MOUNT GIBSON MINING LIMITED

MINE CLOSURE PLAN EXTENSION HILL HEMATITE OPERATION

Mineral Field Number(s): 59

Version 3

Date of Submission: 16 September 2015



Mount Gibson Mining Limited
ABN 32 074 575 885

Contact Details

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DMP Mine Closure Plan Checklist

Q. No.	Mine Closure Plan (MCP) checklist	Y/N/NA	Page No.	Comments
1	Has the Checklist been endorsed by a senior representative within the tenement holder/operating company? (See bottom of Checklist.)	Y	iv	
2	How many copies were submitted to DMP?	Hard copies = 2 Electronic = 1		
Cover Page, Table of Contents				
3	Does the cover page include; • Project Title • Company Name • Contact Details (including telephone numbers and email addresses) • Document ID and version number • Date of submission	Y	Cover page	
4	Has a Table of Contents been provided?	Y	v	
Scope and Project Summary				
5	State why is the MCP is submitted (as part of a Mining Proposal or a reviewed MCP or to fulfil other legal requirements)	Y	3	
6	Does the project summary include; • Land ownership details; • Location of the project; • Comprehensive site plan(s); • Background information on the history and status of the project	 Y Y Y Y	 5 2 & 6 Fig 1 6	
Legal Obligations and Commitments				
7	Has a consolidated summary or register of closure obligations and commitments been included?	Y	9	
Data Collection and Analysis				
8	Has information relevant to mine closure been collected for each domain or feature (including pre-mining baseline studies, environmental and other data)?	Y	Sect 4	

Q. No.	Mine Closure Plan (MCP) checklist	Y/N/NA	Page No.	Comments
9	Has a gap analysis been conducted to determine if further information is required in relation to closure of each domain or feature?	Y	Sect 4.3 &10.2	
Stakeholder Consultation				
10	Have all stakeholders involved in closure been identified?	Y	36	
11	Has a summary or register of stakeholder consultation been provided, with details as to who has been consulted and the outcomes?	Y	Table 15	
Final land use(s) and Closure Objectives				
12	Does the MCP include agreed post-mining land use(s), closure objectives and conceptual landform design diagram?	Y	Sect 6 Fig 3	
13	Does the MCP identify all potential (or pre-existing) environmental legacies, which may restrict the post mining land use (including contaminated sites)?	Y	Sect 10.2	There were no pre-existing legacies. Domains with high risk of contamination are listed as requiring contamination assessment.
Identification and Management of Closure Issues				
14	Does the MCP identify all key issues impacting mine closure objectives and outcomes?	Y	Sect 7.2	
15	Does the MCP include proposed management or mitigation options to deal with these issues?	Y	Sect 7.3	
16	Have the process, methodology, and rationale been provided to justify identification and management of the issues?	Y	Sect 7.1	
Closure Criteria				
17	Does the MCP include an appropriate set of specific closure criteria and/ closure performance indicators?	Y	Table 21	
Closure Financial Provisioning				
18	Does the MCP include costing methodology, assumptions and financial provision to resource closure implementation and monitoring?	Y	Sect 9	

Q. No.	Mine Closure Plan (MCP) checklist	Y/N/NA	Page No.	Comments
19	Does the MCP include a process for regular review of the financial provision?	Y	62	
Closure Implementation				
20	Does the reviewed MCP include a summary of closure implementation strategies and activities for the proposed operations or for the whole site?	Y	Sect 10	
21	Does the MCP include a closure work program for each domain or feature?	Y	Sect 10.2	
22	Have site layout plans been provided to clearly show each type of disturbance?	Y	Fig 1	
23	Does the MCP contain a schedule of research and trial activities?	Y	Sect 4.2.2	
24	Does the MCP contain a schedule of progressive rehabilitation activities?	Y	Sect 10.3	
25	Does the MCP include details of how unexpected closure and care and maintenance) will be handled?	Y	Sect 10.2	
26	Does the MCP contain a schedule of decommissioning activities?	Y	Sect 10.3	
27	Does the MCP contain a schedule of closure performance monitoring and maintenance activities?	Y	Sect 11	
Closure Monitoring and Maintenance				
28	Does the MCP contain a framework, including methodology, quality control and remedial strategy for closure performance monitoring including post-closure monitoring and maintenance?	Y	Sect 11	
Closure Information and Data Management				
29	Does the mine closure plan contain a description of management strategies including systems, and processes for the retention of mine records?	Y	Sect 12	
30	Confidentiality	N		

Corporate Endorsement:

I hereby certify that to the best of my knowiedge, the information within this Mine Closure Plan and checklist is true and correct and addresses ail the requirements of the Guidelines for the Preparation of a Mine Closure Plan approved by the Director General of Mines.

Name: REECE OLNEY **Signed**: ______________________

Position: RESIDENT MANAGER **Date**: 16/9/15

(NB: The corporate endorsement must be given by tenement holder(s) or a senior representative authorised by the tenement holder(s), such as a Registered Manager or Company Director)

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Executive Summary

This Mine Closure Plan (MCP) has been developed by Mount Gibson Mining Limited (MGM) in accordance with the Department of Mines and Petroleum (DMP) and Environmental Protection Authority (EPA) *Guidelines for Preparing Mine Closure Plans* (2011). The MCP is intended to assist with planning for mine closure activities at the Extension Hill Hematite Project (the Project) and ensure that consideration and preparation for mine closure is undertaken throughout the life of the Project.

For the purposes of this MCP, the Project does not include MGM's hematite storage and loading facilities at the Geraldton Port Facility.

MGM objectives for closure are consistent with the DMP's objective and are summarised as follows:

- To seek compliance with all legally binding commitments and obligations, relating to mine closure;
- To ensure stakeholders interests to be considered during the mine closure process;
- To achieve the agreed set of completion criteria to the satisfaction of the responsible authorities;
- To establish a safe and stable post mining land surface;
- To minimise downstream effects on vegetation due to interruption of drainage;
- To continue to monitor environmental performance during decommissioning, rehabilitation and post closure stages of the project and take appropriate action until the approved completion criteria have been met;
- To re-establish vegetation that provides a self-generating ecosystem comprising local native vegetation which resembles the surrounding environment as closely as practical;
- To leave the site in a safe, stable, non-polluting and tidy condition with no remaining plant or infrastructure that is not required for post operational use or agreed use by other stakeholders; and
- To identify any potential soil, surface water or groundwater pollution associated with the operations and formulate an action plan to address this.

MGM aims to achieve these objectives through the implementation of the site Environmental Management System.

1. Purpose and Scope

Mount Gibson Mining Limited (MGM) mine and process hematite at the Extension Hill Hematite Operation (the ‘Project’) located within the Mt Gibson Range in the Mid-West region of Western Australia. The Project is located approximately 350 km north east of Perth, approximately 70 km south west of Paynes Find and approximately 83 km north east of Wubin. It is immediately adjacent to Great Northern Highway and within the Shire of Yalgoo. The Project extends over mine and exploration tenements and includes the rail siding in the Shire of Perenjori, approximately 86 km west of the mine.

MGM commenced mining at the Project in December 2010. The current Project design involves mining 14.5 million tonnes of direct shipping grade ore (DSO), over a minimum operational lifetime of 5 years.

The Project includes the hematite mine pit (Extension Hill), hematite waste dump, run of mine (ROM) pad, low grade ore stockpiles, water storage facilities, mineral processing infrastructure, haul roads, a rail siding facility, workshops, logistical support buildings, administration buildings and an accommodation village. For the purposes of this MCP, the Project does not include MGM’s hematite storage and loading facilities at the Geraldton Port Facility as these facilities are managed in accordance with lease conditions administered by the Geraldton Port Authority (GPA).

This Mine Closure Plan (MCP) has been prepared to assist MGM in closing the Project in a manner that meets corporate closure obligations such that there is no unacceptable liability to the state of Western Australia. The scope and structure of this MCP is as follows:

Section 1: Outlines the scope and purpose of the MCP.

Section 2: Provides an overview of the history and status of the project, including land ownership, tenure, location, and an overview of operations and main mine components.

Section 3: Summarises the legal obligations and specific legally binding closure commitments relating to the Project, with reference to the closure obligations register.

Section 4: Provides environmental data relevant to closure, including a summary of baseline studies completed prior to project commencement, information on the climatic conditions, geology and soils (including waste characteristics and materials balance), surface water, groundwater, flora and fauna, social environment, lessons learnt from progressive rehabilitation and key knowledge gaps. A brief discussion of how these aspects impact on closure of the Project is also included.

Section 5: Describes the process used to identify stakeholders relevant to mine closure, lists the stakeholders identified and provides a summary of how each has been, and will continue to be, consulted in relation to mine closure.

Section 6: Identifies the post-mining land use and closure objectives based on the proposed land use.

Section 7: Outlines the risk assessment process for identifying the key closure issues, and provides a summary of identified key risks and management measures.

Section 8:	Describes the development of site specific completion criteria by which success of closure will be measured.
Section 9:	Describes the process used to estimate the closure financial provision, including the internal calculations and third party review.
Section 10:	Provides a closure implementation plan that includes (i) high level planned, unplanned and care and maintenance closure scenarios, (ii) general closure provisions for different areas and stages of closure, (iii) work programs for all Project closure domains, including domain descriptions, knowledge base, work program, and post-closure monitoring requirements.
Section 11:	Describes the proposed environmental monitoring program and maintenance response requirements.
Section 12:	Provides a description of how closure relevant information and data will be managed during ongoing closure planning and implementation

This MCP has been developed in accordance with the Department of Mines and Petroleum (DMP) and Environmental Protection Authority (EPA) *Guidelines for Preparing Mine Closure Plans* (2011). The MCP is intended to meet the requirements of the DMP, specifically:

- For mining operations that have a Mining Proposal and/or a Notice of Intent (NOI) approved under the *Mining Act 1978* prior to 1 July 2011, DMP will require existing mine closure plans and rehabilitation plans to be reviewed in accordance with the guidelines and submitted to DMP by 30 June 2014. (DMP and EPA, 2011).
- All Mine Closure Plans approved by DMP on or after 1 July 2011 must be regularly reviewed over the life of a mine. The *Mining Act 1978* requires these Plans to be reviewed and submitted for approval by DMP every three (3) years or such other time as specified in writing by DMP. (DMP and EPA, 2011).

This MCP supersedes the existing *Conceptual Closure Plan* (ATA Environmental, 2006) in relation to only the hematite component of the Mount Gibson Iron Ore Mine and Infrastructure Project (as approved by the Minister for the Environment under Ministerial Statement 753). This MCP will be included as an additional appendix in the next review of the *Extension Hill and Extension Hill North Environmental Management Plan* (the EMP) (MGM & EHPL, 2008). It is acknowledged that this MCP predominantly addresses the hematite component of the Mount Gibson Iron Ore Mine and Infrastructure Project in addition to some small scopes of work undertaken in relation to the magnetite component of the project. The plan will be revised to incorporate the magnetite component of the project when the project development studies have been completed and the project is more fully defined. Until such time as the magnetite MCP is approved, the existing *Conceptual Closure Plan* (ATA Environmental, 2006) and the mine closure component of the EMP remain the approved mine closure documents for the magnetite component of the Mount Gibson Iron Ore Mine and Infrastructure Project under Ministerial Statement 753.

This MCP is a live document that will evolve as new information is gathered and additional studies are undertaken. The *Strategic Framework for Mine Closure* (ANZMEC & MCA, 2000), *Guidelines for Preparing Mine Closure Plans* (DMP and EPA, 2011) and the *Mine Closure and Completion Handbook* (Department of Industry Tourism and Resources, 2006) have been considered as part of the document preparation.

1.1 Legislative Framework

The legal closure objectives for the Project (refer to Section 3) stem predominantly from the requirements under the *Environmental Protection Act 1986* and the *Mining Act 1987*. There are numerous other key Commonwealth and State legislation which are also applicable to closure planning, as listed below.

- *Aboriginal Heritage Act 1972*
- *Agriculture and Related Resources Protection Act 1976*
- *Dangerous Goods Safety Act 2004*
- *Dangerous Goods (Transport) Act 1998*
- *Conservation and Land Management Act 1984*
- *Contaminated Sites Act 2003*
- *Environmental Protection Act 1986*
- *Environment Protection and Biodiversity Conservation Act 1999*
- *Land Administration Act 1997*
- *Mining Act 1978*
- *Mines Safety and Inspection Act 1994*
- *Native Title Act 1993*
- *Rights in Water and Irrigation Act 1914*
- *Soil and Land Conservation Act 1945*
- *Wildlife Conservation Act 1950*

This legislation, as amended at the time of writing, has been taken into account when developing this MCP. For further information on the approvals sought and obtained for the operational phase of the Project, refer to the *Extension Hill Hematite Project Mining Proposal 2 February 2010* (Registration ID: 25961) and any subsequent addendums (Registration ID: 36990 and 48322) (the 'Mining Proposal').

2. Project Summary

2.1 Land Ownership and Tenure

With the exception of two general purpose leases at the rail siding in Perenjori held by MGM, the Project tenements are held by Extension Hill Pty Ltd (EHPL), which is a subsidiary company of Asia Iron Australia Pty Ltd.

EHPL and MGM (a wholly owned subsidiary of Mount Gibson Iron Limited) are approved to undertake mining activities at the Mount Gibson Iron Ore Mine and Infrastructure Project, pursuant to Ministerial Statement 753. The Extension Hill Hematite Haulage Project, which includes the development and operation of the Perenjori Rail Siding, was approved by Ministerial Statement 786.

An agreement is in place between EHPL and MGM that allows MGM to undertake hematite mining on the EHPL held tenements. This agreement, called the Extension Hill Hematite Agreement, was signed on 30 August 2005. A supplemental agreement, the Extension Hill Hematite Agreement First Supplemental Deed was signed in February 2011.

The two companies are responsible for two different stages of the approved project:

- Stage 1: MGM will mine and crush the hematite ore at Extension Hill (the Project).
- Stage 2: EHPL propose to mine and process the magnetite ore.

Note that there may be a period of overlap between the stages where they are occurring simultaneously.

The following mining tenements are relevant to the Project and the focus of this MCP:

- G59/30
- G59/33
- G59/34
- L59/63
- L59/69
- L59/87
- M59/338
- M59/339
- M59/526
- G59/41 (Magnetite Exploration Village)
- G59/45 (Magnetite Sprayfield)
- G70/232 (Perenjori Rail Siding Area, tenement held by MGM who has sole responsibility)
- G70/238 (Perenjori Rail Siding Area, tenement held by MGM who has sole responsibility)

MGM's contact personnel for the Project are:

Mr Jim Beyer *Chief Executive Officer* Mount Gibson Iron Ltd Ph: (08) 9426 7500 Fax: (08) 9485 2305 Email: jim.beyer@mtgibsoniron.com.au	Mr Reece Olney *Resident Manager* Extension Hill Ph: (08) 6314 0215 Fax: (08) 6270 5417 Email: reece.olney@mtgibsoniron.com.au

EHPL's contact personnel for the Project is:

Mr Ben McLernon *Manager Environment and Community* Ph: (08) 9216 2661 Fax: (08) 9322 9801 Email: benmclernon@extensionhill.com.au

2.2 Extension Hill Hematite Project

MGM mine and process hematite ore from Extension Hill and Extension Hill North and transport the processed hematite ore to Geraldton for shipping via Perenjori rail siding. Mining commenced in December 2010 and the first shipment of ore from this site left Geraldton Port in December 2011.

The Project as currently designed will produce 14.5 million tonnes of DSO over a minimum operational lifetime of 5 years. The current estimate is that mining in the current pit will be completed in *August 2016*.

Mine Site

- The mine site is located within the Mt Gibson Range in the Mid-West region of Western Australia within the Shire of Yalgoo.
- The hematite and associated waste rock is mined via conventional open pit methods of blasting and excavation.
- The excavated hematite is loaded onto dump trucks and transported to a processing area for crushing and screening.
- The overburden and waste rock material from the open pit mining operation is stockpiled in a purpose-designed dump to the east of the hematite mine pit. The Run of Mine (ROM) pad is located to the west of the pit.
- To operate the mine, ancillary infrastructure and facilities including, crushing and screening plant, office buildings, workshops, crib rooms, an accommodation village, waste water treatment plant, bioremediation, bore fields, landfill, haul roads and access tracks have been constructed (Figure 1).
- The Great Northern Highway has been diverted west of its original alignment to ensure the infrastructure and public access is a safe distance away from blasting activities that occur at the mine.

Road Haulage

- After processing the hematite is transported by road to Perenjori via Wanarra East Road, Wanarra Road and the Perenjori to Rothsay Road.
- The public roadway from the mine site to the rail siding has been upgraded to a sealed, two lane roadway. This roadway passes beneath the Great Northern Highway with a constructed bridge supporting the realigned highway.

Rail Haulage

- The rail siding is located 2 km to the south-east of the Perenjori township, south-east of the intersection of the Wubin-Mullewa and Perenjori-Rothsay Roads.
- The rail siding facility is located on private land, for which MGM has acquired freehold title.
- The rail siding is accessed from the Perenjori-Rothsay Road and provides two open stockpile areas of approximately 600,000 tonnes capacity each (one for lump and one for fines product) on either side of a train line spur. An additional overflow stockpile with approximately 150,000 tonne capacity will be constructed as required.
- The rail siding links into the Brookfield, formerly WestNet, rail line south of Perenjori, from which hematite product is transported by rail to the Geraldton Port via Mullewa by Aurizon.

Figure 1 shows the layout of the Project. For further Project information refer to the Mining Proposal.

The total disturbance area of approximately 233ha for the Project to date is shown in Table 1.

Table 1 Project Disturbance to Date

Tenement	Disturbance Type*	Disturbance Area (ha)
G59/30	Mine Haul Roads	0.68
	Hematite Waste Dump	44.66
	Topsoil/Tritter Stockpile	8.86
	Total	**54.2**
G59/33	Accommodation Camp	5.00
	Access Roads	0.99
	Potable Pipeline	0.43
	Total	**6.42**
G59/34	ROM/Crusher/Stockpile	5.9
	Access Roads	9.4
	Workshops	1.07
	Security Hut/Hardstand	0.17
	Total	**16.54**
G59/41	Exploration Village	2
	Exploration Tracks/Pads	0.19
	Total	**2.19**
G59/45	Camp Site Infrastructure	0.71
	Total	**0.71**
L59/63	ROM/Crusher/Stockpile	3

Tenement	Disturbance Type*	Disturbance Area (ha)
	Offices/Workshop	2.24
	Access Roads	0.56
	Total	**5.8**
L59/69	Sewage Pond	1.08
	Mine Roads	0.97
	Total	**2.05**
L59/87	Mine Roads	2.94
	Total	**2.94**
M59/338	Mine Roads	1
	Potable Water Pipeline	0.42
	Hematite Explosives Depot	0.29
	Total	**1.71**
M59/339	ROM/Crusher/Stockpile	5
	Access Roads	17
	Turkey's Nest	2.01
	Borrow Pit	7.53
	Mine Pit	50.05
	Waste Dump	9.1
	Tritter/Topsoil Stockpile	12
	Magnetite Stockpile Area	1.96
	Total	**104.65**
M59/526	Putrescible Landfill Facility	0.27
	Total	**0.27**
G70/ 232**	Rail Siding	22.1
	Total	**22.1**
G70/ 238**	Rail Siding	13.7
	Total	**13.7**
Total for Project		**233.28**

3. Identification of Closure Obligations and Commitments

The Project is bound by rehabilitation and closure commitments specified in relevant legislation, approval documents and tenement conditions. This section identifies legally binding conditions, commitments and obligations under existing legislation and existing approvals. Subsequent sections (7 and 10) of this document detail activities that will be undertaken to achieve compliance with commitments and meet completion criteria.

The regulator issued documents ultimately stem from legislation but these are treated separately for the purposes of this document. Relevant legislation is addressed in Section 3.1. The regulator issued documents for this Project which contain conditions relevant to rehabilitation and closure are the tenement conditions, Ministerial Statements 753 and 786, Prescribed Premises Licence L8495/2010/2 and two Program of Works approvals for exploration activities (Section 3.2). The proponents also made commitments relating to rehabilitation and closure in the Mining Proposal and subsequent addendums (Section 3.3). Pursuant to the *Guidelines for Preparing Mine Closure Plans*, these commitments have been summarised into obligations registers in Tables 2 to 4.

3.1 Legislation Obligations

Rehabilitation and closure obligations that are drawn directly from current legislation are summarised in a legal obligations register (Table 2), pursuant to the *Guidelines for Preparing Mine Closure Plans*. These listed requirements were considered during the development of the closure task register (Table 29). Compliance with this legislation will be achieved through the implementation of the closure activities identified in Section 10 and the operational implementation of the site environmental management system.

Table 2 Closure Obligations and Commitments Register - Legislation

Legislation	Section Reference	Requirement Relevant to Closure
Contaminated Sites Act 2003 *Contaminated Sites Regulations 2006*	Part 2, Section 11 Part 2, Section 6	The owner or occupier of the site must report any known or suspected contaminated sites.
Contaminated Sites Act 2003	Part 3	The proponents must remediate any sites classified as *contaminated – remediation required*.
Environmental Protection Act 1986	Part IV, Section 47	The proponents must implement the proposal in accordance with the Ministerial Statement issued under Section 45(5).
Environmental Protection (Controlled Waste) Regulations 2004	Section 3(4) and Schedule 1	All products listed in Schedule 1 are to be treated and disposed of pursuant to the controlled waste regulations.
Environmental Protection (Unauthorised Discharges) Regulations 2004	Section 3 and 4	The proponents must not allow discharge into the environment or burning of materials listed in Schedules 3 and 4 respectively.
Mining Act 1978	Part IV, Section 84AA	A mine closure plan is required to be reviewed every three years.

Mining Act 1978	Part IV, Section 63	All holes, pits, trenches and other disturbances on the surface of the land which are likely to endanger the safety of any person are to be made safe.
Mining Safety and Inspection Act 1994	Part IV, Section 42	The principal employer must notify the district inspector before mining operations are suspended or abandoned.
Soil and Land Conservation Act 1945	Part V, Section 32	The proponent shall take adequate precautions to prevent or control soil erosion, salinity or flooding; or the destruction, cutting down or injuring of any tree, shrub, grass or any other plant on land where land deregulation is occurring or likely to occur.

