigation were submitted by IWS in July 2020 (IWS 2020). **Presented in this report are the final findings and recommendations of IWS, based on both the desktop investigation and a field-based survey of the Cave and its immediate surrounds**, which was performed during 30 September – 2 October 2020. **Note that the present report must be read in conjunction with the desktop and field-based Geotechnical Investigation Report by Geoid Geotechnical Engineers (Geoid) (Section 13 Appendix 3).**

2. Assessment Team

IWS is a bat specialist consultancy founded in 2014 by Kate MacEwan, a former founding member of Natural Scientific Services (NSS) for 11 years. IWS team members have conducted close to 40 long-term pre-construction bat monitoring studies, and 10 long-term operational bird and bat monitoring studies for wind energy facilities in southern Africa. IWS team members were also involved with the bat sensitivity analysis of the Strategic Environmental Assessment for South Africa's Renewable Energy Development Zones (REDZs), and have performed numerous other bat specialist assessments and inventories for caves, mines and protected areas in Africa. For this project IWS was assisted by volunteer bat expert Julio Balona. The geotechnical assessment was sub-contracted to Geoid, directed by Stuart Morgan. Geoid is a geotechnical consulting company with a sub-specialisation in dolomite engineering and GIS modelling.



2.1 Kate MacEwan

Kate is a SACNASP registered zoologist and environmental scientist with a BSc Honours in Zoology from Wits University. She has over 22 years of zoological and practical bat conservation experience, and wide diversity of contacts with various African bat academics and biologists. Kate is currently the chairperson for the South African Bat Assessment Association (SABAA), and a member of the Gauteng and Northern Regions Bat Interest Group (GnorBIG). Kate is a co-author on several bat species accounts in the latest southern African Red Data mammal listings (Child *et al.* 2016), and the lead / co-author of the current South African Good Practice Guidelines for bat monitoring studies at wind energy facility (WEF) developments during pre-construction (edition 5; MacEwan *et al.* 2020) and operation (edition 2; Aronson *et al.* 2020).

2.2 Dr Caroline Lötter

Caroline has since 2011 worked with Kate on multiple long-term bat monitoring studies for proposed WEFs, and is also a co-author of the current South African Good Practice Guidelines for bat monitoring studies at WEF developments pre-construction (edition 5; MacEwan *et al.* 2020). Caroline is SACNASP accredited as a Professional Natural Scientist in the field of Zoology, and obtained a PhD in Zoology on the conservation biology of the rare Giant Bullfrog (*Pyxicephalus adspersus*). As previously a Senior Faunal Specialist and project manager at NSS, Caroline has performed numerous impact assessments on vertebrate and invertebrate fauna throughout South Africa and as far afield as Sierra Leone. Caroline is a member of the SABAA, GnorBIG, and the Zoological Society of Southern Africa.

2.3 Trevor Morgan

Trevor has worked with Kate for almost 10 years as the senior technical specialist on all the various bat projects. He has served as an active member on the Executive Committee of the GNorBIG for several years. He is very knowledgeable on South African bats and has extensive experience with bat detectors, their related software, mist-netting and harp-trapping. By trade, Trevor is an electrician and an inventor, and has constructed his own harp trap and heterodyne bat detector. Trevor's considerable field-based involvement in all long-term bat monitoring studies performed by NSS and IWS has been invaluable.

2.4 Julio Balona

Julio is the Chairman of the Gauteng and Northern Regions Bat Interest Group. He has spent the last fifteen years deeply involved in the world of bats, learning about their biology specifically in the African context, with extensive practical experience gained on numerous field trips. In between studying bats, he has also given many public education talks on the subject, and has assisted IWS in the field on a number of occasions.

2.5 Stuart Morgan

Stuart Morgan is a registered professional civil engineer with the Engineering Council of South Africa (Reg No. 980456), with a specialisation in geotechnical engineering and a sub-specialisation in dolomite engineering and GIS modelling. He holds a BSc Eng (Civil) and an MSc Eng (Civil) from the University of the Witwatersrand and is a full member of the South African Institute of Civil Engineers (SAICE). He has over 26 years of post-graduate practical experience in civil engineering, with a focus on geotechnical matters, having worked throughout the SADC region and beyond. Stuart is the managing director and one of the principal engineers of Geoid Geotechnical Engineers, and has served as a former committee member of the SAICE Geotechnical Division. He is presently actively involved in a wide range of civil engineering projects, including those in dolomitic terrain, and has experience in the full regulatory process of dolomite development from concept through to construction, with expertise in dolomite sinkhole remediation and ground improvement.



3. Environmental Setting

In assessing local bat diversity and habitats, and potential impacts on these from the proposed project, the following local and regional environmental features were taken into consideration.

3.1 Geology & Caves

In South Africa, karst formations (caves and sinkholes) are most often associated with soluble rocks like limestone, dolomite, and gypsum, and for at least 15 South African bat species, geology is the most important limiting environmental factor (Salata, 2012). Large populations of bats, particularly species from the genera *Miniopterus*, *Rhinolophus* and *Myotis*, often occupy these types of caverns. In Limpopo Province, caves are protected under Chapter 10 of the Limpopo Environmental Management Act 7 of 2003 (LEMA; **Section 4.3.1**).

The Mooivallei Bat Cave is situated in dolomite of the Malmani Subgroup (Chuniespoort Group; Transvaal Supergroup; Geoid, 2020). The Cave has two entrance holes called “mokondos” (i.e. vertical solution pits in secondary limestone), which have been fenced to prevent livestock from falling in (Nemai Consulting, 2018a; **Figure 1**). The mokondos lead to a wide but low, dry chamber, which formed from a collapse in cherty dolostone. When Martini and Moen (1996) inspected Mooivallei Bat Cave, they reported that it had been exploited for guano, and that “only a few bats were.. seen”. According to Nemai Consulting (2018a), the cave-roosting Smithers’ Horseshoe Bat (*Rhinolophus smithersi* – previously *R. hildebrandtii*) and Natal Long-fingered Bat (*Miniopterus natalensis* – previously *M. schreibersii*) occur in the area. Findings from IWS’ recent survey of the Cave are presented in **Section 6**.

Situated approximately 34 km east of Mooivallei Bat Cave, are the Gatkop Caves. Here, at least eight bat species have been recorded including the **Endangered** Percival’s Trident Bat (*Cloeotis percivali*), and thousands of *M. natalensis* (Kearney and Seamark, 2012). As such, the Gatkop Caves have high conservation importance for bats (Kearney and Seamark, 2012), and the Mooivallei Bat Cave could have an ecological connection to Gatkop Cave. Other lesser known caves in the area include the Thabazimbi Mine Cave (Cairncross *et al.* 2016) and the Rookpoort Cave (Kearney and Seamark, 2012), 9 km and 40k m east of the Mooivallei Bat Cave respectively. The ecological connectivity between these caves is discussed in **Section 6.5**.

3.2 Hydrology

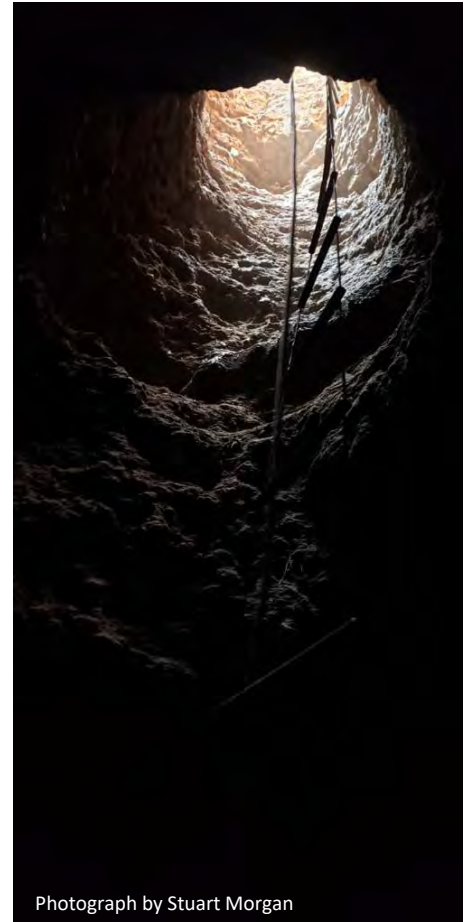
The Crocodile (West) River, which is situated approximately 500 m south-west of Mooivallei Bat Cave (**Figure 1; Figure 2**), is considered to represent the most important source of drinking water for locally occurring bat species. Elsewhere in the vicinity of the Cave, additional sources of surface water are largely limited to farm dams and reservoirs. Since the diversity and activity of insects (and other fauna) is expected to be locally concentrated at and around the River, this riparian system also represents important bat foraging habitat (Akasaka *et al.* 2009; Hagen and Sabo, 2012; Sirami *et al.* 2013). Furthermore, bats are known to use rivers as movement corridors (Serra-Cobo *et al.* 2000; Salata, 2012). According to the national Department of Water Affairs (2011), “The Crocodile West River catchment is one of the most developed river catchments in the country. It is characterised by the sprawling urban and industrial areas of northern Johannesburg and Pretoria, extensive irrigation downstream of Hartbeespoort Dam and large mining developments north of the Magaliesberg.” Farmers have also expressed concern about potential impacts of the MCWAP-2 on the Crocodile (West) River and underground aquifers (GBN-JV, 2020b).

3.3 Vegetation & Land-use

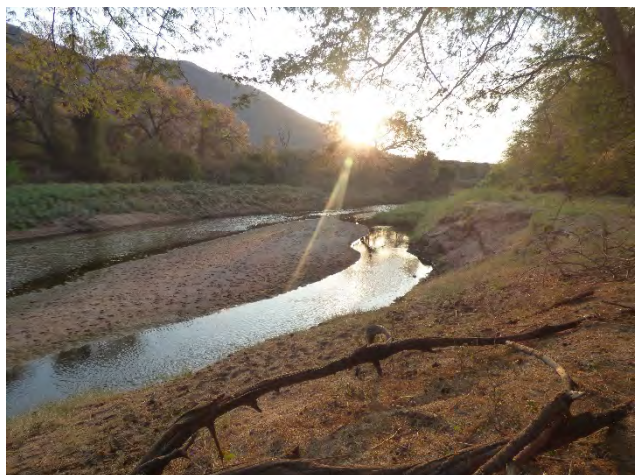
Mooivallei Bat Cave is situated in Dwaalboom Thornveld, and the nearby Crocodile (West) River supports Subtropical Alluvial Vegetation (Mucina and Rutherford, 2006; **Figure 1; Figure 2**), which likely provides important foraging and roosting habitat for bats.



The predominant forms of land-use in the region include game farming, mining, and cultivated crop and livestock farming. Cultivated (especially irrigated) crops in the Crocodile River catchment potentially provide important foraging habitat for certain bats. Natural caves and old mine tunnels in the region provide roosting habitat for certain cave-roosting bat species. Buildings in the region, which are concentrated around Thabazimbi, provide roosting habitat for various roof-roosting bat species.



Cave fencing and entrance holes



River with Subtropical Alluvial Vegetation

Figure 1 Photographs of Mooivallei Bat Cave and the nearby Crocodile (West) River



4. Important Legislation and Conservation Considerations

4.1 International Agreements

4.1.1 Convention on Biological Diversity (CBD)

It is recognized by the CBD that biological diversity is about more than plants, animals and micro-organisms and their ecosystems – it is about people and our need for food security, medicines, fresh air, clean water, shelter, and a healthy environment in which to live. It is an international convention signed by 150 leaders at the Rio 1992 Earth Summit. South Africa is a signatory. An important principle encompassed by the CBD is the precautionary principle which essentially states that where serious threats to the environment exist, lack of full scientific certainty should not be used as a reason for delaying management of these risks. The burden of proof that the impact will not occur lies with the proponent of the activity posing the threat.

4.1.2 (Bonn) Convention on the Conservation of Migratory Species (CMS) of Wild Animals

The CMS Convention, signed in 1979, serves to conserve terrestrial, marine and aerial migratory species throughout their range. South Africa is a party to this Convention, which affords protection to various migratory animals including bat species such as the Natal Long-fingered Bat (*Miniopterus natalensis*).

4.2 National Legislation

4.2.1 National Environmental Management: Biodiversity Act (NEM:BA)

NEM:BA (Act 10 of 2004) provides for the management and conservation of South Africa's biodiversity within the framework of the National Environmental Management Act (Act 107 of 1998); the protection of species and ecosystems that warrant protection; the fair and equitable sharing of benefits arising from bioprospecting involving indigenous biological resources; the establishment and functions of a South African National Biodiversity Institute; and for matters connected therewith. Under NEM:BA, the Threatened or Protected Species (ToPS) Regulations (2015) provide, inter alia, for the listing of national Threatened or Protected Species. Presently no bat species is listed as a Threatened or Protected Species under NEM:BA.

4.3 Provincial Legislation

4.3.1 Limpopo Environmental Management Act (LEMA)

LEMA (Act 7 of 2003) pertains, inter alia, to provincial protected areas, Specially Protected Wild Animals (SPWAs) and Protected Wild Animals (PWAs), the preservation of caves and cave formations, mountain catchments, limited development areas, and pollution (including noise, vibration and shock). Under LEMA no bat species is listed as a SPWA or PWA, but under **Chapter 10 Section 70 (2) “No person may – (b) disturb or alter the natural atmosphere of a cave in any manner.”**

4.4 Protected Areas

The Hanover and Ben Alberts / Thabazimbi private nature reserves flank Mooivallei Bat Cave to the west and east, respectively (**Figure 3**). In the Ben Alberts Reserve, at least eight bat species have been recorded (FIAO 2020), which are mentioned in **Section 6.1**.

4.5 Limpopo Conservation Plan (C-Plan)

The Crocodile (West) River and its riparian vegetation have been identified as a provincial Irreplaceable Critical Biodiversity Area (CBA1), and the terrestrial area wherein the Mooivallei Bat Cave is situated has been classified as an Important CBA (2) (**Figure 3**). **CBAs are areas of high biodiversity value which are usually at risk of being lost and usually identified as critical or important in meeting biodiversity targets.**



MCWAP-2: Mooivallei Bat Cave Risk Assessment

Date: 30 October 2020 – finalized 8 December 2020



Figure 2 Hydrological features and vegetation types around Mooivallei Bat Cave



MCWAP-2: Mooivallei Bat Cave Risk Assessment

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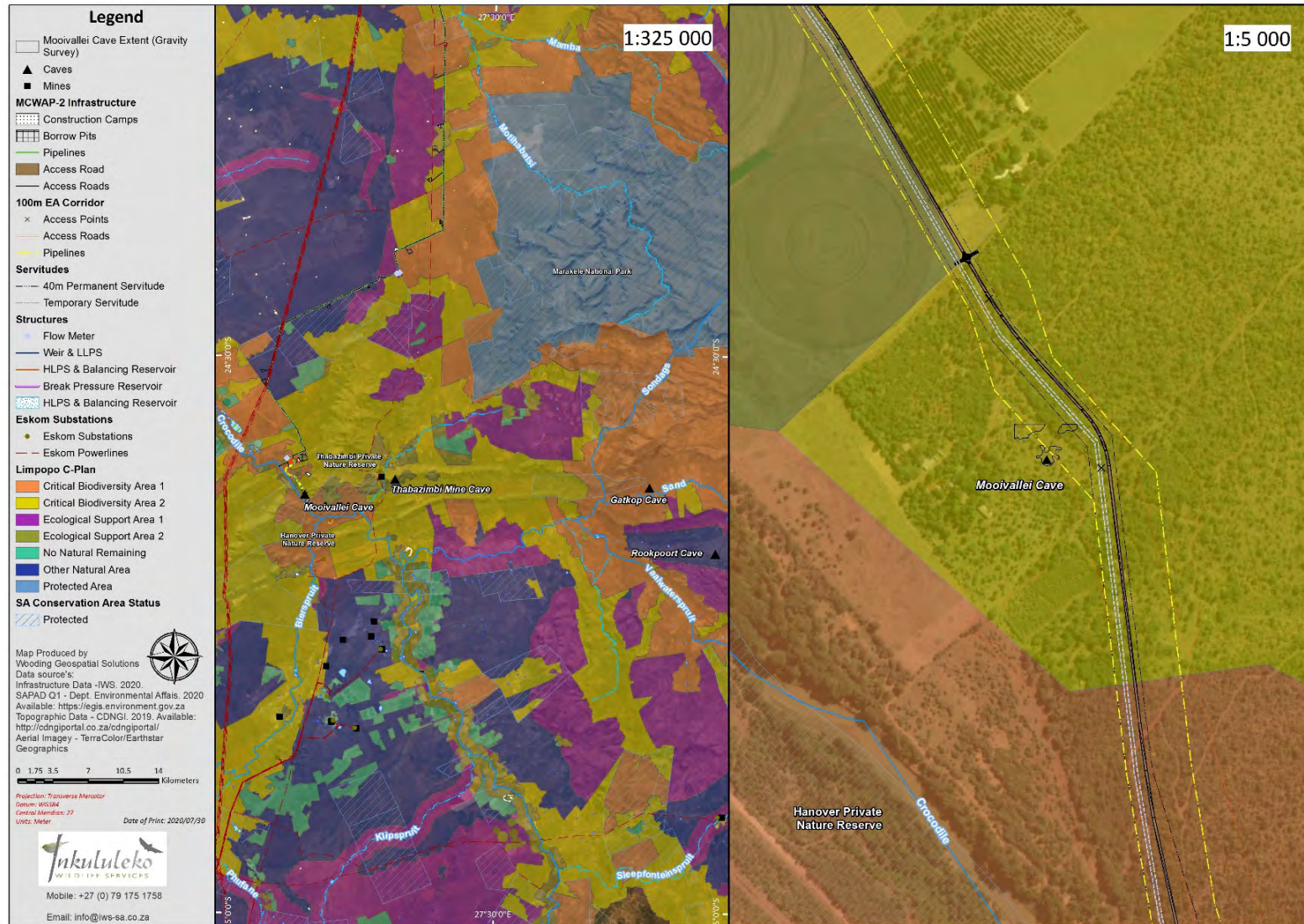


Figure 3 Mines, protected areas, and provincial Critical Biodiversity Areas around Mooivallei Bat Cave



5. Methodology

5.1 Sources of Information

The present assessment was based on a review of existing project specialist reports, the proposed layout of project infrastructure (including proposed alternative pipeline routes near the Cave), regional bat records, scientific publications, best practice guidelines, and other pertinent information (listed under **Section 10 References**).

5.2 Bat Species Likelihood of Occurrence

The in situ Likelihood of Occurrence (LoO) of regionally occurring bat species was determined based on the: i) bat species records and predicted distribution maps published in Monadjem *et al.* (2010), Salata (2012) and Jacobs *et al.* (2013); ii) bat species records provided online by MammalMAP (FIAO 2020) for the quarter degree square (QDS) 2427CB wherein the site (and part of the Ben Alberts Nature Reserve) is situated; iii) the IWS 30 September – 2 October site visit, including our observations of the Cave and its bats, other local habitats and land-use, live-captured bats, and the calls of bat species recorded in the Cave and surrounds; and iv) the IWS team's accumulated bat data and professional knowledge, expertise and judgement.

The local Likelihood of Occurrence (LO) of regionally-occurring bat species was rated as:

- **Present**, if a species was recorded during our survey.
- **High**, if a species has previously been recorded in QDS 2427CB, and/or in the surrounding region.
- **Moderate**, if local ecological conditions seem potentially suitable for a species.
- **Low**, if local ecological conditions seem unsuitable for a species, or if a species occurs only marginally and/or is very scarce.

Species known to definitely not occur within the region were not listed.

5.3 Fieldwork

The methods used during our field-based bat investigation are shown in **Figure 4**, and involved:

On 30 September 2020:

- Discussion with Annie, the wife of Mooivallei Portion 10 owner Gary Bauer, regarding the Cave and its bats.
- Day time visual inspection of the accessible interior of Mooivallei Bat Cave, and bats that were noticeably roosting inside the Cave; and recording of bat calls inside the Cave using an ultrasonic EchoMeter 3 (EM3) bat detector. Safe access into the Cave was provided by the Speleological Exploration Club.
- Recording of bat calls (from sunset to sunrise) using one ultrasonic SongMeter 2 (SM2) bat detector placed at an entrance hole of the Cave, and one placed in the Subtropical Alluvial Vegetation on the nearby bank of the Crocodile (West) River.
- Civil twilight visual observation of aerial bat activity around the Cave.
- Live-capture of bats using two harp traps placed outside the entrance holes of the Cave. Captured bats were photographed and released immediately, or soon after capture.
- Night time recording of bat calls using an EM3 bat detector, whilst driving slowly (<20 km/h) from the Cave to the tarred road to Thabazimbi.



On 1 October 2020:

- Discussion with Annie regarding potential bat roosts in local buildings.
- Day time visual inspection of the proposed weir and borrow pit sites on the Crocodile (West) River, and for potential bat roosts in abandoned buildings on Mooivallei Portion 11, and the homestead of Annie and Gary Bauer on Portion 10.
- Day time visual assessment of potential bat foraging habitat whilst driving to and from site, and while walking and driving on and around Portions 10 and 11, with special attention given to wooded natural areas, cultivated fields, gardens, and surface water resources.
- Civil twilight visual observation of aerial bat activity at the nearby Crocodile (West) River.
- Erection of two harp traps and two mist nets to live-capture bats in the Subtropical Alluvial Vegetation along the River.
- Night time recording of bat calls using an EM3 bat detector whilst driving slowly (<20 km/h) from the River to the tarred road to Thabazimbi.

On 2 October 2020:

- Discussion with Gary Bauer regarding the Cave, local bats, and the proposed project.

The methods used to survey the Cave's stability and extent are described in the Geoid (2020) report under Section 13 Appendix 3.

5.4 Data Analysis

Wildlife Acoustics Compressed (.wac) files of bat calls recorded by the SM2 and EM3 detectors were converted to wave (.wav) and zero crossing (.zc) files using the Kaleidoscope software program (Wildlife Acoustics Inc., USA). The converted call data were then analyzed in AnalookW (Titley Scientific, Australia) and BatSound (Pettersson Elektronik, Sweden) to identify bat species based on their diagnostic call characteristics.

5.5 Sensitivity Mapping

Features which were incorporated into the sensitivity mapping included Mooivallei Bat Cave and the Crocodile (West) River and its associated Subtropical Alluvial Vegetation. As there are currently no bat sensitivity mapping guidelines for pipeline developments in South Africa, IWS used recommendations for the buffering of caves and other bat important features, which have been published in the latest Gauteng Department of Agriculture and Rural Development (GDARD 2014) "Requirements for Biodiversity Assessments," and the latest "South African Best Practice Guidelines for Pre-construction Monitoring of Bats at Wind Energy Facilities" by MacEwan *et al.* (2020), respectively.

5.6 Determination of Risks and Recommended Mitigation

Finally, findings from the combined IWS and Geoid desktop- and field-based investigations, and discussions with GBN-JV on proposed MCWAP-2 activities in the vicinity of the Mooivallei Bat Cave, were used to: i) determine risks of the project to the Cave and local bats; and ii) prescribe recommended measures to mitigate these, so that the project Environmental Management Programme (EMPr) may be accordingly updated.

5.7 Limitations

The field survey was limited to two days and two nights during a single season (i.e. spring). Consequently, only a snapshot of bat diversity in the Cave was recorded. If the Cave were to be visited during other times of the year, potentially a different diversity (richness and/or abundance) of bat species would be recorded.





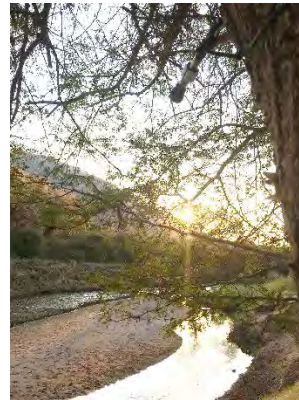
Photograph by
Stuart Morgan



Photograph by
Stuart Morgan



Survey of Cave with EchoMeter and hand-held net



SongMeter and microphone near the Cave, and near the River



Harp traps near the Cave, and near the River



Mist nets near the River

Figure 4 Examples of sampling methods used during the IWS field survey from 30 September to 2 October 2020





Figure 5 IWS' sampling effort at and around Mooivallei Bat Cave, including where the calls of different bat species were recorded along driven transects, and where bat guano was found during active searching for bat roosts

6. Results and Discussion

6.1 Potentially Occurring Bat Species

The Savanna Biome supports a high diversity of bats (Monadjem *et al.* 2010), and in the area where Mooivallei Bat Cave is situated, an estimated 24 bat species may occur (**Table 1**). Species that were rated during our desktop study with a High or Medium-High Likelihood of Occurrence (LoO) in and around the Cave included: cave-roosting bat species that are common in the greater Thabazimbi region *viz.* the Bushveld, Smither's and Blasius's horseshoe bats (*Rhinolophus simulator*, *R. smithersi* and *R. blasii*, respectively), the Natal Long-fingered Bat (*Miniopterus natalensis*), Sundevall's Leaf-nosed Bat (*Hipposideros caffer*), Temminck's Myotis (*Myotis tricolor*), Percival's Short-eared Trident Bat (*Cloeotis percivali*); bat species that are more or less ubiquitous across South Africa *viz.* the Egyptian Free-tailed Bat (*Tadarida aegyptiaca*), Cape Serotine (*Neoromicia capensis*) and Egyptian Slit-faced Bat (*Nycteris thebaica*); and bat species that are common in the Savanna Biome *viz.* Yellow-bellied House Bat (*Scotophilus dinganii*), Rusty Pipistrelle (*Pipistrellus rusticus*), and Zulu Serotine (*Neoromicia zuluensis*).

In the Ben Alberts Nature Reserve, which adjoins Mooivallei Portion 10, *H. caffer*, *N. thebaica*, *M. tricolor*, *R. blasii*, *R. simulator*, *R. smithersi*, and *S. dinganii* have been recorded (FIAO 2020). There is also a record of the Large-eared Slit-faced Bat (*Nycteris macrotis*) from the Reserve (FIAO 2020). However, as there is no published record of this species in South Africa (Monadjem *et al.* 2010), and since there are no morphological or call data accompanying the above-mentioned record, it is not considered reliable, and is likely a record of *N. thebaica*.

Of the 24 bat species listed in **Table 1**, the following five are most conservation important (CI):

- Percival's Short-eared Trident Bat (*C. percivali*): Regionally Red Listed as **Endangered** (Child *et al.* 2016).
- Smither's Horseshoe Bat (*R. smithersi*) (previously *R. hildebrandtii*): Red listed as **Near Threatened** both regionally (Child *et al.* 2016) and globally (IUCN 2020-1).
- Blasius's Horseshoe Bat (*R. blasii*): Regionally Red Listed as **Near Threatened** (Child *et al.* 2016), and experiencing a global population decline (IUCN 2020-1).
- Sundevall's Leaf-nosed Bat (*H. caffer*): Currently not Red Listed, but experiencing a global population decline (IUCN 2020-1).
- Natal Long-fingered Bat (*M. natalensis*) (previously thought to be *M. schreibersii*): known to roost in large numbers (sometimes hundreds or thousands of individuals) and to migrate hundreds of kilometres (Miller-Butterworth *et al.* 2003; Kearney *et al.* 2016; MacEwan *et al.* 2016).

6.2 Mooivallei Cave

On 30 September during our day time survey of Mooivallei Bat Cave, we counted at least 200 *R. simulator*, and observed an appreciable accumulation of bat guano (**Figure 6**). The calls of *R. simulator* and two additional bat species, *H. caffer* and *M. tricolor*, were recorded by the EM3 whilst we were inside the Cave (**Figure 8**).

Between sunset and midnight on 30 September we captured in the harp trap closest to the targeted Cave entrance hole, at least 77 *R. simulator*, 68 *H. caffer*, 34 *N. thebaica*, four *M. tricolor*, and one *C. percivali* (**Figure 7**). Potentially another one or two *C. percivali* specimens escaped from the harp trap before capture.

Of the calls recorded by the SM2, which was placed at the same entrance hole, and which operated between sunset and sunrise on 30 September and on 1 October (**Figure 8**), the vast majority (~90%) were made by *R. simulator*, followed by *H. caffer* (~4%).