3.2 Regulator Issued Obligations

Under the authority of the *Environmental Protection Act 1986*, the Minister for the Environment authorised the Project subject to the conditions issued in Ministerial Statements 753 and 786. A prescribed premises licence (L8495/2010/2) was issued for this Project to allow scheduled premises activities including beneficiation of ore, landfill and sewage facilities. The Department of Mines and Petroleum has placed conditions on the underlying tenements, pursuant to the *Mining Act 1978* and has attached conditions to Program of Works approvals for exploration activities.

The compliance conditions associated with rehabilitation and closure from these regulator issued obligations are reflected in Table 3. Compliance with these conditions will be met through the implementation of the closure actions identified in Section 10 and the ongoing implementation of the site environmental management system.

The regulator issued documents contain other conditions relating to operational environmental management, reporting and incident response however only the conditions directly related to closure are included in the closure commitments register.

3.3 Proponent Commitments

The proponents made closure and rehabilitation commitments, and identified management strategies during the project planning and assessment phase. These commitments and strategies are included in the Mining Proposal and subsequent addendums. The commitments directly related to rehabilitation and closure are included in Table 4 and will be met through the implementation of the closure actions identified in Section 10 and the ongoing implementation of the site environmental management system. A number of other commitments were made in relation to operational environmental management and monitoring, however these are managed under the Environmental Management Plan and are not replicated here.

Table 3 Closure Obligations and Commitments Register – Regulator Issued

Source: Tenement Conditions	
Tenement No. (Condition No.)	**Closure Condition**
General Purpose Leases G59/30 (8); G59/33 (6); G59/34 (14); G70/232 (6); G70/238 (5). Miscellaneous Leases L59/63 (8); L59/69 (9); L59/87 (21). Mining Leases M59/338 (13); M59/339 (12); M59/526 (10).	All topsoil being removed ahead of all mining operations from sites such as pit areas, waste disposal areas, ore stockpile areas, pipeline, haul roads and new access roads and being stockpiled for later respreading or immediately respread as rehabilitation progresses.
Miscellaneous Lease L59/69 (3)	All topsoil that may be removed ahead of pipelaying operations to be stockpiled for replacement in accordance with the directions of the Inspector.
Miscellaneous Lease L59/87 (5)	All topsoil that may be removed ahead of pipelaying operations to be stockpiled for replacement in accordance with the directions of the Environmental Officer, Department of Mines and Petroleum.
General Purpose Leases G59/41 (8); G59/45 (9).	All topsoil and vegetation being removed ahead of all mining operations and being stockpiled appropriately for later respreading or immediately respread as rehabilitation progresses.
General Purpose Leases G59/41 (10); G59/45 (11).	All rubbish and scrap is to be progressively disposed of in a suitable manner.
General Purpose Leases G59/30 (9); G59/33 (7); G59/34 (15); G70/232 (7); G70/238 (6). Miscellaneous Leases L59/63 (9); L59/69 (10); L59/87 (22). Mining Leases M59/338 (14); M59/339 (14); M59/526 (11).	At the completion of operations, all buildings and structures being removed from site or demolished and buried to the satisfaction of the Director, Environment Division, DMP.
General Purpose Leases G59/41 (9); G59/45 (10).	At the completion of operations, all buildings and structures being removed from site or demolished and buried to the satisfaction of the Executive Director, Environment Division, DMP.
General Purpose Leases G59/30 (10); G59/34 (16). Miscellaneous Leases L59/63 (9); L59/69 (10); L59/87 (22). Mining Leases M59/338 (14); M59/339 (14); M59/526 (11); M59/339 (15).	At the completion of operations, or progressively where possible, all waste dumps, stockpiles, roads, processing plant, and all other disturbed areas being rehabilitated to form long term safe, stable, non polluting landforms which are integrated with the surrounding landscape and support self-sustaining, functional ecosystems comprising suitable native providence species to the satisfaction of the Director Environment Division, DMP.

General Purpose Lease G59/33 (8) Miscellaneous Lease L59/87 (23) Mining Lease M59/526 (12)	At the completion of operations, or progressively where possible, all other disturbed areas being rehabilitated to form long term safe, stable, non polluting landforms which are integrated with the surrounding landscape and support self-sustaining, functional ecosystems comprising suitable native providence species to the satisfaction of the Director Environment Division, DMP.
Miscellaneous Lease L59/63 (10)	At the completion of operations, or progressively where possible, all stockpiles, roads, processing plant, and all other disturbed areas being rehabilitated to form long term safe, stable, non polluting landforms which are integrated with the surrounding landscape and support self-sustaining, functional ecosystems comprising suitable native providence species to the satisfaction of the Director Environment Division, DMP.
Mining Lease M59/338 (15)	At the completion of operations, or progressively where possible, all roads, and all other disturbed areas being rehabilitated to form long term safe, stable, non polluting landforms which are integrated with the surrounding landscape and support self-sustaining, functional ecosystems comprising suitable native providence species to the satisfaction of the Director Environment Division, DMP.
General Purpose Leases G59/41 (13); G59/45 (14).	On the completion of operations or progressively where possible, all waste dumps, tailings storage facilities, stockpiles or other mining related landforms must be rehabilitated to form safe, stable, non-polluting structures which are integrated with the surrounding landscape and support self sustaining, functional ecosystems comprising suitable, local provenance species or alternative agreed outcome to the satisfaction of the Executive Director, Environment Division, DMP.
General Purpose Leases G59/30 (14); G59/33 (11); G59/34 (20); G70/232 (10); G70/238 (9); G59/45 (14). Miscellaneous Leases L59/63 (13); L59/69 (13); L59/87 (26). Mining Leases M59/338 (19); M59/339 (19); M59/526 (16).	The Lessee submitting to the Director, Environment Division, DMP, a brief annual report outlining the project operations, minesite environmental management and rehabilitation work undertaken in the previous 12 months and the proposed operations, environmental management plans and rehabilitation programmes for the next 12 months. This report to be submitted each year in: • October.
General Purpose Lease G59/34 (8) Mining Leases M59/338 (5); M59/339 (5); M59/526 (5).	Unless the written approval of the Environmental Officer, Department of Industry and Resources is first obtained, the use of scrapers, graders, bulldozers, backhoes or other mechanised equipment for surface disturbance or the excavation of costeans is prohibited. Following approval, all topsoil being removed ahead of mining operations and separately stockpiled for replacement after backfilling and/or completion of operations.
General Purpose Lease G59/34 (9) Mining Leases M59/338 (4); M59/339 (4); M59/526 (4).	All waste materials, rubbish, plastic sample bags, abandoned equipment and temporary buildings being removed from the mining tenement prior to or at the termination of exploration program.

General Purpose Lease G59/34 (10) Mining Leases M59/338 (3); M59/339 (3); M59/526 (3).	All costeans and other disturbances to the surface of the land made as a result of exploration, including drill pads, grid lines access tracks, are to be backfilled and rehabilitated to the satisfaction of the Environmental Officer. Backfilling and rehabilitation being required no later than 6 months after excavation unless otherwise approved in writing by the Environmental Officer, Department of Industry and Resources.
General Purpose Lease G59/34 (11) Mining Leases M59/338 (2); M59/339 (2); M59/526 (2).	All surface holes drilled for the purpose of exploration are to be capped, filled or otherwise made safe after completion.
Miscellaneous Lease L59/69 (5)	On the completion of the life of mining operations in relation to this licence the holder shall: • remove all installations constructed pursuant to this licence; • cover over all wells and holes in the ground to such degree of safety as shall be determined by the District Inspector of Mines; and • on such areas cleared of natural growth by the holder or any of its agents, the holder shall plant trees and/or shrubs and/or any other plant as shall conform to the general pattern and type of growth in the area and as directed by the Inspector and properly maintain same until the Inspector advises regrowth is self supporting; unless the Warden orders or consents otherwise.
Miscellaneous Lease L59/87 (7)	On the completion of the life of mining operations in connection with this licence the holder shall: • remove all installations constructed pursuant to this licence; and • on such areas cleared of natural growth by the holder or any of its agents, the holder shall plant trees and/or shrubs and/or any other plant as shall conform to the general pattern and type of growth in the area and as directed by the Environmental Officer, Department of Mines and Petroleum and properly maintain same until the Environmental Officer advises regrowth is self supporting; unless the Minister responsible for the Mining Act 1978 orders or consents otherwise.
Mining Lease M59/526 (13)	Placement of waste material must be such that the final footprint after rehabilitation is located outside of the zone of potential pit instability.
General Purpose Leases G59/41 (15); G59/45 (16).	A Mine Closure Plan is to be submitted in the Annual Environmental Reporting month specified in tenement conditions in the year specified below, unless otherwise directed by an Environmental Officer, DMP. The Mine Closure Plan is to be prepared in accordance with the "Guidelines for Preparing Mine Closure Plans" available on DMP's website: - 2014
Source: Ministerial Statement 753 (24 October 2007)	
Condition No.	**Closure Condition**

14-1*	Prior to ground-disturbing activities, the proponent shall prepare a Preliminary Closure Plan in consultation with the Department of Environment and Conservation, the Department of Industry and Resources, the Department of Water, the Australian Bush Heritage Fund, the Australian Wildlife Conservancy, the Pindiddy Aboriginal Corporation and the relevant Local Governments, which describes the framework to ensure that the mine area and the services corridor are left in an environmentally acceptable condition and provides: 1. the rationale for the siting and design of plant and infrastructure as relevant to environmental protection; 2. a conceptual description and design of the final landform at closure; 3. for the long-term management of groundwater and surface water systems affected by the mining operations and services corridor; 4. for the management of noxious materials to avoid the creation of contaminated areas (including acid-generating materials); 5. a rehabilitation program, which aims to restore the original vegetation communities to areas disturbed by the mining operations and construction within the services corridor, and includes completion criteria to be met; and 6. for the monitoring and response to the progress towards the re-establishment of the floristic communities as part of the rehabilitation of the area, including studies on the composition of the floristic communities on Extension Hill North.
14-2	The proponent shall make the Preliminary Closure Plan required by condition 14-1 publicly available in a manner approved by the CEO.
14-3	At least two years prior to the anticipated date of closure, or at a time agreed with the Environmental Protection Authority, the proponent shall prepare a Final Closure Plan, to the requirements of the Minister for the Environment on advice of the Environmental Protection Authority. The objectives of this Plan are to: • Achieve construction of landforms which are stable, non-polluting and aesthetically compatible with the surrounding landscape; and • Ensure that closure planning and rehabilitation are carried out in a coordinated, progressive manner and are integrated with development planning, consistent with current best practice, and the agree end land uses. The Final Closure Plan shall set out details and measures for: 1. removal or, if appropriate, retention of plant and infrastructure in consultation with relevant stakeholders; 2. final landforms and the extent of the mine void; 3.long-term management of groundwater and surface water systems affected by the waste rock dumps, the mine void and the services corridor; 4. identification of contaminated areas, including provision of evidence of notification and proposed management measures to relevant statutory authorities; and 5. rehabilitation of all disturbed areas, including the mine area and the services corridor, to ensure establishment of sustainable vegetation communities with local species and local provenance, consistent with the reconstructed landscape and surrounding vegetation and in accordance with the completion criteria.
14-4	The proponent shall implement the Final Closure Plan required by condition 14-3 until such time as the Minister for the Environment determines, on advice of the CEO, that the proponent's closure responsibilities have been fulfilled.

14-5	The proponent shall make the Final Closure Plan required by condition 14-3 publicly available, in a manner approved by the CEO.
Source: Ministerial Statement 786 (19 February 2009)	
Condition No.	**Closure Condition**
6-8	Generally within six months following the completion of construction, but in the case of borrow pits, within six months following their closure, the proponent shall commence rehabilitation by replacing top soil in all disturbed areas, and thereafter shall progressively rehabilitate by means of planting flora and vegetation to achieve pre-proposal composition, extent and condition.
6-9	For five years following the completion of construction, the proponent shall monitor progressively and submit a report at the conclusion of the five-year period on the performance of the rehabilitation required by condition 6-8 to the CEO of the Department of Environment and Conservation.
Source: Prescribed Premises Licence L8495/2010/2 (2 May 2014)	
Condition No.	**Closure Condition**
1.3.4	The Licensee shall manage the landfilling activities to ensure: (a) Waste is placed to ensure all faces are stable and capable of retaining rehabilitation material; and (b) Rehabilitation of a cell or phase takes place within 6 months after disposal in that cell or phase has been completed.
1.3.5	The Licensee shall ensure that cover is applied and maintained on all accessible waste in accordance with Table 1.3.3 and that sufficient stockpiles of cover are maintained on site at all times.
Source: Program of Work Approval for Exploration on M59/454-I and M95/609-I Reg ID:47374 (27 May 2014)	
Rehabilitate all exploration disturbances within 6 months of the disturbance occurring.	
Submit an Exploration Rehabilitation Report once all rehabilitation work has been completed.	
Source: Program of Work Approval for Exploration on M59/454-I and M95/609-I Reg ID:47841 (7 July 2014)	
Rehabilitate all exploration disturbances within 6 months of the disturbance occurring.	
Submit an Exploration Rehabilitation Report once all rehabilitation work has been completed.	

* Note that this condition has already been meet, as acknowledged by the Department of Environment and Conservation in correspondence dated 7 August 2008. This MCP will supersede the previously approved document in relation to only the hematite component of the Mt Gibson Iron Ore Mine and Infrastructure Project.

** Commitments relating to the magnetite component of the Mt Gibson Iron Ore Mine and Infrastructure Project have been omitted, except where they are also applicable to the hematite component.

Note that DoIR is now the Department of Mines and Petroleum (DMP) and DEC is now the Department of Environment Regulation (DER)) and the Department of Parks and Wildlife (DPaW).

Table 4 Closure Obligations and Commitments Register – Proponent Commitments and Management Strategies

Source: Revised Addendum to Mining Proposal (30 January 2013)	
Section/Page No.	**Closure Commitment**
Section 5.2.1 Page 34	Following waste dump construction, the bunds will be removed and surface water flows reestablished, thus no surface water shadowing impacts are anticipated upon completion.
Section 5.2.1 Page 34	Mine closure and rehabilitation monitoring will include monitoring for potential vegetation impacts.
Section 5.2.1 Page 35	In the event that the mineralised waste stockpile is still present at the completion of operations, a drainage system will be designed and installed to prevent erosion through the valley between the stockpile and the waste dump. A bund will be constructed at the western end of the valley to prevent runoff from the remaining Extension Hill slopes from entering the valley. The base of the valley and the inner toe of the mineralised waste stockpile and the waste dump will be rock sheeted to minimise erosion. A sediment sump of sufficient capacity to contain a 1 in 50yr, 72hr rainfall event for a minimum 10 hour retention time will be installed at the eastern end of the valley. The sediment sump will discharge via a rock lined spillway.
Section 5.5 Page 36	Topsoil (top 100mm of material) and substrate, as determined by MGM's HSEC Department in consultation with EHPL and as discussed with DMP, will be removed and stockpiled for use in rehabilitation activities;
Section 5.5 Page 36	Substrate will be harvested such that there is sufficient material available to provide approximately a 300mm layer on the waste dump, in the event that the rock armour battering trials discussed in Sections 4.2.4 and 5.8.2 prove ineffective or unachievable.
Section 5.8.2 Page 38	The design and management will incorporate the recommendations of Landloch (2012) in relation to landform tops, landform shape and rehabilitation monitoring, specifically: • The waste dump will be designed with appropriate crest bunding and appropriate cross-bunding to ensure runoff is retained on top of the landform; • The waste dump top will be deep ripped prior to final topsoil respread to increase infiltration capacity; • The corners of the waste dump will have a radius of curvature of at least 100m; • Rehabilitation monitoring of the waste dump will include measurement of erosion trends; and • MGM will conduct a rehabilitation trial to test the recommendations of Landloch (2012) in relation to sheeting batter slopes with rock amour and the application of fertilisers (refer to Section 4.2.4 for trial details). These recommendations will implemented as deemed appropriate based on the trial results.
Section 11 Page 50	The final Hematite Mine Closure Plan will be submitted to the DMP for approval by the end of October 2014.
Source: Mining Proposal (2 February 2010)*	
Section/Page No.	**Closure Commitment**
Section 5.1.1 Page 40	Cleared vegetation and topsoil to be stockpiled for use in rehabilitation.

Section 5.3.3 Page 45	Cleared vegetation to be trittered and stockpiled for use in rehabilitation, this material will be stockpiled in designated topsoil dump areas.
Section 5.3.3 Page 46	Disturbed areas to be recovered with topsoil to a depth of 100mm where practicable.
Section 5.3.3 Page 46	Local provenance seed material to be used for seeding in rehabilitation works.
Section 5.3.3 Page 46	Quantitative monitoring of vegetation regrowth in rehabilitated areas.
Section 5.3.3 Page 46	Remediation of areas showing inadequate regrowth.
Section 5.3.3 Page 46	MGM will re-establish the significant flora communities (Group 10 level) as part of the rehabilitation of the area.
Section 5.4.1 Page 49	Disturbed areas will be progressively rehabilitated and will aim to reflect the pre disturbance state as closely as possible. Vegetation debris, logs and rocks will be returned to areas that have been disturbed as they provide microhabitats for recolonising fauna.
Section 5.4.1 Page 49	All exploration drill holes will be temporarily capped on completion of drilling and permanently capped as soon as possible.
Source: Extension Hill Project Mining Proposal - Accommodation - Tenements G59/41 and G59/45" (17 November 2011)	
Section/Page No.	**Closure Commitment**
Section 7.1	EHPL proposes to re-instate the Gunduwa Village and the Exploration Camp site to the pre-mining land use. The pre-mining land use is pastoral lease managed for conservation.
Section 7.2	On closure EHPL proposes to remove all built facilities from the village site and rehabilitate the site in accordance with the following principles: • Re-establishment of a stable landform with erosion protection for long-term stability; • Creation of a post-construction landform that resembles the pre-construction landform as closely as practicable; • Replacement of topsoil; • Spreading of vegetation debris to return organic matter to the area, and provide additional seed sources; • Additional seeding and planting of seedlings if regeneration from topsoil is insufficient; and • Rehabilitation monitoring.

* Any commitments made in the *Mining Proposal* which were superseded or altered in the *Revised Addendum to Mining Proposal* have not been included in this table. Commitments that are repeated within a single document are only included in this table once.

3.4 Guidelines

MGM has planned for and will undertake closure with due regard to applicable policies and guidelines for mine rehabilitation and closure, including:

- Safety Bund Walls around Abandoned Open Pit Mines (Department of Minerals and Energy, 1997);
- Contaminated Sites Management Series - Reporting of Known or Suspected Contaminated Sites (Department of Environment and Conservation, 2006);
- Contaminated Sites Management Series - Potentially Contaminating Activities, Industries and Land Uses (Department of Environment and Conservation, 2004);
- Guidelines for Preparing Mine Closure Plans (DMP and EPA, 2011); and
- Guidance Statement No. 6 Rehabilitation of Terrestrial Ecosystems (EPA 2006).

4. Collection and Analysis of Closure Data

Data presented in this section is based on existing information available from applicable site studies and investigations, and site data registers. This data and information has been collected:

- Using recognised or accepted methodologies and standards;
- Incorporating appropriate quality management systems and procedures; and
- In consideration of the wider receiving environment, receptors and exposure pathways.

This section provides an overview of data relevant to the closure of the site.

4.1 Environmental Data

A significant component of the information in this section has been taken directly from the EMP and the Mining Proposal. This information has been updated where further surveys or studies have been conducted.

4.1.1 Climate

The Project is located within two major climatic regions. Mt Gibson experiences a semi-desert Mediterranean climate. This climate type is characterised by hot, dry summers with 9 to 11 months of dry weather and mild, wet winters (Payne et al., 1998). Rainfall in the area averages 280 mm per annum (based on Paynes Find, 60km to the north east) (Rockwater, 2005). Almost 70% of the annual rainfall falls between the months of March to August. The winter rainfall is associated with southerly low pressure systems, while the summer rainfall is derived from thunderstorm activity associated with northerly low pressure systems. Rainfall is both irregular and variable. The average annual temperature for Paynes Find is 27.9°C, and ranges from 18.4°C (July) to 37.1°C (January).

Winds in the Midwest region have a distinct seasonal and diurnal pattern. Winds at Paynes Find in spring and summer are dominated by light to moderate easterlies in the mornings with weak southerlies to south westerlies in the late afternoons. The wind pattern in the autumn and winter months is dominated by light winds from the northwest, typically in the afternoons. Winds in spring are typically moderate to strong westerly winds in the afternoons. Wind strength is significantly stronger in all seasons closer to the coast.

The site weather station has been in place since February 2011 so it cannot be used for long term weather analysis. The annual rainfalls recorded on site over this period are 387mm, 346mm, 255mm *and 240mm* for 2011, 2012, 2013 *and 2014* respectively. Note that the 2011 dataset does not include January.

4.1.2 Topography

The Project is located within the Mount Gibson Range. The Mt Gibson Range is a folded ridge of Banded Ironstone Formation, which reaches an elevation of 451 mAHD. At the toe of the range, the land has low topography ranging from elevations of 320 to 360 mAHD.

4.1.3 Geology

The Mt Gibson Range forms part of the Retaliation Belt, which contains successions of mafic volcanics and a sedimentary sequence dominated by Banded Iron Formation (BIF) and chert, with subordinate felsic tuff and agglomerate, and semipelitic schist. The geology of the Mt Gibson area consists of a sequence of Archaean sediments and volcanics. Refer to the Mining Proposal for more information.

4.1.4 Seismicity

According to the Earthquake hazard map of Australia produced by Gaull et al. (1990), the Mount Gibson area has been classified as having an acceleration coefficient value of approximately 0.10 with regards to the 10% chance of experiencing seismic activity within the next 50 years. For comparative purposes, the equivalent value for Perth is 0.09.

4.1.5 Surface Water

Surface drainage in the Mt Gibson Range area is primarily characterised by ephemeral flows. An ephemeral drainage line intermittently flows from Iron Hill North in a south easterly direction to a claypan located 4 km south-southeast of the Extension Hill hematite mine site. Two smaller salt lakes are located approximately 2 km to the south of the claypan. A second ephemeral drainage line intermittently flows in a north easterly direction from Iron Hill East while a third drainage line also flows in north easterly direction from Extension Hill South. Both of the latter drainage lines result in ephemeral sheet flow across the plain after periods of irregularly occurring heavy rain, with the drainage leading to the Lake Monger paleo-drainage system, 30 km to the north of Extension Hill (MGM & EHPL, 2008).

4.1.6 Groundwater

Regular groundwater monitoring is conducted in accordance with Groundwater Licences issued by the Department of Water, under the *Rights in Water and Irrigation Act 1914.*

The productive aquifers encountered were in banded iron formation, at depths commencing at 48-78 m below ground surface (bgs) and extending to depths in the range 85-135 m bgl. (Rockwater, 2008b).

The groundwater is brackish to saline, with salinities ranging between 1,600 and 11,000 mg/L of Total Dissolved Solids. Values of pH ranged from 7.1-8.5, i.e. the water is neutral to alkaline. There were no trends evident in the salinity and pH data. The groundwater is of a sodium chloride type with moderately high concentrations of sulphate. (Rockwater, 2008a)

The results of the baseline groundwater analysis and the most recent groundwater analysis are included in Table 5. Piper diagrams depicting the annual monitoring results are included in Figure 2 and show little variation year to year.

No significant effects relating to groundwater quality are anticipated at the completion of mining. Results to date show some fluctuations which may be attributable to natural variation. There have been intermittent spikes recorded in some analytes, including iron, zinc, manganese, magnesium and calcium but no significant long term increases. Water abstraction appears to result in an increased total dissolved solids concentration (TDS) in EH1P and EH2P, however data collected from EH2P, after a lengthy period of abstraction followed by an extended rest period showed that the TDS decreased to near baseline concentrations following an extended rest period. Monitoring will continue throughout operations and mine closure to ensure that groundwater quality is not detrimentally impacted by the operations.

Table 5 Groundwater Analysis

		EH1P		EH2P		EH3P		EH4P	
	Date	20/01/08	17/11/14	16/01/08	17/11/14	9/01/08	17/11/14	12/01/08	17/11/14
pH	Units	7.8	7.3	7.8	7.6	7.7	7.6	7.8	7.7
EC*	µS/cm	4800	6300	5000	5000	15000	11000	13000	7900
TDS#	mg/L	2600	3700	2600	2900	11000	6300	8300	4700
Calcium	mg/L	37	56	14	18	57	38	55	28
Magnesium	mg/L	75	130	52	55	360	210	310	130
Sodium	mg/L	910	1100	980	1000	2900	2000	2400	1500
Potassium	mg/L	41	52	44	46	120	95	55	70
Chloride	mg/L	1400	1800	1300	1300	5100	3300	4400	2300
Sulphate	mg/L	340	350	360	320	990	630	870	470
Nitrate	mg/L	1.8	4.4	1.9	5.2	<0.25	<5	<0.25	<2.5
Fluoride	mg/L	0.16	<2.5	0.54	<2.5	<0.25	<5	<0.25	<2.5
Bicarbonate	mg/L	200	200	280	320	280	310	340	300
Carbonate	mg/L	<2	<5	<2	<5	<2	<5	<2	<5
Iron	mg/L	<0.005	0.47	<0.02	0.05	0.11	0.12	0.11	0.08
Manganese	mg/L	0.11	0.1	0.017	0.009	0.036	0.056	0.074	0.044
Silica	mg/L	31	41	39	46	27	38	28	30

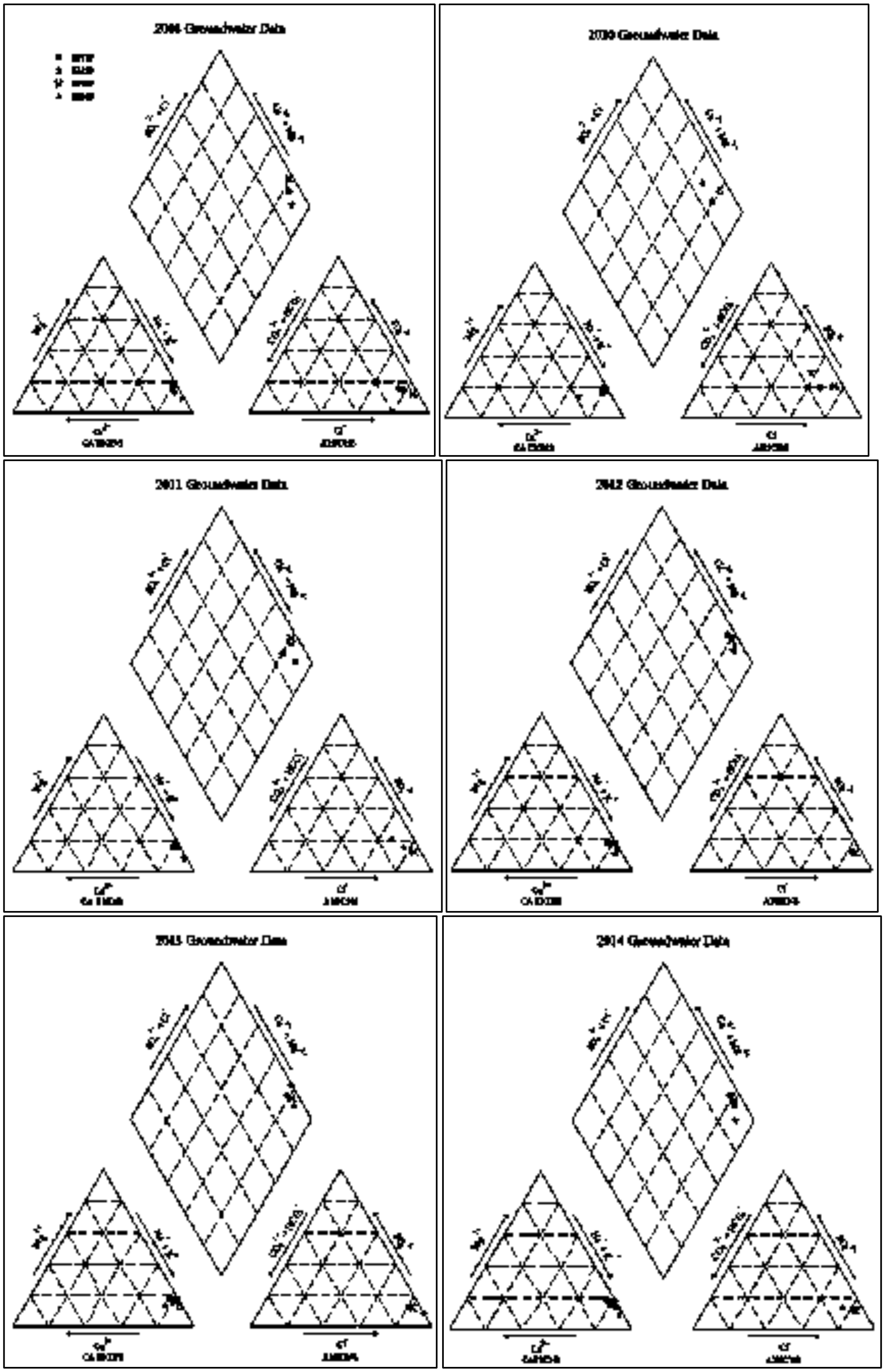

Figure 2 Groundwater Data - Piper Diagrams

4.1.7 Vegetation and Flora

The Mt Gibson Ranges occurs on the boundary of the Austin Botanical District of the Eremaean and the Avon Botanical District of the Southwest Botanical Provinces (Beard, 1990). They are located in the Avon Wheatbelt bioregion (McKenzie *et al.* 2003) near the junction of the Yalgoo and Coolgardie Interim Biogeographical Regional Assessment (IBRA) bioregions. As a consequence, the floristic composition of the area is considered to be representative of all three Bioregions. The area has been recognised for its biological diversity (Vital Options Consulting, 2004).

The following baseline vegetation and flora studies have been conducted in the Project area:

- Observations on the Presence and Distribution of Rare Flora, Especially *Darwinia masonii,* near Mt Gibson (Muir Environmental, 1995);
- A survey of the flora and vegetation of the Mt Gibson area (Bennett Environmental, 2000);
- A vegetation assessment and rare flora search between Perenjori and Mt Gibson as well as a search for rare flora on select hills within a 50 km radius of Mt Gibson (Paul Armstrong and Associates, 2004);
- A targeted search for declared rare flora *Darwinia masonii* to determine the population size, distribution and age structure at Mt Gibson (ATA Environmental, 2004);
- An assessment of the significance of the floristic communities on the BIF at Mt Gibson and on BIF hills within 20 km (E.A, Griffin and Associates, 2005). This report details the finding of two flora and vegetation surveys undertaken at Mt Gibson between November 2004 and January 2005 in line with the new Guidance Statement No. 51 *Flora and Vegetation Surveys for Environmental Impact Assessment in Western Australia* (EPA, 2004) (ATA, 2006a);
- A flora and vegetation survey undertaken by the DEC of the Yilgarn Craton at Mt Gibson and surrounding areas in spring 2005 (Meissner R and Caruso Y, 2008);
- Targeted surveys of Mt Gibson and the surrounding area for *Lepidosperma gibsonii*, conducted in 2006 and 2008 (ATA, 2006b; Coffey, 2008a; 2008b);
- A census of *Darwinia masonii* on Mt Gibson Range (Eco Logical 2014).

Vegetation Communities

The Mt Gibson Ranges contain diverse vegetation communities including woodland, Mallee, thicket and heath associations. Sixty vegetation associations have been identified across the Project tenements (ATA Environmental 2005a, 2006b; Bennett Environmental Consulting, 2000).

The ridges of the Mt Gibson Ranges support certain flora of conservation significance and a variety of vegetation communities, with Acacia species, Melaleuca species and *Allocasuarina acutivalvis* subsp. *prinsepiana* being the dominant taxa. The woodland plains typically consist of *Eucalyptus loxophleba* subsp. *supralaevis* or mallees of *E. brachycorys* and *E. hypochlamydea* subsp. *hypochlamydea*, which are often associated with *Callitris collumellaris* and *Eucalyptus loxophleba* subsp. *supralaevis* (MGM, 2008).

Significant Vegetation Communities

The Mt Gibson Range contains floristic communities that are recognised as distinct from the floristic communities on other areas of BIF within the Yilgarn Craton. The floristic communities in the Mt Gibson Ranges have been assessed at a number of levels and geographical areas, all of which meet the EPA's definition of significance, i.e. a geographically restricted community. A number of botanists in both government and private organisations undertook this work.

The subtleties in the differences between the communities, when assessed at different levels, have made the floristic communities a complex environmental factor with technical uncertainty. Accordingly, the various assessments were reviewed to determine the appropriate definition of significant floristic community for management and rehabilitation purposes. This review concluded that the definition should be the "Group 10" level. Four floristic communities identified at Group 10 level are geographically restricted to the Mt Gibson Ranges and thus meet the EPA's definition of a significant floristic community. Refer to the *Extension Hill and Extension Hill North Environmental Management Plan* (MGM & EHPL, 2008).

Flora

A total of 285 plant taxa were recorded about the mine site by Bennett Environmental Consulting (2000) reflecting that the Project is located at the junction of three bioregions. The dominant families are Asteraceae (41 native taxa, 6 introduced), Myrtaceae (28 native taxa), Mimosaceae (22 native taxa), Chenopodiaceae (21 native taxa), Poaceae (11 native taxa, 5 introduced taxa) and Proteaceae (13 native taxa). A small percentage of the plant taxa are weeds. Complementary surveys on the sandplains and woodlands (ATA Environmental, 2005a) recorded 192 native and one weed species. (MGM & EHPL, 2008) *There was significant overlap in the species identified in the original and complementary surveys.*

Priority Flora

Three gazetted (WA) rare flora *Darwinia masonii*, *Lepidosperma gibsonii* and *Eucalyptus synandra* have been recorded in the area. *Darwinia masonii* and *Eucalyptus synandra* are also listed as vulnerable under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act).

The Project will clear both *Darwinia masonii* and *Lepidosperma gibsonii*, and also *Acacia cerastes* which is listed as a Priority 1 species under the *Wildlife Conservation Act 1950*. The scale of the effect on each of these species is shown in Table 6. For more information on these species, refer to the EMP (MGM & EHPL, 2008). An additional population of *Lepidosperma gibsonii* has recently been discovered outside of the mining area but is yet to be definitively quantified. DPaW (2014b) provide an estimate of the current *Lepidosperma gibsonii population* (Table 6). The identification of this new population has been confirmed by the WA Herbarium. A census of *Darwinia masonii* was conducted in 2014 and the current known population of this species is also greater than at the time of Project approval (Table 6).

Table 6 Impact on Significant Flora Species*

Species	Known Abundance at the Mt Gibson Area	Approximate No. taken by current Mining Activities	References
Darwinia masonii	20,965	1,702	Ecological 2014
Lepidosperma gibsonii	est 60,000	820	ATA 2006, Coffey 2008a, Coffey 2008b, DPaW 2014b
Acacia cerastes	1,702	120	ATA 2006

* Adapted from Table 1 in the *Extension Hill and Extension Hill North Environmental Management Plan* (MGM & EHPL, 2008).

The Botanic Gardens and Parks Authority (BGPA) was commissioned to conduct further research on the DRF species, *Darwinia masonii* and *Lepidosperma gibsonii*, in accordance with the Research Proposal. The outcomes of this research are summarised in the Report to Sponsors (Appendix A).

Other significant flora that have been recorded about the mine site include *Chamelaucium* sp. Yalgoo (P1), *Persoonia pentisticha* (P2), and *Grevillea scabrida* (P2). None of these other significant flora species or populations will be affected by mining activities. (MGM & EHPL, 2008).

Introduced Flora Species

Very few weeds occur within the tenements and only one of the weeds recorded within the Project tenements is a ‘Declared’ weed (under the *Agriculture and Related Resources Protection Act 1976*) within the Shire of Yalgoo. The Declared species (*Emex australis*) was represented by one individual (MBS Environmental, 2013), which has subsequently been removed.

Table 7 lists the weeds that have been recorded at or within the vicinity of the Mt Gibson Ranges. Each species is assigned a rating for impact on biodiversity based on their potential invasiveness, distribution and ability to change the structure, composition and function of ecosystems, as per the Environmental Weed Strategy for Western Australia (DEC 1999).

Table 7 Weeds Recorded Within or Adjoining the Mt Gibson Tenement Areas

Scientific Name	Common Name	Rating for Potential Impact on Biodiversity^
Acetosa vesicaria (formerly *Rumex vesicaria*)	Ruby Dock	High
Anagallis arvensis	Scarlet Pimpernel	Moderate
Artctotheca calendula	Capeweed	Moderate
Brassica tournefortii	Mediterranean Turnip	High
Bromus diandrus	Great Brome Grass, Brome Grass, Ripgut	High
Bromus rubens	Red Brome	Moderate
Carrichtera annua	Ward’s Weed	High
Centaurea melitensis	Maltese Cockspur	Moderate
Echium plantagineum	Paterson’s Curse	High
Ehrharta longiflora	Annual Veldtgrass	Moderate

Scientific Name	Common Name	Rating for Potential Impact on Biodiversity^
Emex Australis	Doublegee	Low
Erodium botrys	Long Storksbill	Low
Hedypnois rhagadiodes	Cretin Weed	Mild
Hordeum leporinum	Barley Grass	Moderate
Hypochaeris glabra	Smooth Catsear	Moderate
Medicago truncatula	Barrel Medic	Mild
Monoculus monstrosus (formerly *Osteospermum clandestinum)*	Stinking Roger	Low
Pentaschistis airoides	False Hairgrass	Moderate
Petrorhagia dubia (formerly *Petrorhagia velutina*)	Velvet Pink	Mild
Polycarpon tetraphyllum	Fourleaf Allseed	Low
Rostraria pumila	Tiny Bristle Grass	Moderate
Sisymbrium orientale	Indian Hedge Mustard	Moderate
Sonchus oleraceus	Common Sowthistle	Moderate
Spergularia rubra	Sand Spurry	Moderate
Trifolium tomentosum	Clover	Low
Ursinia anthemoides	Ursinia	Moderate
Verbesina enceliodes	Crown Beard	Low

^ In accordance with DEC (1999).

Of the species recorded at or in the vicinity of the Mt Gibson Ranges, Paterson's Curse (*Echium plantagineum*), Ruby Dock (*Rumex vesicarius*), Maltese Cockspur (*Centaurea melitensis*) and Ward's Weed (*Carrichtera annua*) are highly invasive weeds (Bennett Environmental Consulting, 2000).

Paterson's Curse has been recorded at Paynes Find while Ruby Dock, Maltese Cockspur and Wards Weed are all common throughout the Goldfields. The population of these weeds at or within the vicinity of the Mt Gibson Ranges is isolated.

4.1.8 Fauna

The Mt Gibson area contains diverse fauna assemblages representing 130 species including 64 species of birds, 55 species of reptiles and 11 species of mammals, of which five have been introduced (ATA Environmental, 2005b; Terrestrial Ecosystems, 2014). The area about the mine site can be divided into three broad fauna habitat types: the flat sand plains, the flat woodlands, and the slopes and iron stone ridges.

During a recent vertebrate fauna survey, it was concluded that there was no obvious or significant change in the vertebrate fauna assemblage recorded in the eucalypt woodland or sand plain sites. Similarly, there was no obvious or detectable change in the vertebrate fauna assemblage on the ironstone ridge, except that Woolley's Pseudantechinus is now present on the control ridge (Terrestrial Ecosystems, 2012; 2014).

Threatened Fauna

A number of fauna species that have special ecological status under State and/or Commonwealth government legislation, have been previously recorded or have the potential to occur in the vicinity of the Mt Gibson Ranges (Table 8). The known habitat requirements of species that are likely or known to occur in the tenement area (highlighted in bold) are described further in the EMP.

Table 8 Significant vertebrate species recorded or listed as potentially occurring in the Mount Gibson Range area

Species	Status under Wildlife Conservation Act	Status under Commonwealth EPBC Act	Comment
Malleefowl *Leipoa ocellata*	Schedule 1	Vulnerable	Species *occurs* in the tenement area
Carnaby's Black-Cockatoo *Calyptorhynchus latirostris*	Schedule 1	Endangered	Species *unlikely* to occur in the tenement
Western Spiny-tailed Skink *Egernia stokesii badia*	Schedule 1	Endangered	Species *occurs* in the tenement area
Peregrine Falcon *Falco peregrinus*	Schedule 4		Species *occurs* in the tenement area
Slender-billed Thornbill (western sub-species) *Acanthiza iredalei iredalei*		Vulnerable	Species is *likely* to occur in the tenement area but not on-site
Hooded Plover *Charadrius rubricollis*	Priority 4	Migratory	Species is *likely* to occur in the tenement area but not on-site
White-bellied Sea-Eagle *Haliaeetus leucogaster*		Migratory	Species may *occasionally* be seen in the tenement area
Fork-tailed Swift *Apus pacificus pacificus*		Migratory	Species may *occasionally* be seen in the tenement area
Rainbow Bee-eater *Merops ornatus*		Migratory	Species *occurs* in the tenement area
Numbat *Myrmecobius fasciatus*	Schedule 1		Species is *highly unlikely* to occur in the tenement area
Major Mitchell's Cockatoo *Cacatua leadbeateri*	Schedule 4		Species *occurs* in the tenement area
Australian Bustard *Ardeotis australis*	Priority 4		Species is *likely* to occur in the tenement area
Bushstone Curlew *Burhinus grallarius*	Priority 4		Species is *likely* to occur in the tenement area
Carpet Python *Morelia spilota imbricata*	Schedule 4		Species is *highly unlikely* to occur in the tenement area
Woma Python	Schedule 4		Species is *unlikely* to occur

Species	Status under Wildlife Conservation Act	Status under Commonwealth EPBC Act	Comment
Aspidites ramsayi			in the area
Cyclodomorphus branchialis	Priority 2		Species is *unlikely* to occur in the tenement area
Shield-backed Trapdoor Spider *Idiosoma nigrum*	Schedule 1		Species *occurs* in the tenement area

Annual Malleefowl (*Leipoa ocellata*) mound monitoring surveys are conducted to monitor the local Malleefowl population. The most recent survey, conducted in November and December 2012 recorded 10 active Malleefowl mounds. A detailed examination of the particular mounds that were active suggested that mining activities have had no significant impact on the local Malleefowl population.

Rainbow Bee-eaters (*Merops ornatus*), Major Mitchell's Cockatoos (*Cacatua leadbeateri*), Western Spiny-tailed Skinks (*Egernia stokesii badia*) and Shield-backed Trapdoor Spiders (*Idiosoma nigrum*) are listed species that have also been sighted in the area since the commencement of operations.

4.1.9 Soils

The Department of Agriculture and Food (Payne *et al*, 1998) discussed the soils of the Project area, their wind and water erosion potential and inundation risk. The soils of the Project area vary between the solid banded ironstone formation rocks on the tops of hills, to scattered rocks on the hill slopes. Sandy soils with scattered small rocks on the surface and red or yellow sands are also present. Soils of the Project area (from Payne *et al*, 1998) are shown in Table 9 below.

Table 9 Soils of the Extension Hill Hematite Project (from Payne et. al. 1998)

Land Type	Soil Type
Hill slopes, ridges and crests	Stony soils; Shallow stony red earths; Shallow red earths
Sand plains	Shallow red clayey sands; Shallow yellow clayey sands; Deep red sands
Alluvial plains, drainage zones	Deep red earths; Shallow red earths; Shallow to deep clays
Lake margins	Shallow red clayey sands
Lake beds	High saline soils

4.1.10 Characterisation of Waste Rock

The waste material to be mined in the hematite pit has been geochemically characterised by Graeme Campbell & Associates (2005) as benign (Appendix B).

The waste material consists primarily of weathered BIF, clay, chert and basalt, all of which are classified as non acid-forming. Geochemical test work indicates there is no potentially acid forming (PAF) material within the hematite pit profile.

Detailed testing and analysis was undertaken by Orica to determine the fragmentation of rock following blasting. Core samples were analysed for their clay content in the weathered area on the north west side of the pit (Roger Townend & Associates, 2005). The assessments concluded that the rock is hard, geologically competent with little clay in the overall deposits. The clay present showed no swelling properties.

The physical properties of the ore and waste material at Extension Hill are not expected to impact adversely on the long-term stability or rehabilitation of the waste dump (MGM, 2010).

Landloch (2012) have undertaken further characterisation studies of waste rock material (Tables 10 – 12 are taken directly from Landloch (2012)). For the purposes of this assessment the 'fine component' is material with <2mm diameter and the coarse component is >16mm diameter. The complete report is included in Appendix C.

The results indicate that the material is generally non-saline, mildly acidic, not prone to dispersion or tunnel erosion, and has low soil fertility. Although local vegetation is considered to be adapted to site conditions, additional fertilisation may be required to counteract nutrient losses during the material handling and stockpiling processes (Landloch, 2012).