MCWAP-2: Mooivallei Bat Cave Risk Assessment

Date: 30 October 2020 – finalized 8 December 2020



Table 1 List of confirmed and potentially occurring bat species

FAMILY	SPECIES ¹	COMMON NAME ^{1,2}	LIKELIHOOD OF OCCURRENCE ^{1,2,3}	RED LIST STATUS GLOBAL ⁴	SA ⁵	ENDEMISM ¹	EVIDENCE OF OCCURENCE
EMBALLONURIDAE	<i>Taphozous mauritanus</i>	Mauritian Tomb Bat	Present	LC(U)	LC		Photographed by G. Bauer
HIPPOSIDERIDAE ⁷	<i>Cloeotis percivali</i>	Percival's Short-eared Trident Bat	Present*	LC(U)	EN		Caught, and calls recorded
HIPPOSIDERIDAE	<i>Hipposideros caffer</i>	Sundevall's Leaf-nosed Bat	Present*	LC(D)	LC		Caught, and calls recorded
MINIOPTERIDAE	<i>Miniopterus natalensis</i>	Natal Long-fingered Bat	Present*	LC(U)	LC		Calls recorded. Photographed by G. Bauer
MOLOSSIDAE	<i>Chaerephon pumilis</i>	Little Free-tailed Bat	Present	LC(U)	LC		Calls recorded
MOLOSSIDAE	<i>Tadarida aegyptiaca</i>	Egyptian Free-tailed Bat	Present*	LC(U)	LC		Calls recorded
NYCTERIDAE	<i>Nycteris thebaica</i>	Egyptian Slit-faced Bat	Present*	LC(U)	LC		Caught
RHINOLOPHIDAE	<i>Rhinolophus simulator</i>	Bushveld Horseshoe Bat	Present*	LC(D)	LC		Caught, and calls recorded
RHINOLOPHIDAE	<i>Rhinolophus smithersi</i>	Smithers's Horseshoe Bat	Present*	NT(S)	NT		Caught, and calls recorded
VESPERTILIONIDAE	<i>Myotis tricolor</i>	Temminck's Myotis	Present*	LC(U)	LC		Caught, and calls recorded
VESPERTILIONIDAE	<i>Neoromicia capensis</i> ⁶	Cape Serotine	Present	LC(S)	LC		Calls recorded
VESPERTILIONIDAE	<i>Neoromicia zuluensis</i>	Zulu Serotine	Present	LC(U)	LC		Calls recorded
VESPERTILIONIDAE	<i>Pipistrellus rusticus</i>	Rusty Pipistrelle	Present	LC(U)	LC		Calls recorded
VESPERTILIONIDAE	<i>Scotophilus dinganii</i>	Yellow-bellied House Bat	Present	LC(U)	LC		Calls recorded
PTEROPODIDAE	<i>Epomophorus crypturus</i>	Peter's Epauletted Fruit Bat	High	LC(U)	LC		Fruit bat most likely seen by G. Bauer
RHINOLOPHIDAE	<i>Rhinolophus blasii</i>	Blasius's Horseshoe Bat	Medium-High*	LC(D)	NT		Potentially recorded in Ben Alberts N.R. ²
VESPERTILIONIDAE	<i>Laephotis botswanae</i>	Botswana Long-eared Bat	Medium-High	LC(U)	LC	N-End	
RHINOLOPHIDAE	<i>Rhinolophus clivosus</i>	Geoffroy's Horseshoe Bat	Medium*	LC(U)	LC		
RHINOLOPHIDAE	<i>Rhinolophus darlingi</i>	Darling's Horseshoe Bat	Medium*	LC(U)	LC		
MOLOSSIDAE	<i>Sauromys petrophilus</i>	Roberts's Flat-headed Bat	Low	LC(S)	LC	Sthrn Africa	
PTEROPODIDAE	<i>Epomophorus wahlbergi</i>	Wahlberg's Epauletted Fruit Bat	Low	LC(S)	LC		
PTEROPODIDAE	<i>Eidolon helvum</i>	African Straw-colored Fruit Bat	Low	NT(D)	LC		
PTEROPODIDAE	<i>Rousettus aegyptiacus</i>	Egyptian Rousette	Low*	LC(S)	LC		
VESPERTILIONIDAE	<i>Myotis welwitschii</i>	Welwitsch's Myotis	Low	LC(U)	LC		

Status: D = Declining; EN = Endangered; LC = Least Concern; NT = Near Threatened; S = Stable; U = Unknown. **Endemism:** N-End = Near-Endemic

Sources: ¹Monadjem *et al.* (2010); ²FIAO (2020); ³Jacobs *et al.* (2013); ⁴IUCN (2020-2); ⁵Child *et al.* (2016); ^{6,7}Simmons and Cirranello (2020)

Note: ⁶New species name: *Laephotis capensis*; ⁷New family name: RHINONYCTERIDAE; *Species known to roost inside caves





Figure 6 Aggregations of *R. simulator*, bat guano, and one of several dead bats in the Mooivallei Bat Cave

Although *N. thebaica* was live-captured at the Cave entrance, its low-intensity calls were not recorded by the SM2 (as is typically the case for this species). Roughly 2% and less than 1% of the calls recorded at the Cave were those of *M. tricolor* and *C. percivali* (**Figure 8**).

Our visual observations, counts of live-captured bats, and the bat call recordings indicated that during our survey of Mooivallei Bat Cave, ***R. simulator* was the most abundant bat species in the Cave, followed by *H. caffer*, *N. thebaica*, *M. tricolor* and *C. percivali* (in descending order of abundance).**

Considering that a greater number of bat species was captured and recorded, compared to what was seen inside the Cave, **certain bats must have been roosting in chambers that were not easily accessible, and the Cave is more extensive than it appears.** The image in **Section 11 Appendix 1**, from the Gravity Survey by GeoFocus (2020) also suggests that additional chambers occur (north-east, north-west, and in connection to) Mooivallei Bat Cave. Chambers with stalactites and/or stalagmites have reportedly been found by others (Annie and Gary Bauer pers. comm.), but since these were not observed during our survey, access to these chambers may either be very unobtrusive and restricted, or no longer possible due to collapsed earth.

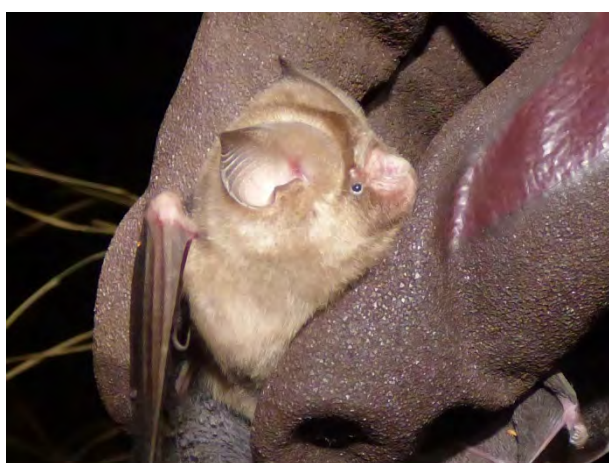
The SM2 at the Cave also recorded calls of various other bat species (**Figure 8**). Of these, the majority were made by the cave-dwelling *M. natalensis*, which was neither seen inside, nor captured at the entrance of the Mooivallei Bat Cave (**Figure 7**). This suggests that this species was only flying / foraging in the vicinity of the Cave, and that the detected individuals roost instead in a cave(s) and/or mine tunnel(s) somewhere else. **Additional surveys could, however, reveal that *M. natalensis* is present in the Cave at other times of year.**

The confirmed **presence of six cave-dwelling bat species at the Cave, including the very sensitive, scarce, and Endangered *C. percivali*, makes the Mooivallei Bat Cave an important cave for bat conservation.**





Endangered Percival's Short-eared Trident Bat (*Cloeotis percivali*)



Declining Sundeval's Leaf-nosed Bat (*Hipposideros caffer*)



Temminck's Myotis (*Myotis tricolor*)



Egyptian Slit-faced Bat (*Nycteris thebaica*)



Bushveld Horseshoe Bat (*Rhinolophus simulator*)

Figure 7 Bat species that were captured in a harp trap at the entrance of Mooivallei Bat Cave

Six other bat species recorded by the SM2 at the Cave (**Figure 8**) included *T. aegyptiaca*, *S. dinganii* (or possibly the Long-tailed Serotine, *Eptesicus hottentotus*), *N. capensis*, *M. midas*, *P. rusticus* and *C. pumilus* (in descending order of call number; **Table 2**). These are not typical cave-dwelling bat species, and were recorded whilst flying / foraging in the vicinity of the Cave.



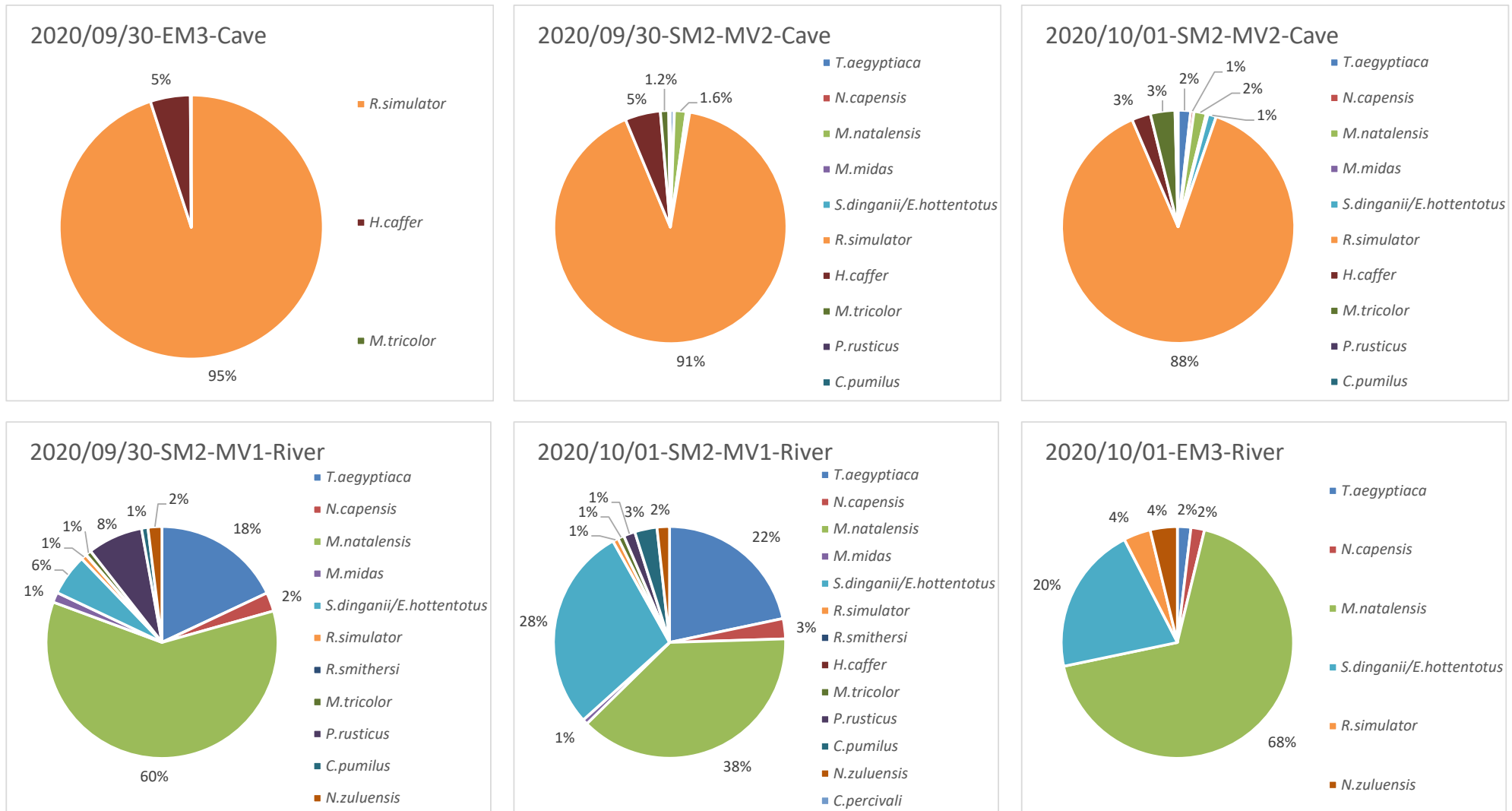


Figure 8 Diversity of bat species recorded by EM3 and SM2 ultrasonic bat detectors placed inside or outside the Cave or at the nearby Crocodile (West) River



Table 2 Number of calls recorded by different bat species at Mooivallei Bat Cave and the Crocodile (West) River

	2020/09/30- EM3-Cave	2020/09/30- SM2-MV2-Cave	2020/10/01-SM2- MV2-Cave	2020/09/30- SM2-MV1-River	2020/10/01- SM2-MV1-River	2020/10/01- EM3-River
<i>T.aegyptiaca</i>		39	119	280	300	1
<i>N.capensis</i>		3	32	41	39	1
<i>M.natalensis</i>		121	117	934	527	36
<i>M.midas</i>		15	17	22	10	
<i>S.dinganii/ E.hottentotus</i>		21	80	90	395	11
<i>R.simulator</i>	854	6780	6076	12	11	2
<i>R.smithersi</i>				1		
<i>H.caffer</i>	44	366	180			
<i>M.tricolor</i>	1	86	235	12	12	
<i>P.rusticus</i>		6	16	120	22	
<i>C.pumilus</i>		4	13	14	43	
<i>N.zuluensis</i>				30	24	2
<i>C.percivali</i>		6				

In total, **12 bat species** were recorded by the SM2 at Mooivallei Bat Cave (Figure 8; Table 2), which included **three CI species, viz. the Endangered *C. percivali*, the Declining *H. caffer*, and *M. natalensis*** (which can roost in very large numbers in caves such as the nearby Gatkop Caves; Kearney and Seamark, 2012).

The cave-dwelling and Near Threatened *R. blasii* was not recorded during our brief survey, but has apparently been recorded in the adjoining Ben Alberts Nature Reserve (FIAO 2020), and was rated with a Medium-High likelihood of occurrence. *R. blasii* roosts in small groups of up to four individuals (Monadjem *et al.* 2010) and although it might have evaded capture, no calls of this species were recorded on any detector.

6.3 Crocodile (West) River

No bats were captured by the harp traps and mist nets at the River, possibly because the prevailing full moon made the traps and nets visible to passing bats. However, the SM2 at the River recorded the same species of bats that were recorded at Mooivallei Bat Cave, with two exceptions: one call of the **Near Threatened *R. smithersi* was also recorded**; whilst no call of the **Endangered *C. percivali*** was recorded (Table 2). There was also a distinct difference in the species-specific proportion of calls between the River and the Cave (Figure 8).

The majority (roughly 40-70%) of calls recorded at the River by the SM2 and EM3 were those of the cave-dwelling and migratory *M. natalensis*, followed by the more generalist *T. aegyptiaca*, *S. dinganii*, *P. rusticus*, *N. capensis*, *C. pumilus*, *N. zuluensis*, and *M. midas*, and lastly, the cave-dwelling *M. tricolor*, *R. simulator*, and *R. smithersi* (in descending order of call number; Table 2). This suggests that **the River and its riparian vegetation may represent important (foraging, dispersal and/or migratory) habitat for *M. natalensis***, which occurs in large colonies in the nearby Gatkop Caves.

Although not the focus of the present assessment, IWS incidentally recorded a high diversity of other mammal species at the River. A motion-sensitive camera placed near the SM2 by the River captured photographs of (among other large mammals), a **Leopard (*Panthera pardus*) – a species that is Red Listed as globally Vulnerable (IUCN 2020). Evidently, the River and its Subtropical Alluvial Vegetation provide habitat that is used by a number of threatened mammal (and potentially other animal) species.**

Leopard (*Panthera pardus*)
Photograph from Julio Balona



6.4 Surrounding landscape

On 1 October we inspected occupied and abandoned buildings on Mooivallei Portion 10, Portion 11, and in the adjoining perimeter of the Ben Alberts Nature Reserve (**Figure 9**). On Portion 10 we found evidence of bat roosting in a chicken coop (**Figure 9**).

Very limited evidence of bat roosting was found in abandoned buildings on Portion 11 and on the perimeter of the Ben Alberts Nature Reserve. Only a derelict thatch lapa in the Reserve was found to be used as a night-roost, where scattered guano, moth wings and legs (**Figure 9**) revealed feeding by possibly *N. thebaica*.



Abandoned lapa, with evidence of bat night-roost activity (in the form of bat guano, and moth wings and legs)



Abandoned buildings, where no obvious evidence of bat activity was found



Building (chicken coop) with bat guano

Figure 9 Buildings that were searched for evidence of bat roosting



From information and photographs supplied by Gary and Annie Bauer (pers. comm.), at least three bat taxa have roosted on their property. These include the eave-roosting Mauritian Tomb Bat (*Taphozous mauritanus*), tree-roosting fruit bats - which most likely represented Peter's Epauletted Fruit Bat (*Epomophorus crypturus*), and a sizeable aggregation of *M. natalensis*, which previously roosted in an outbuilding (Figure 10).

During our driven transects from site to the main tar road to Thabazimbi, the EM3 recorded near the River and Cave mostly calls of *M. natalensis*. In the agricultural area between Portion 10 and the main tar road, calls of *N. zuluensis* and *N. capensis* were recorded (Figure 5). *N. capensis* is a common roof-roosting bat species, while *N. zuluensis* is associated with woodland savanna “where it is closely tied to riparian habitats” (Monadjem *et al.* 2020).

During our visit to Mooivallei it was also reported to us (Annie and Gary Bauer, pers. comm.) that, according to nearby neighbours, a cave is also present on the remaining extent or “Portion 11” of Mooivallei 342 KQ. However, the exact location of this second Mooivallei cave is unknown and, as such, it remains unexplored. This could be regarded as an additional, important limitation of this study.



Mauritian Tomb Bat
(*Taphozous mauritanus*)



Natal Long-fingered Bats
(*Miniopterus natalensis*)

Figure 10 Photographs taken by Gary Bauer at Mooivallei of bats

6.5 Summary

In total, 14 bat species were confirmed as present on Mooivallei Portion 10. Sonograms of the calls of 12 of these species are provided in Section 12 Appendix 2. In addition, a fruit bat species (most likely *E. crypturus*) has been reported from the property (Annie and Gary Bauer, pers. comm.). This is a high number of bat species for a small piece of land. Eight of the confirmed species are cave-dependent, four of which are conservation important. The presence of the very sensitive, scarce and Endangered *C. percivali*, in particular, makes the Mooivallei Bat Cave an important cave for bat conservation. The Cave is also more extensive than it appears. The presence of the conservation important, cave-dwelling *R. smithersi* and *M. natalensis* at the River (but not inside the Cave during our survey), indicates that: the River is also an important habitat (used for drinking, foraging, dispersal and/or migration) for cave-dwelling bats; and there is bat connectivity between Mooivallei Bat Cave and other caves and/or mine tunnels in the region, which may be facilitated by the River. The Cave and the River are therefore both important from a local and regional bat conservation perspective.



7. Key Project Concerns

7.1 Direct Concern

As identified and assessed during the Environmental Impact Assessment (EIA; Nema Consulting, 2018b), and as seconded by IWS, the concern in relation to the construction of the proposed MCWAP-2 in the vicinity of Mooivallei Bat Cave is the potential **disturbance to, or destruction of the Cave** and as such, **disturbance to, or loss of an appreciable diversity of bats, including conservation important species such as the very sensitive, scarce and Endangered *C. percivali*.**

The local vulnerable D4 dolomite zone also presents a significant risk to the structural integrity of the proposed pipeline. Ground improvement solutions in close proximity to the Cave are considered inappropriate, presenting either intolerable risk to its structural integrity, or a possible loss of habitat. Surface structural solutions introduce similar stability risks to the Cave (Geoid 2020).

The following potential impacts on bats as a result of Cave instability and/or collapse, vibrations, noise and light pollution are identified as, but not limited to:

- **Habitat loss** through cavern collapse.
- Direct **fatalities** due to falling rock and soil.
- **Microclimate change** within the Cave making conditions unfavourable for maternity colonies to reproduce normally, and/or for bats to safely go into and out of torpor.
- Daytime disturbance of sleeping bats, resulting in potentially **harmful energetic expenditure** associated with unnecessary flight activity.
- Daytime emergence of bats, resulting in their **increased risk of predation**.
- Increased **light pollution** outside of the Cave, which can interrupt circadian rhythms, affect foraging success, and may also deter bats from lit environments.

7.2 Associated Concerns

7.2.1 Weir Construction and Abstraction

Construction of the proposed weir and associated infrastructure will result in **localized destruction and degradation of Subtropical Alluvial Vegetation, and upstream and downstream disturbance of the Crocodile (West) River**. This could adversely impact drinking, foraging, dispersal and/or migration of bats not only from the Cave, but also from habitats, including other caves and mine tunnels in the region. In addition, destruction and disturbance of this habitat will adversely impact various other wildlife such as the Vulnerable Leopard.

Furthermore, it is likely, following construction of the weir and prior to abstraction commencing, that the elevated water level in the River upstream of the weir could cause a concomitant rise in the dolomite aquifer (provided there is physical hydraulic connectivity - which is not established), and a **risk of minor flooding upstream of the weir**, depending on the height of the weir structure (Geoid 2020).

With the water level measured at 12 m in borehole PBHP05, it is possible that the Mooivallei Bat Cave may become partially flooded in the process, temporarily altering this natural habitat. Following the commencement of weir abstraction, the water level may subside again while the dolomite aquifer re-establishes a new equilibrium. This **rise and subsequent fall in the groundwater surface may result in the undesirable erosion of unconsolidated fines, increasing the overall instability of the Cave, and potentially precipitating further cave openings - even small-scale collapse** (Geoid 2020). This could negatively impact the integrity of the pipeline, and would adversely impact bats in the Cave.



7.2.2 Crop-land Irrigation

It appears that nearby farms are irrigating from groundwater rather than from surface water reserves, based on the sharp gradient in the groundwater surface recorded between PBHP05 (12.5 m) and PBHP08 (22.4 m) – despite their common elevation (917 m a.s.l.) and mere 700 m lateral separation (Geoid 2020).

Either there is a comparatively small underground water body which is sensitive / responsive to the effects of dewatering or, alternatively, abstraction is occurring at a higher rate than the natural aquifer recharge rate, resulting in a very sizeable cone of depression (Geoid 2020). **Further dewatering could lead to cavern collapse in the local dolomitic rock (Stuart Morgan pers. comm.), which could adversely impact the integrity of the proposed pipeline. The Mooivallei Bat Cave and its bats could in turn be adversely impacted by cavern collapse and flooding from pipeline damage / failure.**

8. Conclusions

- The **pipeline corridor as is currently proposed, is assessed to be fatally flawed**, as it presents an intolerable structural integrity risk to the Mooivallei Bat Cave, its bats, and even the pipeline itself.
- Due to the presence in and around the Mooivallei Bat Cave of the very sensitive, scarce and **Endangered** *C. percivali* and other conservation important cave-dependent bat species, and a potentially important ecological connectivity between this Cave and others such as the Gatkop Caves, the **above risk to the structural integrity of Mooivallei Bat Cave due the proposed pipeline in its current alignment is considered unacceptable.**

9. Recommendations and Way Forward

Identified sensitive / conservation important locations and areas and recommended buffers around these are shown in **Figure 11**, and the rationale around the designation of these sensitive areas, and the recommendations that apply within each, are provided below.

- **High sensitive: Mooivallei Bat Cave, and a 200 m buffer to the west, and a 500 m to the east of it**
The designation of the High sensitive areas is necessary to: i) protect the Cave and its bats from destruction or disturbance from rock-breaking (whether by blasting or other methods), rock excavation, noise, vibrations, light pollution and other forms of disturbance during construction; and ii) possible leakage, damage or failure of the pipeline during operation and subsequent flooding of the Cave. The High sensitive areas represent **strict “no-go” areas** wherein there must be no disturbance from construction or operation of the MCWAP-2. Consequently, **the proposed 100 m pipeline corridor will need to be re-aligned around these High sensitive areas.**

A 200 m buffer is prescribed to the west of the Cave because here it is anticipated (Stuart Morgan pers. comm.) that in the alluvium alongside the River, excavation and construction activities should be easier, and the impact of this should be less severe and more easily mitigated and rehabilitated (compared to further upslope where there is dolomite). In the absence of more pertinent provincial or national guidance, the 200 m buffer recommendation to the west of the Cave is supported by the minimum 200 m buffer requirement for bat important features stipulated in the MacEwan *et al.* (2020) guidelines for bats at wind farm sites.

A 500 m buffer is prescribed to the east of the Cave because here it is anticipated (Stuart Morgan pers. comm.) that in the dolomite to the east of the Cave, excavation and construction activities will be more difficult, and more rock-breaking (involving blasting or other methods) and excavation will be required, and the impact of this will be more severe, and not easily mitigated or rehabilitated



(compared to downslope where there is alluvium). Of key concern is that rock-breaking by whatever means could compromise the Cave's stability and/or climate, and/or also disturb bats from dust, noise, vibrations and light. Of additional concern is that the Cave and its bats would likely be adversely impacted in the event of possible leakage, damage or failure of the pipeline, if this is constructed upslope (east) of the Cave. The closer the pipeline is constructed east of the Cave, the greater the probable risk of Cave and/or bat destruction or disturbance. In the absence of more pertinent provincial or national guidance, the 500 m buffer recommendation to the east of the Cave is supported by GDARD (2014) 500 m buffer requirement for caves (albeit in Gauteng).

The High sensitive 200 m west and 500 m east buffers around the Cave represent strict "no-go" areas" where any form of disturbance (ranging from rock-breaking to light pollution) should be prohibited during all phases of the MCWAP-2.

■ **Moderate-High sensitive: Crocodile (West) River and adjoining Subtropical Alluvial Vegetation**

The River and its adjoining riparian vegetation were rated with Moderate-High sensitivity given: i) the known importance of surface water to bats for both drinking, foraging and navigating; ii) our recorded presence of conservation important bat (and other wildlife) species in the riparian zone; iii) the potential importance of the River and its riparian vegetation in maintaining bat connectivity between the Mooivallei Bat Cave and other caves and mine tunnels in the region; but also considering that iv) the River and riparian vegetation are deemed to possess a greater potential for regeneration (albeit over a long time period), compared to the Cave – especially if this were to collapse. Within the River and its riparian vegetation, the footprint of disturbance from proposed MCWAP-2 activities in these habitats should be minimized as far as possible, and rigorous impact mitigation and habitat rehabilitation measures (as prescribed in existing aquatic, wetland and ecological studies for the MCWAP-2), should be diligently implemented.

■ **Moderate sensitive: 500 m Cave buffer, 50 m homestead roost buffer, and 50 m riparian buffer**

A 500 m buffer around Mooivallei Bat Cave, a 50 m buffer around the Bauer homestead (where appreciable evidence of bat roosting was observed and reported; **Figure 10**), and a 50 m buffer around the terrestrial edge of River's Subtropical Alluvial Vegetation is prescribed to minimize disturbance of the biological rhythms, emergence, non-visual sensorial capabilities, foraging, competition, predation, and migration (Jones, 2008; Patriarca and Debernardi, 2010) of local bats, especially those using Mooivallei Bat Cave, including in particular, the very sensitive **Endangered** *C. percivali*. The Moderate (and High) sensitive 500 m Cave buffer is supported by the GDARD (2014) 500 m buffer requirement for caves.

Within the Moderate sensitive areas, we recommend the following:

- **Prohibit blasting** (use non-explosive rock-breaking methods instead) to avoid impacting the Cave's stability and climate, and to avoid disturbing bats from noise and vibrations. Non-explosive rock-breaking methods are permissible within the Moderate sensitive 500 m Cave buffer *except* where this overlaps with the no-go High sensitive 200 m west and 500 m east Cave buffers. In other words, between 200 m to 500 m west of the Cave, rock-breaking is permissible using non-explosive methods. Blasting could occur beyond 500 m from the Cave.
- **Restrict construction activities to daylight hours** to avoid disturbing bats when they are active, in particular at dusk, in the late evening, and pre-dawn.
- **Prohibit artificial lighting** (during construction and operation).



- **Minimize noise** (during construction and operation) especially during summer and, in particular, after rain (when many insects and bats are most active).
- **Effectively rehabilitate** all areas where native vegetation was destroyed or disturbed during construction, and where permanent infrastructure was not developed.

As there was only limited evidence of bat night-roost activity in the derelict lapa near the proposed weir, a Moderate sensitive 50 m buffer around this night-roost has not been prescribed. However, **should the night-roost in the lapa have to be destroyed during construction of the MCWAP-2, another small night-roost structure will need to be built within 100 m of the lapa.**

In addition, to fully evaluate the potential impact of the MCWAP-2 on the Mooivallei Bat Cave and its bats, a low-intensity bat monitoring programme is recommended for implementation during and after construction.