The rocks sampled are considered to be suitable for rock armouring the batter slopes due to the high densities and low erodibility (Table 12) (Landloch, 2012).

Table 10 Basic chemical and physical characterisation data for the fine component of Extension Hill materials (Landloch 2012)

Test Parameter		Units	Sample ID											
			Sandy Soil 1	Sandy Soil 2	Sandy Soil 3	Sandy Soil 4	Laterite Soil 1	Laterite Soil 2	Laterite Soil 3	Laterite Soil 4	BIF 1	BIF 2	Goethite 1	Goethite 2
$EC_{1:5}$		*dS/m*	0.16	0.07	0.06	0.09	0.09	0.07	0.06	0.05	0.08	0.21	0.05	0.09
$pH_{1:5}$		*pH units*	5.19	5.20	4.80	4.74	4.85	4.61	4.53	4.37	5.06	7.93	7.94	8.38
Exchangeable Cations	ECEC	*meq/100g*	5.39	2.59	2.02	2.50	3.00	2.68	2.28	2.17	2.94	4.53	3.10	4.69
	K	%	6.76	8.26	5.77	5.78	5.7	5.21	5.32	4.70	4.94	6.34	5.4	6.2
	Ca	%	67	65.0	52.5	62.5	53.2	50.6	43.6	31.6	57.7	46.8	62.0	67.3
	Mg	%	17.5	14.2	13.0	12.9	16.0	13.8	17.9	13.70	23.8	18.3	25.8	19.6
	Na^	%	**8.48**	**6.9**	**10.2**	**10.0**	**14.60**	**11.1**	**10.4**	**9.10**	**13.0**	**28.4**	**6.90**	**6.80**
	Al	%	0.25	5.6	18.55	8.79	10.50	19.30	22.90	40.80	0.62	0.12	0.0	0.14
Emerson Index		Class	**3**	6	5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Clay Mineralogy·		-	K+I	K	K	K	K	K	K	K	K	K+I	K	K
Particle Size Distribution*	Clay	%	22.8	13.7	16.6	20.0	23.8	24.5	24.8	26.1	19.5	20.1	27.6	26.4
	Silt	%	0.00	0.00	0.00	0.0	1.02	0.71	0.31	0.00	0.52	0.21	0.40	0.72
	Fine Sand	%	26.9	20.4	36.5	36.3	44.9	42.3	38.1	37.7	22.8	27.0	42.9	41.6
	Coarse Sand	%	50.3	65.8	47.0	43.7	30.2	32.5	36.6	36.3	57.0	52.7	29.1	31.3

*Clay: <0.002mm; Silt 0.002-0.02mm; Fine Sand 0.02-0.2mm; Coarse Sand 0.2-2.0mm

^ Equivalent to Exchangeable Sodium Percentage (ESP)

· Clay mineralogy estimated based on the ratio of ECEC to clay. K: kaolinite, I: illite

ND: No data due to lack for fine fraction or inability to form bolus with soil (too sandy)

Table 11 Fertility characterisation data for the fine component of Extension Hill materials (Landloch 2012)

Test Parameter		Units	Sample ID											
			Sandy Soil 1	Sandy Soil 2	Sandy Soil 3	Sandy Soil 4	Laterite Soil 1	Laterite Soil 2	Laterite Soil 3	Laterite Soil 4	BIF 1	BIF 2	Goethite 1	Goethite 2
Total N		mg/kg	675	597	392	491	665	656	390	355	380	154	482	649
Total P		mg/kg	78.3	47.5	83.4	93.5	190	193	174	158	205	48	258	215
Available P (Colwell)		mg/kg	17.8	10.2	13.8	13.9	15.9	17.5	7.3	7.6	5.22	2.02	11.9	22.6
Available K (Colwell)		mg/kg	231	161	116	109	124	117	84.4	73.8	104	172	123	141
Organic Carbon		%	1.24	0.83	0.61	1.4	1.71	1.78	0.7	0.53	0.7	0.26	0.92	1.4
Available S (KCl)		mg/kg	14.5	10.3	16	14.1	18.7	15.4	19.5	24.6	25.9	24.7	16.4	16.6
Extractable Micronutrients	Cu	mg/kg	0.62	0.06	0.01	0.01	0.07	0.07	0.4	0.3	0.23	0.1	0.52	0.43
	Zn	mg/kg	0.44	0.23	0.16	0.13	0.62	0.23	0.14	0.12	1.34	1.51	0.47	2.97
	Mn	mg/kg	10.3	3.6	2.38	3.12	9.32	3.96	8.55	1.95	5.2	0.14	13.7	13.9
	Fe	mg/kg	33.3	41.3	22.6	40.4	40	39.8	11.6	10.1	27.4	8.97	20.2	30.9

Table 12 Rock particle density and water adsorption values for the coarse component of samples from Extension Hill (Landloch 2012)

Sample ID	No. Rocks Sampled	Mean Rock Particle Density (g/cm^3)	Mean Water Absorption (%)
Sandy Soil	ND	ND	ND
Laterite	3	2.7	3.0
BIF	12	3.3	1.5
Goethite	6	3.4	4.3

ND: No data due to lack of coarse fraction

4.2 Other Closure Related Data

4.2.1 Key Rehabilitation Materials

Soil

In order to meet the future rehabilitation requirements of the Project, MGM has harvested and stockpiled various rehabilitation materials since the commencement of construction. These include topsoil and growth mediums, and seed and plant material.

The estimated quantities of topsoil/growth media required for rehabilitation are listed in Table 13. The quantity of material available and the location it was initially collected from is also included in this table. It is intended at this stage that the material that was initially sourced from Extension Hill, within the current mine pit footprint, will be used to rehabilitate the waste rock dump in order to replicate the pre-mining landform as closely as possible. This material will be mixed with rocky waste material*, where practicable,* to reduce erosion potential.

In addition to the administration, workshop and crusher areas, 'other areas' also includes the turkey's nest, topsoil stockpile area, explosives magazine and haul roads. Some of these locations are within vegetation communities that align more closely with the pre-mining waste dump area communities so will be rehabilitated with the surplus of material from those areas. There may be a shortfall of material collected directly from the administration area vegetation communities due to areas such as the pre-existing airstrip which were already cleared prior to mining so had no topsoil available for collection. These areas will be supplemented with material from the waste dump area if required. To prevent contamination of vegetation communities, subsoil from the waste dump area may be used in place of topsoil and seeded with an appropriate vegetation mix. This methodology may be refined following the receipt of external advice.

Table 13 Rehabilitation Material Required

Rehabilitation Area	Material Required (m^3)	Volume Available (m^3)	Material source
Waste Dump	*34,976* topsoil/growth media *69,952* rocky waste material	23,931 17,238 N/A	Mine pit topsoil Mine pit growth media Mine pit waste rock
Mineralised Waste Stockpiles	*17,462* topsoil/growth media *34,942* rocky waste material	82,861 N/A	Waste dump area topsoil Mine pit waste rock
ROM Pad	5,321 topsoil/growth media		
Village/Sewage Pond	4,184 topsoil/growth media	9,958	Village/Sewage pond area topsoil/growth media
Magnetite Stockpile	1,960 topsoil/growth media	2,063	Magnetite stockpile area topsoil
Other areas (admin, crusher, workshop, etc)	75,233 topsoil/growth media	19,349 + excess from above	Admin/Workshop/Crusher/Turkey's nest area topsoil/growth media
Magnetite village	2,000 topsoil	2,880	Village footprint
Total	**152,655** topsoil/growth media	**158280**	

In addition to the materials that will be utilised in rehabilitation (Table 13), there are additional rehabilitation materials available for use as required (Table 14). The tritter material may be spread over rehabilitated areas.

Table 14 Additional Rehabilitation Material Available

Source Location	Component	Volume (m3)
Waste Dump	Tritter	6,564
	Subsoil	123,586
Mine Pit	Tritter	12,669

Plants

In October 2008, MGM harvested material from both of the Declared Rare Flora species which were anticipated to be impacted by the Project. Ten cuttings were taken from each of 301 genotypes of *Darwinia masonii* and clumps of 250 genotypes of *Lepidosperma gibsonii* were collected. These materials were delivered to Nuts About Natives Nursery in Karnup, Western Australia for propagation. From these, 169 genotypes of *Darwinia masonii* and 194 genotypes of *Lepidosperma gibsonii* have been considered successfully initiated (Croxford 2009). Cuttings and divisions from these genotypes will be made available, as required for future rehabilitation works.

Seed

Three *external* seed collection programs have been conducted to collect a broad range of representative flora species. During March and April 2008 a total of 44 kg of native seed was collected and an additional 83 kg of native seed was collected during November and December 2008 resulting in seed stocks from 33 native species. The third seed collection program was conducted in December 2011, resulting in an additional 34 kg of native seed collected.

An internal seed collection program has also been undertaken, such that the current seed stock contains 181kg from 65 species.

4.2.2 Rehabilitation Research

Landloch (2012) undertook a soil characterisation assessment and used the data to conduct erosion modelling for the Extension Hill waste dump (Appendix C). The key recommendations were that the waste dump should be covered with a 2:1 rock/topsoil mixture, have a maximum 18º slope and no berms. MGM and Landloch tested the achievability of the recommended Landloch batter designs, as discussed in the Extension Hill Hematite Project Revised Addendum to Mining Proposal (MGM, 2013). A computerised "particle size distribution" (PSD) analysis based on calibrated high quality (> 5 mega pixel resolution) digital photographs of the completed trial batter surface has been conducted and samples of a rehabilitated surface have been analysed to determine if the specifications relating to rock particle size, density, content and cover were achieved. Landloch (2014) confirms that the rock particle size, density and content were achieved. The targeted rock cover was not initially evident as the trial area had not received sufficient rain fall prior to sampling. Following a laboratory simulated rainfall event it was confirmed that the targeted rock cover was achieved after the application of approximately 300mm of rain (Landloch, 2014). The surface is predicted to have low erosion potential

(Landloch, 2014). This demonstrated that the rock armouring recommendations could be achieved where sufficient suitable material is available, however the achievability of this recommendation of the entire waste dump is limited by material availability. As a result, the current intent is to adopt the default waste dump design with a 10m berm (described in Section 4.2.4 of the Extension Hill Hematite Project Revised Addendum to Mining Proposal (MGM, 2013)). Rocky waste will be incorporated into the batter surface to provide rock armouring where practicable. The waste dump design is discussed further in Section 10.2.2.

MGM are funding a rehabilitation research PhD project conducted by the University of Western Australia (UWA), commenced in 2014 aimed at identifying soil, plant and atmosphere interactions and their influence on mine waste cover system performance. This project was designed to incorporate the Landloch (2012) recommendation for of a 2:1 rock/topsoil mixture. Advice received from DMP inspectors during a site inspection in October 2013 has resulted in an adjustment to the trial location. Preliminary results for this study are expected to be released in third quarter 2015.

4.3 Analysis of Data – Identification of Information Gaps

An analysis of knowledge gaps has been completed, based on the closure information reviewed as part of preparation of this MCP, assessment of closure obligations and commitments (Section 3), completion of the risk assessment (Section 7), and development of implementation plans (Section 10). The following items are considered knowledge gaps that are currently being addressed.

4.3.1 Dust

The Midwest region of WA is known to have high ambient dust levels due to climatic conditions (Payne *et al*. 1998). Uncertainty currently exists with regard to the ambient level of total suspended particles (TSP). As such, potential dust effects are currently being monitored by dust deposition monitoring and direct vegetation monitoring. TSP is being monitored at a control and a putative ‘impact’ site to enable a comparison with weather data and assist in assessing the likelihood of dust effecting rehabilitation success.

4.3.2 DRF Establishment on Waste Rock Landforms

Botanic Gardens and Parks Authority (BGPA) have completed an extensive conservation and restoration research program focussed on the two declared rare flora (DRF) species, *Darwinia masonii* and *Lepidosperma gibsonii* (BGPA 2010). This program included two translocation trials, one which established a group of *Darwinia masonii* from cuttings on an old drill pad on Iron Hill East, and a second one that trialled four different substrates found on site (deep red loam/clay, white-yellow sands, gravelly, and rocky loams) using nursery stock of *Darwinia masonii* and *Lepidosperma gibsonii*.

A key recommendation stemming from this work is the future need to conduct a translocation trial, implementing the relevant learnings from the previous trials, to demonstrate if these species (particularly *Darwinia masonii*) can be re-established on the rehabilitated waste rock dump. *A trial was commenced in June 2015 involving 5 nursery propagated Darwinia masonii and 15 wild grown Darwinia masonii harvested from natural regrowth in topsoil stockpiles.*

Additional research opportunities arising from BGPA's research and established priorities are currently being determined in consultation with the Department of Parks and Wildlife, through the completion of DRF Recovery Plans including:

- Mapping of soil or regolith data for the region to refine distribution models to improve understanding and predictions of the habitat and restoration requirements for *Darwinia masonii*.
- Annual collection of a sample of (>10) infructescences of *Darwinia masonii* from each TPFL group to assess rates of seed predation and seed fill.
- Further research into seedling production under lab, glasshouse or field conditions appears promising and may provide a preferable approach to providing a genetically diverse and numerous source of restoration plants.
- Review the role of birds including the White-fronted Honeyeater in *Darwinia masonii* pollination.

The projects considered valuable to the rehabilitation success and long term survival of these species will be included in the Recovery Plans and implemented.

5. Stakeholder Consultation

5.1 General Stakeholder Consultation

MGM conducts stakeholder consultation in accordance with the Stakeholder Liaison Management Standard Work Instruction (Appendix D). The principle objective of this procedure is to facilitate communication, engagement and involvement with identified stakeholders. MGM will continue to employ the principles of being a 'good neighbour', including open, positive and respectful relationships with its neighbours.

MGM regularly liaises with a number of key stakeholders and will continue to do so throughout the life of the Project, and at decommissioning. MGM liaises formally and/or informally with the following identified key stakeholders:

- Department of Environment Regulation
- Department of Parks and Wildlife
- Office of the Environmental Protection Authority
- Department of Mines and Petroleum
- Department of Water
- Department of the Environment (Cth)
- Shire of Yalgoo
- Shire of Perenjori
- Shire of Dalwallinu
- North Central Malleefowl Conservation Group
- Australian Wildlife Conservancy
- Bush Heritage Australia
- Pindiddy Aboriginal Corporation
- Extension Hill Pty Ltd
- The Badimia People

MGM sponsors the Annual Perenjori Agricultural Show and operates a stall at the show to provide an opportunity for members of the public to speak directly to mine site personnel.

MGM actively contributes to the local community through Public Benefit Funds in the Shires of Perenjori and Yalgoo. This presents further liaison opportunities through attendance at events sponsored or funded by MGM, such as the Latham Bowls Club Re-opening and the Blues for the Bush Concert.

MGM and EHPL both fund and actively participate in the Gundawa Regional Conservation Association, a group which also provides opportunities for key stakeholders in the area to liaise with mine site personnel.

Biannual meetings are held with the Badimia Monitoring and Liaison Committee at which a project update is provided to keep these key stakeholders up to date with the current mining activities. The committee members also have an opportunity to raise any queries they may have.

MGM has granted requests from various groups for tours of the mine site, including the Shires of Yalgoo and Dalwallinu, Bush Heritage Australia, the Badimia Monitoring and Liaison Committee and the Department of Agriculture and Food. Tours generally include a visit to the site look out where the mine pit and waste dump can both be seen and the aesthetic legacy of the site can be explained.

As a part of stakeholder communication, MGM will accept and address communications/ complaints through its Environmental Management System. MGM will ensure prompt and accountable follow-up to these communications. MGM engages in informal discussions with key stakeholders on an ongoing basis which also presents opportunities for these stakeholders to raise any issues, including those relating to mine closure planning.

5.2 Closure Specific Stakeholder Consultation

MGM hosts an annual Project Update and Environmental Discussion meeting with key stakeholders (previous attendees include local shires, neighbours, Department of Environment and Community, and the North Central Malleefowl Preservation Group). These meetings provide a forum to discuss environmental management and closure planning issues. MGM present information relating to the current operations, proposed future operations, and proposed closure objectives and activities. Active participation and open discussion are encouraged from all attendees.

Formal consultation specific to mine closure planning that has been conducted subsequent to the submission of the Public Environmental Review is summarized in a Stakeholder Consultation Register (Table 15). Table 15 also includes consultation that was not specifically aimed at closure planning but during which closure related queries were raised.

The planned future stakeholder consultation program is shown in Table 16. The current estimate for the cessation of mining from the current pit is *August 2016*. If the rate of mining were to increase, these consultations would be brought forward as appropriate. In the event that the Iron Hill Project is approved and the mine life is extended, the timeframes for this future consultation may be extended as appropriate.

A community exit strategy will be designed in consultation with the local community approximately 1 year before planned mine closure. It would consider mine closure and withdrawal of community funding and assistance to the local community, direct and indirect employees and their families to plan for the staged withdrawal of these mining activities and the flow on benefits. Mitigation has already commenced with the agreement with the Perenjori Public Benefit Fund committee that any money not spent in a period will remain in the Fund and be used to extend the life of the Fund beyond mine closure. The acceptance of Sinosteel Midwest Corporation Limited into the existing Perenjori Public Benefit Fund program will also aid consistency and maintain the program beyond MGM’s withdrawal.

Information relating to the community exit strategy will be shared through public information sessions and specific discussions with specialty groups, such as the North Central Malleefowl

Preservation Group and recipients of offset benefits via Ministerial Statement 753 should closure correspond to end of the life of the project.

5.2.1 Aesthetics/Visual Amenity

During the mine closure consultations identified in Table 15 discussions around post mining land use have included a description of what will remain of the site post closure, ie an open mine pit and rehabilitated landforms. In order to manage visual amenity, the post mining landforms are intended to replicate aspects of the pre-mining landscape as closely as possible. Due to the delay in the magnetite component of the project, the waste rock dump is not raised to the approved elevation and the eastern mine pit wall is not as low, thus the waste rock dump may not be clearly visible to the public from the Great Northern Highway at closure.

The mine pit will remain an open void and the northern, southern and eastern walls will remain visible to the public road users on the Great Northern Highway. There has been some discussion previously around issues such as access to water in the pit by feral goats and the salinity of any water in the pit, however there have been no significant concerns raised regarding the visual amenity of the pit. A query regarding the potential to backfill the pit was raised and the response that this is not currently a viable option was accepted (due to financial constraints and the burial of the magnetite resource).

At the 2014 Project Update and Environmental Discussion Meeting (28/5/2014) the intent to rehabilitate the ROM pad in situ was also discussed as this will then remain a noticeable feature on the landscape. There were no concerns raised regarding this.

The site visits scheduled for *September and October* 2015 will provide opportunities for the general public to gain a thorough understanding of what will remain visible post closure and for the public to provide and MGM to receive further input.

Table 15 Mine Closure Stakeholder Consultation Summary

Date	Description of Consultation	Stakeholders	Stakeholders Comments / Issues	Proponent Response and / or Resolution	Stakeholder Response
23 May 2008	Project update and environmental discussion meeting. Closure planning was discussed and attendees were asked to review the draft Conceptual Closure Plan (CCP) and provide comments prior to submission to regulators.	Shire of Perenjori; Australian Wildlife Conservancy; Australian Bush Heritage Fund (now Bush Heritage Australia); Pindiddy Aboriginal Corporation; Extension Hill Pty Ltd	AWC requested that consideration to be given to the establishment of sandalwood in rehabilitation activities. ABHF raised concerns regarding feral goats accessing water trapped in pit.	The proponent has collected some sandalwood seeds during seed collection programs. Abandonment bunds around the open pits will be positioned and constructed in accordance with the DMP Guidelines, *Safety Bund Walls for Abandoned Open Pit Mines*.	No comments were received regarding the CCP.
25 Jun 2008	Submission of complete Environmental Management Plan (EMP).	Department of Environment	No comments relating to mine closure.		Approval of the EMP received 7 Aug 2008.
27 Jun 2008	Meeting to discuss mine closure planning and any other environmental concerns. Attendees asked to review the draft Conceptual Closure Plan (CCP) and provide comments.	Shire of Yalgoo	The Shire of Yalgoo acknowledged that mine closure will have little social impact on the Shire of Yalgoo, however they have requested that the upgraded Wanarra Road be kept open for access to the eastern side of the Great Northern Hwy after the cessation of mining.	MGM do not have any objection to this, however this decision will ultimately be made by EHPL following the cessation of their operations.	Letter received from the Shire on 22 July 2008 stating that the CCP appears satisfactory – nothing to add at that stage.

Date	Description of Consultation	Stakeholders	Stakeholders Comments / Issues	Proponent Response and / or Resolution	Stakeholder Response
12 Sep 2008	Letter received from Shire of Perenjori.	Shire of Perenjori	Shire of Perenjori requested that the option to allow the Shire to take over the Perenjori Rail Siding following the cessation of the Project be included in the MCP.	This option will be considered in the MCP.	Acceptable
24 Sep 2008	Conceptual Closure Plan submitted.	Department of Industry and Resources (now DMP); Shire of Perenjori; Department of Water; Department of Environment and Conservation; Australian Wildlife Conservancy; Australian Bush Heritage Fund (now BHA); Pindiddy Aboriginal Corporation; Shire of Yalgoo.	No comments received.	N/A	N/A
14 Apr 2010	Annual project update and environmental discussion meeting. Discussed MGM's proposed post mining land use. Identified and described MGM's proposed closure objectives.	Shire of Perenjori; Australian Bush Heritage Fund (now Bush Heritage Australia); Pindiddy Aboriginal Corporation; Extension Hill Pty Ltd; North Central Malleefowl Preservation Group	Queries raised regarding the fate of the Wanarra Road borrow pits. Bush Heritage Australia would like them rehabilitated but the Shire of Perenjori would like any pits containing additional material to be left open and handed over the Shire.	Borrow pits are required to be rehabilitated within 6 months of their closure. Potential borrow pits that contain priority flora will not be cleared. If any material is left in any borrow pits we can seek permission from DEC to hand them over to the Shire.	Acceptable

Date	Description of Consultation	Stakeholders	Stakeholders Comments / Issues	Proponent Response and / or Resolution	Stakeholder Response
3 May 2012	Annual project update and environmental discussion meeting. Discussed MGM's proposed post mining land use. Overview of MGM's proposed closure objectives.	Shire of Dalwallinu; Bush Heritage Australia; Pindiddy Aboriginal Corporation; Extension Hill Pty Ltd; North Central Malleefowl Preservation Group; Australian Wildlife Conservancy; Wanarra Station; Department of Environment and Conservation	No issues raised.	N/A	N/A
4 Jun 2013	Annual project update and environmental discussion meeting. Discussed MGM's proposed post mining land use and MCP submission date. Discussed the importance of identifying, refining and adapting post mining land use to provide the greatest benefit to the larger community.	Shire of Perenjori; Shire of Yalgoo; Pindiddy Aboriginal Corporation; North Central Malleefowl Preservation Group; Wanarra Station; Department of Environment and Conservation	Shire of Perenjori – asked about remaining life of mine.	Current ore body estimated to be depleted sometime in 2016 but LOM may be extended by future exploration being planned.	Acceptable
11 Mar 2014	Draft Mine Closure Plan submitted for review	Extension Hill Pty Ltd	Minor comments received regarding the appropriate tenement holder contacts.	Details updated. MCP submitted for final review and approval to submit to DMP 26 Jun 2014.	Letter approving submission received 6 Aug 2014.
28 May 2014	Annual project update and environmental discussion meeting.	North Central Malleefowl Preservation Group; Bush Heritage Australia;	DPaW asked if IH will be included in MCP.	The current MCP does not include IH because it is not yet approved. The MCP will	Acceptable

Date	Description of Consultation	Stakeholders	Stakeholders Comments / Issues	Proponent Response and / or Resolution	Stakeholder Response
	Discussed current estimated LOM, implications of Iron Hill (IH) exploration on mine closure. MCP discussed in detail.	Australian Wildlife Conservancy; Extension Hill Pty Ltd; Shire of Dalwallinu; Department of Parks and Wildlife		be periodically reviewed and updated so it may be included at a future stage or may have a separate MCP.	
	Displayed and discussed each of MGM's proposed closure objectives generally and proposed post mining land use. Discussions will be held with individual stakeholders as to which of the pre-existing tracks they require to remain open.		BHA asked when rehabilitation will start and what areas will actually be rehabilitated.	Rehabilitation has already commenced in some areas, such as borrow pits that are no longer required. The current intent is to commence rehabilitation of the waste dump towards the end of 2015 if there is no firm indication of magnetite mining commencing by then. Displayed and discussed each domain and the associated closure objectives, design criteria and activities, as per the MCP.	Acceptable
	Discussion of DMP Mine Rehabilitation Fund (MRF).		DPaW asked if companies get back any of the MRF contributions if they pay for their own rehabilitation (MRF).	We do not.	Acceptable
			Shire of Dalwallinu asked if the pit will become hyper-saline when it fills with water.	Hematite mining will not go below the groundwater table so only rainwater will be in pit. Discussion on magnetite project .	Acceptable

Date	Description of Consultation	Stakeholders	Stakeholders Comments / Issues	Proponent Response and / or Resolution	Stakeholder Response
			Query raised regarding back filling the pit.	MGM will not back fill the pit as this is not financially viable and would bury the magnetite resource. The final landform will be the open pit with abandonment bunding and the rehabilitated waste dump. The ROM pad is also likely to be rehabilitated *in situ*.	Acceptable
3 Jun 2014	Meeting to discuss closure and environmental issues – went through the presentation from the 28 Jun 2014 meeting.	Pindiddy Aboriginal Corporation	Query raised regarding the number of *Darwinia masonii* that will be left after mining, particularly if IH progresses.	The IH project (if approved) will impact on another population of *Darwinia masonii* (referred to consultation letter sent previously for details). MGM has obligations under the Ministerial Statement to translocate this plant into undisturbed areas of the Mt Gibson ranges and MGM intends to attempt to re-establish it on the rehabilitated waste rock dump.	Acceptable
8 Aug 2014	Mine Closure Plan submitted for review	Department of Mines and Petroleum	Letter received 8 Dec 2014.	Comments currently being addressed.	N/A
2 Oct 2014	Telephone discussion regarding Mine Closure Plan submission	Office of Environmental Protection Authority	Requested clarification on due date for final MCP as required under Ministerial Statement 753 which assessed the combined hematite and magnetite project.	The hematite and magnetite components can be treated separately. The hematite MCP should be submitted to EPA with DMP approval letter attached.	Acceptable

Date	Description of Consultation	Stakeholders	Stakeholders Comments / Issues	Proponent Response and / or Resolution	Stakeholder Response
17 Nov 2014	Biannual meeting to review the project funded DPaW officer's role.	Extension Hill Pty Ltd; Department of Parks and Wildlife	DPaW queried the term 'life of mine' as it relates to their funding.	EHPL advised that legal advice will be sought regarding status of the funding obligation upon cessation of hematite mining in the event that magnetite mining is yet to progress.	No response yet - pending legal advice from proponents.
10 Dec 2014	Perenjori Public Benefits Committee Meeting	Shire of Perenjori; Perenjori community representative; Sinosteel Midwest Corporation Limited	Comment that the funding for the period does not all need to be spent as this will extend the life of the program beyond mine closure.	Agreed with the comment. The money that remains in the account at mine closure will enable additional funding periods.	Acceptable
10 Apr 2015	*Biannual Badimia Monitoring and Liaison Committee meeting*	*Badimia representatives; Extension Hill Pty Ltd; Yamatji Marlpa Aboriginal Corporation*	*No closure related issues were raised.*	*N/A*	*N/A*
26 May 2015	*Project update and environmental discussion meeting. Stakeholders were issued with a copy of the Mine Closure Plan prior to the scheduled meeting to enable them to prepare comments/queries.*	*Shire of Perenjori; Shire of Yalgoo; Shire of Dalwallinu; Australian Wildlife Conservancy; Bush Heritage Australia; Pindiddy Aboriginal Corporation; Extension Hill Pty Ltd; North Central Malleefowl Preservation Group; Department of Parks and Wildlife; Department of Mines and Petroleum*	*Query about including the proposed Iron Hill Project in the Mine Closure Plan.* *Is there scope to include local school children in rehabilitation activities?* *Will seed be sourced from the site?*	*Iron Hill will be either included in the current MCP or addressed in a separate one once the proposed Project as part of the approvals process.* *Unlikely due to safety concerns during ongoing mining operations but may be considered in future if there are interested school groups in the area.* *There is seed available from the site but alternative supplementary sources are being investigated – this is*	

Date	Description of Consultation	Stakeholders	Stakeholders Comments / Issues	Proponent Response and / or Resolution	Stakeholder Response
				dependent upon a response from Dept of Parks and Wildlife to our query regarding 'local provenance' definition.	
			How will it be determined which access tracks remain open if landholders disagree?	*A decision will be made in consultation with all relevant stakeholders and may take into account justification for retaining the access and the historical status, ie did the track exist prior to the operation commencing.*	
			Further information relating to the fauna survey, seed stocks, vegetation monitoring, access to data and rehabilitation techniques was requested by AWC prior to the meeting.	*These queries were addressed and the relevant information supplied. Minor updated clarifications were made in the rev 3 of the Mine Closure Plan.*	*The stakeholder advised at the meeting that their queries had been addressed satisfactorily.*

Date	Description of Consultation	Stakeholders	Stakeholders Comments / Issues	Proponent Response and / or Resolution	Stakeholder Response
24 Jul 2015	*Telephone communications*	*Extension Hill Pty Ltd*	*The current production and monitoring groundwater bores are to be retained post hematite operation closure. The existing groundwater licence does not expire until 2023 and the Dept of Water approved Operating Strategy for these bores includes the magnetite operation so anticipates the retention of the bores.*	*Proponent will send a request for this to be confirmed in writing.*	*Agreed,*

Table 16 Future Stakeholder Consultation Program

Date	Description of Consultation	Stakeholders	Specific Issues to be Addressed
Oct 2015	Community meetings – Shire of Perenjori, Shire of Yalgoo and Shire of Dalwallinu	General communities of the Shires of Perenjori, Yalgoo and Dalwallinu	Post mining land use. Closure exit strategy.
Sept 2015	*Letter correspondence* *Site visit, if required*	Extension Hill Pty Ltd; Pindiddy Aboriginal Corporation; Australian Wildlife Conservancy	Post hematite mining land use – areas EHPL and landowners may require in future, ie access roads, water bores.
Oct 2015	*Letter correspondence* *Site visit, if required*	Department of Parks and Wildlife; Environmental Protection Authority; Department of Mines and Petroleum	Water bores, access tracks that may be required post hematite mining.
Nov 2015	Site tours	General communities of the Shires of Perenjori, Yalgoo and Dalwallinu	Site tour and discussion on post mining land use and aesthetics following mining.

Date	Description of Consultation	Stakeholders	Specific Issues to be Addressed
Oct 2015	Biannual Badimia Monitoring and Liaison Committee meeting	Badimia representatives; Extension Hill Pty Ltd; Yamatji Marlpa Aboriginal Corporation	Project update. Post mining land use. Closure exit strategy.
Nov 2015	Annual general meeting	Gunduwa Regional Conservation Association	Withdrawal of MGM funding and MGM's role within the association post closure.
Nov 2015	Meeting	North Central Malleefowl Preservation Group	Malleefowl monitoring post mining.
Apr 2016	Biannual Badimia Monitoring and Liaison Committee meeting	Badimia representatives; Extension Hill Pty Ltd; Yamatji Marlpa Aboriginal Corporation	Project update. Post mining land use. Closure exit strategy.
May 2016	Project update and environmental discussion meeting.	Shire of Perenjori; Shire of Yalgoo; Shire of Dalwallinu; Australian Wildlife Conservancy; Bush Heritage Australia; Pindiddy Aboriginal Corporation; Extension Hill Pty Ltd; North Central Malleefowl Preservation Group; Department of Parks and Wildlife; Department of Mines and Petroleum	Project update. Mine closure planning generally and any issues raised by stakeholders. Progressive rehabilitation progress.
Oct 2016	Biannual Badimia Monitoring and Liaison Committee meeting	Badimia representatives; Extension Hill Pty Ltd; Yamatji Marlpa Aboriginal Corporation	Project update. Post mining land use. Closure exit strategy.
Jan 2017	Revision and resubmission of Mine Closure Plan	Department of Mines and Petroleum; Office of Environmental Protection Authority	Mine Closure Plan
Apr 2017	Biannual Badimia Monitoring and Liaison Committee meeting	Badimia representatives; Extension Hill Pty Ltd; Yamatji Marlpa Aboriginal Corporation	Project update. Mine closure progress.

Date	Description of Consultation	Stakeholders	Specific Issues to be Addressed
May 2017	Project update and environmental discussion meeting.	Shire of Perenjori; Shire of Yalgoo; Shire of Dalwallinu; Australian Wildlife Conservancy; Bush Heritage Australia; Pindiddy Aboriginal Corporation; Extension Hill Pty Ltd; North Central Malleefowl Preservation Group; Department of Parks and Wildlife; Department of Mines and Petroleum	Project update. Mine closure progress and any issues raised by stakeholders.

6. Post-Mining Land Use and Closure Objectives

6.1 Post Mining Land Use

At this stage it is considered that the most likely fate of the Project footprint is that it will become part of the larger footprint that will be disturbed when the underlying magnetite orebody is mined. However, MGM accept that appropriate closure planning should account for the possibility that the magnetite mine may not proceed in the Hematite mine's timeframe and so this section of the MCP is structured around this 'non-magnetite mining scenario'.

6.1.1 Mine Site

The following post mining land use hierarchy is taken from the Department of Mines and Petroleum (DMP) and Environmental Protection Authority (EPA) *Guidelines for Preparing Mine Closure Plans* (2011):

1. Reinstate "natural" ecosystems as similar as possible to the original ecosystem.
2. Develop an alternative land use with higher beneficial uses than the pre-mining land use.
3. Reinstate the pre-mining land use.
4. Develop an alternative land use with other beneficial uses than the pre-mining land use.

In this case the pre-mining land use, particularly on the areas of land owned by the Australian Wildlife Conservancy, Bush Heritage Australia and the Pindiddy Aboriginal Corporation, was to 'Reinstate "natural" ecosystems as similar as possible to the original ecosystem'. Thus items 1 and 3 of the post mining land use hierarchy achieve the same objective.

MGM aims to re-establish a stable, productive land surface that requires minimal ongoing maintenance and management. As such, the current proposed post mining land use is to reinstate "natural" ecosystems as similar as practicable to the original ecosystem. Discussions with key stakeholders will be continued throughout the life of the Project and the final post mining land use may include some aspects of item 2 in the post mining land use hierarchy (development of an alternative land use with higher beneficial uses) where opportunities are identified and would be beneficial to the environment and/or community. This is based on the assumption, at this time, that magnetite mining does not commence.

Direct stakeholders, including the underlying landowners, tenement holders and regulators will be consulted to determine which mine roads and tracks are to be left open following closure as the area had numerous pre-existing tracks which enabled local landowners and the Department of Environment and Conservation (now the Department of Parks and Wildlife) access to conduct flora and fauna surveys.

Located within a prominent wildflower area, the potential for tourism at the site will also be considered and discussed with the local Shires and neighbours. This may involve retaining some additional mine roads. Management and maintenance of areas left open at the request of stakeholders will become the responsibility of those stakeholders.

In the event that magnetite mining does progress, MGM would aim to rehabilitate infrastructure areas not required by the magnetite project to the above-mentioned post mining land use. The waste dump and mine pit however would be incorporated into the greater magnetite development footprint and any remaining rehabilitation materials will be handed over to the magnetite proponent for use and future rehabilitation as part of the handover of the areas of responsibility.

6.1.2 Rail Siding

The Shire of Perenjori has expressed an interest in taking over the Perenjori rail siding when MGM ceases hematite mining and transport operations. Appendix E contains a letter from the Shire of Perenjori to this effect. This request will be taken into account when determining the final land use for the rail siding.

6.2 Closure Objectives

The EPA's objective for decommissioning and closure is:

'*To ensure, as far as practicable, that rehabilitation achieves a stable and functioning landform which is consistent with the surrounding landscape and other environmental values.*'

In line with this objective, MGM objectives for closure are as follows:

- To seek compliance with all legally binding commitments and obligations, relating to mine closure;
- To ensure stakeholders interests to be considered during the mine closure process;
- To achieve the agreed set of completion criteria to the satisfaction of the responsible authorities;
- To establish a safe and stable post mining land surface;
- To minimise downstream effects on vegetation due to interruption of drainage;
- To continue to monitor environmental performance during decommissioning, rehabilitation and post closure stages of the project and take appropriate action until the approved completion criteria have been met;
- To re-establish vegetation that provides a self-generating ecosystem comprising local native vegetation which resembles the surrounding environment as closely as practical;
- To leave the site in a safe, stable, non-polluting and tidy condition with no remaining plant or infrastructure that is not required for post operational use or agreed use by other stakeholders; and
- To identify any potential soil, surface water or groundwater pollution associated with the operations and formulate an action plan to address this.

MGM aims to achieve these objectives through the implementation of the site Environmental Management System throughout the Project life and, as appropriate, until the completion criteria are met or the Project is handed over to the magnetite project.

7. Identification and Management of Closure Issues

7.1 Risk Management Process

MGM employ a risk based approach to identifying and assessing potential issues and appropriate management strategies. MGM have developed a risk management procedure with reference to AS/NZ ISO 31000:2009 Risk Management which provides the processes and tools for the management of risks that, if left untreated, would have the potential to cause harm to individuals or otherwise impact upon the success of the operation. This includes the environmental risks associated with the mine closure process.

It is the intent of MGM to manage risks to meet or exceed the standard required by relevant specific regulations, standards or industry code of practice. Where no applicable such regulations or standards exist, the management actions will be aimed at eliminating or reducing the risk to as low as reasonably practicable.

The introductory sections of this document establish the context for this risk assessment (Sections 1, 2 and 4). Specific closure related risks are identified and discussed in Section 7.2 and are evaluated in Table 20. Management actions required to address the identified risks are also included in Table 20. The risks are evaluated according to the maximum reasonable consequence (Table 17) and likelihood (Table 18) for the risk with the nominated management controls in place to determine the residual risk level (Table 19).

Table 17 Maximum Reasonable Consequence

Level	Cost to Business	Health & Safety	Environmental	Community & Reputation	Operational	Legal Compliance
1	**Insignificant Up to $10k**	First Aid Injury Nuisance Value	No or very low environmental impact. Impact confined to a land area of <10m² or involves a hydrocarbon spill of <80L or <legal reporting limit.	Isolated complaint. No media inquiry	Loss equivalent to one hour of production interruption	Low level legal issue.
2	**Minor $10k - $1m**	Medical Treatment Injury Restricted Work Injury	Low environmental impact. Rapid clean-up by site staff and/or contractors. Impact contained to area currently impacted by operations e.g. Hydrocarbon spill >80L and <1000L.	Small numbers of sporadic complaints. Local media inquiries	Loss equivalent of up to one day of production interruption	Minor legal issue, non-compliances and breaches of regulations
3	**Moderate $1m - $10m**	Single Lost time Injury	Moderate environmental impact. clean-up by site staff and/or contractors. Impact confined within lease boundary. E.g. exceeds a license or Ministerial condition or death of a protected species caused by mining such as the Northern Quoll or Mallee fowl. Long term land or marine impact. Potential <$500k fine	Serious rate of complaints, repeated complaints from the same area (clustering) Increased Local media interest.	Loss equivalent of greater than one day and less than fourteen days of production interruption	Breach of regulation with possible prosecution and moderate penalties.
4	**Major $10m - $50m**	Multiple lost time injuries. Admission to intensive care unit or similar. Serious chronic long term effects. Permanent disability	Major environmental impact. Considerable clean-up effort required using site and external resources. Impact may extend beyond the lease boundary. Site shut down by Environmental regulators. Potential >$500k fine	Increasing rate of complaints, repeated complaints from the same area (clustering) Increased national/Local media interest.	Loss equivalent of greater than fourteen days and less than two months of production interruption...	Breach of regulation resulting in investigation by regulator. Prosecution, major penalties or other action likely, suspended operations. Potentially serious litigation
5	**Catastrophic Over $50m**	Fatality (s)	Severe environmental impact. Local species destruction and likely long recovery period. Extensive clean-up involving external resources. Impact on a regional scale.	High level of concern or interest from local community. National and/or international media interest.	Loss equivalent to more than two months of production interruption	Potential jail terms for executives, high fines, multiple litigation action

Table 18 Consquence and Likelihood Matrix

		What would the Consequence of an occurrence be?				
		1	2	3	4	5
Likelihood		Insignificant	Minor	Moderate	Major	Catastrophic
	Almost Certain: to happen. (Expected to happen in most circumstances, e.g. once per week)					
	Likely: To happen at some point. (Will probably occur in most circumstances. E.g. once per month)					
	Possible: heard of it so it might happen. (Should occur at some time, e.g. once per year.)					
	Unlikely: Not likely to happen. (Could occur at some time e.g. once per ten years.)					
	Rare: Practically impossible. (e.g. greater than thirty years.)					

Table 19 Risk Levels

Risk Level	Priority	Example Risk Response Action
Extreme	1	Detailed research and planning required; determine whether activity or task should be stopped pending further investigation
Significant	2	Senior management attention; immediate corrective and preventative action required
Moderate	3	Management responsibility assigned; corrective and preventative action plan developed
Low	4	Manage by routine procedures; accept risk

7.2 Identification of Closure Specific Risk Sources

This document focuses on the environmental risks that relate solely to mine closure activities. There are a number of environmental risks that were identified as part of operational mining activities, which will remain risks during closure activities, such as vehicle movements and hydrocarbon spills. These are adequately addressed within the existing environmental management system and are not repeated in this document.

DMP and OEPA (2011) have identified common closure specific sources of risk which are discussed below. During a risk review workshop in April 2014, environmental and mining personnel from both MGM and EHPL identified additional closure specific sources of risk which are also discussed below.

7.2.1 Acid Mine Drainage

'The waste material to be mined in the hematite pit has been geochemically characterised by Graeme Campbell & Associates (2005) as benign.

The waste material to be mined consists primarily of weathered BIF, clay, chert and basalt, all of which are classified as non acid-forming. Geochemical test work indicates there is no potentially acid forming (PAF) material within the hematite pit profile.' (MGM, 2010).

Acid mine drainage is therefore considered a low risk for this site. In the event that PAF is discovered, it will be encapsulated in a suitably designed cell within the waste dump to minimise the potential for leaching into groundwater or surface water bodies.

7.2.2 Mine Pit Lakes

The hematite pit does not extend below the natural groundwater level. The evaporation rate exceeds the annual rainfall rate (as evidenced by the site sewage evaporation pond records and supported by data from the Shire of Yalgoo and Paynes Find (Wilshaw, 2008)), there will be no permanent water body in the mine pit. There may be some water pooling after significant rainfall events, however this will be intermittent and will occur at times when there is also natural water pooling in the surrounding environment so will not result in an artificially inflated population of grazing animals. This is not considered a significant risk for this project and requires no additional management.

7.2.3 Dispersive Materials

Landloch (2012) confirmed the conclusion of Roger Townend & Associates (2005) that there is little to no clay present in the waste material on site. Landloch (2012) concluded that ‘the soils and wastes can be considered generally not prone to dispersion’ and ‘not prone to tunnel erosion’.

The clay that was present was mostly the kaolinite types which do not shrink and swell when dried and wetted (Landloch, 2012). They surface seal readily but are erodible. Erosion is discussed further in Section 7.2.5. Dispersive and clay materials are not considered a significant risk for this project and require no additional management.

7.2.4 Fibrous Materials

Although some fibrous materials records were identified during exploration drilling programs, these were located at depths beyond the extent of the hematite mine pit. There are no fibrous materials within the waste material for this project. This is considered a potential risk for the project due to the presence of fibrous materials in the deeper samples. In the event that fibrous materials are encountered a fibrous material management plan will be drafted and implemented to ensure safe handling of the material and appropriate encapsulation within a suitably designed cell in the waste dump.

7.2.5 Stability of the Landform

MGM engaged external consultants in 2012 to conduct an assessment of the waste material and assist in landform design to provide a stable waste rock dump.

There was little to no clay present in most samples taken from the site, however the clay that is present is of an erodible type. There were insufficient quantities present for this to pose a significant risk, providing *appropriate management is undertaken*.

Landloch (2012) assessed the rocky waste material and found it to have high density and low water absorption values, making it highly suitable for rock armouring erodible surfaces. *Landloch (2012) recommending rock armouring the waste dump batters to reduce erosion potential. Rocky waste material will be preferentially placed on the outer slopes of the waste dump, where practicable and will be mixed with topsoil during contour ripping of the final batter.*

Poor rehabilitation resulting in erosion and compromising the stability of the landform remains a key closure risk. Management strategies are discussed further in Section 7.3.