- During construction: IWS or another SACNASP-registered bat specialist to inspect if there is any change in the status of the bat populations inside the Cave, and to conduct bat activity monitoring for two warm, low-wind nights outside of the Cave entrances while construction activity is active at the closest point to the Mooivallei Bat Cave.
- Post-construction: Three or more months after construction has been completed, IWS or another SACNASP registered bat specialist to inspect if there is any change in the status of the bat populations inside the Cave, and to conduct bat activity monitoring for two warm, low-wind nights outside of the Cave entrances. This post-construction monitoring trip should occur within the same season as the pre-construction monitoring trip.
- Any further recommendations arising from the monitoring programme must be implemented.
- **Should additional caves (such as the alleged cave on Portion 11, mentioned by Gary and Annie Bauer, pers. comm.) or bat roosts be discovered during construction or operation of the MCWAP-2, IWS (www.iws-sa.co.za) or the South African Bat Assessment Association (www.sabaa.org.za) should immediately be contacted.**
- From the literature that IWS has reviewed, it does not seem that Mooivallei Bat Cave was assessed from an archaeological or palaeontological perspective. A heritage specialist with appropriate expertise should perhaps be consulted in this regard.
- Occasional vehicle and human traffic, and minor maintenance work on the pipeline during operation, are not expected to exert a significant impact on the Cave or its bats. **It is, however, imperative that the pipeline is maintained in good working order, and that possible leakage, damage or failure of the pipeline is effectively rectified without delay – especially if the pipeline is constructed upslope (to the east) of the Cave.**



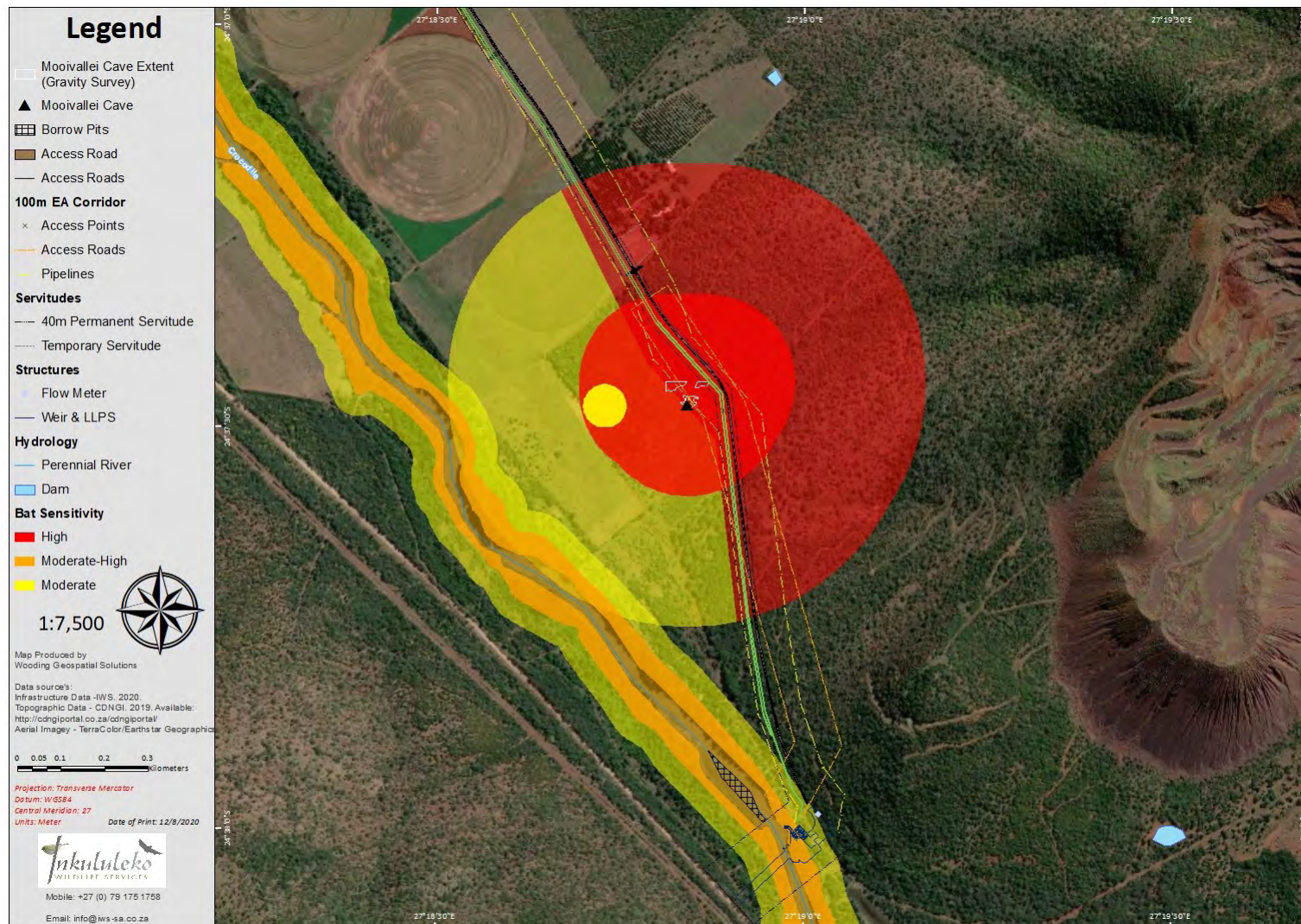


Figure 11 Proposed buffers for the Mooivallei Bat Cave and nearby Crocodile (West) River and its Subtropical Alluvial Vegetation



10. References

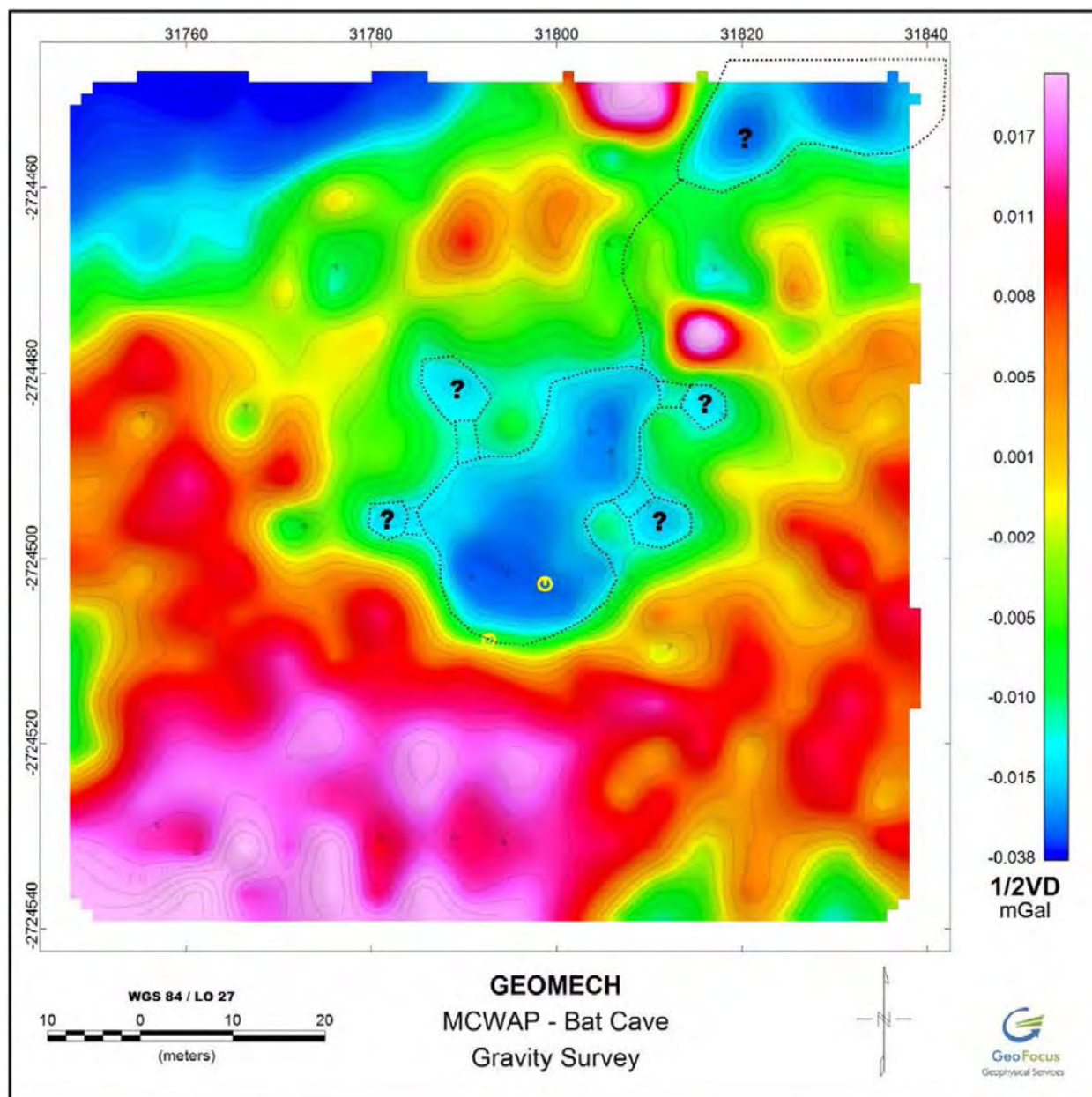
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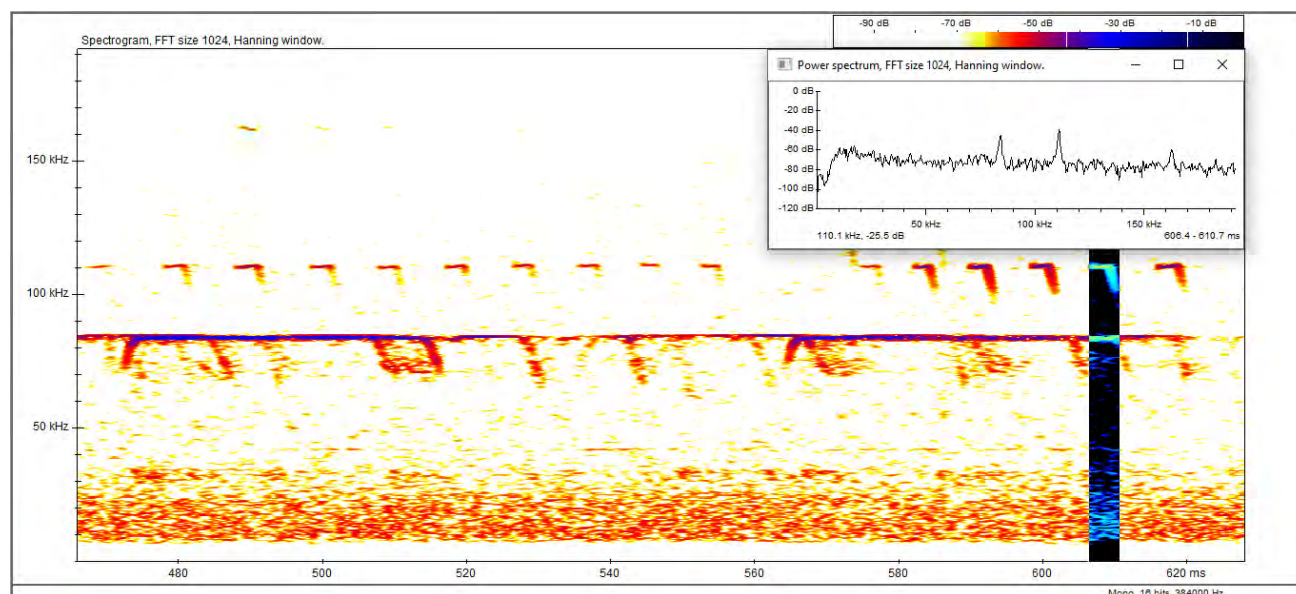
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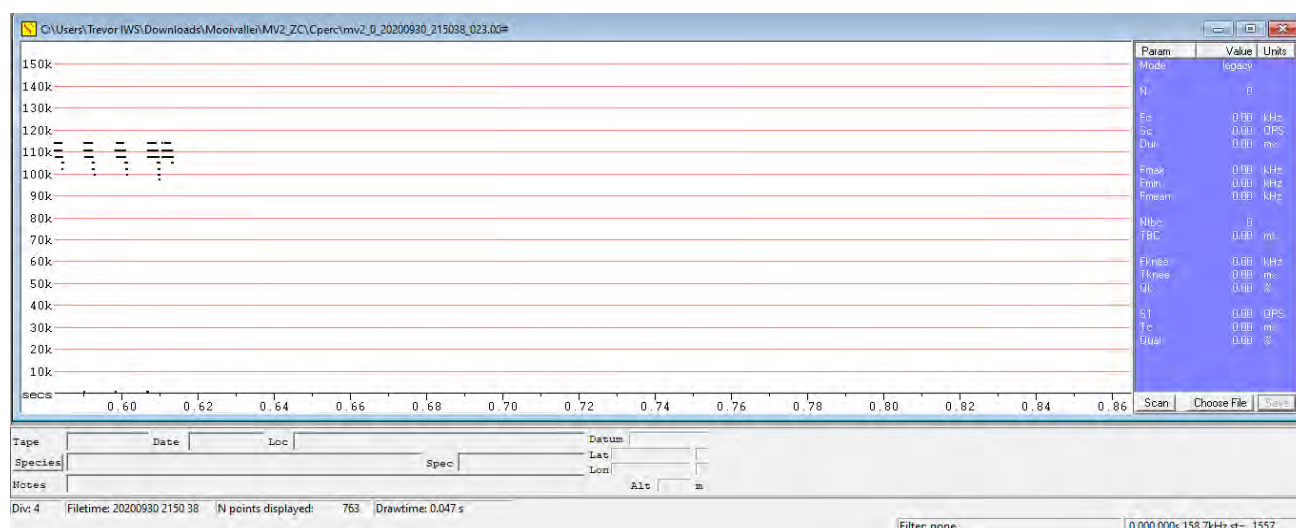
11. Appendix 1: Gravity Survey image of Mooivallei Bat Cave and its immediate surrounds (from GeoFocus, 2020)