7.2.6 Revegetation

Successful re-establishment of vegetation on the waste dump is important to create a habitat suitable for future flora and fauna colonisation. Factors that may affect this are the stability of the landform (discussed in Section 7.2.5), surface nutrient availability and growth media quality.

Landloch (2012) acknowledge that the material generally has low soil fertility but topsoil and growth media handling and stockpiling may further degrade the material, beyond the already low natural nutrient levels. Fertiliser addition may be required to address this.

Re-establishment of the vegetation communities that persisted on Extension Hill prior to mining will be targeted during rehabilitation, however it is evident from vegetation mapping and fire history data of the site that a broad impact such as direct clearing or fire may result in pioneer species and different communities establishing. It may take a significant amount of time for these original communities to re-establish.

Grazing by both native and non native fauna species may potentially affect rehabilitation success, with kangaroos and rabbits being the most commonly sighted grazers on site.

Management actions to address the risks associated with revegetation success are included in Section 7.3.

7.2.7 Public Access

The site is located in close proximity to and is partially visible from the Great Northern Highway. Public access to the site must restrict inadvertent access to the mine pit.

7.3 Management of Closure Issues

The management actions required to address the risks identified in Section 7.2 are identified in Table 20. Evaluation of the residual risks shows that the three key sources of risk are landform instability, failure of flora and fauna re-establishment and public access to the site.

The key management actions to address these risks are detailed in Table 20, with further supporting information contained within the identified Site Work Instructions (SWIs). The current version of the SWIs referred to in Table 20 are included in Appendix F, however it is noted that these are live documents which are regularly reviewed and updated as part of the continuous improvement process.

Table 20 Management of Closure Issues

Risk Source	Hazard	Management Actions	L	C	Risk Level
Acid mine drainage from the mine pit or waste dump enters the surrounding environment	Surface and groundwater contamination Soil contamination Flora and fauna mortalities	In the event that PAF material is identified it will be encapsulated in a suitably designed cell within the waste dump	R	2	Low
Formation of mine pit lakes	Freshwater lakes sustain an inflated population of introduced fauna species Saline lakes contaminant surface and groundwater	Nil required	R	2	Low
Presence of dispersive materials in waste	Tunnel erosion causing landform failure	Rock armouring *and/or contour ripping* of the landform batters (Rehabilitation Management Site Work Instruction)	R	2	Low
Presence of fibrous materials in waste	Human and fauna health concerns	In the event that fibrous materials are encountered a fibrous material management plan will be drafted and implemented to ensure safe handling of the material and appropriate encapsulation within a suitably designed cell in the waste dump.	U	2	Low
Landform instability	Erosion of material into the surrounding environment Failure of the landform	Slope batter angle 18^0 Rock armouring and*/or* contour ripping of batter slopes *Water retention on the landform surface through*	U	3	Mod

	structure Compromised revegetation success	*bunding and compartmentalisation.* Refer to Rehabilitation Management SWI			
Insufficient native flora and fauna re-establishment	Insufficient soil nutrient and seed loads Weed species outcompeting native species Grazing by herbivores (native or non native)	Fertilisation and seeding of rehabilitation areas, as required (Rehabilitation Management SWI) Regular monitoring to identify and eradicate weeds in and around rehabilitated areas (Weed Management SWI) Assessment of grazing impacts during rehabilitation monitoring inspections and fencing/baiting programs, as appropriate	P	2	Mod
Public Access	Inadvertent public access to the open mine pit resulting in injury	Abandonment bunds around the open mine pit (Rehabilitation Management SWI) Appropriate fencing and signage at main site access points	U	3	Mod

8. Development of Completion Criteria

Completion criteria have been developed for the Project in accordance with the ANZMEC (2000) guidelines that state that completion criteria should:

- Be specific enough to reflect unique set of environmental, social and economic circumstances;
- Be flexible enough to adapt to changing circumstances without compromising objectives;
- Include environmental indicators suitable for demonstrating that rehabilitation trends are heading in the right direction;
- Undergo periodic review resulting in modification, if required, due to changed circumstances or improved knowledge; and
- Based on targeted research which results in more informed decisions.

These preliminary completion criteria have been cross referenced to the appropriate closure objectives (Table 21). Completion criteria may be further refined in consultation with the relevant stakeholders prior to the completion of operational mining.

Table 21 Completion Criteria

Aspect	Closure Objective	Completion Criteria	Measurement Tools
Compliance	To seek compliance with all legally binding commitments and obligations on MGM, relating to mine closure	Compliance with identified legal obligations, as per Table 2, Table 3 and Table 4.	Audit against legal obligations (Table 2, Table 3 and Table 4) conducted by an internal or external auditor as required
Community	To enable stakeholders interests to be considered during the mine closure process	All relevant stakeholders have been consulted and any concerns raised have been formally addressed.	Site complaints register Records of consultations as per Table 16
Compliance	To achieve the agreed set of completion criteria to the satisfaction of the responsible authorities	Compliance with completion criteria.	Audit against completion criteria (Table 21) conducted by an internal or external auditor as required
Landforms	To establish a safe and stable post mining land surface	The waste dump has been contoured to be water shedding, spread with top soil, ripped and geotechnically stable. Pit perimeter resembles topography of surrounding environment. Abandonment	Rehabilitation records Abandonment bunds around the open pit has been constructed

Aspect	Closure Objective	Completion Criteria	Measurement Tools
		bunding surrounding open pit in accordance with DMP Guidelines, *Safety Bund Walls for Abandoned Open Pit Mines* (DMP, 1997). The final rehabilitated landform: • has been ripped, and contoured to resemble the surrounding landscape • has been contoured to allow natural drainage patterns to be re-established • is stable and non-erosive	in accordance with the DMP Guidelines Rehabilitation records Visual monitoring/ Inspections of landform stability during the post closure monitoring and maintenance period
Surface Water, Vegetation	To minimise downstream effects on vegetation due to interruption of drainage	Drainage re-established to areas dependent on overland flow.	Drainage plans implemented
Monitoring	To continue to monitor environmental performance during decommissioning, rehabilitation and post closure stages of the project	Monitoring results are included in an annual environmental report to regulators.	Monitoring of environmental aspects as listed in Table 36.
Vegetation	To re-establish vegetation that provides a self generating ecosystem comprising local native vegetation which resembles the surrounding environment as closely as practical	Revegetated areas are well established and represent a self sustaining vegetation community (based on at least two seasons of seed production) and are similar to the surrounding environment in terms of flora (based on >60% control site biodiversity (EPA, 2006), >60% stems per hectare and <10% weed cover).	Annual quantitative survey of vegetation (including species and stem count comparisons) in designated monitoring plots in rehabilitated areas in comparison to local control site for up to 5 years
Pollution, Waste	To leave the site in a safe, stable, non-polluting and tidy condition with no remaining plant or infrastructure that is not required for post operational use or agreed use by other stakeholders	All processing and supporting infrastructure has been dismantled and removed from site and disposed of appropriately unless approved agreements are in place for retention. All buildings and ancillary infrastructure has been removed from site and the	Record of agreements for handover of any remaining infrastructure Record of agreements for handover of any remaining

Aspect	Closure Objective	Completion Criteria	Measurement Tools
		surface ripped on the contour to relieve compaction unless approved agreements are in place for retention. All production and monitoring bores will be left in place for use by EHPL in ongoing monitoring. All pipelines and pumps have been flushed and removed from site (above ground) or left buried (below ground) unless approved agreements are in place for retention. All bulk hydrocarbon storage tanks have been emptied and removed. All haul roads and tracks have been rehabilitated with natural drainage lines re-established except where approved agreements are in place for retention.	infrastructure Record of agreement for retaining bores Record of agreements for any remaining pipelines Decommissioning records Record of agreements for any remaining roads and tracks
Contamination	To identify any potential soil, surface water or groundwater pollution associated with the operations and formulate an action plan to address this	All sites contaminated with hydrocarbons or chemicals have been remediated with levels of contaminants in soil, ground or surface water in accordance with the DEC Guideline 2003 *Assessment Levels for Soil, Sediment and Water*.	Visual assessment of high risk disturbance areas during decommissioning and closure activities. Soils (and surface water and groundwater, if required) analysis using accredited laboratory analysis and field measurements.

9. Financial Provisioning for Closure

9.1 Current Provisioning

MGM currently have an established corporate procedure in place to provide for decommissioning and rehabilitation of its mining operations, which is in line with International Financial Reporting Standards (IFRS).

9.1.1 Method

Closure cost calculations were generated by an external consultant in February 2013 following review of relevant documentation and a site inspection. The closure cost summary is shown in Table 22. This estimate was calculated in accordance with the Australian Accounting Standard 137 (AASB 137) and therefore does not recognise the potential salvage value of equipment. These costs will be regularly reviewed by mine site management in consultation with MGM's financial department.

Table 22 Summary of Estimated Closure Costs (adapted from Golder Associates 2013)

Item	**Cost (AUD $)**
Demolition (Table 23)	391,100
Rehabilitation – Mining Landforms (Table 24)	640,200
Rehabilitation – Other Areas (Table 25)	701,200
Other Closure Costs (inc pit bunding) (Table 26)	270,000
Post Closure Monitoring and MRF (Table 27)	*1,311,800*
Magnetite Components (Table 28 Closure Cost Estimate - Existing Magnetite Components)	100,000
Contingency (10%)	*341,430*
Total	***3,755,730***

'Demolition' includes the costs associated with the decommissioning, demolition and disposal of all plant and other infrastructure, either by removal from site or *in situ* burial as appropriate, such that no equipment or built facilities remain from any closure domain. Table 23 provides a breakdown of these costs. Note that the cost of decommissioning the water bores (estimated at $44,400) has been removed as EHPL have indicated that they require these to remain accessible.

Table 23 Decommissioning and Demolition Costs (adapted from Golder Associates 2013)

Closure Domain	**Item**	**Cost (AUD $)**
N/A	Mobilisation	32,000
Crushing and Screening Plant, Offices,	Disconnection of site services	5,000

Closure Domain	Item	Cost (AUD $)
Workshops and other Infrastructure; Bulk Hydrocarbon Storage; Accommodation Village and Sewage Facilities; Water Supply Bores and Pipes		
Crushing and Screening Plant, Offices, Workshops and other Infrastructure	Crushing, screening, stackers and load out facility	71,600
	Crushing and screening circuit concrete	10,900
	Heavy vehicle and main workshop	26,500
	Tyre bay and used tyres	9,600
	Workshop areas concrete	11,360
	Main stores area	22,350
	Stores area concrete	1,850
	Light poles	4,300
	Spectrolabs workshop	1,650
	Turkeys' nest	10,750
	Weighbridge facility	12,700
	Main administration buildings	28,650
	Security gate house	4,800
Bulk Hydrocarbon Storage	Fuel farm	6,300
	Fuel farm area concrete	10,800
Explosives Magazine and ANFO Storage Yard	Explosives compound	6,500
	Dyno depot	2,150
Haul Roads and Access Tracks	Demolish old Great Northern Highway	56,100
Accommodation Village and Sewage Facilities	Camp site accommodation	18,050
	Camp site concrete	5,500
	Camp site evaporation pond	8,600
N/A	Demobilisation	32,000
	Total	**391,100**

'Rehabilitation – Mine' includes the costs associated with earthworks (battering, rock/topsoil placement, contour ripping and bunding), seeding and fertilisation of the waste dump, mineralised waste and ROM pad. These calculations were based on hourly operational costs for equipment, operators and seeding costs used in recent rehabilitation at MGM's nearby Tallering Peak site, published equipment performance data from the equipment suppliers and verbal quotations for fertiliser. Golders Associates (2013) assumed that crushing and screening would be required to achieve the rock cover recommendations of Landloch (2012), however it has been demonstrated that the desirable rock cover requirements can be met without this processing (Landloch 2014) so these costs have been removed. Table 24 identifies the costs attributed to each landform.

Table 24 Rehabilitation of Mining Landforms (adapted from Golder Associates 2013)

Activity	Waste Dump ($)	Mineralised Waste ($)	ROM ($)
Batters			
Batter down	148,900	78,500	2,700
Rock cover placement	86,300	54,300	3,000
Topsoil placement	21,600	13,600	15,400
Contour ripping	20,800	13,000	1,500
Upper Surface			
Bund	33,800	17,800	3,300
Topsoil placement	25,800	7,900	4,800
Deep ripping	12,400	3,800	200
All surfaces			
Seeding	40,000	20,300	2,000
Fertiliser	4,900	2,500	1,100
Total	**394,500**	**211,700**	**34,000**

'Rehabilitation – Other Areas' includes the costs associated with ripping/scarification or capping (as required), topsoil placement and seeding of all other disturbed areas of the site, including haul roads, laydown areas, accommodation camp, pipeline corridors and the evaporation pond.

Table 25 Other Operational Areas Rehabilitation Cost Estimates (Golder Associates 2013)

Treatments	Activity	Cost ($)
24 ha of deep ripping, topsoil placement and seeding	Topsoil	18,400
	Ripping	21,860
	Fertiliser	2,160
	Seeding	26,400
Sub-total		**68,900**
52 ha of scarification by grader, topsoil placement and seeding	Topsoil	40,040
	Scarification	2,400
	Fertiliser	4,680
	Seeding	57,200
Sub-total		**104,320**
21 ha of scarification and seeding only	Scarification	970
	Fertiliser	1,890
	Seeding	23,100

Sub-total		**25,960**
1 ha of engineered cap, topsoil, scarification and seeding	Capping	500,000
	Topsoil	770
	Scarification	50
	Fertiliser	90
	Seeding	1,100
Sub-total		**502,010**
TOTAL		**701,190**

'Other Closure Costs' includes the installation of a safety abandonment bund around the pit, pursuant to the DMP's *Safety bund walls around abandoned open pit mines* and assessment of any potentially contaminated land in accordance with the requirements of the *Contaminated Lands Act 2003*. Further information is included in Table 26.

Table 26 Other Closure Cost Estimates (Golder Associates 2013)

Item	Description	Cost ($)
Pit abandonment safety bund	3300m @ $40/m	132,000
Initial contaminated land survey	Identify potential contaminated sites, report and prepare follow up work (if required)	38,000
Contaminated land detailed survey	Test samples and determine extent of contamination	100,000
Total		**270,000**

'Post Closure Monitoring' includes provisions for monitoring of weeds, declared rare flora, malleefowl and dust. It also includes inspections of the rehabilitation and a provision for erosion repairs and the Mine Rehabilitation Fund Levy.

Table 27 Post Closure Monitoring and Adaptive Management (adapted from Golder Associates 2013)

Activity	Per Annum ($)	Total ($)
Weed survey	15,000	75,000
Declared rare flora monitoring	*30,000*	*150,000*
Malleefowl mound monitoring	*25,000*	*125,000*
Dust monitoring	15,500	77,500
Rehabilitation inspections	7,000	35,000
Erosion repair (nominal)	100,000	500,000
Contingency (excluding MRF levy) – 15%	32,400	162,000
MRF Levy	37,460*	187,300
Total	***262,360***	***1,311,800***

*Actual cost from 2014 MRF return

Table 28 Closure Cost Estimate - Existing Magnetite Components

Item	Description	Cost ($)
Exploration Village	Removal of all infrastructure including fencing and sprayfield and site rehabilitation including release of some buildings to Badimia traditional owners	75,000
Magnetite Stockpile	Removal of ore to waste dump (major component), deep ripping, return of topsoil and seeding.	25,000

9.2 Reduction of Liability

MGM is actively reducing long term liability by taking a progressive approach to managing site decommissioning and rehabilitation issues.

This approach includes, but is not limited to:

- Management of environmental risk as part of day to day business;
- Progressive rehabilitation as areas become available; and
- Progressive decommissioning of old or disused infrastructure associated with the mine operation.

MGM will also be undertaking ongoing research and investigations to identify the most appropriate methods for closure of the operations.

9.3 Bond and Lease Relinquishment

9.3.1 Bond

In addition to the internal provision, MGM will also maintain an environmental performance bond on the leases granted by the DMP in accordance with the requirements of the *Mining Act 1978* or pay the agreed Mine Rehabilitation Fund amounts.

Mine sites containing significant infrastructure previously required an unconditional performance bond (UPB). There is currently a shift from UPBs to annual payments of agreed Mine Rehabilitation Fund contributions, pursuant to the *Mining Rehabilitation Fund Act 2012*. Both systems rely on calculations of the rehabilitation liability based on site specific disturbance data.

9.3.2 Bond and Lease Relinquishment

MGM and EHPL have registered for the Mine Rehabilitation Fund (MRF) and will continue to focus on liability reduction through ongoing rehabilitation of areas as they become available. As a result, DMP have relinquished the UPBs for the MGM held tenements at the rail siding and it is anticipated that the remaining UPBs over the EHPL held mine site tenements will also be released.

MGM will work with the DMP to ensure the parties are satisfied that the rehabilitated area is safe, stable, and that the agreed completion criteria are met.

10. Closure Implementation

10.1 Progressive Rehabilitation

MGM aim to minimise the potential impacts associated with vegetation clearing, earthworks and disturbed areas by implementing a rehabilitation program. Where possible, rehabilitation is undertaken on a progressive basis throughout the life of the Project, in accordance with the Rehabilitation Management SWI and in view of the following long-term closure objective:

- To re-establish a stable productive land surface that requires minimal ongoing maintenance and management.

MGM will aim to achieve this objective by undertaking the re-vegetation of disturbed areas with a self-sustaining system of native species. These species will be similar (>60%) in diversity and density (stems per hectare) to pre-mined conditions.

Management practices and commitments outlined in the Rehabilitation Management Procedure include:

- Topsoil will be respread and the surface profile deep ripped along the contour to reduce the erosion potential and promote water capture and infiltration;
- Revegetation will be undertaken using direct seeding methods of local species where required;
- Where practicable, fauna refuges and habitat areas will be created in rehabilitated areas using logs and other vegetative debris; and
- Areas of disturbance to be rehabilitated will be surveyed and the size and location recorded on a site plan for future monitoring.

10.2 Closure Task Register

For the purposes of closure planning, the Project has been divided into specific closure domains. These domains and their respective closure activities are discussed in further detail in this section and are summarised in Table 29. A closure task register has been included which summarises specific closure activities required for each domain (Table 29). Scheduling for closure activities is discussed in Section 10.3. The domain closure program and tasks is pre-supposed on EHPL not deciding to commence or having commenced magnetite mining before MGM's site closure is required.

The identified closure domains for the Project are:

- Mine Pit;
- Waste Dump;
- Crushing and Screening Plant, Workshop, Offices and Other Infrastructure;
- Bulk Hydrocarbon Storage;
- Explosives Magazine and ANFO Storage Yard;
- Haul Roads and Access Tracks;

- Accommodation Village;
- Sewage Treatment Facilities;
- Water Supply Bores and Pipes;
- Rail Siding;
- Magnetite Stockpile; and
- Exploration Village.

Table 29 Closure Task Register

Domain	Closure Objective	Closure Design Criteria	Closure Activities
Mine Pit	• Establish a safe and stable post mining land surface	• Pit perimeters resembling topography of the surrounding environment • Abandonment bunding surrounding open pits in accordance with DMP Guidelines, *Safety Bund Walls for Abandoned Open Pit Mines* (DMP, 1997)	• Ensure pit walls are stable • Construct appropriate abandonment bunding around the open pit
Waste Dump	• Establish a safe and stable post mining land surface • Re-establish vegetation that provides a self-generating ecosystem comprising local native vegetation which resembles the surrounding environment as closely as practical • Minimise downstream effects on vegetation due to interruption of drainage • Continue to monitor environmental performance during decommissioning, rehabilitation and post closure stages of the project and take appropriate action until the approved completion criteria have been met	• Batters ≤18 degrees • Optimal topsoil cover with cleared vegetation material • Passive drainage diversion and downstream re-distribution • Self generating function comprising appropriate pre-mining vegetation communities at >60% composition of control sites	• Progressively batter final waste dump slopes and contour to blend with topography • Direct replacement of topsoil where practical or respread stockpiled topsoil and vegetation where practical • Deep rip on the contour • Seed with local native species if required • Establish appropriate surface water diversion works • Monitor as per Section 11.
Crushing and Screening Plant, Offices, Workshops, and Other	• Leave site in a safe, stable, non-polluting and tidy condition with no remaining plant or infrastructure that is not required for post operational use or agreed use by	• No remaining plant or infrastructure that is not required for post-operational use	• Dismantle and remove buildings and infrastructure (including crushing facilities) unless agreed with key stakeholders • Excavate and remove and/or bury

Domain	Closure Objective	Closure Design Criteria	Closure Activities
Infrastructure	other stakeholders		concrete footings • Steel structures, pipes and other metal fabrications will be removed from site for sale or recycling where practicable • Bury remaining inert material which are not suitable or practicable for sale or recycling • All machinery and pumps will be removed from site and disposed of or sold • All electrical equipment will be removed from site and disposed of or sold • All other materials will be disposed of in accordance with DER and Shire requirements. • Remediate any hydrocarbon contaminated soils • Contour to restore natural drainage • Rip surface to alleviate compaction and encourage regrowth of native vegetation • Respread stockpiled topsoil and vegetation
Bulk Hydrocarbon Storage	• Leave site in a safe, stable, non-polluting and tidy condition with no remaining plant or infrastructure that is not required for post operational use or agreed use by other stakeholders • Identify any potential long term soil, surface water or groundwater pollution associated with the operations and formulate an action plan to address this	• No remaining plant or infrastructure that is not required for post-operational use • Soils significantly contaminated with hydrocarbons or chemicals to be bioremediated.	• Remove any residual hydrocarbon materials from the bulk storage tanks and transfer to a licensed facility for disposal • Remove empty bulk hydrocarbon storage vessels from site • Sample the storage site for the presence for hydrocarbon contamination • If any contamination is identified develop an action plan for further sampling and remediation