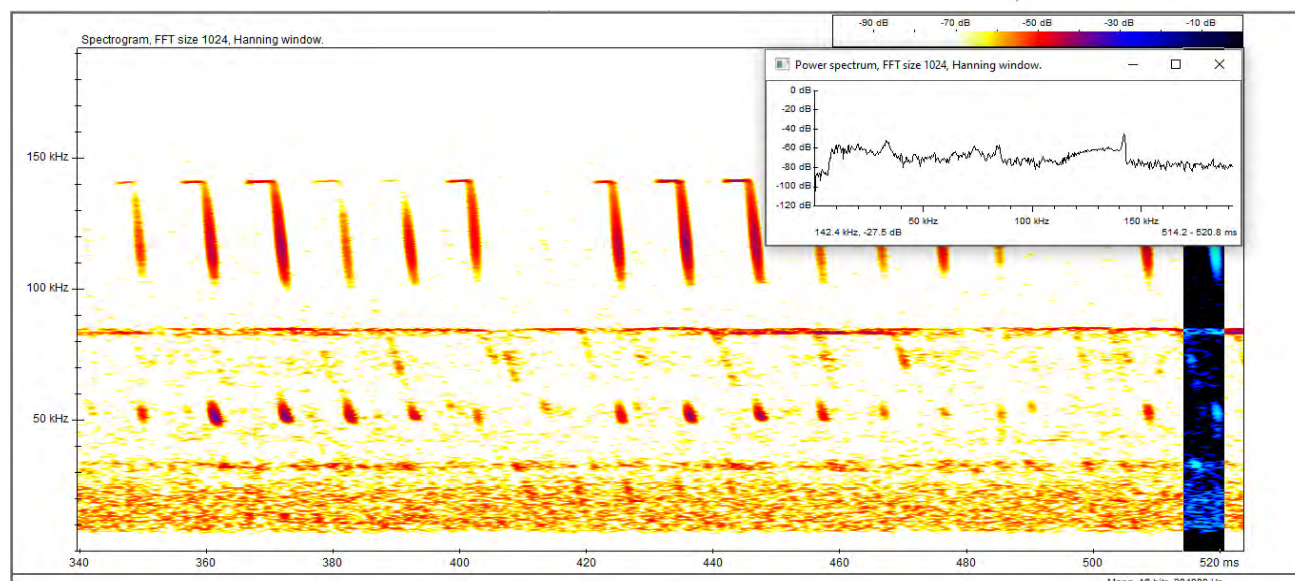


12. Appendix 2: Sonograms of the calls of 12 bat species recorded at Mooivallei

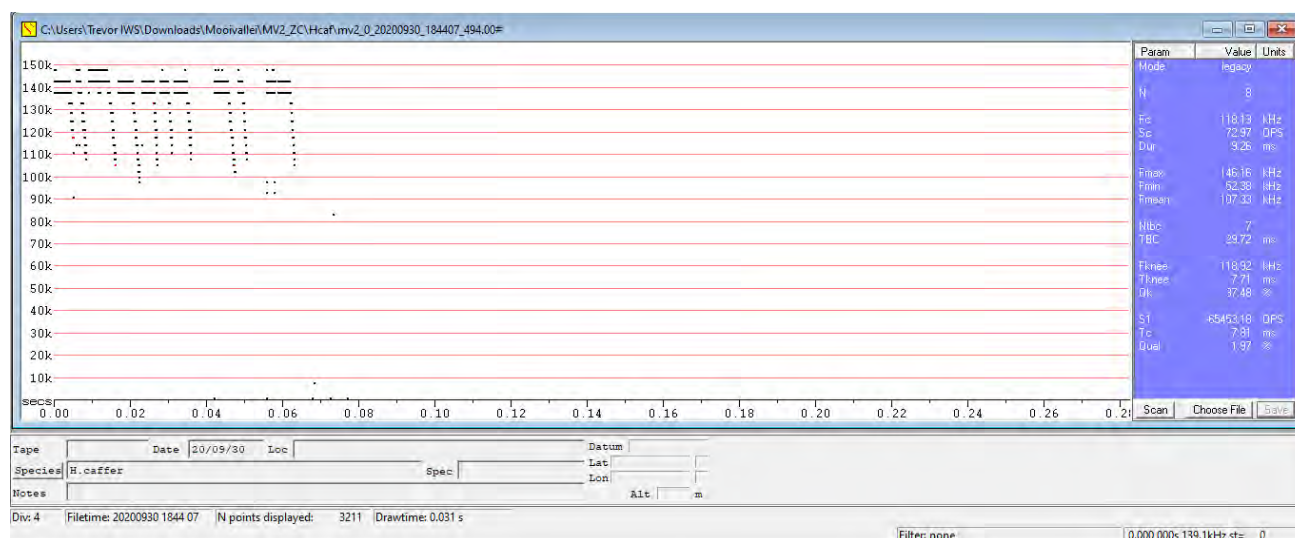


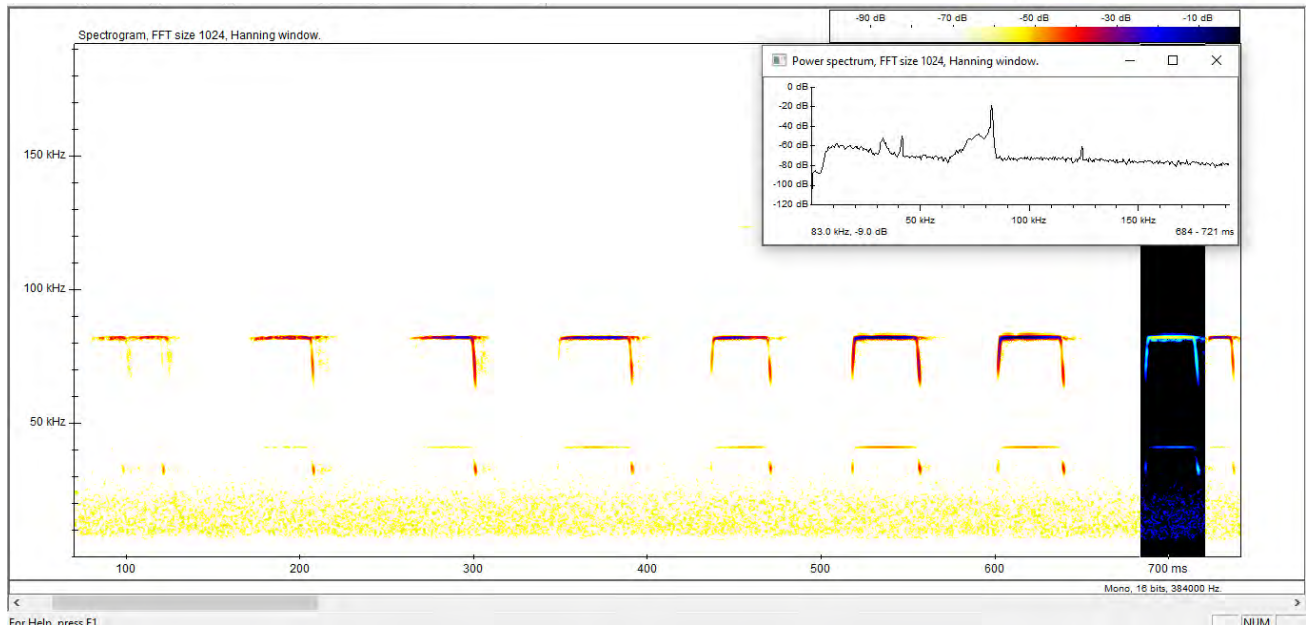
C. percivali



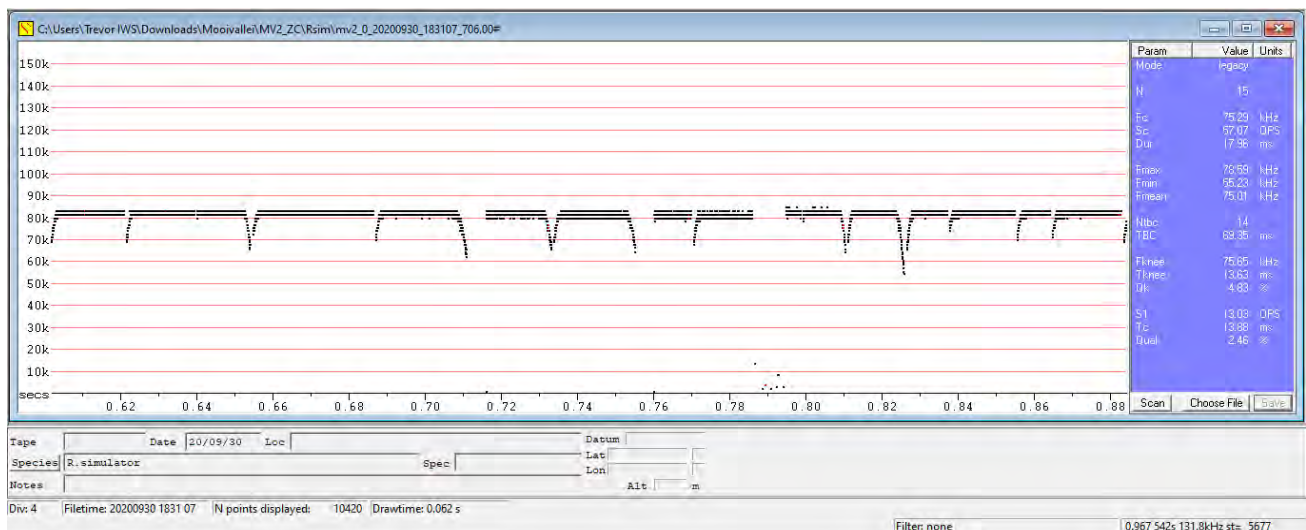


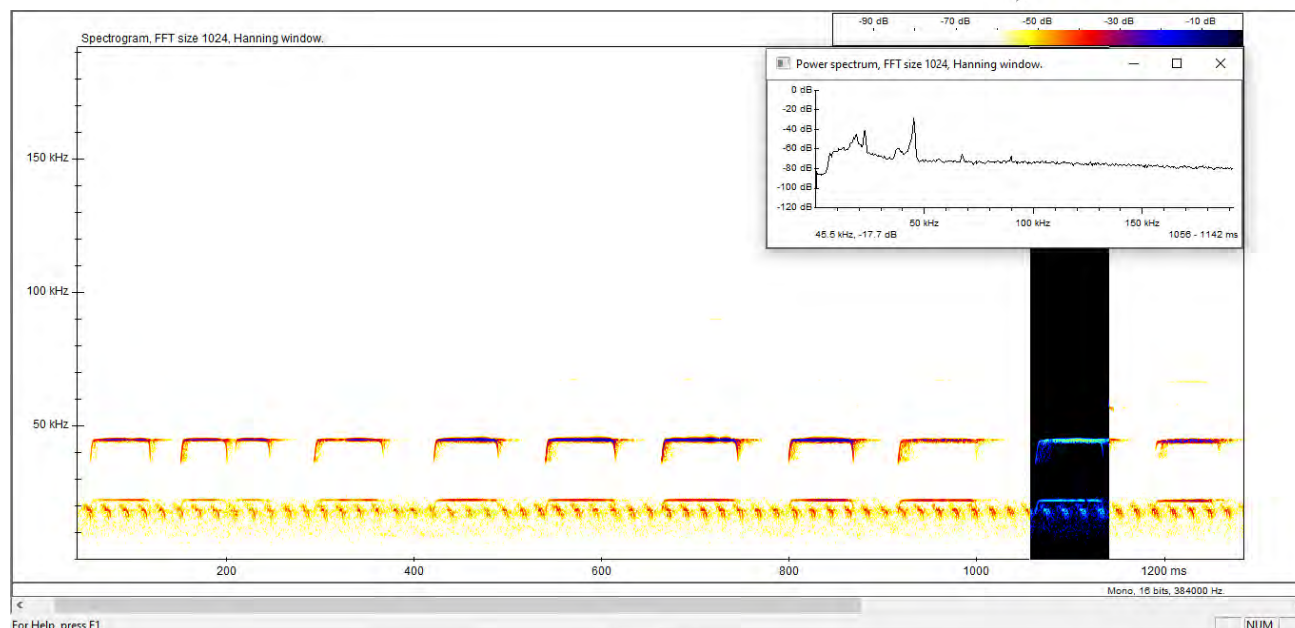
H. caffer



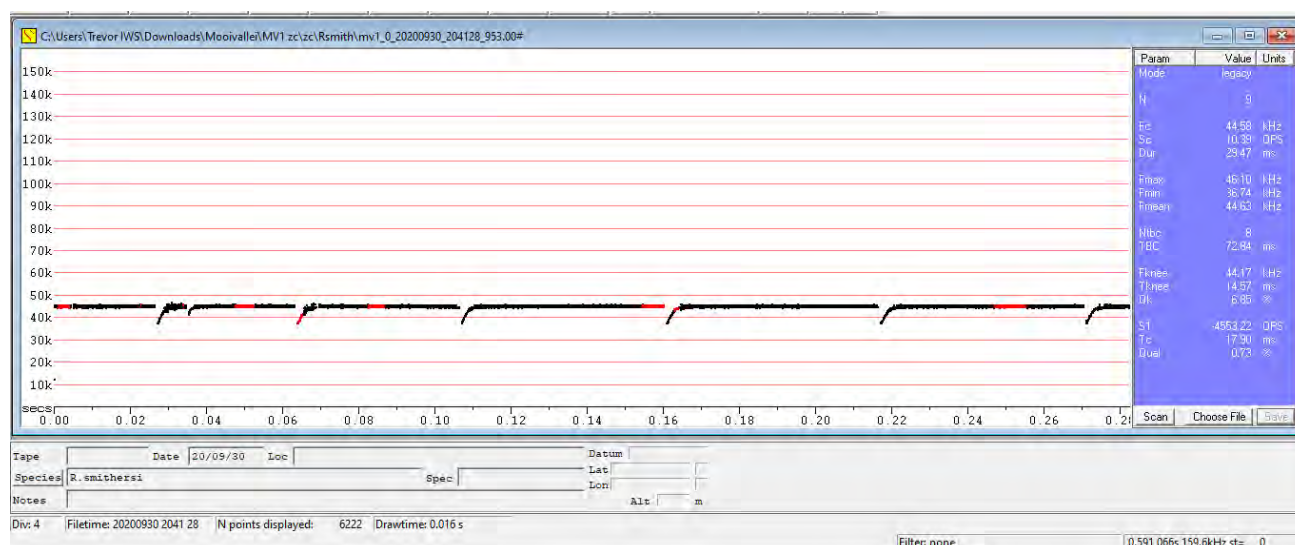


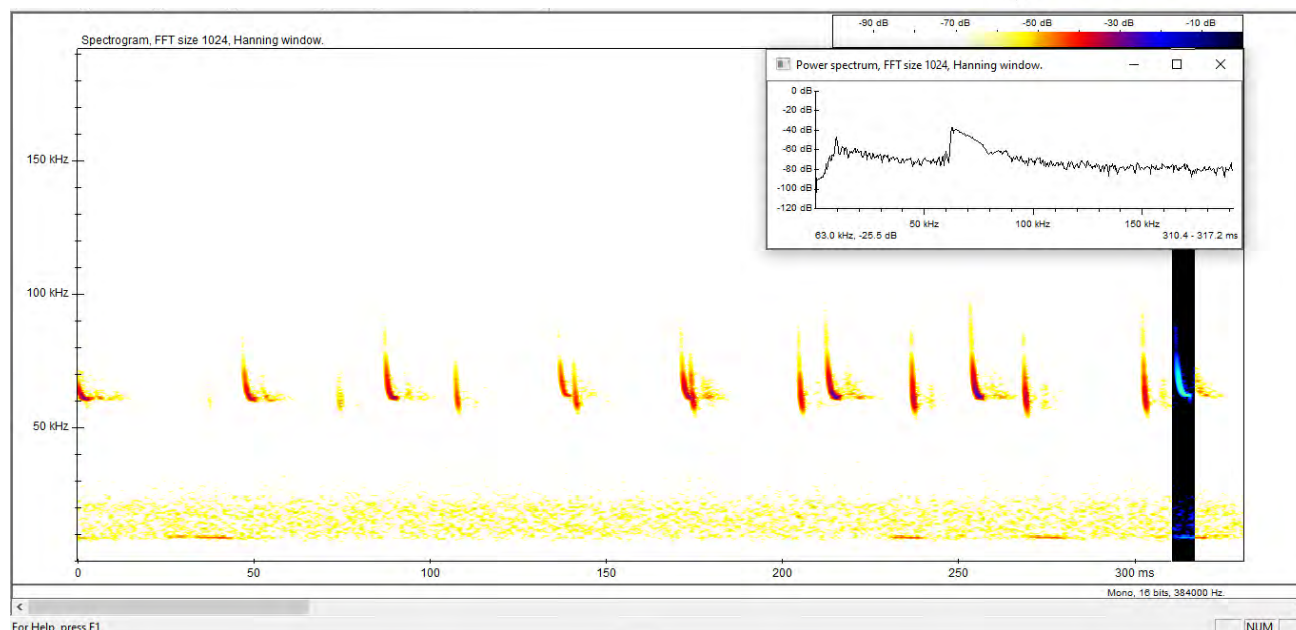
R.simulator



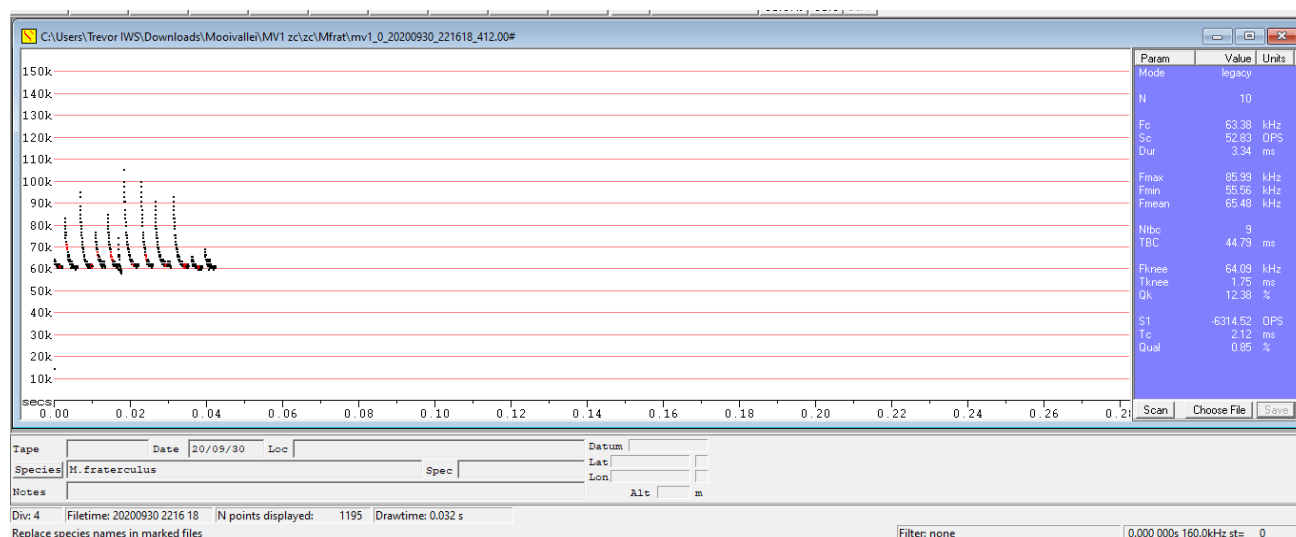


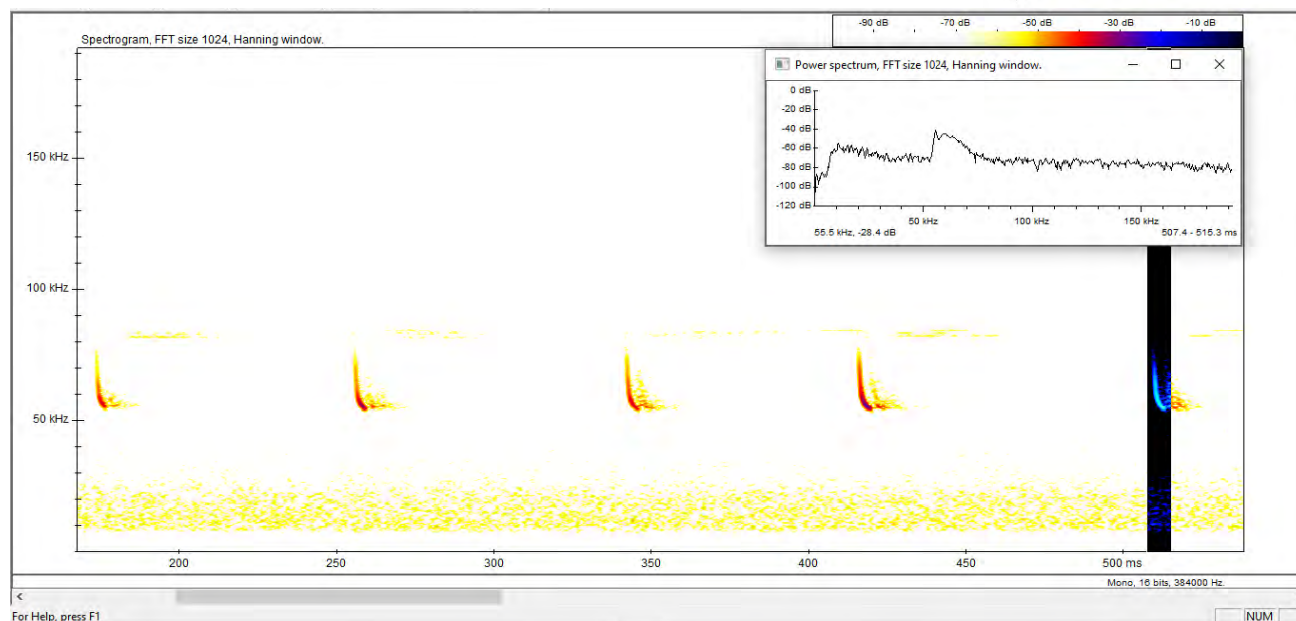
R. smithersi



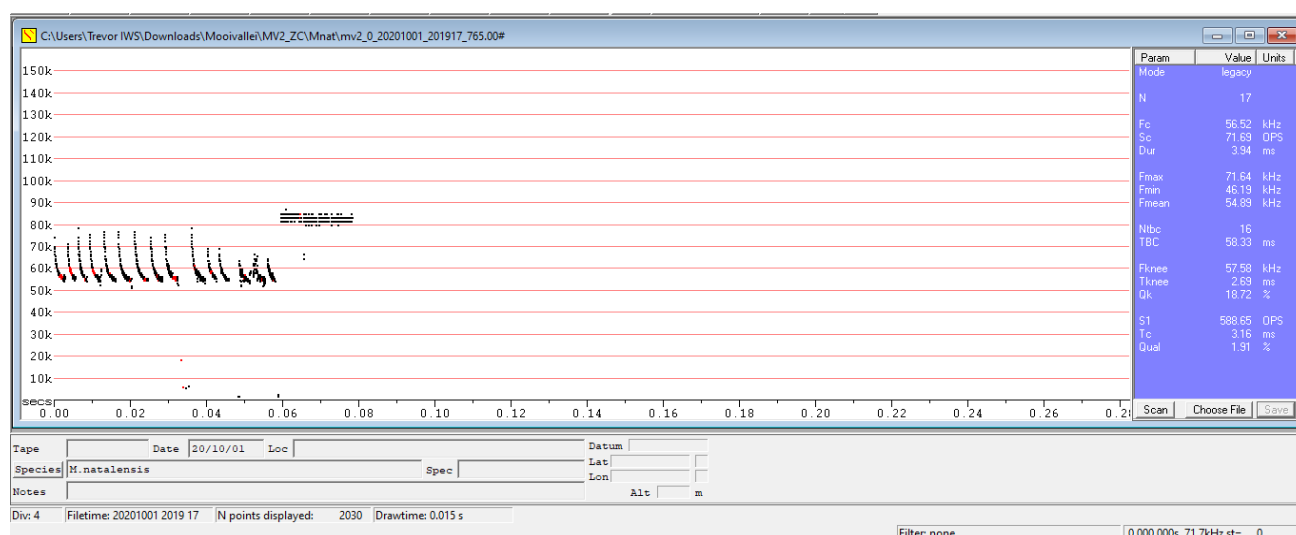


M. fraterculus



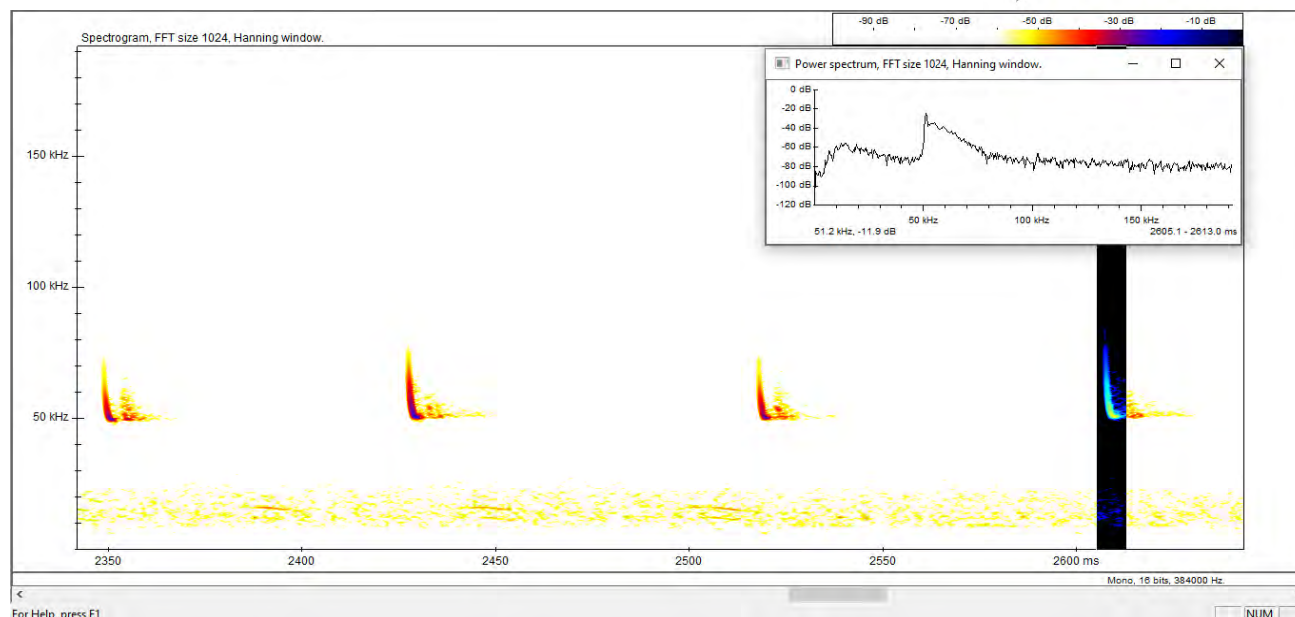


M. natalensis

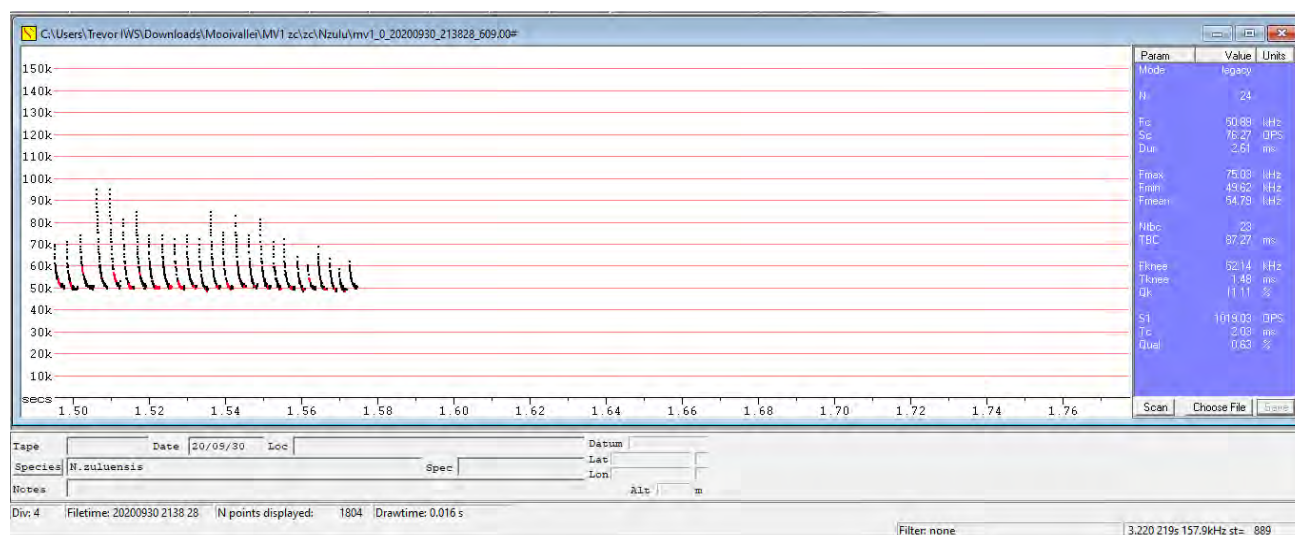


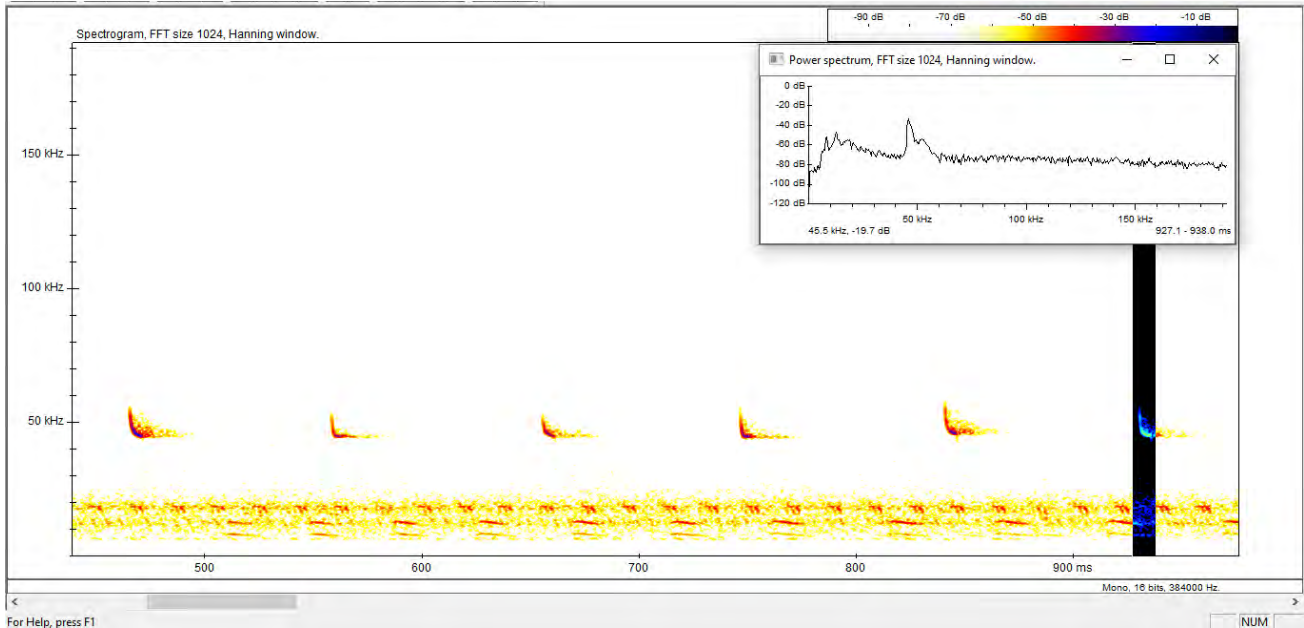
MCWAP-2: Mooivallei Bat Cave Risk Assessment

Date: 30 October 2020 – finalized 8 December 2020

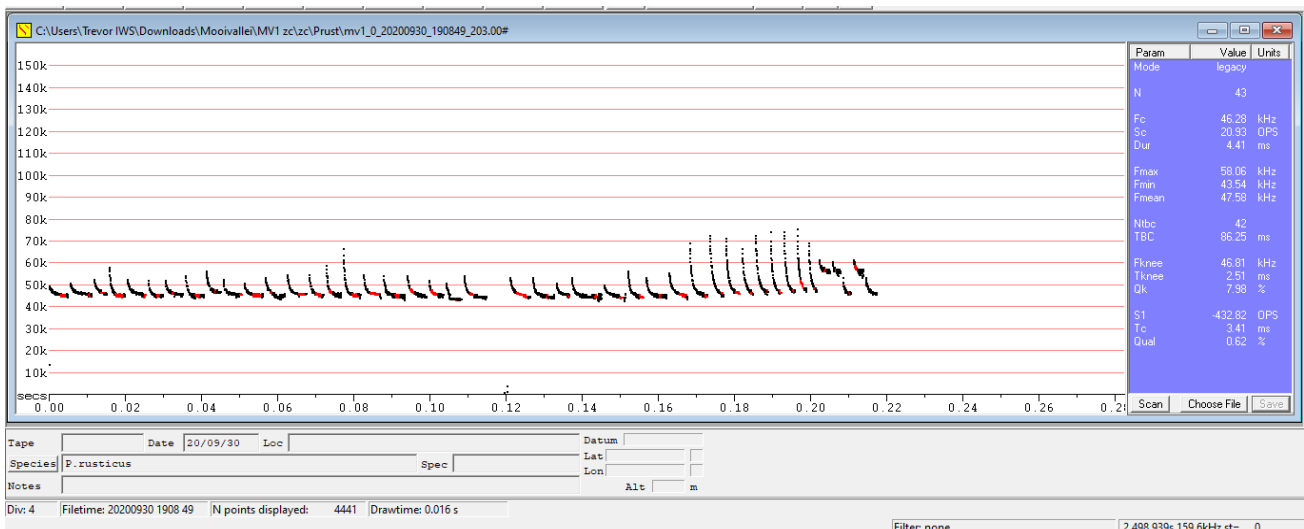


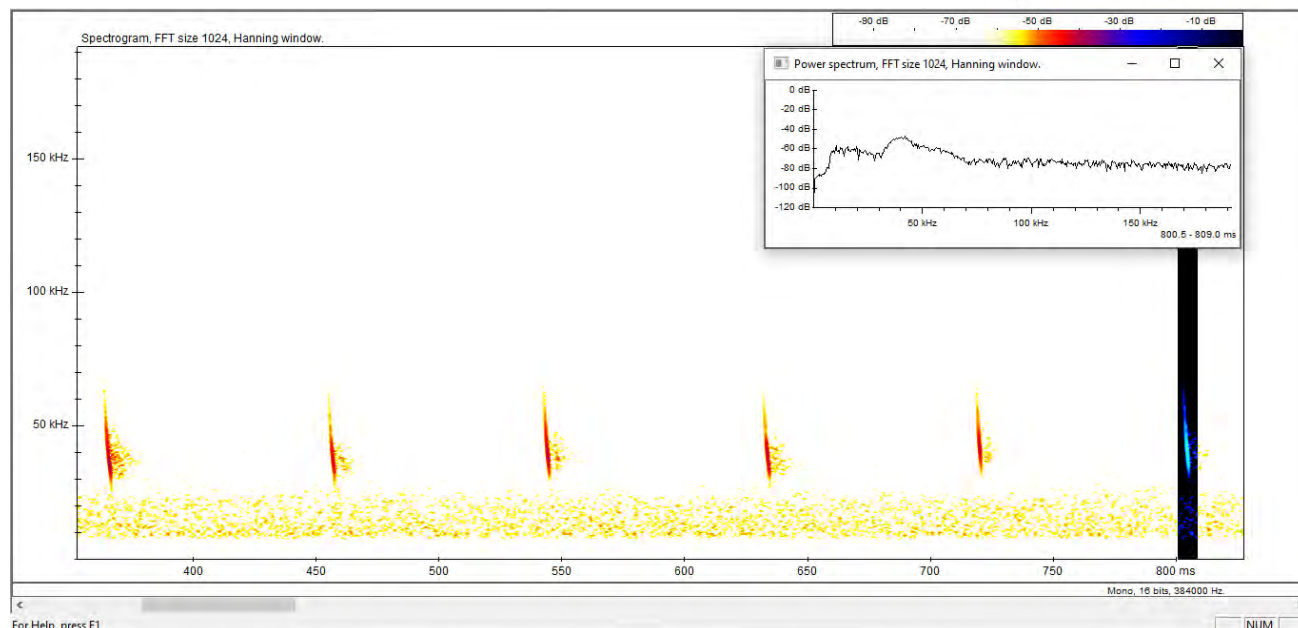
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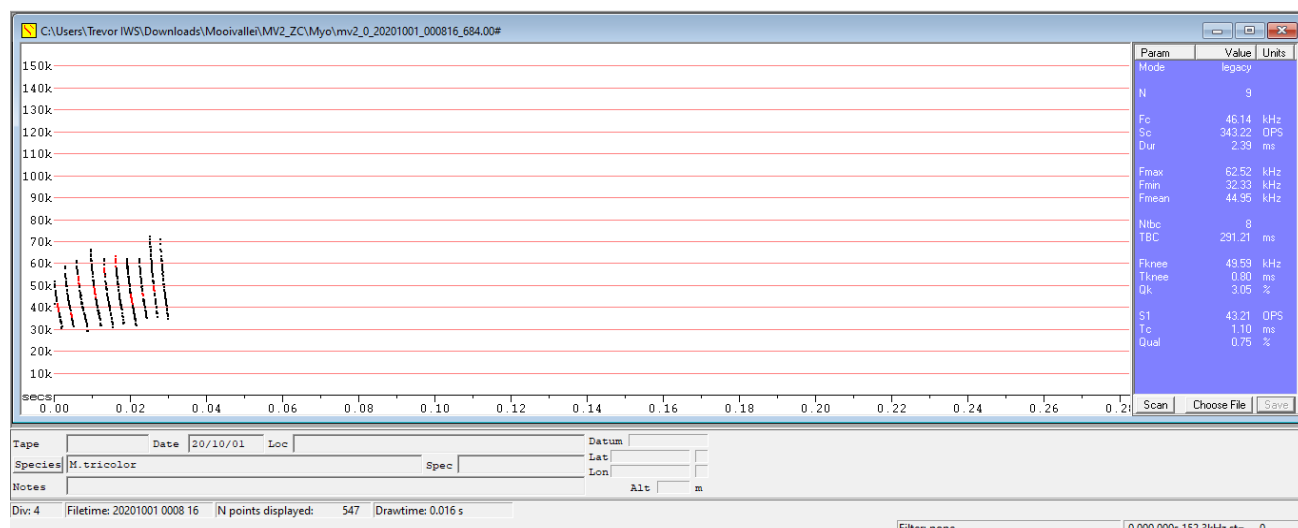


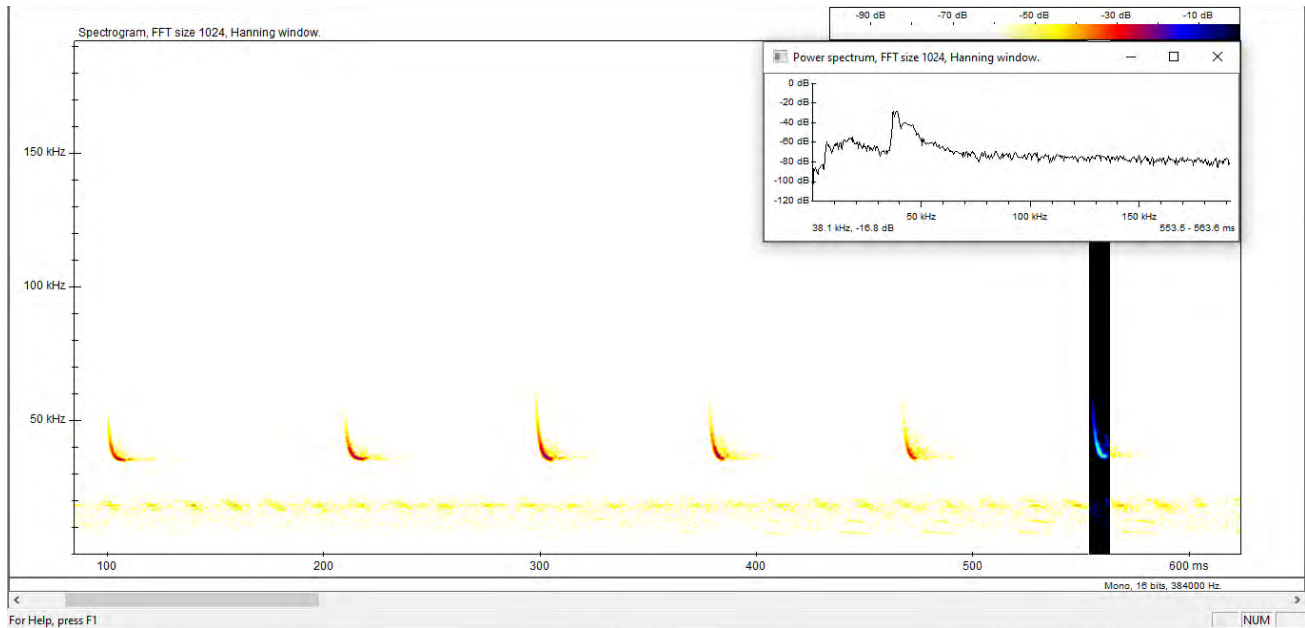
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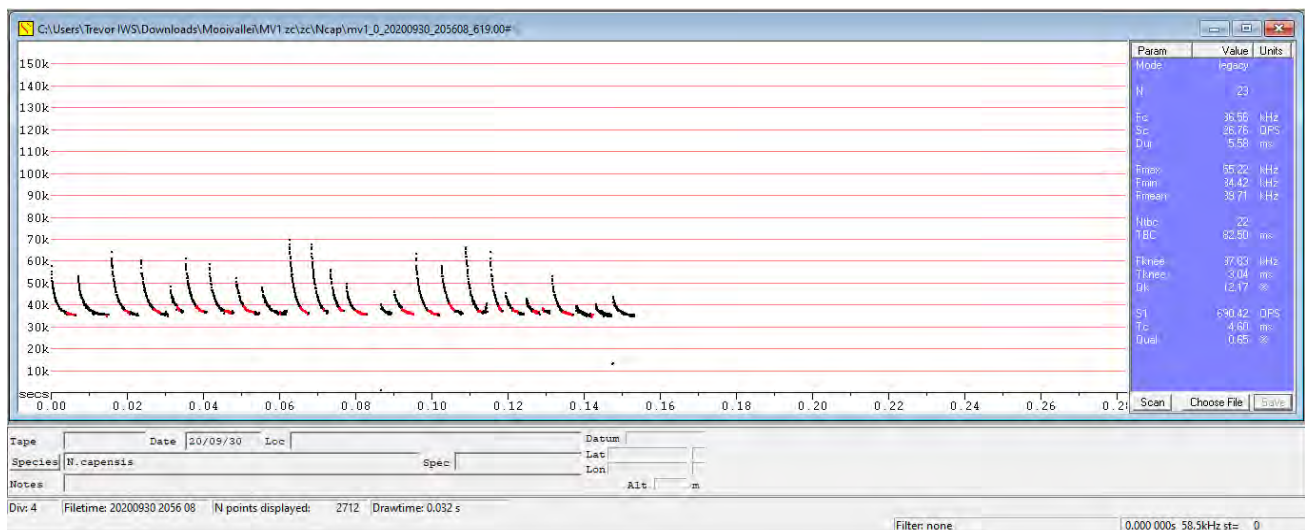


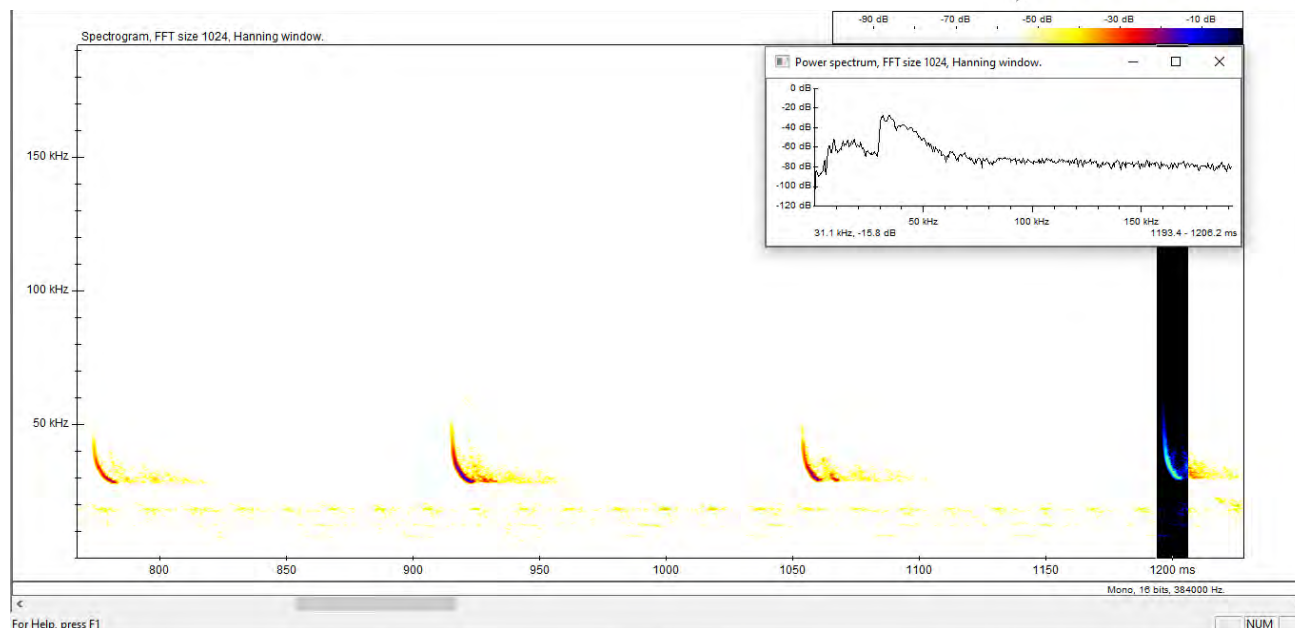
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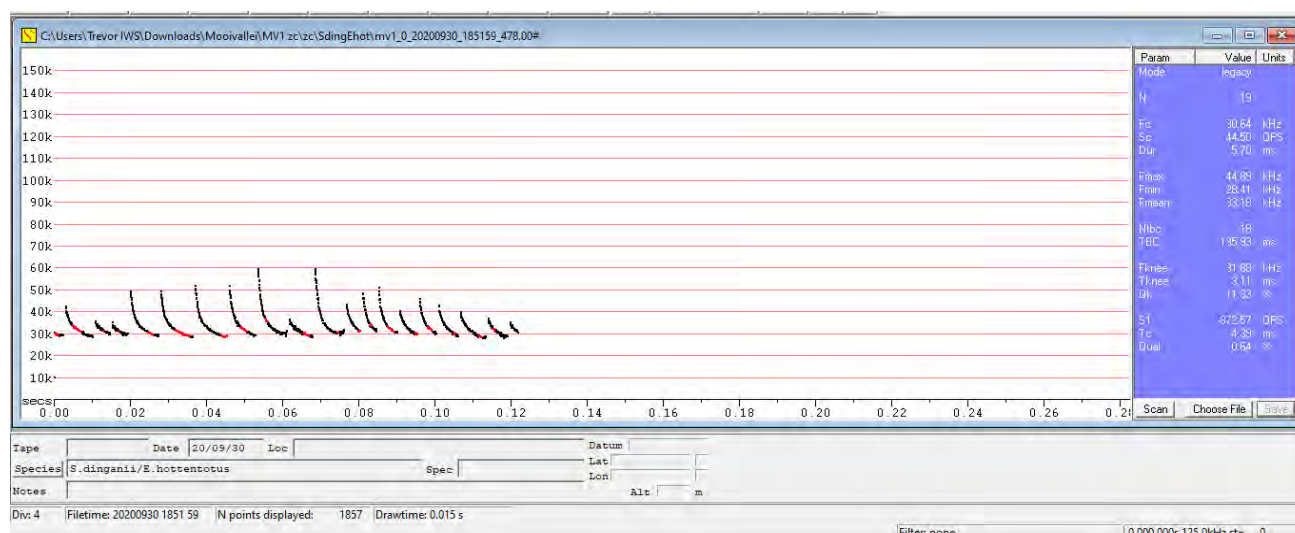


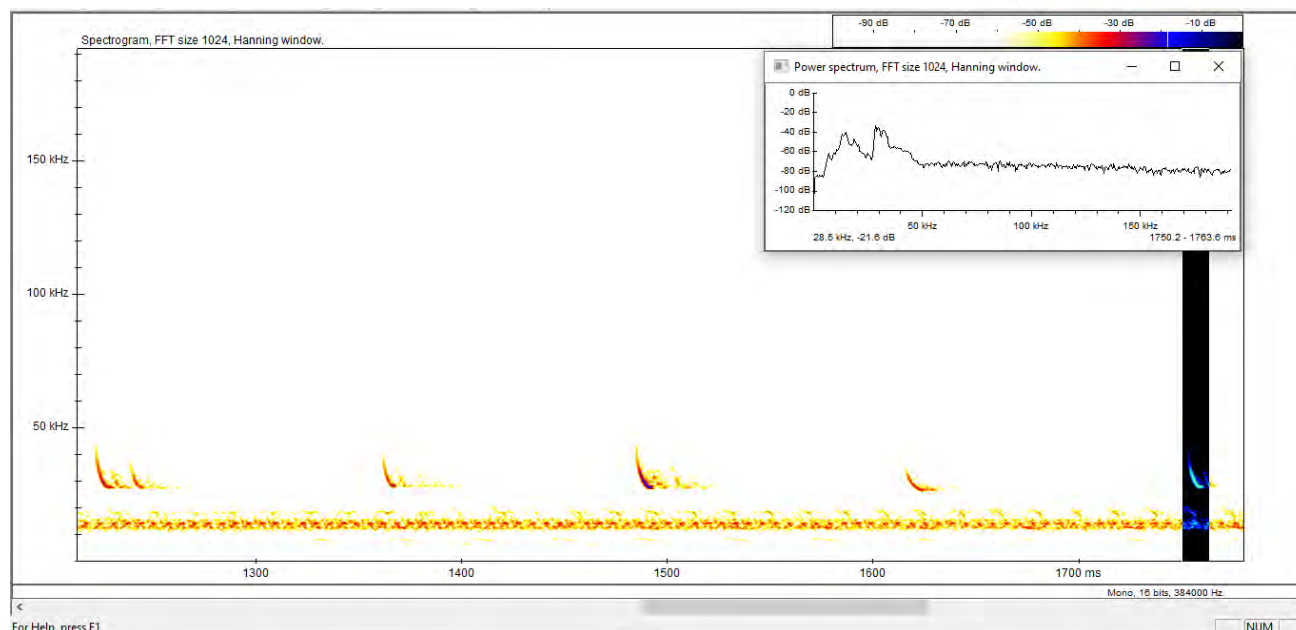
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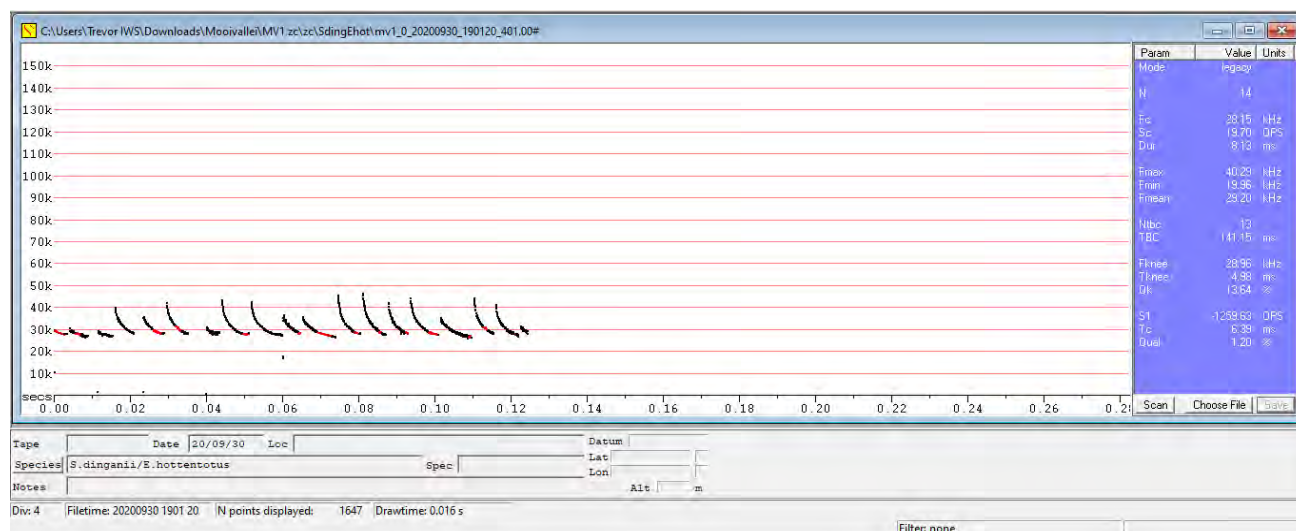


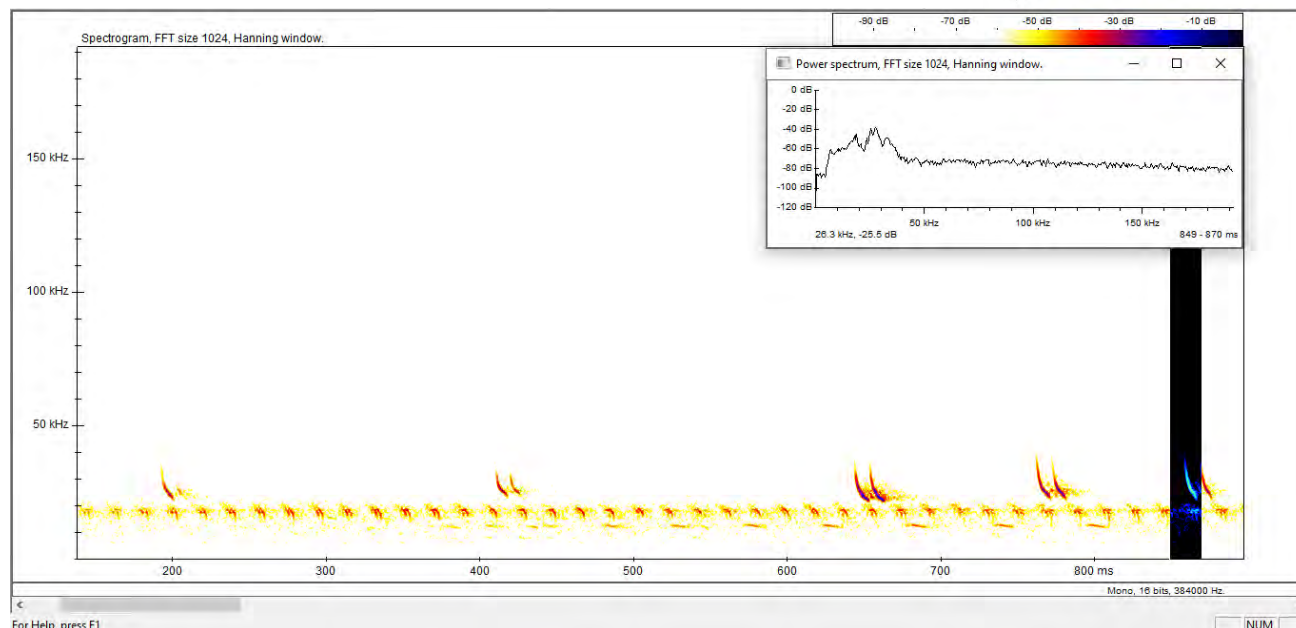
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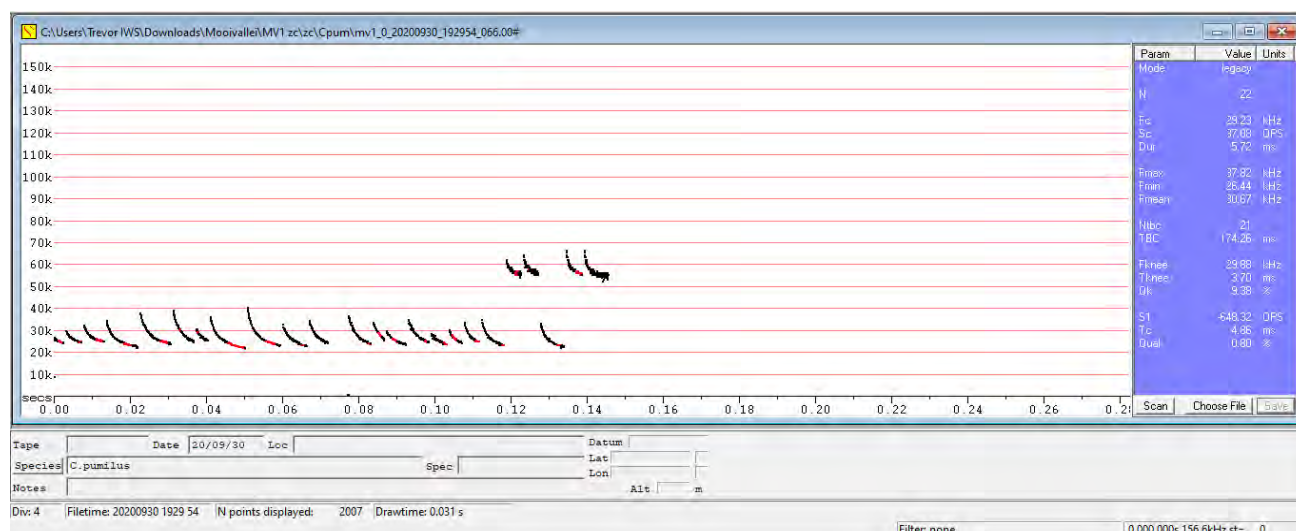


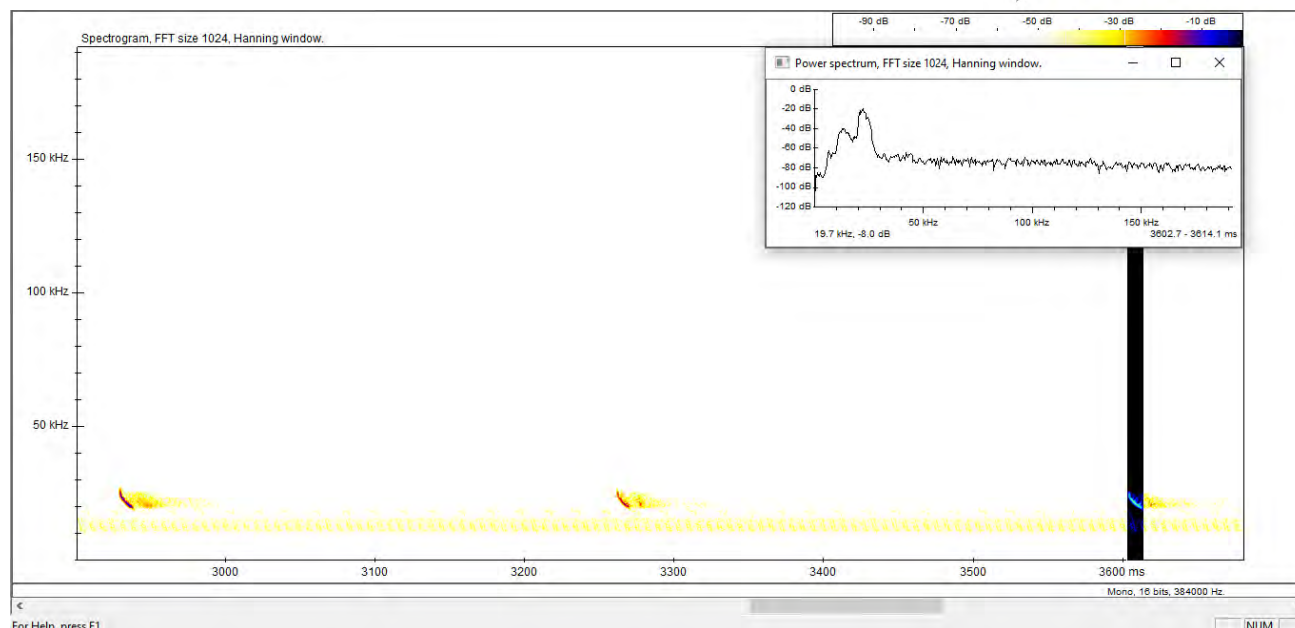
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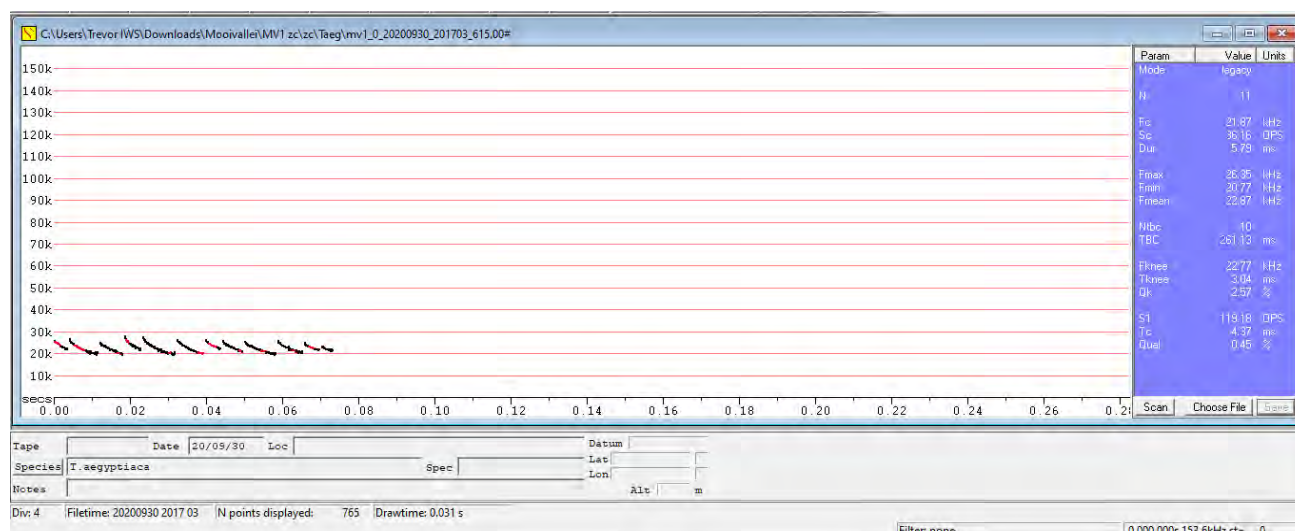


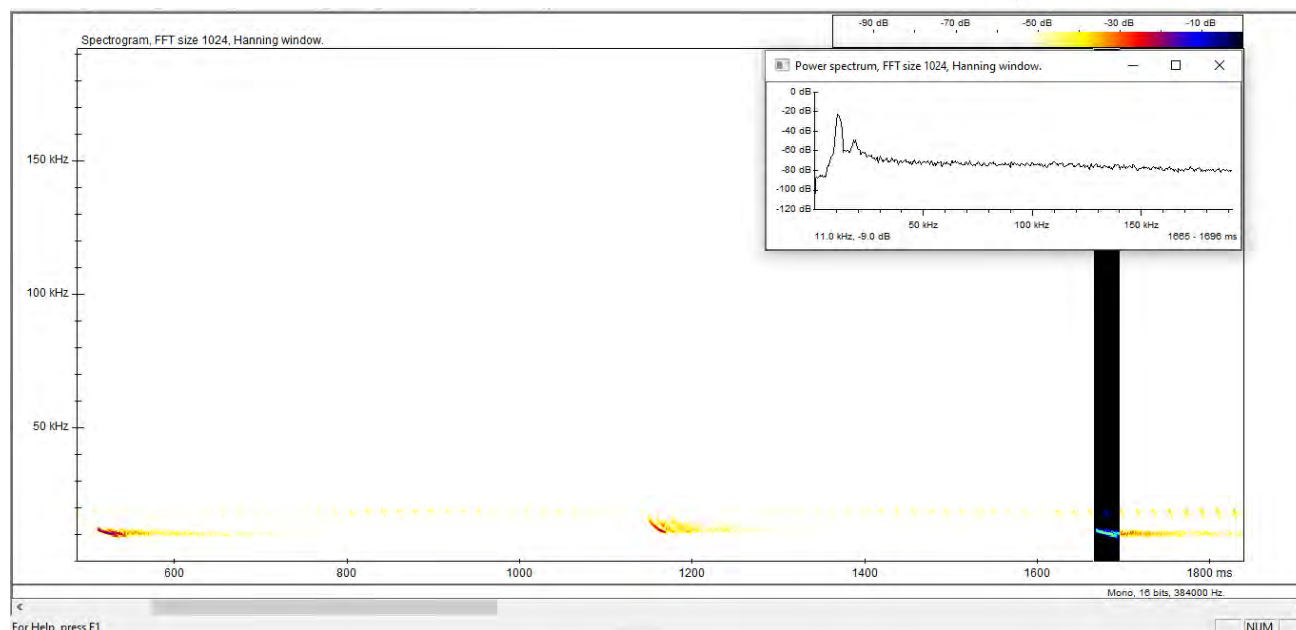
C. pumilus



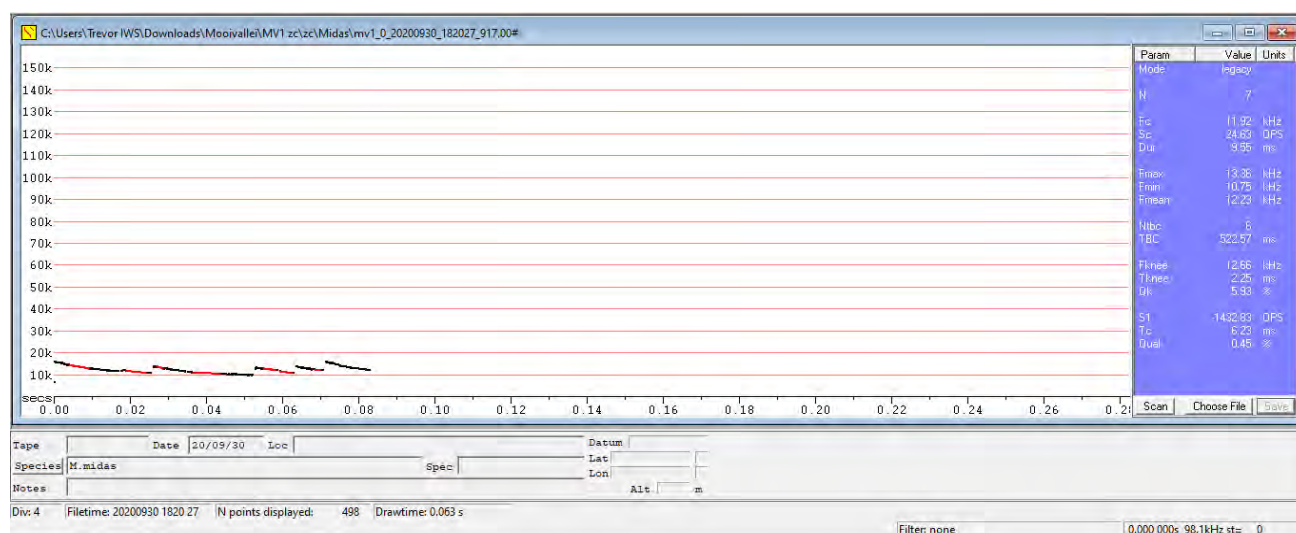


T. aegyptiaca





M. midas



13. Appendix 3: Geotechnical Assessment of Mooivallei Bat Cave by Geoid (2020)

P.T.O.





MOKOLO CROCODILE WATER AUGMENTATION PROJECT PHASE 2 (MCWAP-2):

Mooivallei Bat Cave

GEOTECHNICAL INVESTIGATION REPORT

REPORT NO: GGE/20022/2

October 2020

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Contents

1.	Introduction and Terms of Reference	1
2.	General Site Description	1
3.	Cave Description	2
4.	Fieldwork	2
5.	Background Information	3
5.1	Overview	3
5.2	Geological Context	3
5.3	Residual Gravity	3
5.4	Groundwater	3
5.5	Summary of Test Pit and Borehole Profiles	4
6.	Fieldwork Findings	5
6.1.1	Independently Recorded Cave Dimensions	5
6.1.2	Measurement Correspondence With Geophysics	5
6.1.3	Measurement Correspondence With Speleological Association Depictions	5
6.1.4	Rock Formation	6
6.1.5	Groundwater	6
7.	Geotechnical Assessment	7
7.1	External Factors Impacting on Geohydrology	7
7.1.1	Crop-land Irrigation	7
7.1.2	Weir Construction and Abstraction	7
7.2	Excavation Assessment	7
7.3	Dolomitic Issues	8
7.3.1	SANS 1936:2012 Dolomite Designation	8
7.3.2	Implication of D4 Mitigation Measures on the Bat Cave	8
7.3.3	Requisite Structural Solutions	8
7.3.4	Alternative Ground Improvement Mitigation Measures	9
8.	Conclusions	10
9.	Recommendations	11

Appendices

Appendix A:	Figures
Appendix B:	Supporting Geotechnical Information

Figures

Figure 1:	Regional Topographical Setting
Figure 2:	Regional Geological Setting
Figure 3:	Geotechnical Investigation Fieldwork Positions
Figure 4:	Geophysics Survey Overlay

List of Report Abbreviations

CBR -	California Bearing Ratio (test)
CRB -	Concrete Retaining Block
C4 / G6 / G9..-	Material Classification (per TRH14)
DCP -	Dynamic Cone Penetrometer
DPL -	Dynamic Probe Light (=DCP)
DPSH -	Dynamic Probe Super Heavy
GM -	Grading modulus
ngl -	Natural Ground Level
NMC -	Natural Moisture Content (%)
OMC -	Optimum Moisture Content (%) (at Mod AASHTO compactive effort)
PI -	Plasticity Index
SANS -	South African National Standard
TP.. -	Test Pit number
TRH14 -	Technical Recommendations for Highways
UCS -	Unconfined Compressive Strength

1. Introduction and Terms of Reference

Geoid Geotechnical Engineers have been appointed by the environmental specialist, Inkululeko Wildlife Services (Pty) Ltd, to provide a high-level geotechnical assessment of the potential ground stability risks impacting on the Mooivallei Bat Cave as a consequence of the proposed Mokolo Crocodile Water Augmentation Project Phase 2 (MCWAP-2).

Under the present scheme, the cave falls partially within the proposed 100m MCWAP corridor between the chainages of km 1.0 and km 1.15, within which a new 1.4m-1.9m diameter pipeline will be placed between 1m and 3m below ground level. As the concept allow for the pipeline location anywhere within the corridor, there is a very real risk of the cave being impacted either directly or indirectly by both the physical construction activities – excavation / blasting vibrations etc – as well as the ongoing operational actions of the pipeline itself and the ancillary water abstraction works upstream of the cave.

This report supplements our original desktop assessment of the site¹, based on a physical non-invasive walk-over inspection of both the hosting farm, as well an internal survey of the bat cave itself on the 30th September 2020.

2. General Site Description

The site hosting the bat cave is fully contained on a single farm portion, Re/10 of the farm Mooivallei 342-KQ, located approximately 9km WSW of the town of Thabazimbi. The position of the cave falls within the very gentle western pediment slopes of an adjacent ridge, which is extensively mined by open-cast methods on the east side of the watershed (Figure 1, Appendix A).

Vegetation is sparse and of an African savannah nature, comprising mixed woodland-grassland with widely spaced small trees forming an open canopy as depicted in the image below.



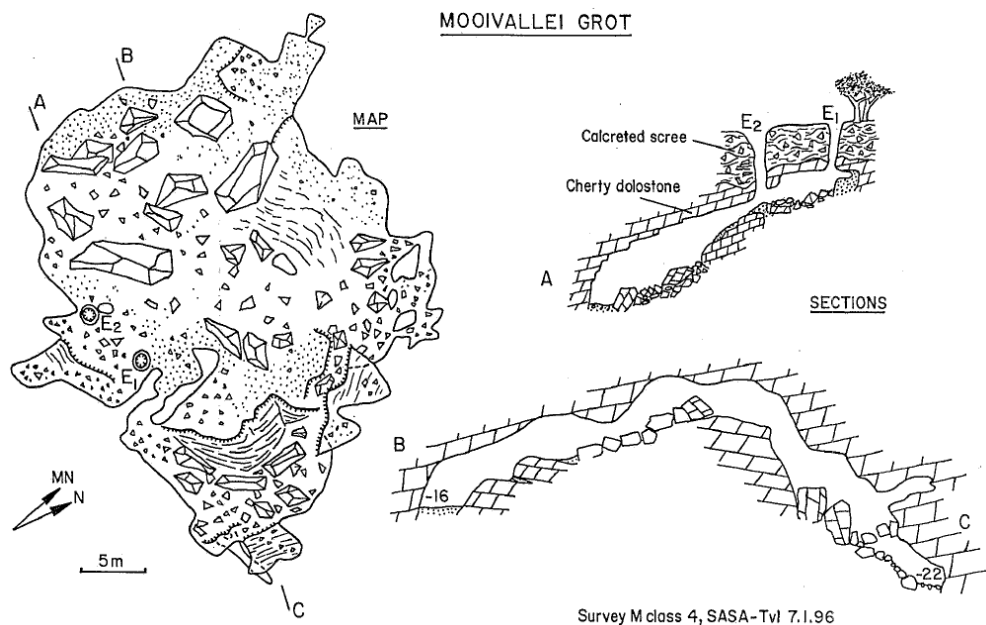
Several small non-perennial streams emanate from this ridge and drain west-through-south-westwards towards the north-west-bound Crocodile River, a major tributary of the Limpopo River, which passes through the Vlieëpoort just south of the bat cave. None of these were streams active at the time of our inspection. The Crocodile River is significantly lower-lying passing through a moderately deeply incised river bed passing through a wide, relatively flat floodplain (depicted below) which is extensively cultivated downstream of Re/10.



The proposed alignment of the corridor follows a nominally north-westwards trajectory from the weir and abstraction works at Vlieëpoort through to the balancing reservoir and high-lift pump station sedimentation works at km 5.2, which incorporates an inexplicable “chicane”, causing the corridor to partially traverse the bat cave, which may, otherwise, be missed altogether if the corridor alignment were straightened or slightly realigned to remove this feature.

3. Cave Description

The dimensions of the bat cave are somewhat imprecise, and mapped using a combination of geophysical resistivity and gravity techniques², supplemented by an historic mapping of the cave floor³ (depicted below), which is georeferenced and overlaid on our Figure 3, Appendix A. The latter report references the cave as comprising two chambers, some 10m deep, located close to a river – presumably the Crocodile River – despite which, there was no mention of any standing water in the cave, which was, moreover, reported as being *dry and dusty*.