Domain	Closure Objective	Closure Design Criteria	Closure Activities
			• Excavate and remove and/or bury concrete footings • Remove scrap metal from site for recycling • Bury remaining inert scrap materials not suitable for sale or recycling • Contour to restore natural drainage • Rip surface to alleviate compaction and encourage regrowth of native vegetation • Respread stockpiled topsoil and vegetation
Explosives Magazine and ANFO Storage Yard	• Leave site in a safe, stable, non-polluting and tidy condition with no remaining plant or infrastructure that is not required for post operational use or agreed use by other stakeholders • Identify any potential long term soil, surface water or groundwater pollution associated with the operations and formulate an action plan to address this	• No remaining plant or infrastructure that is not required for post-operational use • Soils significantly contaminated with hydrocarbons or chemicals to be remediated	• Remove all explosives and associated equipment • Dismantle the magazine and infrastructure and remove from site • Sample the site for the presence for any contamination • If any contamination is identified develop an action plan for further sampling and remediation • Excavate and remove and/or bury concrete footings • Remove scrap metal from site for recycling • Bury remaining inert scrap materials not suitable for sale or recycling • Contour to restore natural drainage • Rip surface to alleviate compaction and encourage regrowth of native vegetation • Respread stockpiled topsoil and vegetation
Haul Roads and Access Tracks	• Establish a safe and stable post mining land surface	• No remaining plant or infrastructure that is not required	• Stakeholder consultation to determine post operational use for haul roads and

Domain	Closure Objective	Closure Design Criteria	Closure Activities
	• Re-establish vegetation that provides a self-generating ecosystem comprising local native vegetation which resembles the surrounding environment as closely as practical • Continue to monitor environmental performance during decommissioning, rehabilitation and post closure stages of the project and take appropriate action until the approved completion criteria have been met	for post-operational use • Self generating function comprising appropriate pre-mining vegetation communities based on >60% composition of natural control sites	access tracks • Haul roads and access tracks not required by stakeholders will be rehabilitated • Remove culverts and other associated infrastructure • Remediate any soil contaminated with hydrocarbons • Respread stockpiled topsoil and vegetation material • Deep rip to alleviate compaction and encourage regrowth of native vegetation • Seed with local native vegetation if necessary • Fencing and signage will be left in place at any remaining site access tracks to prevent inadvertent public access
Accommodation Village and Sewage Facilities	• Leave site in a safe, stable, non-polluting and tidy condition with no remaining plant or infrastructure that is not required for post operational use or agreed use by other stakeholders	• No remaining plant or infrastructure that is not required for post-operational use	• Power, water and drainage systems to be shut off and the buildings removed from site for sale • Empty sewage from the treatment facilities and transfer to an approved facility for disposal by a licensed operator • Dismantle and remove the sewage treatment facilities from site for sale • Remove scrap metal for recycling • Bury remaining inert scrap materials not suitable for sale or recycling • Excavate and remove and/or bury concrete footings • Remediate any soil contaminated with hydrocarbons • Contour to restore natural drainage

Domain	Closure Objective	Closure Design Criteria	Closure Activities
			• Rip surface to alleviate compaction and encourage regrowth of native vegetation • Respread stockpiled topsoil and vegetation
Water Supply Bores and Pipes	• Leave site in a safe, stable, non-polluting and tidy condition with no remaining plant or infrastructure that is not required for post operational use or agreed use by other stakeholders	• No remaining plant or infrastructure that is not required for post-operational use	• Water supply bores will be retained for post decommissioning monitoring *and future use in the magnetite operations* • Above ground pipes and pumps to be flushed and removed form site • Below ground pipes will be cut off below ground surface and remain buried *unless agreement from key stakeholders to retain for future use* • Disturbed areas contoured, ripped and seeded with local native species if required
Rail Siding	• Leave site in a safe, stable, non-polluting and tidy condition	• Discussions will occur with relevant stakeholders	• If MGM has no further use for the rail siding a decision will be made in relation to sale of the property. In addition discussions will occur with key stakeholders including the Shire of Perenjori
Magnetite Stockpile	• Establish a safe, stable and non-polluting post-mining landform which supports vegetation growth and is erosion resistant over the long-term. • Re-establish a self-generating ecosystem comprising local native vegetation using seed sourced from the immediate area • Establish a system free of weed species	• Stockpile removed • Area revegetated and self sustaining.	• Remove any remnant ore • Rip compacted areas and respread topsoil stockpiles back over area. • Reseed with local provenance following topsoil respreading.
Exploration	• All redundant infrastructure to be	• Village and supporting	• Remove ancillary services including

Domain	Closure Objective	Closure Design Criteria	Closure Activities
Village	salvaged and disposed of appropriately • Items with beneficial uses post-operation may be left in situ following negotiation with post-closure land users (roads and buildings) • Revegetation cover is appropriate and self-sustaining	infrastructure removed • Area revegetated and self sustaining.	above ground fuel tank, containerised WWTP, Potable water tanks and WWTP sprayfield. • Offer accommodation buildings to traditional owners and provide sufficient time for them to remove buildings (Required under Native Title Agreement). • Remove all buildings and services (buried and above ground). • Remove fencing • Rip compacted areas and respread topsoil stockpiles back over area. • Reseed with local provenance following topsoil respreading.

10.2.1 Mine Pit

Description

The current hematite mine pit design details, as per the *Extension Hill Hematite Project Revised Addendum to Mining Proposal* (MGM, 2013) are summarised in Table 30. The area disturbed for the mine pit is approximately 50ha.

Table 30 Pit Design Details

Pit Design	Details
Pit Length	1,200m
Pit Width	500m
Pit Depth	100m (from highest point to lowest point)
Bench Height	5m
Batter Angle	50°
Berm Width	5-7.5m
Haul Road Width	21m
Haul Road Gradient	1:10

Note: Batter angle and berm width are variable with geotechnical domain

Proposed Post Mining Land Use, Closure Objectives and Closure Design Criteria

The proposed post mining land use for the hematite mine pit is to ensure that the pit is safe and stable, restrict access and leave the pit open.

The relevant closure objectives and closure design criteria are listed in Table 29.

Closure Activities

Once mining is complete, an abandonment bund is required around the open pit to ensure public safety. Abandonment bunds will be constructed in accordance with the DMP Guidelines, *Safety Bund Walls for Abandoned Open Pit Mines* (DMP, 1997) *and as agreed by the Department of Mines and Petroleum*.

Surface water is to be diverted around the pit and drainage designed to replicate pre-disturbance conditions as closely as possible.

Note that the base of the pit will be above the groundwater table.

Information Gaps and Uncertainty

Further information may be required regarding the pit wall stability.

Unexpected and Unplanned Closure

In the event of a permanent unexpected and unplanned closure, the rehabilitation activities listed above will be re-evaluated and, where applicable carried out.

In the event of a temporary unexpected and unplanned closure, appropriate site security measures (including the installation of signage and fencing where required) are to be taken and the pit is to left as is, providing there is no immediate risk of pit wall failure or other safety issues.

Decommissioning

At decommissioning, the abandonment bunds will be constructed around any remaining voids. These bunds will be constructed in accordance with the DMP Guidelines, *Safety Bund Walls for*

Abandoned Open Pit Mines (DMP, 1997) *and as agreed by the Department of Mines and Petroleum*.

Performance Monitoring

The success of mine closure activities will be monitored, as per Section 11.

10.2.2 Waste Dump

Description

Waste dump design details are summarised in Table 31. The northern end of the dump footprint is used for the stockpiling of mineralised waste material that may be amenable to processing and sale in the future. If economic circumstances do not justify the processing and sale of the mineralised waste it will be rehabilitated as a second waste dump with the design details as summarised in Table 32.

The waste dump is being constructed progressively from north to south, in two vertical stages. The dump design philosophy has considered the haulage distance from the working areas and the local topography. The waste dump has been designed to cater for the planned waste that will be produced from the pit. A swell factor of 1.3 has been applied to the volume of material to ensure that the final design volume will be suitable. The overall height of the waste dump is currently not expected to exceed 35m above the adjacent plains (Figure 3). The dump toe is located outside the proposed Magnetite pit limits as specified in the *Safety Bund Walls Around Abandoned Open Pit Mines Guideline* (DMP 1997).

Surface water will be managed through the retention and infiltration of rainfall on the surface of the landform and the berms and the promotion of infiltration on the slopes. The final waste dump landform will not require a toe drain or associated settlement pond to manage runoff from the dump. However, if the mineralised waste stockpile remains at the completion of the operation, drainage will be required to manage surface water in and around this area. A bund will be constructed at the western end of the valley between the waste dumps to divert runoff from the remaining Extension Hill slopes. The inner toes of the mineralised waste stockpile and the waste dump will be rock sheeted to minimise erosion. A sediment sump of sufficient capacity to contain a 1 in 25yr, 72hr rainfall event for a minimum 10 hour retention time will be installed at the eastern end of the valley. The sediment sump will discharge via a rock lined spillway to minimize scouring.

Table 31 Hematite Waste Dump Final Landform Design Criteria

Design Criteria	
Expected maximum height	35m above the surrounding landscape
Length**	800m
Width**	475m
Berm width	10m at the 352.5RL level
Batter angle	18°
Total area**	36Ha
Estimated storage	6,300,000m^3

capacity**	

** Does not include the contents of mineralised waste stockpiles.

Table 32 Hematite Mineralised Waste Stockpile Final Landform Design Criteria

Design Criteria	
Estimated maximum height	35m above the surrounding landscape
Length	450m
Width	400m
Berm width	10m at the 352.5RL level
Batter angle	18°
Total area	17.5Ha
Estimated storage capacity	2,500,000m^3

Proposed Post Mining Land Use, Closure Objectives and Closure Design Criteria

The proposed post mining land use for the waste dump is to reinstate "natural" ecosystems as similar as possible to the original ecosystem.

The relevant closure objectives and closure design criteria are listed in Table 29.

Closure Activities

The design and management will incorporate the recommendations of Landloch (2012) in relation to landform tops, landform shape and rehabilitation monitoring, specifically:

- The waste dump will be designed with appropriate crest bunding and appropriate cross-bunding to ensure runoff is retained on top of the landform;
- The waste dump top will be deep ripped prior to final topsoil respread to increase infiltration capacity;
- Rehabilitation monitoring of the waste dump will include regular visual inspections to identify erosion trends; and
- *The achievability of the Landloch (2012) rock armouring recommendations were trialled as stipulated in the Extension Hill Hematite Project Revised Addendum to Mining Proposal (MGM, 2013). MGM and Landloch have shown that the specifications can be achieved if suitable rocky waste material is available (refer to Section 4.2.2). Due to decline in iron ore value, a change to the mining strategy has resulted in reduced waste rock mining; consequently, the availability of suitable material is a limiting factor on the overall achievability of rock armouring the entire waste dump landform to the specifications of Landloch (2012). MGM will endeavor to preferentially place rocky waste material on the slopes of the waste and encapsulate finer material within the landform. Topsoil will then be spread across all batter faces and contour ripping will achieve mixing of the topsoil with underlying material and reduce erosion potential.*

The complete Landloch (2012) report is included as Appendix C.

Information Gaps and Uncertainty

UWA are undertaking further studies to confirm that the waste dump design is capable of maintaining sufficient vegetation re-growth through a soil, plant and atmosphere interactions study. Refer to Section 4.2.2 for further details.

Unexpected and Unplanned Closure

In the event of a permanent unexpected and unplanned closure, the waste dump is to be stabilised at its current height and extent. Rehabilitation activities listed above are to be carried out.

In the event of a temporary unexpected and unplanned closure, dust minimisation activities are to be undertaken and the open dumping face is to be made safe. Appropriate safety bunding is to be installed.

Decommissioning

At decommissioning, the closure activities identified above are to be instigated.

Performance Monitoring

The success of mine closure activities is to be monitored, as per Section 11.

10.2.3 Crushing and Screening Plant, Offices, Workshops and Other Infrastructure

Description

The Project includes one crushing and screening facility (complete with a workshop and office/crib room), a heavy vehicle workshop and tyre bay, administration offices, a stores warehouse and small laydown yards utilized by contractors.

Proposed Post Mining Land Use, Closure Objectives and Closure Design Criteria

The proposed post mining land use for the infrastructure areas is to reinstate “natural” ecosystems as similar as possible to the original ecosystem.

The relevant closure objectives and closure design criteria are listed in Table 29.

Closure Activities

The key closure activities for these areas, as summarised in Table 29 relate to the removal or on site burial of infrastructure and equipment. All functional equipment, buildings and recyclable waste materials are to be removed from site and disposed of or sold. Inert waste materials that cannot be recycled or sold may be buried on site, in accordance with relevant licences and legislation.

Any contaminated areas are to be investigated and remediated, as per the Contaminated Sites Management Series.

Following the removal of infrastructure and waste materials, the area is to be contoured to allow natural surface water drainage. Rehabilitation is to be undertaken in accordance with the Rehabilitation Management SWI, including ripping of compacted ground, topsoil re-spread and seeding with native seed mixes where required.

MGM intends to rehabilitate the ROM pad in situ employing the same key characteristics, ie batter slopes, methodology, as for the waste rock dump and mineralised waste dump.

Information Gaps and Uncertainty

Nil identified.

Unexpected and Unplanned Closure

In the event of a permanent unexpected and unplanned closure, the closure activities above are to be carried out.

In the event of a temporary unexpected and unplanned closure, equipment and infrastructure is to be secured and locked up. A site security plan is to be implemented.

Decommissioning

At decommissioning, the closure activities identified above are to be initiated.

Performance Monitoring

The success of mine closure activities is to be monitored, as per Section 11.

10.2.4 Bulk Hydrocarbon Storage

Description

There are currently two bulk hydrocarbon storage tanks on site, one 110 kL tank and one 55 kL tank. These tanks are both self-bunded above ground tanks containing diesel fuel.

Proposed Post Mining Land Use, Closure Objectives and Closure Design Criteria

The proposed post mining land use for the bulk hydrocarbon storage area is to reinstate “natural” ecosystems as similar as possible to the original ecosystem.

The relevant closure objectives and closure design criteria are listed in Table 29.

Closure Activities

Closure of the bulk hydrocarbon storage area will involve draining the tanks of any residual diesel fuel and removing them from site.

Bulk hydrocarbon storage areas are identified as high risk areas with regards to hydrocarbon contamination so soil sampling will be required prior to rehabilitation activities. If contamination is detected, these areas will be remediated, as per the Contaminated Sites Management Series.

The area is to be contoured to allow natural surface water drainage and rehabilitation is to be undertaken in accordance with the Rehabilitation Management SWI, including ripping of compacted ground, topsoil re-spread and seeding with native seed mixes where required.

Information Gaps and Uncertainty

Nil identified.

Unexpected and Unplanned Closure

In the event of a permanent unexpected and unplanned closure, the closure activities above are to be carried out once all other major closure activities have been completed.

In the event of a temporary unexpected and unplanned closure, the tanks are to be emptied as much as possible but will remain in situ until the recommencement of operations.

Decommissioning

At decommissioning, the bulk hydrocarbon storage area will be required to provide fuel to the plant and equipment utilised to undertake the closure activities. As such, the closure of the bulk hydrocarbon area will be one of the last major closure items to be completed.

Performance Monitoring

The success of mine closure activities is to be monitored, as per Section 11.

10.2.5 Explosives Magazine and Ammonium Nitrate/Fuel Oil (ANFO) Storage Yard

Description

The Project includes one explosives magazine and one ANFO storage yard.

Proposed Post Mining Land Use, Closure Objectives and Closure Design Criteria

The proposed post mining land use for the explosives magazine and the ANFO storage yard is to reinstate “natural” ecosystems as similar as possible to the original ecosystem.

The relevant closure objectives and closure design criteria are listed in Table 29.

Closure Activities

Closure of the explosives magazine and the Ammonium Nitrate (AN) storage yard will involve the removal of any residual explosives and AN by licenced carriers and in accordance with relevant Dangerous Goods legislation.

The site is to be sampled for contamination in accordance with the Contaminated Sites Management Series. In the event that contamination is detected it is to be removed or remediated, as per the Contaminated Sites Management Series.

The area is to be contoured to allow natural surface water drainage and rehabilitation is to be undertaken in accordance with the Rehabilitation Management SWI, including ripping of compacted ground, topsoil re-spread and seeding with native seed mixes where required.

Information Gaps and Uncertainty

Nil identified.

Unexpected and Unplanned Closure

In the event of a permanent unexpected and unplanned closure, the closure activities described above are to be carried out.

In the event of a temporary unexpected and unplanned closure, the site is to be secured for short term, temporary closures. For long term temporary closures, any explosives or AN is to be removed from site to a secure location.

Decommissioning

At decommissioning, the removal of explosives and AN would be one of the first major closure activities conducted. The remaining closure activities identified above are then to be completed.

Performance Monitoring

The success of mine closure activities is to be monitored, as per Section 11.

10.2.6 Haul Roads and Access Tracks

Description

There are a number of existing and new access tracks and haul roads currently in use as part of the Project.

Proposed Post Mining Land Use, Closure Objectives and Closure Design Criteria

The proposed post mining land use for some of the haul roads and access tracks is to reinstate "natural" ecosystems as similar as possible to the original ecosystem. There are also some haul roads and access tracks that will need to remain open for ongoing monitoring purposes and for access by key stakeholders.

The relevant closure objectives and closure design criteria are listed in Table 29.

Closure Activities

Prior to the closure of any haul roads and access tracks, stakeholder consultation will be undertaken to determine which roads and tracks to keep open and which require rehabilitation. Appropriate signage and fencing will remain in place at any remaining site access tracks to prevent inadvertent public access.

Rehabilitation of haul roads and access tracks will require deep ripping as these areas are likely to be severely compacted. Any drains and culverts in roads that are not going to be kept open must be removed. Consideration of drainage issues must be undertaken for roads that are to remain open and where required, additional drainage may need to be installed in cases where the closure of other roads impacts on the drainage of those left open.

Rehabilitation is to be undertaken in accordance with the Rehabilitation Management SWI, including ripping of compacted ground, topsoil re-spread and seeding with native seed mixes where required.

Information Gaps and Uncertainty

Nil identified.

Unexpected and Unplanned Closure

In the event of a permanent unexpected and unplanned closure, the closure activities above are to be carried out.

In the event of a temporary unexpected and unplanned closure, the site is to be secured and key haul roads and access tracks closed with signage and/or temporary bunding.

Decommissioning

At decommissioning, the closure of haul roads and access tracks will be one of the last closure activities as many will be used to access other areas to conduct closure activities.

Performance Monitoring

The success of mine closure activities is to be monitored, as per Section 11.

10.2.7 Accommodation Village and Sewage Facility

Description

The site accommodation village has been designed to house up to 154 people. In addition to the accommodation blocks, it includes a dry mess, wet mess, office area, storage sheds, laundries, tennis court and gym.

Proposed Post Mining Land Use, Closure Objectives and Closure Design Criteria

The proposed post mining land use for the accommodation village and sewage facility is to reinstate "natural" ecosystems as similar as possible to the original ecosystem.

The relevant closure objectives and closure design criteria are listed in Table 29.

Closure Activities

Closure of the accommodation village will involve the removal of all above ground infrastructure and services. Some buried services and pipes may be cut off below ground and left buried in situ as appropriate.

The sewage evaporation pond will be emptied, with any remaining waste transported off site by a licenced carrier. The liner and sewage pond infrastructure will be removed and disposed of in accordance with relevant legislation. Some elements may be buried on site.

The sewage evaporation pond site is to be sampled for contamination in accordance with the Contaminated Sites Management Series. In the event that contamination is detected it is to be removed or remediated, as per the Contaminated Sites Management Series.

The area is to be contoured to allow natural surface water drainage and rehabilitation is to be undertaken in accordance with the Rehabilitation Management SWI, including ripping of compacted ground, topsoil re-spread and seeding with native seed mixes where required.

Information Gaps and Uncertainty

Nil identified.

Unexpected and Unplanned Closure

In the event of a permanent unexpected and unplanned closure, the closure activities above are to be carried out.

In the event of a temporary unexpected and unplanned closure, the area is to be secured and shut down until the recommencement of operations.

Decommissioning

At decommissioning, the accommodation village and sewage facility will be one of the last areas to be rehabilitated as it will be used to house the closure teams.

Performance Monitoring

The success of mine closure activities is to be monitored, as per Section 11.

10.2.8 Water Supply Bores and Pipes

Description

The location of the water supply bores are shown in Figure 4. There are currently 4 production bores and 3 monitoring bores.

Proposed Post Mining Land Use, Closure Objectives and Closure Design Criteria

The proposed post mining land use for the water supply bores and pipes is to utilise selected bores (and their associated access tracks) to conduct post closure groundwater monitoring and to reinstate “natural” ecosystems as similar as possible to the original ecosystem by removing infrastructure and pipeworks but also develop an alternative land use with higher beneficial uses than the pre-mining land use by securing and retaining the cased bores for potential future use.

The relevant closure objectives and closure design criteria are listed in Table 29.

Closure Activities

Following the nomination of the post closure ground water monitoring bores, the remaining bores are to be securely capped and all infrastructure removed but the bores will remain cased and be accessible for future use. All above ground pipes are to be flushed out and removed from site. Below ground pipes are to be cut off, sealed and remain buried in situ.

Any disturbed areas no longer required are to be rehabilitated in accordance with the Rehabilitation Management SWI, including ripping of compacted ground, topsoil re-spread and seeding with native seed mixes where required.

Information Gaps and Uncertainty

Nil identified.

Unexpected and Unplanned Closure

In the event of a permanent unexpected and unplanned closure, the closure activities above are to be carried out.

In the event of a temporary unexpected and unplanned closure, the water bores are to be capped and shut down until the recommencement of operations.

Decommissioning

At decommissioning, the water bores will be required to produce raw water for dust suppression throughout the closure period. The potable water supply bores will be required for as long as the village is operational or required for use by external stakeholders.

Performance Monitoring

The success of mine closure activities is to be monitored, as per Section 11.

10.2.9 Rail Siding

Description

The Perenjori rail siding facility consists of two primary stockpiles (one lump stockpile and one fines stockpile) either side of the train line. There is capacity for a third overflow stockpile to be created if required. The facility includes offices, a workshop, washdown facility and fuel storage area. The rail siding is described in detail in the *Extension Hill Hematite Haul Road and Rail Siding Project Assessment on Referral Information* (GHD 2008).

Proposed Post Mining Land Use, Closure Objectives and Closure Design Criteria

It is likely that the key rail siding infrastructure will be retained following closure and used for other purposes, either by MGM, a leasee or the Shire of Perenjori. The Shire of Perenjori has indicated an interest in taking over operational control of the rail siding for use as part of its proposed Perenjori Industrial Area.

The relevant closure objectives and closure design criteria are listed in Table 29.

Closure Activities

In the event that the rail siding is taken over by another party a formal agreement will be reached prior to closure to enable a transfer of responsibility and removal of DMP tenements. All relevant legislative notifications of the change of ownership of the rail siding will be made and the site will be safe and stable at the time of handover. Contaminated sites assessments may be required and any contaminated sites discovered must be removed or remediated in accordance with the Contaminated Site Management Series.

Information Gaps and Uncertainty

Nil identified.