4. Fieldwork

A physical site inspection was undertaken on the 30th September 2020 by ourselves, during which time the cave was explored internally with the assistance and under the direction of members of the Speleological Exploration Club (SEC). There were several components to this fieldwork, namely:

- (a) an internal inspection of the bat cave to independently determine the physical dimensions of the void, using a Bosch GLM 120C laser distometer;
- (b) to confirm / otherwise the dimensions of the cave provided in the original mapping³ as well as the indirect geophysical interpretation of the cave extents;
- (c) to assess the nature of the “hanging wall” in the cave and the geotechnical parameters of the rock formation, specifically the nature of the various strata, rock hardness and the presence of any WAD (weathered, altered dolomite), standing water or any indication of surface water ingress beyond the two cave shafts, all of which contribute to its overall stability;
- (d) a walk-over survey to assess the ground surface for evidence of subsidence – particularly any beyond the extremities of the cave, as defined by the geophysics mapping;
- (e) dipping of any borehole piezometers encountered during the walkover to establish the depth to the phreatic surface and provide a view on the stability impacts thereof.



²

GBN Joint Venture (June 2020), MCWAP-2 **Geotechnical Investigation, Dolomite Stability Assessment**, Report No: 2A-R-111E-22.

³

Martini JEJ and Moen, HFG (1996), **Mooivallei Cave**, p22 Bulletin of the South African Speleological Association, c/o Council for Geoscience, Pretoria.

5. Background Information

5.1 Overview

For the purposes of this assessment, the existing geological and geotechnical investigation dataset provided by GBN has been interrogated, with the details relevant to the bat cave included in Appendix B. This includes:

- (i) geological mapping⁴
- (ii) geophysics reports¹
- (iii) percussion borehole logs¹
- (iv) test pit logs⁵

5.2 Geological Context

Regional geological mapping places the bat cave within a dolomitic section of the pipeline - denoted *Site A* in the GBN report⁵ - which broadly stretches from the approximate chainages of km 1.3 to km 3.2, just short of the sedimentation works and high lift pump station. This dolomite of the Malmani Subgroup (Chuniespoort Group; Transvaal Supergroup) is bounded on the south by the banded ironstone of the Penge Formation - which is mined on the adjacent farm - and the quartzite of the Black Reef Formation to the north, around km 3.2 (see Figure 2, Appendix A).

5.3 Residual Gravity

- (i) The regional trend in the gravity is somewhat undulating along the pipeline length in Site A, including several notable troughs.
- (ii) The detailed gravity assessment at the bat cave⁶ exposed a significant gravity low around the cave itself (as expected) with several smaller lows propagating from the main chamber.
- (iii) These lows are interpreted to be a series of smaller peripheral caves within the rock mass, possibly connected to the main cave.
- (iv) The detailed assessment - albeit limited to the bat cave surrounds - serves as an indicator of the voided nature of the dolomite in this vicinity, and the likely conditions which may be prevalent throughout this rock formation - i.e roughly between km 1.3 and km 3.2.

5.4 Groundwater

- (i) As no geohydrological report has been provided for review, the only reported information available pertains to the rest water levels recorded after the drilling of the percussion boreholes during the geotechnical investigation.
- (ii) Although rest water levels were not recorded in PBHP06 due to borehole collapse, standing water was recorded in PBHP05 at 12.5m after 24hours deepening to in excess of 22m, at PBHP08, well within the weathered bedrock horizon.
- (iii) Boreholes located in the floodplain during the walkover survey indicate that the rest water level in the low-lying reaches is in the order of 7.2mbgl (MBH8) and 9.5m (an abstraction borehole servicing Re/10).
- (iv) From both the borehole logs and our independent piezometer reading, we interpret the phreatic surface of the aquifer to fall well below base of the cave, and probably within the interstices / dissolution fissures of the bedrock itself, which has a significant bearing on the overall assessment of the cave stability.

⁴ Geological Survey (1974), 1:250,000 Geological Series, **2426 Thabazimbi**, Government Printer, Pretoria.

⁵ GBN Joint Venture (June 2020), MCWAP-2 **Geotechnical Investigation Factual Report**, Report No: 2A-R-111E-15 (Rev B).

⁶ Geofocus Geophysical Services (January 2020), **WCWAP Geophysical Surveys (Thabazimbi) - Bat Cave Gravity Survey**.

5.5 Summary of Test Pit and Borehole Profiles

The following salient features are expressed in the test pit and borehole profiles, which correspond well with the profile as exposed in the cave (depicted in the images below):



- (i) Tightly packed, coarse colluvial gravels, cobbles and banded chert in an overall loose matrix, persisting from ground surface to between 0.7m and 2.7m depth, with an average depth of 1.5m; underlain by approximately
- (ii) 2m-3m of highly weathered, dolomite-interbedded banded-ironstone, overlying
- (iii) Slightly to highly weathered, chert-poor, soft rock dolomite, typically arising from 5m below ground level and persisting to around 50m depth without proving the underlying rock formations.
- (iv) Percussion logs from the dolomite bedrock show periodic evidence of air loss at depth, associated with low penetration times, indicative of low density material and/or voids in the bedrock - particularly in the vicinity of the bat cave.
- (v) Percussion borehole PBHP06 - being the nearest and possibly most representative profile of the bat cave - records very low penetration times and complete air loss from 32m to 42m, which is logged by GBN as a single cavity, below which the solid, unweathered dolomite bedrock only arises from approximately 50m below ground level.
- (vi) A similar pattern of smaller cavities with complete air loss was encountered from 27m-32m in PBHP07B, closer to the river, indicating that dissolution slots, caves and cavities in the dolomite are fairly common in this area, and ***not specifically confined to the bat cave itself.***

6. Fieldwork Findings

6.1.1 Independently Recorded Cave Dimensions

Taking cognizance of the limited line-of-sight opportunities between the extremities of the cave due to the low “hanging wall” in the centre of the cave, a series of back-sight : fore-sight measurements were required from an accessible vantage point in the centre of the cave to determine an independent set of cave dimensions, which are as follows:

(i)	visible primary axis - roughly north-south:	30m
(ii)	visible secondary axis - roughly east-west:	22m
(iii)	maximum visible depth:	19m
(iv)	eastern shaft depression to cave opening:	1.3m below general ground level
(v)	upper landing of the main shaft:	7m below general ground level

6.1.2 Measurement Correspondence With Geophysics

Using the relative positions of the two vent shafts of the cave for surface orientation purposes, the approximate surface projection of the cave extents were marked out above ground to provide a visual assessment of the cave dimensions. This was, then, checked against the aerial extent of the gravity survey using independent coordinates stored on a Garmin 60CSx handheld GPS, and a physical location recorded by mobile phone overlaid on the KMZ file displayed on GoogleEarth satellite imagery.

Other than necessitating a primary axis rotation about 10° to the north, the comparative results were astoundingly similar, with both the lateral and longitudinal visual measurements in situ corresponding near perfectly with the perimeter of the cave's *main chamber* as *predicted by the gravity survey* (see Figure 4).

What has emerged, then, is extreme confidence in the mapping accuracy of the geophysics assessment, providing confidence to extrapolate the interpretations to the peripheral disseminated caves which were not accessible from the main chamber during our inspection, and could not, therefore, be confirmed.

On the basis of the rudimentary bat count in the cave itself, and the more rigorous harp trapping exercise overnight - which exposed far greater numbers and species diversity - the engineering conclusion is that these disseminated caves are linked to the main chamber through conduits too small to detect at the gravity resolution, and possibly located in the lower bowels of the cave which were not physically accessible.

6.1.3 Measurement Correspondence With Speleological Association Depictions

While presented as conceptual, the two *sectional views* of the cave in the Mooivalei Cave publication ³ are assessed to be very representative of our own measurements and interpretation of the physical cave layout.

We are not, however, in agreement with the *plan view* which does not correspond particularly well with either the gravity survey or our visual measurements and spatial interpretation, and treat this as rather more qualitative than quantitative in value.

It is our view, therefore, that these conceptual depictions be treated as subordinate to the *more definitive gravity survey*, which be used in their stead for determining the aerial extent of the cave(s) - which is significantly smaller than that suggested in the GoogleEarth KMZ file depictions provided by GBN which form the yellow boundary line of our Figures 3-4 which grossly exaggerates the size of the observed cave, which was limited to the main chamber (see Figure 4)

Notwithstanding this, as this exaggerated boundary incorporates the various disseminated caves postulated by the gravity survey as well as the several surface depressions noted by ourselves during the walkover assessment, the areal extent is accepted as a conservative depiction of the upper limit of the cave dimensions.

6.1.4 Rock Formation

The rock formation noted in the cave - depicted in the images adjacent - comprises alternating bands of dolomite and banded ironstone, with the soluble residual material having been eroded and the gravelly residual silt remaining on the cave floor.



Rudimentary surface measurements of the dolomite rock hardness of the “hanging wall” of the cave was found to be no better than an *R2* COLTO Classification, with a UCS of less than 10MPa.

This would, however, represent the most extremely weathered rock, with the weathering profile likely to diminish perpendicular to the exposed surface.

6.1.5 Groundwater

As per the reference 3, the cave floor was found to be *dry and dusty* with no direct / indirect evidence of any shallow groundwater in recent time.

7. Geotechnical Assessment

7.1 External Factors Impacting on Geohydrology

7.1.1 Crop-land Irrigation

Water use permits for the neighbouring farms should be consulted to ascertain the *source of the water* used in the centre-pivot irrigation of the cultivated lands to the north-west of the bat cave – specifically whether this is surface water abstraction derived directly from the Crocodile River, or groundwater abstraction from the dolomite aquifer.

On the basis of the evidently sharp gradient in the groundwater surface recorded between PBHP05 (12.5m) and PBHP08 (22.4m) – despite their common elevation (917masl) and merely 700m lateral separation – we are of the opinion that these farms are irrigating from groundwater rather than surface water reserves.

The magnitude of this cone of depression suggests either a comparatively small water body which is sensitive / responsive to the effects of dewatering or, alternatively, abstraction at a higher rate than the natural aquifer recharge rate, leading to a very sizeable cone of depression.

7.1.2 Weir Construction and Abstraction

It is likely that, following the construction of the weir and prior to surface water abstraction commencing, the elevated water level in the Crocodile River upstream of the weir could cause a concomitant rise in the dolomite aquifer – provided there is physical hydraulic connectivity, which is not established – and the risk of minor flooding upstream of the weir, depending on the height of the structure.

With the groundwater level measured at merely 12m in borehole PBHP05, it is conceivable that the bat cave may become partially flooded in the process, temporarily altering the natural habitat. Following the commencement of weir abstraction, the water level may subside again as the dolomite aquifer reestablishes a new equilibrium. This rise and subsequent fall in the groundwater surface may result in the undesirable erosion of unconsolidated fines in the profile, increasing the overall instability of the cave, and potentially widening fissures or precipitating further cave openings – even small-scale collapse – which could impact negatively on the pipeline.

Regarding the flooding of the mine works from the new weir via old mine tunnels, this may be possible if such tunnels exist. With the mining being undertaken by open cast methods, however, the probability of tunnels existing seems somewhat remote. Were these to exist, prudence dictates that the river-side inlets simply be sealed, prior to the weir construction, to obviate a flooding risk.

7.2 Excavation Assessment

On the basis of the existing dataset provided, *soft excavation* – in terms of SANS 1200D: Earthworks (i.e. can be excavated by pick and shovel) – will account for approximately 85% of the trench volume, with the remaining 15% rated as *Boulder Class A* for the anticipated 1400mm diameter low-lift pipeline.

Although there is no indication from the factual report provided that *hard excavation* – necessitating drill-and-blast methods – will be required in the anticipated depth of trenching, the “hanging wall” of the cave comprises soft rock (R2) dolomite interbedded with medium hard rock (R3) banded ironstone, which is beyond the limits of *intermediate excavation*, necessitating either extensive rock breaking or blasting methods for excavations purposes, both of which have associated vibration risk, impacting on any metastable dolomite.

Despite the depth requirements of the pipeline itself, the requisite structural support necessary for the pipeline to span D4 dolomite would necessitate substantially deeper excavation, likely to bring *hard excavation* vibrations into play.

7.3 Dolomitic Issues

7.3.1 SANS 1936:2012 Dolomite Designation

On the basis of the dolomite stability report¹, *Site A* is generally assigned a *D3 designation*, which mandates the use of precautionary measures to prevent the concentrated ingress of surface water into the ground – as this pertains to the design, construction and operation of the pipeline.

Notwithstanding this, a 475m section of Site A – incorporating boreholes PBHP05, 06 and 07 *which bracket the bat cave* – is **designated D4**, which *mandates site-specific precautions in addition to the D3 requirements*, specifically the *support of the pipeline in the event of a complete loss of support between 5m and 15m*.

7.3.2 Implication of D4 Mitigation Measures on the Bat Cave

In order to comply with the SANS 1936:2012 requirements for D4 zones, two approaches are appropriate:

- (i) acceptance of the loss of support criterion and *accommodating* this using structural methods to bridge the loss of support, or
- (ii) trading the high cost of the structural solutions for ground improvement solutions to *mitigate* the magnitude of the loss of support in order to motivate for substantially lighter structural solutions.

Failure to implement these D4 structural accommodation or ground improvement mitigation measures introduces a *completely intolerable risk of the pipeline rupturing* at the very loss-of-support locale, discharging enormous volumes of water into the metastable and already cavernous dolomite profile. This has the potential to trigger a succession of similar sinkhole events, with enormous collateral damage, including loss of life and property, where such damage claims may be a orders of magnitude higher than the cost of the requisite mitigation measures.

From the borehole records it appears that the pipeline will need to traverse this D4 zone, other than, perhaps, if the corridor were to deviate into the floodplain to the west, where a less extreme dolomitic profile is likely to be present, and one which is underlain by shallow groundwater (on evidence of our borehole dipping), providing a measure of structural stability to the dolomite formation and reducing the magnitude of any catastrophic (sinkhole) failure, were this to occur. Deviation to the west, however, raises other environmental and geotechnical challenges which are not addressed in this report.

7.3.3 Requisite Structural Solutions

Unmitigated structural solutions to support the pipeline are envisaged to necessitate a reinforced / post-tensioned concrete box channel capable of spanning the full loss of support – up to 15m – in the event of ground collapse through the full 475m length of the D4 zone.

Notwithstanding these generic parameters presented in the Code, with the physical dimensions of the cave having actually been measured by ourselves, the 15m loss of support does not, in this instance, adequately address physical reality. Were the pipeline to actually traverse this cave, it would be obliged to span the full width – measured at 22m – in addition to the lateral extent of the disseminated caves, taking the unsupported span to a prohibitively large 32m.

This option would, by nature, increase the excavation depth required for the pipeline – possibly in the order of 1.5m-2m to install structural support – impacting on both the *depth* and *class* of excavation, and possibly necessitating drill-and-blast methods. Significant vibrations due to rock breaking / blasting in close proximity to the bat cave are considered an intolerable environmental risk, as the near-surface bat cave comprises a metastable weathered dolomite profile which may become destabilised, leading to hanging wall / roof collapse and sinkhole formation.

7.3.4 Alternative Ground Improvement Mitigation Measures

Ground improvement solutions typically applied in karstic dolomite include the use of either:

- (i) heavy *dynamic compaction*, in which heavy weights are dropped from high cranes to precipitate collapse and densification of the voided dolomite profile, or
- (ii) lower-impact *compaction grouting* techniques, wherein grout is injected through a grid of boreholes to knit the dolomite profile and mitigate the risk of large diameter catastrophic sinkhole development.

In the present instance, neither of these ground improvement solutions are appropriate in close proximity to the bat cave; DC for reasons of potentially precipitating the collapse of the cave and loss of the natural habitat, and compaction grouting potentially intersecting and inadvertently filling up the cave void, similarly destroying the natural habitat.

8. Conclusions

- (a) The Mooivallei Bat Cave falls within a vulnerable D4 dolomite zone of Site A, which is confirmed by independent site inspection of the farm portion and the cave itself.
- (b) Cave dimensions were independently measured by laser distometer, and found to be approximately 30m on the primary axis of the cave 9 (north-east: south-west) and approximately 22m on the secondary (north-west: south-east) axis, very closely approximating the main chamber of the gravity survey as presented in Figure 4.
- (c) While the lateral extent of the cave - as presented in the GoogleEarth KMZ file provided by GBN - is found to exaggerate the visible extent of the cave, the number and diversity of bats monitored during this fieldwork exercise suggest that the various gravity lows comprise a number of disseminated caves leading off the main chamber via narrow conduits, to the extent that the perimeter of the cave as presented is considered adequately conservative.
- (d) The cave is voided to approximately 19m - 22m below ground level, with the highest point of the cave floor merely 7m below ground level.
- (e) The “hanging wall” of the cave within this upper 7m of the profile was found to comprise *soft rock* (R2) dolomite interbedded with *medium hard rock* (R3) banded ironstone, which is beyond the limits of intermediate excavation, necessitating either extensive rock breaking or drill-and-blast methods for excavations purposes, introducing intolerable risk to the bat habitat.
- (f) The present Code of Practice governing developments on dolomite mandates that the pipeline be designed to span a loss of support of up to 15m, using structural methods, or for the ground to be substantially improved to motivate for lighter structural solutions.
- (g) Despite the requirements of the Code, were the pipeline to directly traverse the cave - as possible within the approved pipeline corridor - the loss of support would need to be upgraded to at least 22m to span the measured minor axis of the primary chamber of the cave, extended to 32m to cover the lateral extent of the disseminated caves.
- (h) Notwithstanding the limited depth requirements of the pipeline itself, the requisite structural support solutions necessary to span the D4 dolomite would necessitate substantially deeper excavation, likely to bring these *hard excavation* conditions into play, introducing intolerable consequential stability risk to the cave itself.
- (i) Ground improvement solutions in close proximity to the bat cave are considered inappropriate, presenting either intolerable vibration risk to the structural integrity of the cave, or a possible loss of habitat.
- (j) On evidence of the above, the approved pipeline corridor as presented is judged to be *fatally flawed*, as this presents an intolerable structural integrity risk to both the cave and the very pipeline itself, necessitating the implementation of an *appropriate buffer* around the cave, which is not currently in place, and for the approved corridor to be deviated either to the east or west to adequately deal with this very real hazard.
- (k) A deviation to the east will, likely, replace *intermediate, boulder* and *hard excavation* with *soft excavation* to the full depth of the pipeline trench, greatly reducing installation costs and the need for dolomite ground improvements and structural spanning solutions, which are likely to be particularly onerous.
- (l) Moreover, even though dolomitic conditions underlie the alluvial deposits of the Crocodile River floodplain, the mitigating impact of a shallow groundwater greatly reduces the stability risk of the dolomite, likely to reduce the D4 designation to at least D3.

9. Recommendations

- (a) From a geotechnical engineering perspective, we recommend that the proposed corridor be realigned to accommodate a minimum buffer of 100m around the conservative perimeter (yellow boundary line) of the cave.
- (b) Should a deviation to the west of the cave be considered feasible from an overall engineering perspective, this is preferred to a deviation to the east, as this eliminates any collateral stability risk to the cave in the event of pipe leakage, as the gradients and elevation would force surface water away from the cave into the river, rather than upslope towards the cave.
- (c) In light of the above, a deviation of the pipeline to the east is not favoured as the collateral risk of a leaking pipeline cannot be adequately mitigated, but may be required to accommodate the ecological constraints of the riparian zone.
- (d) Should this not be possible, the D4 support conditions for the pipeline traversing the dolomite to the east of the cave should be strictly enforced unless further representative geotechnical investigation provides justification for the lesser requirements of a D3 designation.
- (e) It is finally recommended that the buffer requirements of the engineers – provisionally no less than the 100m beyond the cave footprint as presented in Figure 4 – defer to the more onerous buffer requirements of the environmentalists in selecting the revised corridor for the pipeline.

CS Morgan Pr Eng | Director
Geoid Geotechnical Engineers (Pty) Ltd

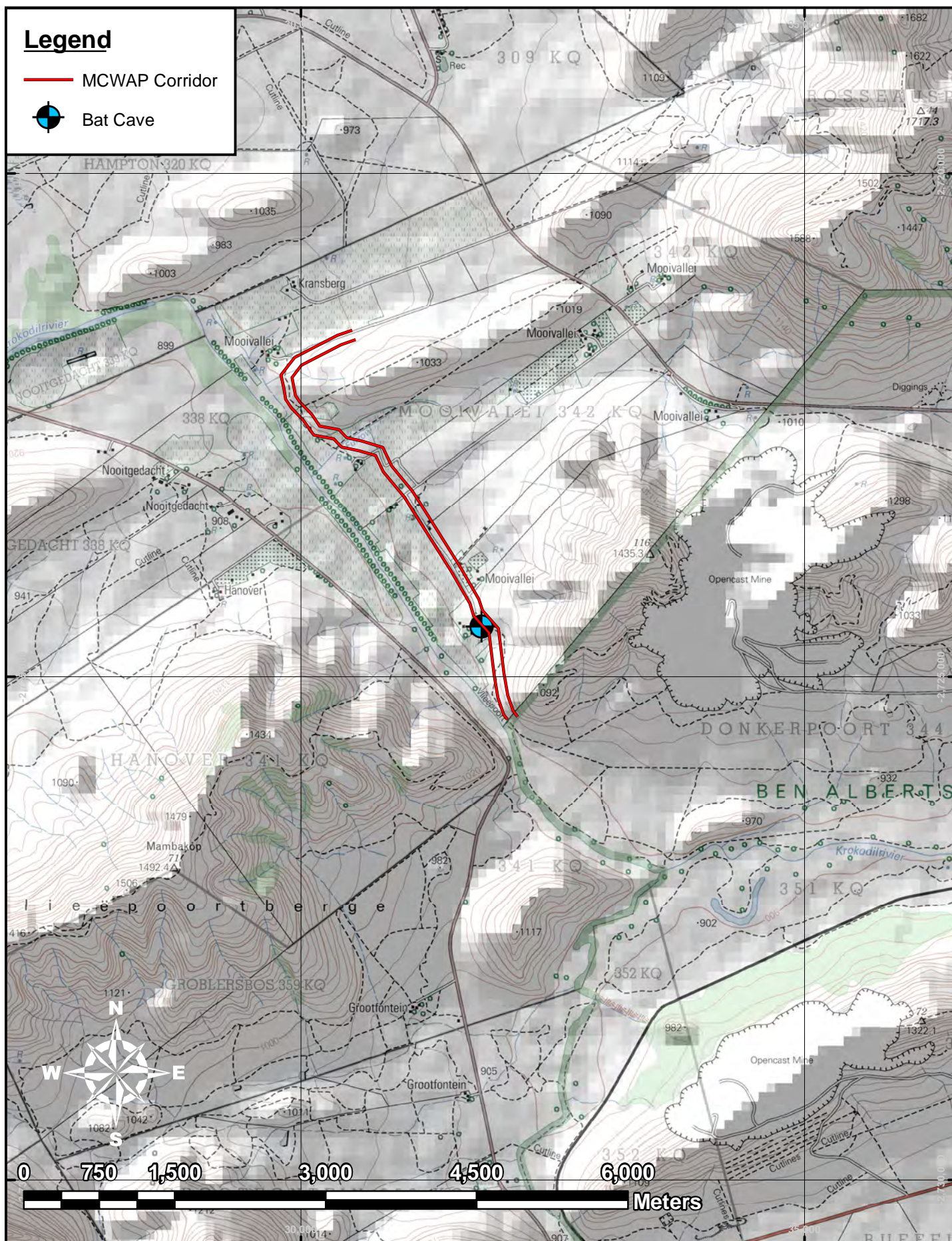
APPENDIX A

Figures

Legend

 MCWAP Corridor

 Bat Cave



PostNet Suite #10134
Private Bag X7005
Hillcrest, KZN, 3610
+27-79-175-1758
info@iws-sa.co.za
www.iws-sa.co.za

TITLE:
**MCWAP: Bat Cave
Regional Topographic Setting**

CLIENT:
GBN Joint Venture

PROJECT NUMBER: **GGE/20022**
DRAWING NUMBER: **Figure 1**
REVISION: **0**
DATE: **20/07/2020**

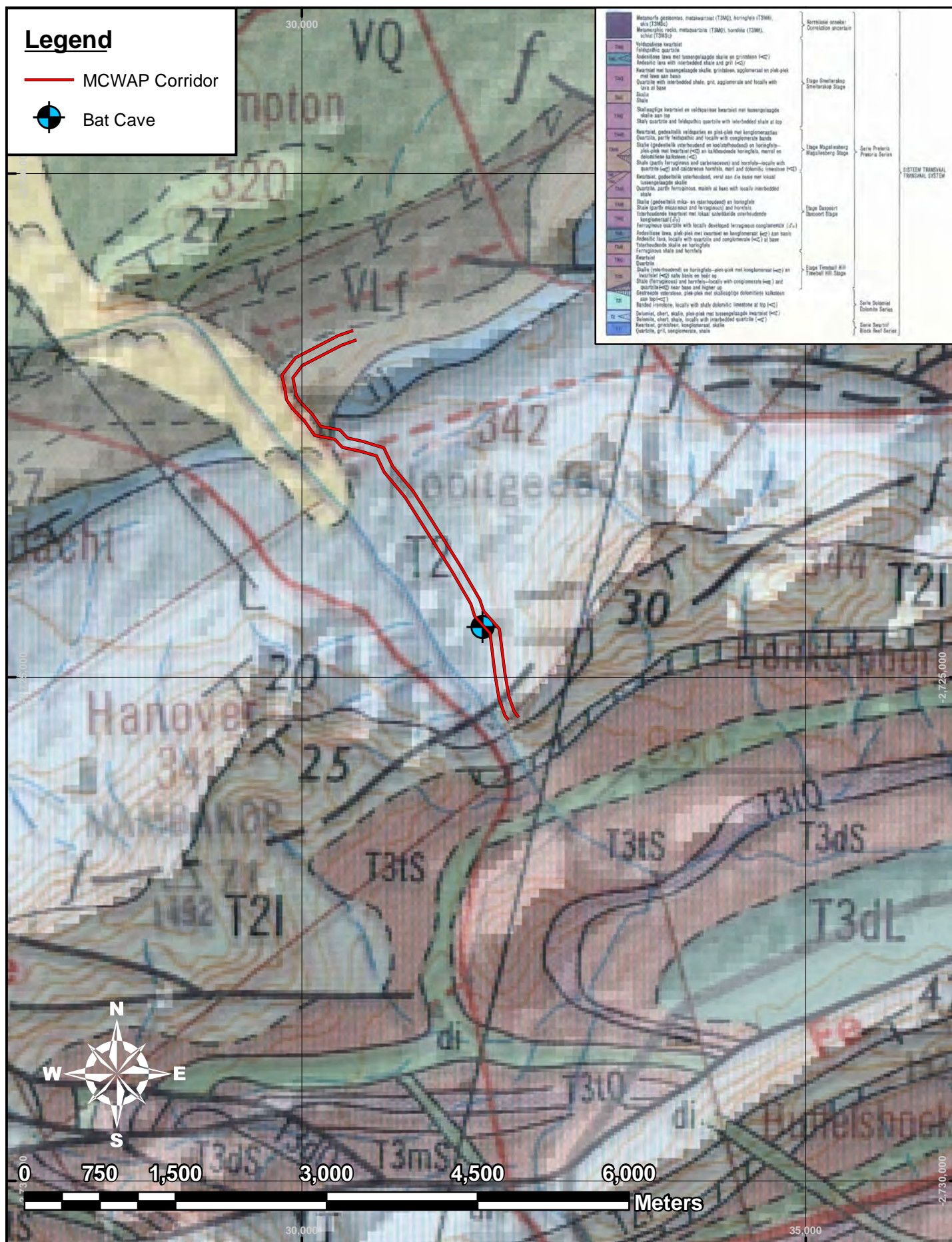
ENGINEER: **CS Morgan**
SCALE (A4): **1:50,000**
DATUM: **WG27**

Legend

— MCWAP Corridor



Bat Cave



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TITLE:

MCWAP: Bat Cave
Regional Geological Setting







CLIENT:

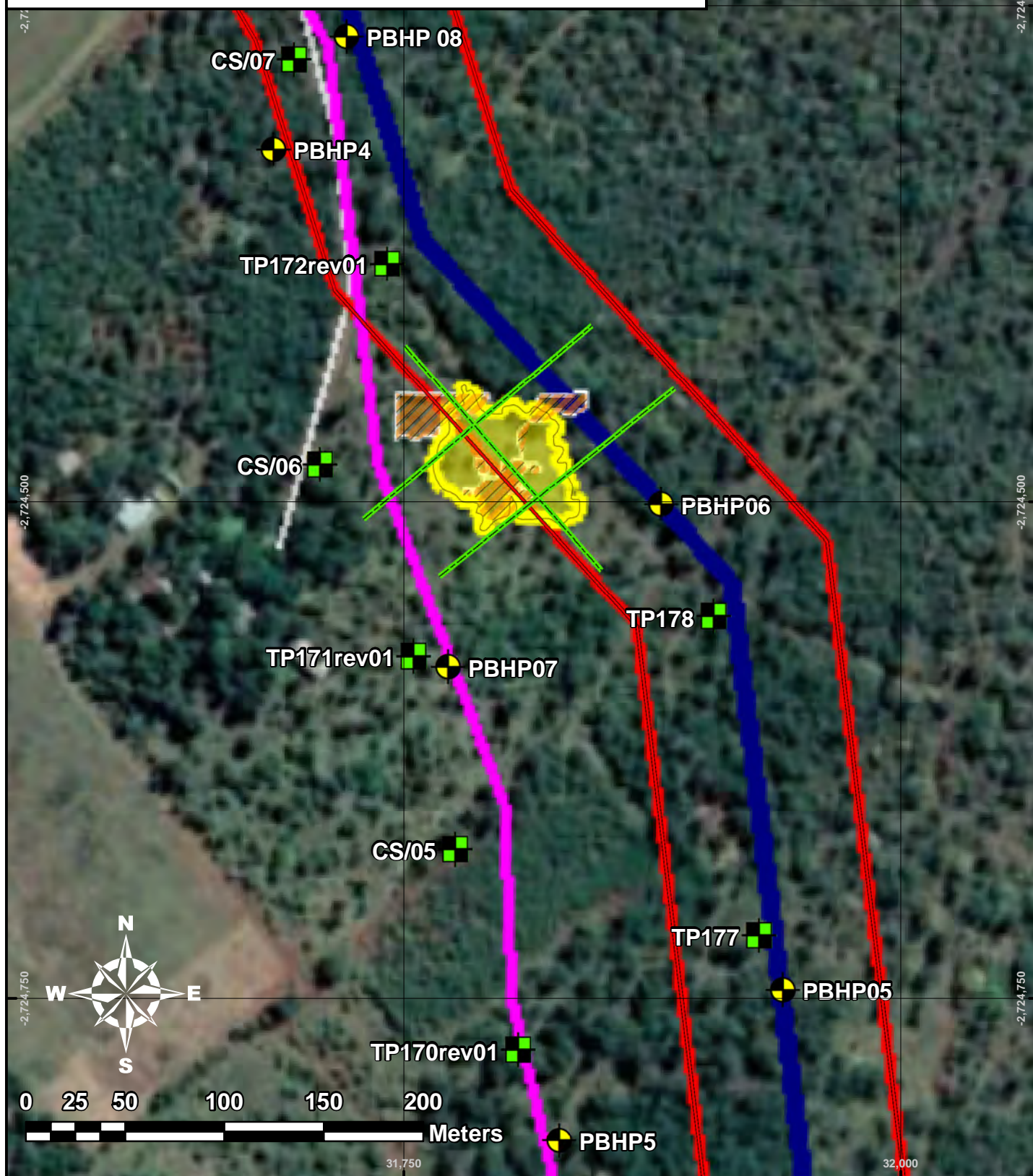
GBN Joint Venture

PROJECT NUMBER: **GGE/20022**
DRAWING NUMBER: **Figure 2**
REVISION: **0**
DATE: **20/07/2020**

ENGINEER : CS Morgan
SCALE (A4) : 1:50,000
DATUM : WG27

Legend

-  Borehole
-  Resistivity
-  Gravity Low
-  Test Pit
-  MCWAP Corridor
-  Bat Cave - Inferred Extent



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TITLE:
**MCWAP: Bat Cave
GI Fieldwork Positions**

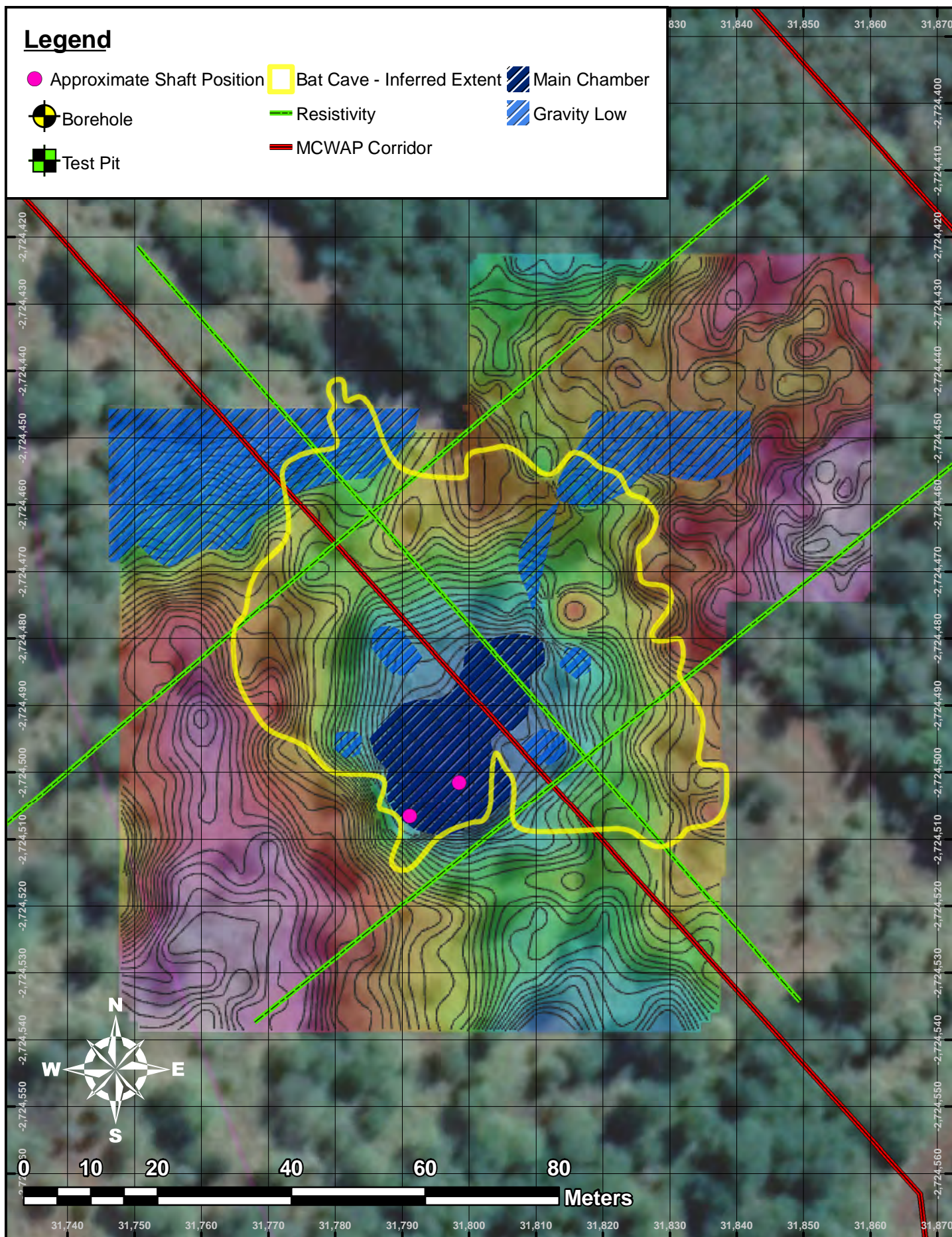
CLIENT:
GBN Joint Venture

PROJECT NUMBER: **GGE/20022**
DRAWING NUMBER: **Figure 3**
REVISION: **0**
DATE: **29/07/2020**

ENGINEER: **CS Morgan**
SCALE (A4): **1:2,750**
DATUM: **WG27**

Legend

- Approximate Shaft Position
 Bat Cave - Inferred Extent
 Main Chamber
- ⦿ Borehole
 — Resistivity
 Gravity Low
- Test Pit
 — MCWAP Corridor



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TITLE:
**MCWAP: Bat Cave
Geophysics Survey**

CLIENT:
GBN Joint Venture

PROJECT NUMBER: **GGE/20022**
DRAWING NUMBER: **Figure 4**
REVISION: **0**
DATE: **26/10/2020**

ENGINEER: **CS Morgan**
SCALE (A4): **1:750**
DATUM: **WG27**

APPENDIX B

Supporting Information

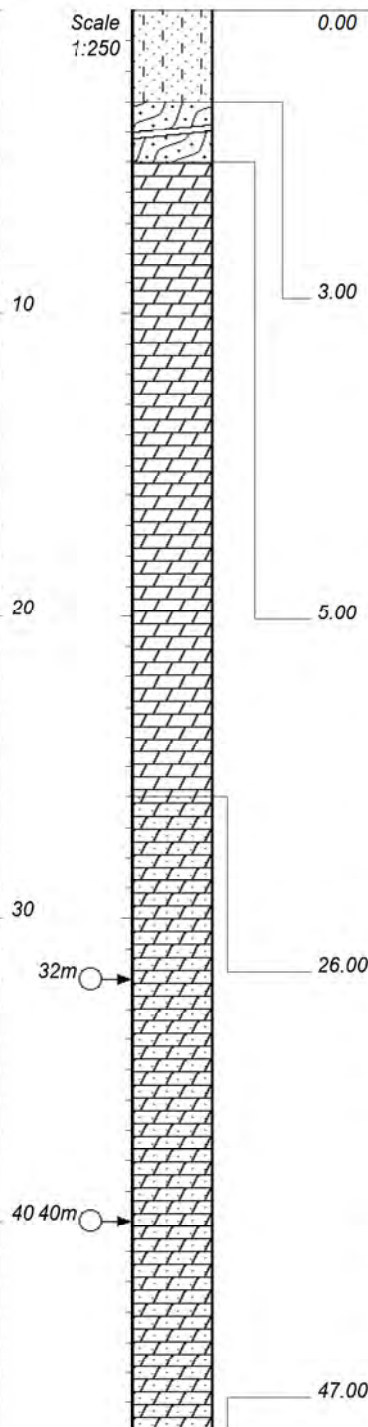


**GBN JOINT VENTURE
MOKOLO CROCODILE WATER AUGMENTATION
PROJECT PHASE 2**

HOLE No: PBHP05B
Sheet 1 of 1

JOB NUMBER: J38167

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	100	0	0.20
	100	0	0.40
	100	0	0.17
	100	0	2.29
	100	0	2.40
	100	0	3.41
	100	0	3.00
	100	0	4.44
	100	0	3.26
	100	0	1.41
	100	0	1.51
	100	0	2.51
	100	0	3.10
	100	0	2.25
	100	0	1.56
900	100	0	2.08
	100	0	1.48
	100	0	1.34
	100	0	1.20
	100	0	1.40
	100	0	1.25
	100	0	2.24
	100	0	2.03
	100	0	1.24
	100	0	2.05
890	100	0	1.24
	100	0	2.24
	100	0	1.23
	100	0	1.47
	100	0	2.19
	100	0	2.41
	100	0	2.31
	100	0	2.13
	100	0	2.37
	100	0	2.38
880	100	0	2.47
	70	30	2.09
	100	0	1.11
	70	30	1.10
	100	0	2.37
	100	0	3.03
	100	0	3.01
	100	0	3.06
	100	0	3.00
	100	0	3.09
870	100	0	3.19



Bulk sample: Dry, reddish brown, silty sand. **Sieve washed:** 70-90% loss. Wet, fine to medium sand of sub-rounded to sub-angular chips of highly weathered ironstone. **Interpretation:** **COLLUVIUM.**

Bulk sample: Dry, reddish brownish, gravelly sand. **Sieve washed:** 50-70% loss. Wet, fine to medium sand of sub-rounded to sub-angular chips of highly weathered ironstone. **Interpretation:** **WEATHERED IRONSTONE, DOLOMITE SERIES.**

Bulk sample: Dry, brownish grey, gravelly sand. **Sieve washed:** 45-65% loss. Wet, coarse sand to fine gravel of sub-angular to angular chips of moderately to slightly weathered dolomite and minor ironstone. **Interpretation:** **WEATHERED DOLOMITE, DOLOMITE SERIES.**

Bulk sample: Wet, brownish grey, gravelly sand. **Sieve washed:** 35-55% loss. Wet, coarse sand to fine gravel of sub-angular to angular chips of moderately to slightly weathered dolomite and traces of ironstone and quartz. **Interpretation:** **WEATHERED DOLOMITE, DOLOMITE SERIES.**

NOTES

- 1) Sieve Aperture: 1.2mm x 1.4mm
- 2) Water level after 24hrs:12.5m
- 3) Water strike at 32m & 40m
- 4) Small cavity at 32m

CONTRACTOR : Geo Mechanics
MACHINE : Percussion
DRILLED BY : Abram Motsepe
PROFILED BY : Tseliso Lebasa

TYPE SET BY : Tseliso Lebasa
SETUP FILE : STANDARD.SET

INCLINATION : Vertical
DIAM : 165 mm
DATE : 03/12/2019
DATE : 04/12/2019

DATE : 12/05/2020 08:58
TEXT : ..B\Thabazimbi\PBHP05B.txt

ELEVATION : 917 m
X-COORD : 27.31544°E
Y-COORD : 24.62689°S

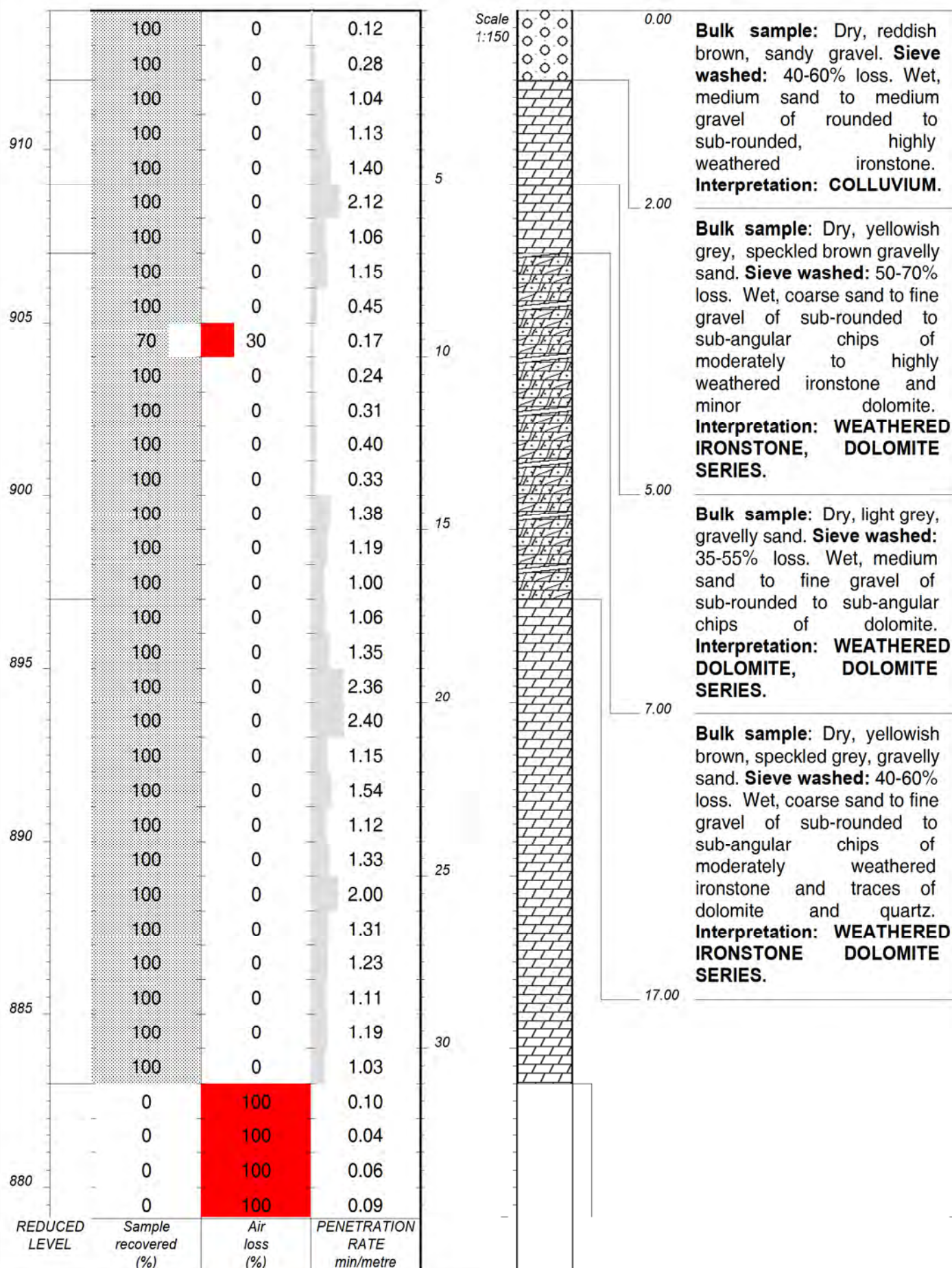
HOLE No: PBHP05B
Thabazimbi



**GBN JOINT VENTURE
MOKOLO CROCODILE WATER AUGMENTATION
PROJECT PHASE 2**

HOLE No: PBHP06B
Sheet 1 of 2

JOB NUMBER: J38167



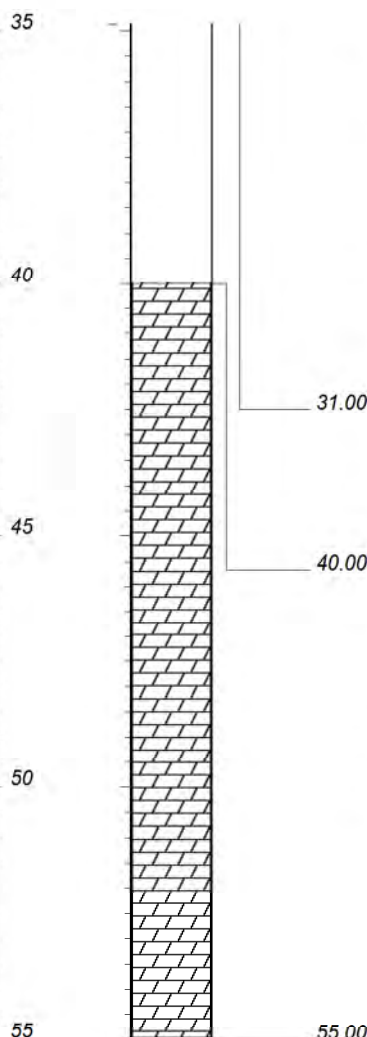


**GBN JOINT VENTURE
MOKOLO CROCODILE WATER AUGMENTATION
PROJECT PHASE 2**

HOLE No: PBHP06B
Sheet 2 of 2

JOB NUMBER: J38167

	0	100	0.09
	0	100	0.08
	0	100	0.10
875	0	100	0.11
	0	100	0.09
	100	0	0.24
	70	30	0.28
	100	0	1.08
870	100	0	0.44
	100	0	0.51
	100	0	1.55
	100	0	1.40
	100	0	0.55
865	100	0	2.21
	100	0	3.11
	100	0	3.21
	100	0	3.28
	100	0	3.02
860	100	0	3.00
	100	0	3.26



Bulk sample: Dry, light grey, blotched yellow, gravelly sand. **Sieve washed:** 35-55% loss. Wet, coarse sand to fine gravel of sub-angular to angular chips of moderately weathered dolomite and traces of ironstone and quartz. **Interpretation:** WEATHERED DOLOMITE, DOLOMITE SERIES.

Bulk sample: Cavity, Nosample. **Sieve washed:** Cavity, No sample. **Interpretation:** CAVITY.

Bulk sample: Drilling solid rock, probably dolomite No sample due to cavity above. **Sieve washed:** Drilling solid rock. No sample due to cavity above. **Interpretation:** DRILLING SOLID ROCK, PROBABLY.

NOTES

- 1) Sieve Aperture: 1.2mm x 1.4mm
- 2) Water level after 24hrs: Hole collapsed at 1.5m
- 3) Large cavity from 32m to 40m

REDUCED LEVEL	Sample recovered (%)	Air loss (%)	PENETRATION RATE min/metre
---------------	----------------------	--------------	----------------------------

CONTRACTOR : Geo Mechanics
MACHINE : Percussion
DRILLED BY : Abram Motsepe
PROFILED BY : Tseliso Lebasa

TYPE SET BY : Tseliso Lebasa
SETUP FILE : STANDARD.SET

INCLINATION : Vertical
DIAM : 165 mm
DATE : 09/12/2019
DATE : 09/12/2019

DATE : 14/05/2020 11:14
TEXT : ..lisoMauniqu\PBHP06B.txt

ELEVATION : 914 m
X-COORD : 27.31500°E
Y-COORD : 24.62465°S

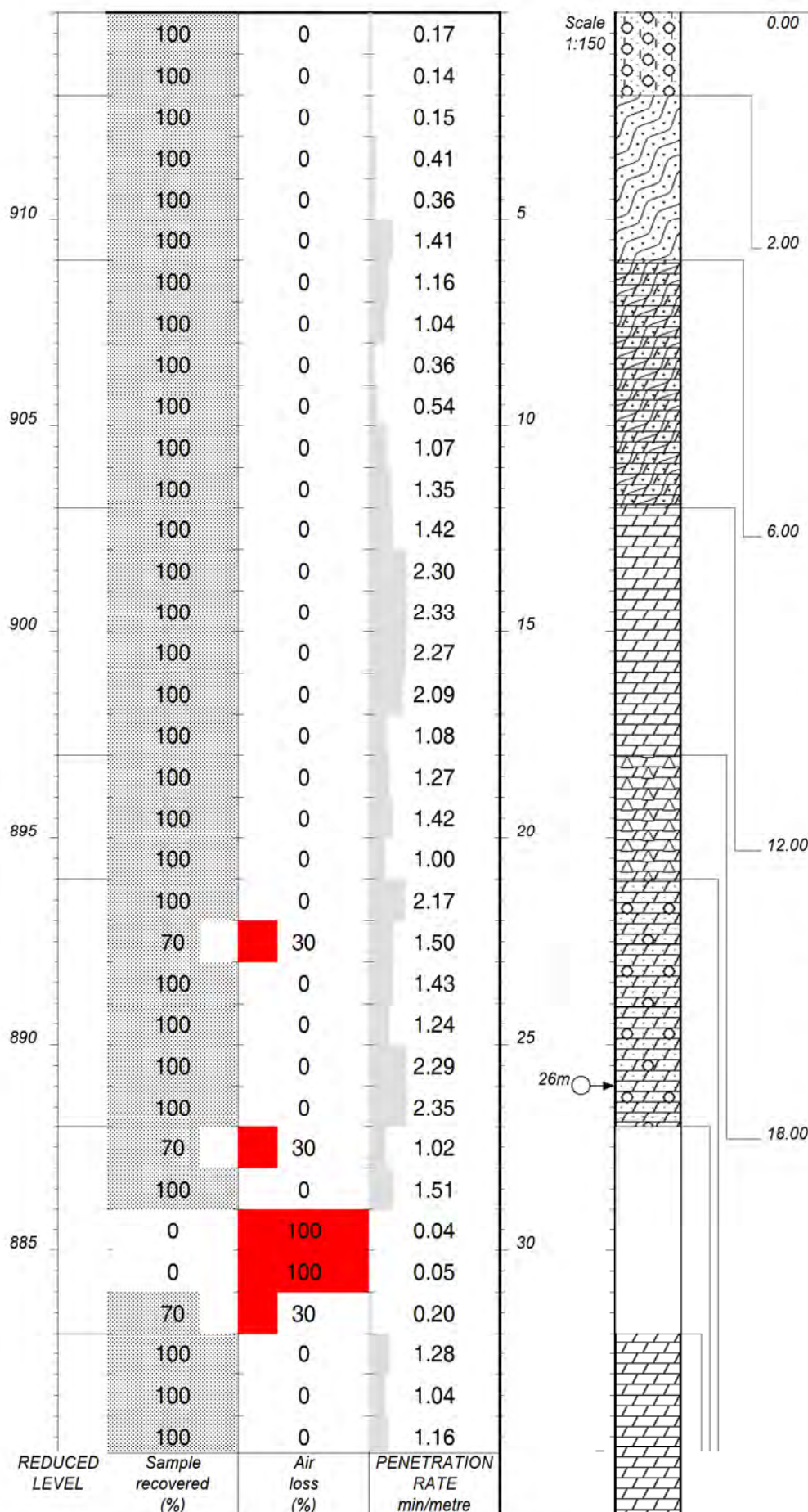
HOLE No: PBHP06B
Thabazimbi



**GBN JOINT VENTURE
MOKOLO CROCODILE WATER AUGMENTATION
PROJECT PHASE 2**

HOLE No: PBHP07B
Sheet 1 of 2

JOB NUMBER: J38167



Bulk sample: Dry, reddish brown, silty sand with some gravel. **Sieve washed:** 40-60% loss. Wet, medium sand to medium gravel of rounded to sub-rounded, highly weathered ironstone. **Interpretation:** COLLUVIUM.

Bulk sample: Dry to slightly moist, reddish brown, gravelly sand. **Sieve washed:** 40-60% loss. Wet, coarse sand to fine gravel of sub-rounded to sub-angular chips of moderately weathered ironstone. **Interpretation:** WEATHERED IRONSTONE, DOLOMITE SERIES.

Bulk sample: Dry to slightly moist, reddish brown, gravelly sand. **Sieve washed:** 40-60% loss. Wet, coarse sand to fine gravel of sub-rounded to sub-angular chips of moderately weathered ironstone and traces of dolomite. **Interpretation:** WEATHERED IRONSTONE, DOLOMITE SERIES.

Bulk sample: Dry to slightly moist, grey, sandy gravel. **Sieve washed:** 35-55% loss. Wet, coarse sand to fine gravel of sub-rounded to sub-angular chips of moderately weathered dolomite. **Interpretation:** WEATHERED DOLOMITE, DOLOMITE SERIES.



**GBN JOINT VENTURE
MOKOLO CROCODILE WATER AUGMENTATION
PROJECT PHASE 2**

HOLE No: PBHP07B
Sheet 2 of 2

JOB NUMBER: J38167

880	100	0	1.51	35
	100	0	2.49	
	100	0	3.07	
	100	0	2.21	
875	100	0	2.31	40
	100	0	2.15	
	100	0	2.44	
	100	0	3.18	
	100	0	3.10	
870	100	0	3.04	45
	100	0	3.09	
	100	0	3.12	
	100	0	3.20	

Bulk sample: Dry to slightly moist, dark brown, speckled grey silty sand. **Sieve washed:** 75-95% loss. Wet, fine to medium sand of sub-rounded to sub-angular chips of highly to moderately weathered dolomite and abundant chert. **Interpretation: WEATHERED DOLOMITE, DOLOMITE SERIES.**

Bulk sample: Dry to wet, grey, blotched yellow, gravelly sand. **Sieve washed:** 45-65% loss. Wet, coarse sand to fine gravel of sub-angular to angular chips of moderately to slightly weathered dolomite. **Interpretation: WEATHERED DOLOMITE, DOLOMITE SERIES.**

Bulk sample: No sample. **Sieve washed:** No sample. **Interpretation: CAVITY.**

Bulk sample: No sample, probably dolomite, due to cavity above. **Sieve washed:** No sample due to cavity above. **Interpretation: HARD ROCK DRILLING, PROBABLY**

NOTES

- 1) Sieve Aperture: 1.2mm x 1.4mm
- 2) Water level after 24hrs: 12m?
- 3) Water added at 4m, 14m, 20m & 25m
- 4) Water strike at 26m

REDUCED LEVEL	Sample recovered (%)	Air loss (%)	PENETRATION RATE min/metre
---------------	----------------------	--------------	----------------------------

CONTRACTOR : Geo Mechanics
MACHINE : Percussion
DRILLED BY : Abram Motsepe
PROFILED BY : Tseliso Lebasa

TYPE SET BY : Tseliso Lebasa
SETUP FILE : STANDARD.SET

INCLINATION : Vertical
DIAM : 165 mm
DATE : 11/12/2019
DATE : 11/12/2019

DATE : 14/05/2020 11:22
TEXT : ..lisoMaunique\PBHP07B.txt

ELEVATION : 915 m
X-COORD : 27.31404°E
Y-COORD : 24.62591°S

HOLE No: PBHP07B
Thabazimbi

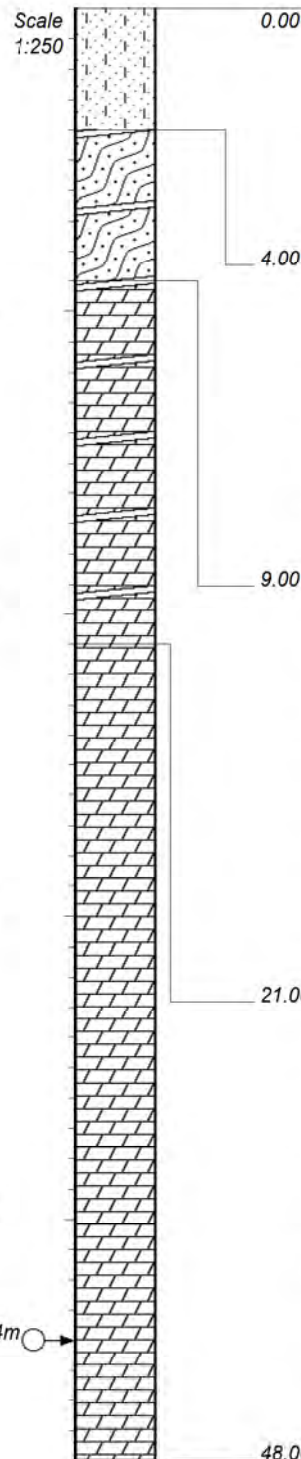


**GBN JOINT VENTURE
MOKOLO CROCODILE WATER AUGMENTATION
PROJECT PHASE 2**

HOLE No: PBHP08
Sheet 1 of 1

JOB NUMBER: J38167

100	0	0.26
100	0	0.31
100	0	0.35
100	0	0.27
100	0	0.31
100	0	0.40
100	0	0.41
100	0	1.00
100	0	0.45
100	0	1.13
100	0	1.45
100	0	1.13
100	0	1.45
100	0	1.33
100	0	1.37
100	0	1.26
100	0	1.42
100	0	1.43
100	0	1.34
100	0	0.45
100	0	2.09
100	0	2.00
100	0	2.10
100	0	2.05
100	0	2.14
100	0	2.28
100	0	2.35
100	0	2.20
100	0	2.00
100	0	1.40
100	0	2.30
100	0	2.32
100	0	2.37
100	0	2.44
100	0	2.23
100	0	2.21
100	0	2.32
100	0	2.35
100	0	2.40
100	0	2.24
100	0	2.11
100	0	2.16
100	0	4.30
100	0	3.00
100	0	3.20
100	0	3.00
100	0	3.10
100	0	3.12



Bulk sample: Dry, reddish brown, silty sand. **Sieve washed:** 55-75% loss. Wet, fine to medium sand of rounded to sub-rounded, highly weathered ironstone. **Interpretation:** COLLUVIUM.

Bulk sample: Dry, reddish brown, silty sand. **Sieve washed:** 40-60% loss. Wet, medium to coarse sand of Sub-rounded to sub-angular chips of moderately to highly weathered ironstone. **Interpretation:** WEATHERED IRONSTONE.

Bulk sample: Dry, greyish brown, speckled yellow, medium to coarse sand. **Sieve washed:** 45-65% loss. Wet, medium to coarse sand of sub-rounded to sub-angular chips of ironstone and minor sub-angular chips of dolomite. **Interpretation:** WEATHERED IRONSTONE, DOLOMITE SERIES.

Bulk sample: Wet, grey, gravelly sand. **Sieve washed:** 35-55% loss. Wet, coarse sand to fine gravel of sub-angular to angular chips of moderately to slightly weathered dolomite and traces of quartz. **Interpretation:** WEATHERED DOLOMITE, DOLOMITE SERIES.

NOTES

- 1) Sieve Aperture: 1.2mm x 1.4mm
- 2) Water level after 24hrs: 22.4m
- 3) Water strike at 44m

REDUCED LEVEL	Sample recovered (%)	Air loss (%)	PENETRATION RATE min/metre
---------------	----------------------	--------------	----------------------------

CONTRACTOR : Geo Mechanics
MACHINE : Percussion
DRILLED BY : Abram Motsepe
PROFILED BY : Tseliso Lebasa

TYPE SET BY : Tseliso Lebasa
SETUP FILE : STANDARD.SET

INCLINATION : Vertical
DIAM : 165 mm
DATE : 06/12/2019
DATE : 06/12/2019

DATE : 12/05/2020 09:00
TEXT : ..BB\Thabazimbi\PBHP08.txt

ELEVATION : 917 m
X-COORD : 27.31313°E
Y-COORD : 24.62239°S

HOLE No: PBHP08
Thabazimbi

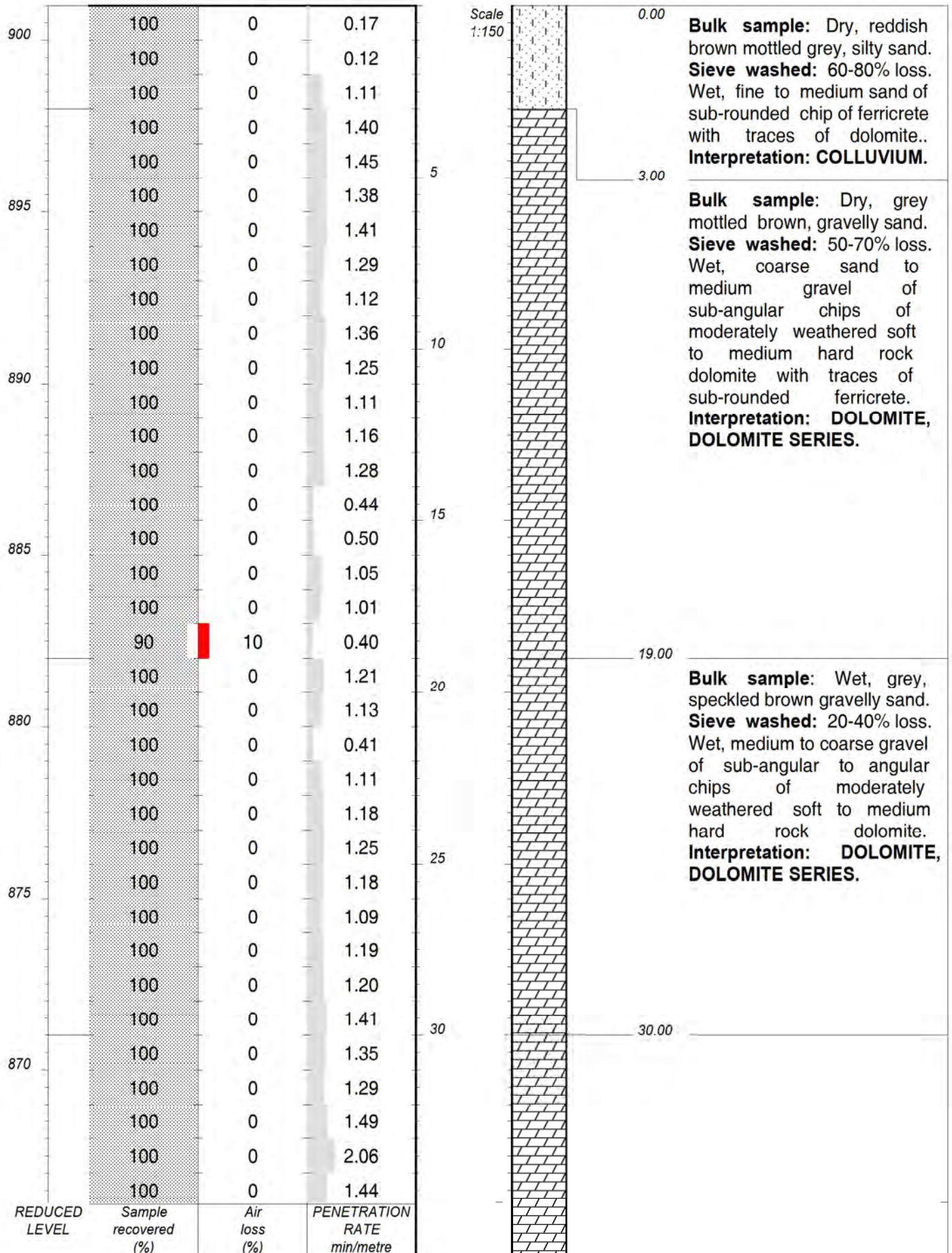


**GBN Joint Venture
Mokolo Crocodile Water
Augmentation Project Phase 2**

HOLE No: PBHP09

Sheet 1 of 2

JOB NUMBER: J38167





GBN JOINT VENTURE
Geotechnical Investigation
MCWAP-2 Pipeline
Thabazimbi to Lephalale
Limpopo Province

HOLE No: TP170
Sheet 1 of 1

JOB NUMBER: J38167

Scale
1:30



0.00

Tightly packed, sub-angular, fine, medium and coarse GRAVEL and COBBLES of banded chert in a matrix of slightly moist, reddish brown, silty sand with an overall consistency of loose: **TALUS**.

1.50

Tightly packed, sub-angular, fine, medium and coarse GRAVEL with minor COBBLES of banded chert in a matrix of slightly moist, reddish brown, silty sand with an overall consistency of loose: **TALUS**.

1.70

Tightly packed, angular, COBBLES and BOULDERS of limestone in a minor matrix of slightly moist, reddish brown, silty sand with an overall consistency of very dense: **RESIDUAL LIMESTONE**.

2.05

NOTES

- 1) No groundwater seepage encountered.
- 2) Refusal at 2.05m.

CONTRACTOR : GEO GROUP
MACHINE : New Holland B90B TLB
DRILLED BY :
PROFIED BY : L. Pfuluwani
TYPE SET BY : LP
SETUP FILE : STANDARD.SET

INCLINATION :
DIAM : 0.6m
DATE : 27/11/2019 - 29/11/2019
DATE : 27/11/2019 - 29/11/2019
DATE : 20/12/2019 14:11
TEXT : ..ELINESOILPROFILES(1).txt

ELEVATION :
X-COORD : 24°37'37.29"S
Y-COORD : 27°18'50.90"E

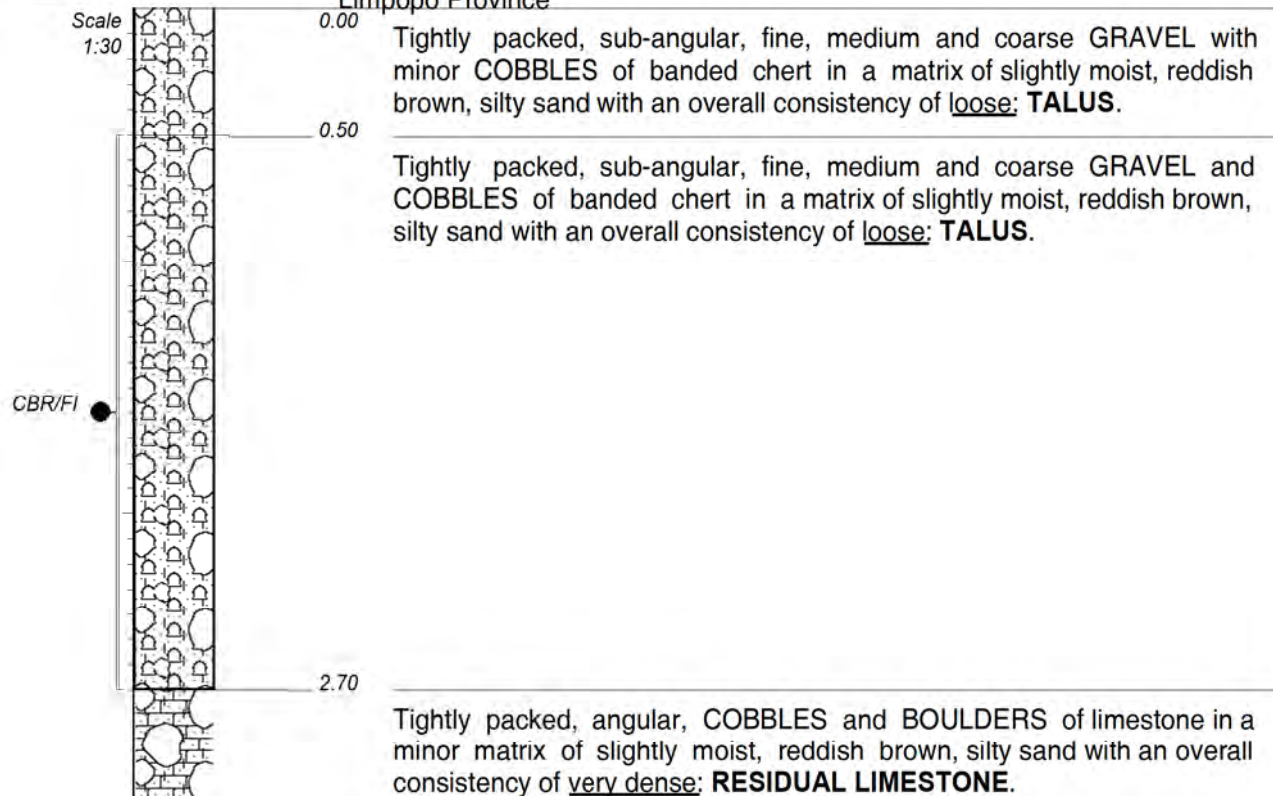
HOLE No: TP170



GBN JOINT VENTURE
Geotechnical Investigation
MCWAP-2 Pipeline
Thabazimbi to Lephalale
Limpopo Province

HOLE No: TP172
Sheet 1 of 1

JOB NUMBER: J38167



NOTES

- 1) No groundwater seepage encountered.
- 2) Disturbed sample taken for CBR/FI at 0.5--2.7m.
- 3) Refusal at 2.70m on limestone boulders.

CONTRACTOR : GEO GROUP
MACHINE : New Holland B90B TLB
DRILLED BY :
PROFIED BY : L. Pfuluwani
TYPE SET BY : LP
SETUP FILE : STANDARD.SET

INCLINATION :
DIAM : 0.6m
DATE : 27/11/2019 - 29/11/2019
DATE : 27/11/2019 - 29/11/2019
DATE : 20/12/2019 14:11
TEXT : ..ELINESOILPROFILES(1).txt

ELEVATION :
X-COORD : 24°37'24.42"S
Y-COORD : 27°18'48.53"E

HOLE No: TP172



GBN JOINT VENTURE
Geotechnical Investigation
MCWAP-2 Pipeline
Thabazimbi to Lephalale
Limpopo Province

HOLE No: TP177
Sheet 1 of 1

JOB NUMBER: J38167

Scale
1:30



0.00

Tightly packed, sub-angular to sub-rounded, coarse GRAVEL and COBBLES of banded ironstone and banded chert in a matrix of slightly moist, brown, silty sand with an overall consistency of loose: **TALUS**.

0.30

Tightly packed, sub-angular to sub-rounded, fine, medium and coarse GRAVEL and COBBLES of banded ironstone and banded chert in a matrix of slightly moist, reddish brown, silty sand with an overall consistency of loose: **TALUS**.

1.95

Tightly packed, sub-angular, BOULDERS of dolomite in a matrix of slightly moist, reddish brown, silty sand with an overall consistency of very dense: **RESIDUAL DOLOMITE**.

2.30

NOTES

- 1) No groundwater seepage encountered.
- 2) Presence of roots at 0--2.3m.
- 3) Refusal at 2.30m on boulders.

CONTRACTOR : GEO GROUP
MACHINE : New Holland B90B TLB
DRILLED BY :
PROFIED BY : L. Pfuluwani
TYPE SET BY : LP
SETUP FILE : STANDARD.SET

INCLINATION :
DIAM : 0.6m
DATE : 27/11/2019 - 29/11/2019
DATE : 27/11/2019 - 29/11/2019
DATE : 20/12/2019 14:11
TEXT : ..ELINESOILPROFILES(1).txt

ELEVATION :
X-COORD : 24°37'35.41"S
Y-COORD : 27°18'55.20"E

HOLE No: TP177



GBN JOINT VENTURE
Geotechnical Investigation
MCWAP-2 Pipeline
Thabazimbi to Lephalale
Limpopo Province

HOLE No: TP178
Sheet 1 of 1

JOB NUMBER: J38167

Scale
1:30



0.00

Closely packed, sub-angular, fine, medium and coarse GRAVEL and COBBLES of banded chert and dolomite in a matrix of slightly moist, reddish brown, silty sand with an overall consistency of loose: TALUS.

0.70

Grey, slightly weathered, fine grained, very hard rock DOLOMITE.

NOTES

- 1) No groundwater seepage encountered.
- 2) Refusal at 0.70m on very hard rock dolomite.

CONTRACTOR : GEO GROUP
MACHINE : New Holland B90B TLB
DRILLED BY :
PROFIED BY : L. Pfuluwani
TYPE SET BY : LP
SETUP FILE : STANDARD.SET

INCLINATION :
DIAM : 0.6m
DATE : 27/11/2019 - 29/11/2019
DATE : 27/11/2019 - 29/11/2019
DATE : 20/12/2019 14:11
TEXT : ..ELINESOILPROFILES(1).txt

ELEVATION :
X-COORD : 24°37'30.19"S
Y-COORD : 27°18'54.38"E

HOLE No: TP178



GBN JOINT VENTURE
Geotechnical Investigation
MCWAP-2 Pipeline
Thabazimbi to Lephalale
Limpopo Province

HOLE No: TP144
Sheet 1 of 1

JOB NUMBER: J38167

Scale
1:30



0.00

Slightly moist to moist, dark brown, loose, intact, silty gravelly SAND, with grass roots: **HILLWASH**.

0.30

Moist, reddish brown, loose, intact, silty gravelly SAND: **HILLWASH**.

0.75

Tightly packed, sub-angular to sub-rounded, medium and coarse grained with minor fine grained GRAVEL of banded chert in a matrix of moist, reddish brown, silty sand with a medium dense consistency: **TRANSPORTED**.

1.15

Tightly packed, sub-angular to sub-rounded, COBBLES of banded chert in a matrix of moist, reddish brown, silty sand with a dense to very dense consistency: **TRANSPORTED**.

3.00

NOTES

- 1) No groundwater seepage encountered.

CONTRACTOR : GEO GROUP
MACHINE : New Holland B90B TLB
DRILLED BY :
PROFIED BY : L. Pfuluwani
TYPE SET BY : LP
SETUP FILE : STANDARD.SET

INCLINATION : Vertical
DIAM : 0.6m
DATE : 27/11/2019 - 29/11/2019
DATE : 27/11/2019 - 29/11/2019
DATE : 20/12/2019 14:11
TEXT : ..ELINESOILPROFILES(1).txt

ELEVATION :
X-COORD : 24°37'17.28"S
Y-COORD : 27°18'45.16"E

HOLE No: TP144

27 January 2020

GEOMECH AFRICA
28 Central Road
Sunrella
Lanseria

Attn Barry Kruger

C 083 616 0399

E barryk@geogroup.co.za

MCWAP geophysical surveys (Thabazimbi) – Bat Cave gravity survey

General

This report presents the results of gravity survey conducted to confirm the presence of, and possibly aid in determining the lateral extent of, dolomitic caves inhabited by bats, duly named the Bat Caves. This work forms part of the Mokolo Crocodile Water Augmentation Project (MCWAP) and is located just W of Thabazimbi in the Limpopo province. A total of 318 gravity stations were acquired on 5m grid covering roughly 0.72ha in late January 2020.

Methodology

Gravity was observed with a Scintrex CG5 gravimeter whilst a Differential GPS (DGPS) recorded station locations. The elevation slopes from NE to SW up to 9m (Figure 1). The relative location of the two cave openings (yellow markers in Figure 1) show a slight depression in the otherwise regular negative SW gradient. Standard gravity processing procedures were applied, firstly reducing

the data to relative Bouguer values by applying Earth Tide (ETC), elevation and Bouguer corrections. Subsequently the regional gravity field, derived by fitting a 1st order plane to the data, was removed from the Bouguer gravity to produce a residual gravity map. Additionally, vertical derivatives (VD) filters were applied to the data which enhanced high gradients.

Results

The residual gravity results, which fall within a peak-to-peak envelope of roughly 0.165 mGal, shows a distinct, oval shaped, gravity low extending N from the cave openings (Figure 2). The gravity results suggest that the cave may extend towards the NE and SE. The vertical derivative (order ½) however shows the gravity low close off in the SE but remain 'open' to the NE. Also, the gravity results suggest that the main cave may connect to several smaller, peripheral caves as shown in Figure 3.

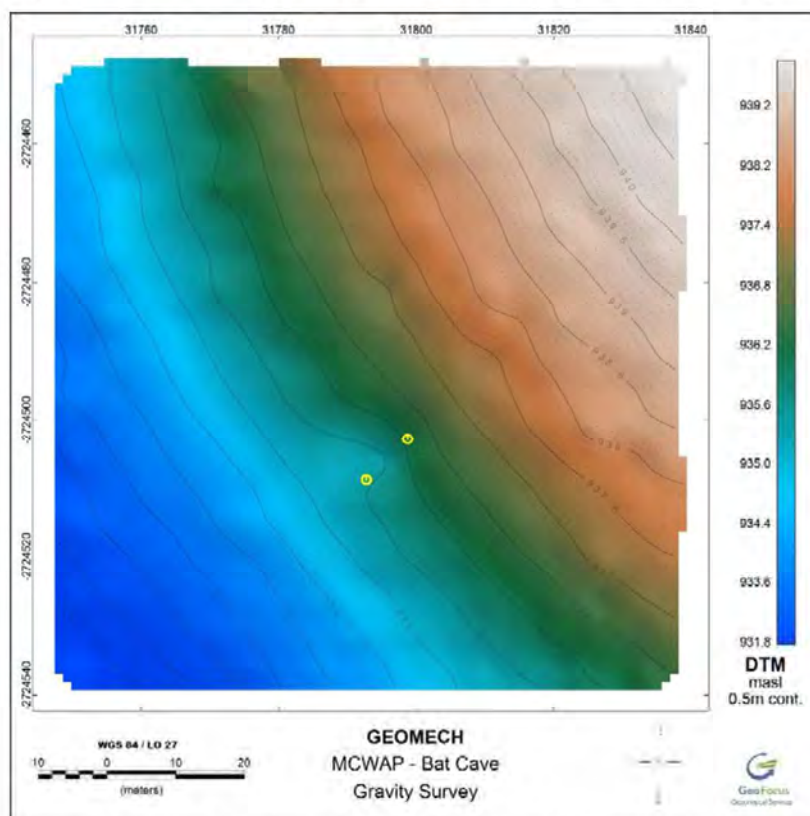


Figure 1: Elevation map & cave openings (yellow markers)

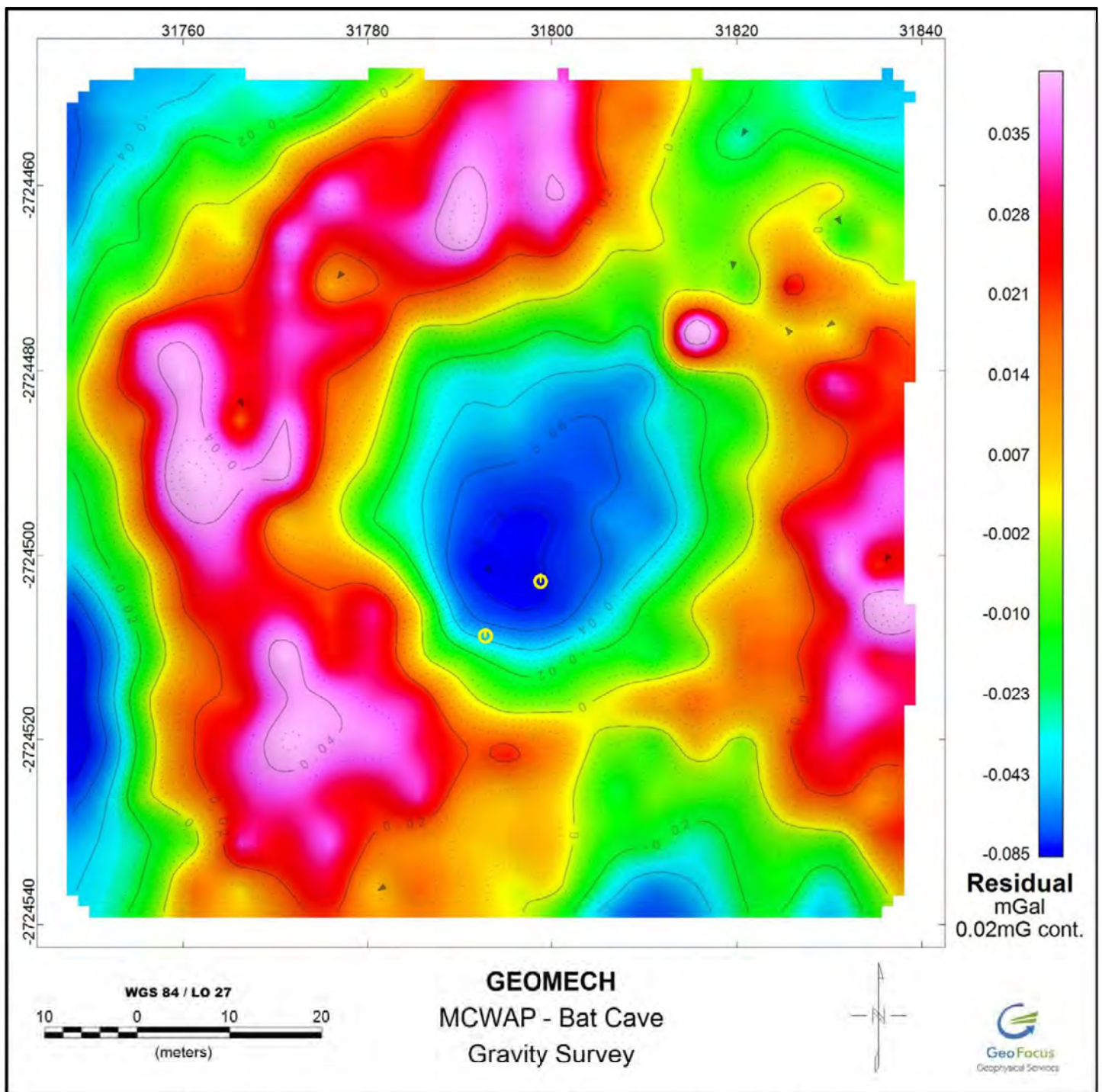


Figure 2: Residual gravity showing distinct gravity low over cave openings (yellow markers) extending NE & SE

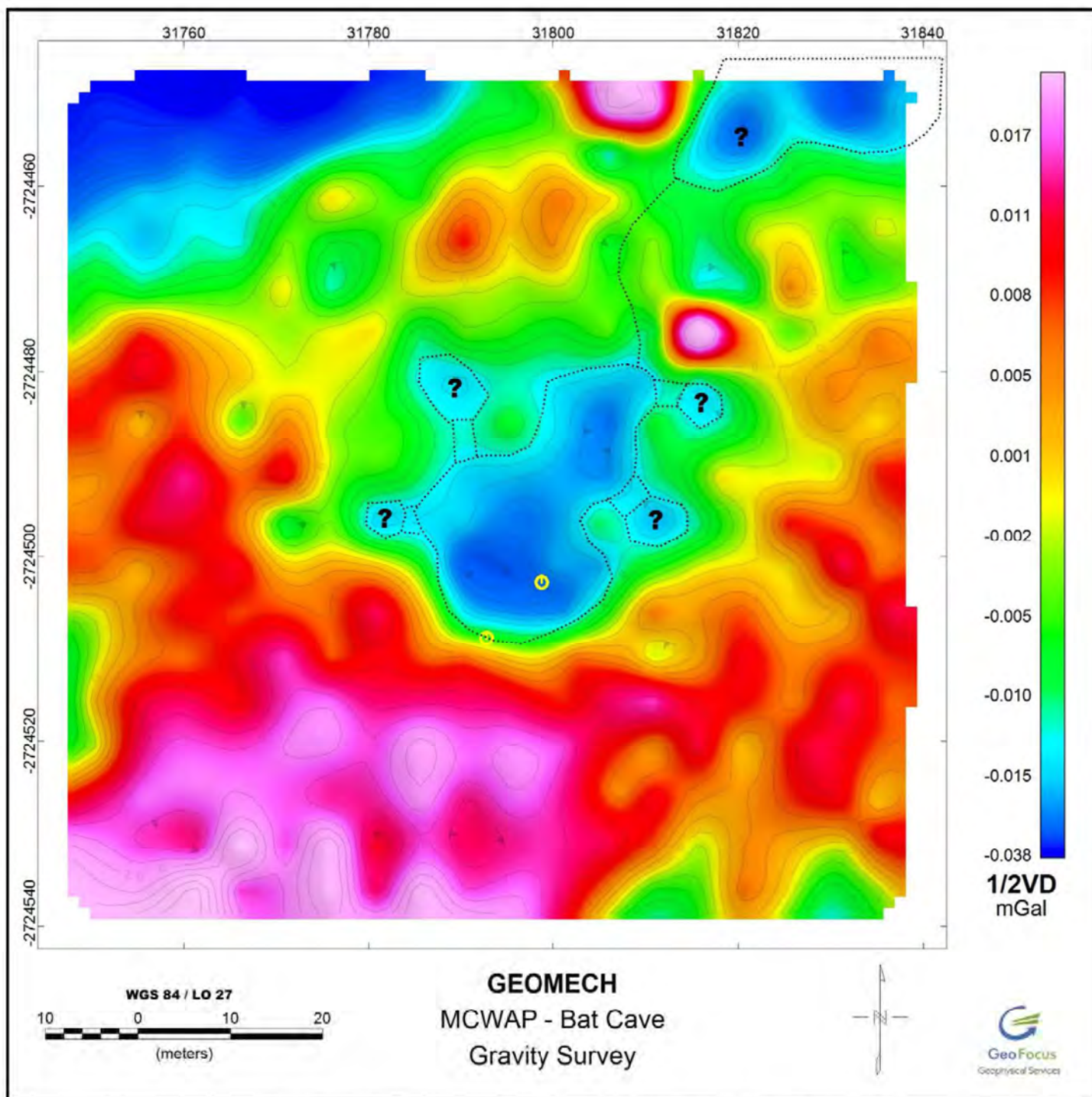


Figure 3: Vertical derivative (order 1/2) of the residual gravity showing possible extension of cave towards the NE as well as several, smaller, peripheral, caves (?)

Summary & recommendations

Gravity appears to have worked very well showing an oval shaped low directly over the cave openings as well as mapping several smaller, peripheral, caves that the main cave may be connected to. More importantly however is the possible extension of the caves toward the NE and it is recommended to extend the survey in this direction.