Unexpected and Unplanned Closure

In the event of a permanent unexpected and unplanned closure, the closure activities above are to be carried out. Existing stockpiles of iron ore are to be railed to the Geraldton Port Facility if possible, depending upon the circumstances of the closure.

In the event of a temporary unexpected and unplanned closure, the rail siding is to be secured and shut down until the recommencement of operations. Dust minimisation activities will be undertaken on any existing stockpiles.

Decommissioning

At decommissioning, the closure activities identified above are to be instigated.

Performance Monitoring

The requirement for performance monitoring will be assessed at closure, based on the final ownership agreement reached.

10.2.10 Magnetite Project – Magnetite Stockpile

Description

A flat pad was prepared to receive magnetite material encountered by MGM during hematite mining operations. At present there is no material stockpiled on this pad. The total area of the pad, drains and topsoil stockpiles is 1.96 hectares.

Proposed Post Mining Land Use, Closure Objectives and Closure Design Criteria

Post mining this area will be returned to a level, revegetated, self-sustaining state. The area is flat so there are no significant surface water issues to be dealt with. Immediately adjacent to the stockpile is a ground water monitoring bore to which access may need to be maintained during post closure groundwater monitoring.

Closure Activities

- Remove any unsaleable material to the waste dump.
- Deep rip compacted areas.
- Respread topsoil and seed with local provenance material if necessary.

Information Gaps and Uncertainty

Nil.

Unexpected and Unplanned Closure

In the event of a permanent unexpected and unplanned closure the closure activities outlined above will be implemented.

In the event of a temporary and unplanned closure the stockpile (if active) will be left in situ as the magnetite ore is non-acid generating and will be in large lumps (no fines) due to the hardness of the material so there will be no environmental impacts.

Decommissioning

At decommissioning the stockpile will be removed. The flat pad may remain in situ as a hardstand area until final closure when the area will be ripped and rehabilitated as outlined above.

Performance Monitoring

Rehabilitated areas will be monitored as outlined in section 11.

10.2.11 Magnetite Project – Exploration Village

Description

The Extension Hill Magnetite Project Exploration Village is constructed on tenement G59/40 and occupies an area of 2 hectares. The camp area includes a containerised waste water treatment plant and spray field and an above ground hydrocarbon storage tank.

Proposed Post Mining Land Use, Closure Objectives and Closure Design Criteria

Post mining this area will be returned to a level, revegetated, self-sustaining state. The area is situated on deep draining yellow sands which due to their high infiltration rate will not be subject to significant water erosion. The area is relatively flat and the rehabilitated landform will be reinstated to a similar form as the surrounding landscape.

Closure Activities

- Remove ancillary services including above ground fuel tank, containerised WWTP, potable water tanks and WWTP sprayfield.
- Offer accommodation buildings to traditional owners and provide sufficient time for them to remove buildings (Required under Native Title Agreement).
- Remove all buildings and services (buried and above ground).
- Remove fencing

- Rip compacted areas and respread topsoil stockpiles back over area.
- Reseed with local provenance following topsoil respreading.

Information Gaps and Uncertainty

Adequate topsoil is available for rehabilitation purposes, however, local seed was not collected from the footprint area. A seed collection program in surrounding area is required to ensure successful rehabilitation at closure.

Unexpected and Unplanned Closure

In the event of a permanent unexpected and unplanned closure the closure activities outlined above will be implemented.

In the event of a temporary and unplanned closure the area is security fenced and can be locked up securely. In order to maintain company assets a caretaker will be present to manage and monitor the site. As the area is open to public vehicles and is not bio-secure, active weed monitoring will remain in place during any unplanned closure.

Decommissioning

At decommissioning the stockpile will be removed. The flat pad may remain in situ as a hardstand area until final closure when the area will be ripped and rehabilitated as outlined above.

Performance Monitoring

Rehabilitated areas will be monitored as outlined in section 11.

10.3 Closure Scheduling

Golder Associates (2013b) estimated the timeframes required for decommissioning the major infrastructure items on site (Table 33). Some of these tasks can be conducted simultaneously and others must be done sequentially. The minimum time expected for this aspect of closure is 20 weeks (Golder Associates 2013b).

Table 33 Estimated Demolition Times for Major Facilities (Golder Associates 2013b)

Activity	Time in Days
Initial disconnection of site services	2
Crushing, screening, stackers and load out facility	24
Crushing and screening circuit concrete	5
Heavy vehicle and main workshop area	10
Tyre bay and used tyres	4
Workshop area concrete	6
Main stores area	9
Stores area concrete	1
Fuel farm	2
Fuel farm concrete	1
Light poles	2
Spectrolabs workshops	1
Explosives compound	3
Turkey’s nest	5
Weighbridge facilities	4
Dyno depot	1
Main administration buildings	11
Security gatehouse	2

Activity	Time in Days
Camp site accommodation	7
Camp site concrete	3
Camp settling pond	4
Lifting and burial of Great Northern Highway pavement	10

The rehabilitation of the major landforms is anticipated to take approximately 13 weeks if the mineralised waste is rehabilitated as a landform (Table 34). If that material is instead sold, this estimate will be reduced by almost 4 weeks and the life of the project will be extended for the period required to process and transport the mineralised waste.

Table 34 Duration of Rehabilitation of Mine Landforms (Golder Associates 2013b)

Activity	Waste dump Time in Days	Mineralised waste Time in Days	ROM pad Time in Days
Battering down slopes	20	11	1
Placing rock cover	5	3	1
Placing topsoil on slopes	2	2	1
Contour ripping slopes	6	4	1
Constructing bund	4	3	2
Placing topsoil on upper surface	2	1	1
Deep ripping upper surface	4	1	1
Seeding all surfaces	8	4	2

The closure schedule created by Golder Associates (2013b) was based on an anticipated date of December 2016 for the completion of mining. Current data suggests that mining will now *cease around August 2016*. Whilst the dates in the Golder Associates (2013b) schedule are no longer correct, the timeframe estimates are still valid. Table 35 shows the new anticipated completion dates for key phases of mine closure. Note that both of these scenarios assume that the mineralised waste material will not be removed from site (by sale). In the event that it is, the ore crushing will continue for a substantially longer period and most of the other closure aspects will also be delayed (with the likely exception of the waste dump rehabilitation).

Table 35 Key Closure Dates

Activity	Original Estimate	Current Estimate
Mining will cease	Dec 2016	*August 2016*
Ore crushing will cease	Dec 2016	*August 2016*
Rehabilitation for landforms completed	Sep 2017	*May 2017*
All plant and equipment removed/disposed	Sep 2017	*May 2017*
Monitoring phase complete	Sep 2022	*May 2022*

A Gantt chart for the decommissioning of key infrastructure is included within the Golder Associates (2013b) decommissioning report (Appendix H). This assumes mobilisation to site of decommissioning crew will occur on 10 July 2017. It will be updated once mining is completed and the actual date of mobilisation is confirmed.

10.4 Incorporation of Domains into the EHPL Magnetite Project

At the time of Project approval it was anticipated that the hematite and magnetite projects would occur more or less consecutively with a short period of transitional overlap. Due to funding constraints the Magnetite portion of the project has been delayed and remains in abeyance with attempts to secure funding ongoing.

There are several domains that would be advantageous for EHPL to take over with the following options having been considered for use by EHPL:

- Waste Dump
- Turkeys Nest
- Borefield
- Main access roads
- Office Hardstand Areas

With the current delay in funding for the magnetite project, MGM will progress with this closure plan on the assumption that magnetite project does not proceed in a timely enough manner to allow the orderly transfer of infrastructure assets prior to mine closure.

In the event that EHPL secures funding and commences the magnetite project then this closure plan will be revised to incorporate a detailed list of infrastructure assets to be handed over from MGM to EHPL for ongoing management.

In any event the borefield and major access tracks will be handed over to EHPL to enable ongoing groundwater and vegetation monitoring to be conducted.

11. Closure Monitoring

Following the completion of the rehabilitation works there will be a period of post closure monitoring. It is expected this will last for approximately five years. The monitoring will be targeted at quantifying those parameters, which directly relate to the site's completion criteria and to identify any long term effects of mining.

The frequency of monitoring may be refined at a later date, based on the results of operational monitoring during the life of the Project and the initial closure monitoring results; however it is anticipated that monitoring of rehabilitated areas using permanent monitoring points will be undertaken on a quarterly basis. This monitoring program will aim to assess:

- The physical stability of the rehabilitated areas;
- The biological structure of the vegetation community; and
- Any public safety aspects.

Annual photographic monitoring and surveys of defined monitoring plots for biodiversity, stem counts and seed production will be undertaken to monitor the progress of revegetated areas. Remedial work for rehabilitated areas will be identified through monitoring and undertaken where necessary.

In addition, the following aspects of the current operational monitoring regime will continue into the closure phase:

- Annual groundwater analysis of samples from the remaining groundwater bores for comparison with baseline data;
- Annual malleefowl mound survey to determine trends in abundance of the breeding population of malleefowl;
- Annual site weed survey to identify and eradicate any new weed populations;
- Dust deposition monitoring to monitor compliance with the deposited insoluble dust guideline value of $4g/m^2$/month; and
- Annual Declared Rare Flora monitoring to identify plant health condition and population trends.

The frequency of monitoring may decrease as rehabilitation progresses and will cease when rehabilitation completion criteria have been met and relinquishment achieved. The anticipated frequency of monitoring is shown in Table 36.

Table 36 Post Closure Monitoring Requirements

Domain	Monitoring Location	Parameter	Frequency
Mine Pit Wall	Set photo points to be established	Visual inspection for failures	Quarterly
Waste Dump	Entire length of waste dump Set photo points to be established	Visual inspection of general condition and erosion	Quarterly

Domain	Monitoring Location	Parameter	Frequency
	Monitoring plot locations to be determined	Presence/absence of seed production of selected individuals within monitoring plots, stem count of monitoring plots, species diversity of monitoring plots	Annually
Waste dump (and surrounds)	To be determined	Dust Deposition	Quarterly
	To be determined	DRF health monitoring as per approved DRF Recovery Plans	Annually
Groundwater bores	Production and monitoring bores	Listed analytes*	Annually
	Production and monitoring bores	Water level	Quarterly
Surrounding areas	Known malleefowl mounds	Monitor as per *National Manual for the Malleefowl Monitoring System* (National Heritage Trust, 2006)	Annually
All	Inspection of all accessible rehabilitated areas	Identification of weed species	Annually

* The annual groundwater analysis will be undertaken at a NATA certified laboratory and will include:

- Total Dissolved Solids, Electrical Conductivity
- Hardness and alkalinity
- Major anions (Calcium, Magnesium, Sodium, and Potassium)
- Major cations (Chloride, Carbonate, Bicarbonate and Sulphate)
- Other analytes from time to time as required by consultation.

12. Management of Information and Data

12.1 Management of Data

The HSEC Department is responsible for the management of data relating to mine closure planning. All information and data shall be maintained in accordance with MGM's Records Management Procedure.

12.2 Reporting

During the operational period of the Project, mine closure reporting will be incorporated into the Annual Environmental Report required for the Project.

Reporting of site inspection findings, monitoring results and potential issues and impacts will be undertaken on an annual basis for the first three years after mine closure. These reports will be provided to the relevant authorities.

Following the first three years of closure, the reports will be reviewed and discussions will be held with DMP if alterations to the agreed monitoring programs are required.

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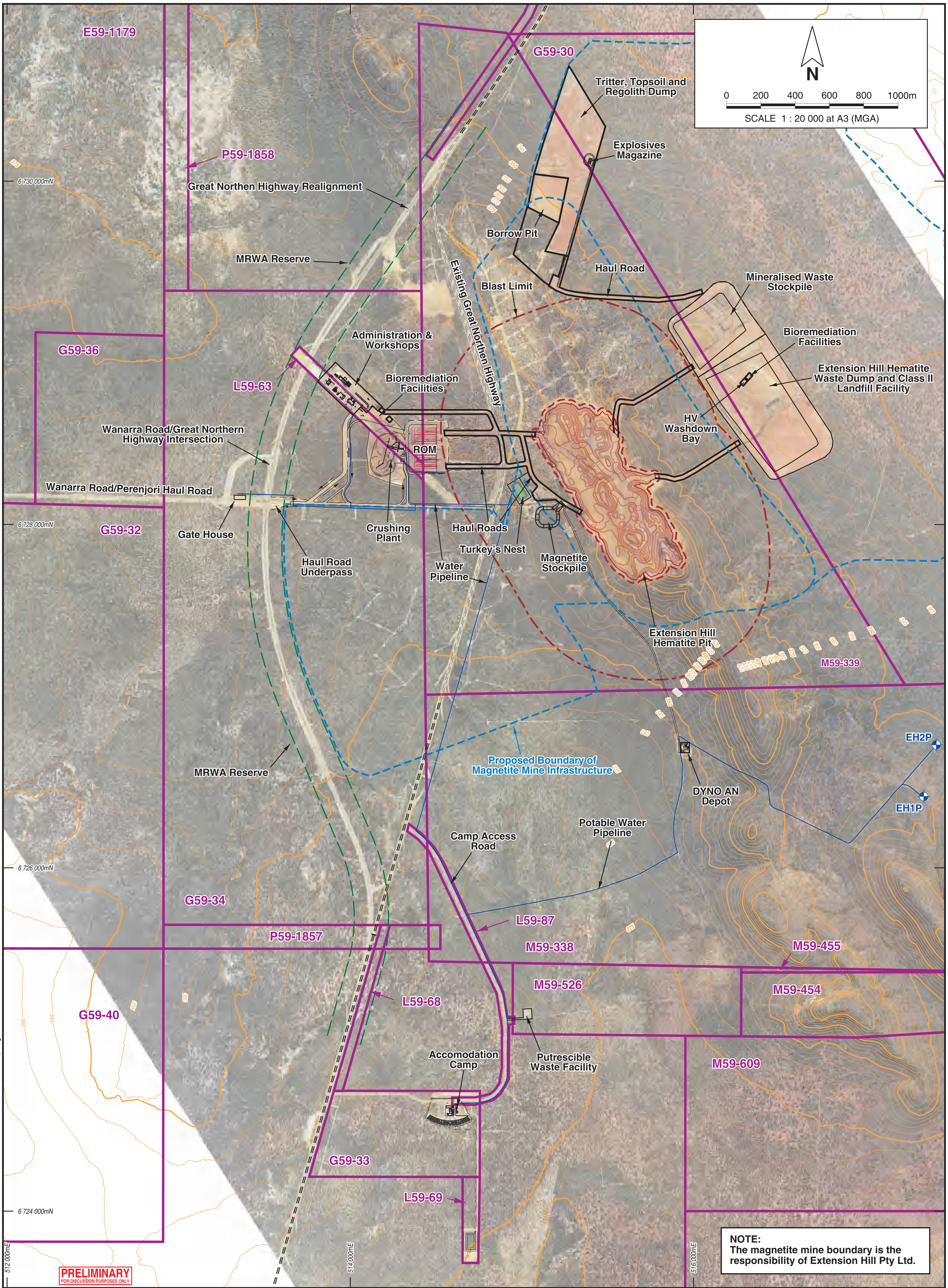
FIGURE 1
SITE LAYOUT



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REVISIONS

REV	DATE	DESCRIPTION	APP
J	14-07-10	GNH REALIGNMENT WORKS - SCHEDULE 2 ADDED	PJ
K	01-03-12	REVISED SITE LAYOUT	GH
L	03-04-12	REVISED SITE LAYOUT	RO
M	29-01-13	REVISED SITE LAYOUT	JS
N	29-01-13	'ITEMS CHANGED' REMOVED	JS

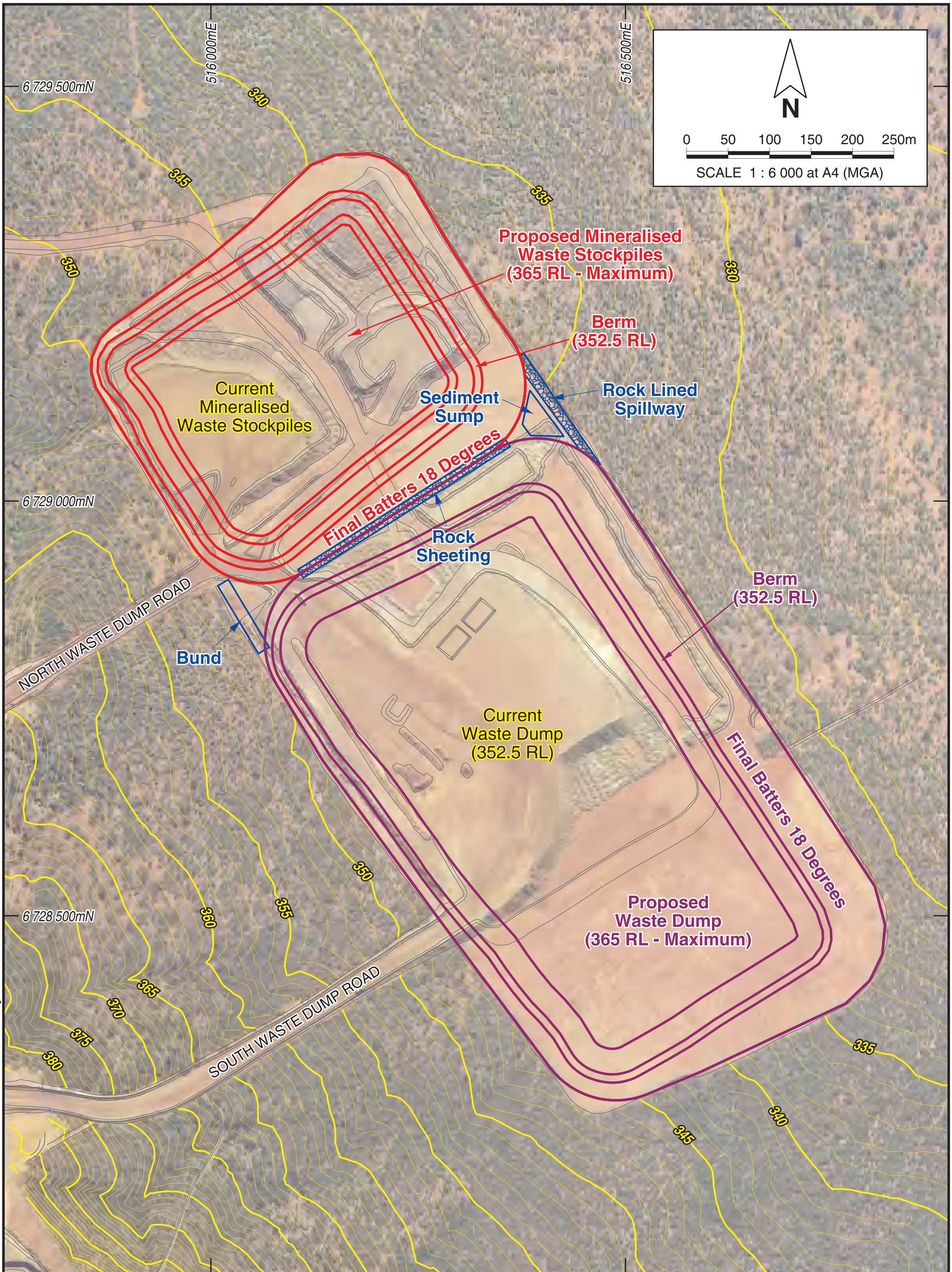
Mount Gibson Iron

AUTHOR	L. CREE	22-04-08
DRAWN	C. REEVES	11-12-12
APPROVED	J. SACKMANN	12-03-14
DRAWING NUMBER		REV
EHH-PPC-MINE-GA-DWG-110_N.dgn		N

EXTENSION HILL HEMATITE PROJECT

EXTENSION HILL MINE LAYOUT

FIGURE 3
WASTE DUMP DESIGN



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Mount Gibson Iron

MOUNT GIBSON HEMATITE PROJECT

HEMATITE WASTE DUMP AND MINERALISED WASTE STOCKPILES - DEFAULT FINAL LANDFORM DESIGN

Drawn: J. Sackmann	Date: 30-01-13
Revised: --	Date: --
	FIGURE 4b

FIGURE 4
GROUNDWATER BORE LOCATIONS


0.5
kilometres
Scale: 1:14,810
N
EH4P
WB1
MB1
EH3P
EH2P
IHMB1
EH1P
Production Bore
Monitoring Bore
Lease Boundary

Appendix A *Darwinia masonii* and *Lepidosperma gibsonii* Conservation and Restoration Research – Report to Sponsors

Darwinia masonii and *Lepidosperma gibsonii*

Conservation and Restoration Research

An integrated research program into the *ex situ* and *in situ* conservation, restoration and translocation requirements of *Darwinia masonii* and *Lepidosperma gibsonii* May 2007- June 2010

Report to Sponsors
October 2010

Botanic Gardens and Parks Authority (Kings Park and Botanic Garden) ("BGPA")

Authors:
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Sponsors:
Mount Gibson Mining Limited (MGM), PO Box 55, West Perth 6872
Extension Hill Pty Ltd (EHPL), PO Box 82, West Perth WA 6872

Table of Contents

1 INTRODUCTION

This research report is based on the *Conservation and Restoration Research Proposal for Darwinia masonii and Lepidosperma gibsonii: An integrated research program into ex situ and in situ conservation, restoration and translocation of Darwinia masonii and Lepidosperma gibsonii 2007-2010.* August 2008. That proposal was developed by BGPA in response to the commitments of Mount Gibson Mining Limited (MGM) and Extension Hill Pty Ltd (EHPL) to fund a 3+ year research program on the declared rare flora species *Darwinia masonii* (Myrtaceae) and *Lepidosperma gibsonii* (Cyperaceae).

This research program is based on, and specifically addresses the objectives of Conditions 6.1 and 7.1 of Ministerial Statement 753, to facilitate the continued *in-situ* survival and improvement in the conservation status of *Darwinia masonii* and *Lepidosperma gibsonii* over time through targeted research which assists the development of a recovery plan for each species. The research proposal document development was also assisted through consultation with DEC Threatened Species and Communities and the EPA.

The project commenced in May 2007, and was described as having a '3 year plus' duration, with the suggestion that the program may be extended subject to achieving requirements as detailed in Ministerial Statement 753.

Acknowledgements:

Staff and students at BGPA made important contributions to this research, and are greatly thanked for their input. Notably these include Jason Stevens, Eric Bunn, David Merritt, Siegy Krauss, Shane Turner and Kingsley Dixon. Annette Johnson, David Symons and Chris Karsten have provided excellent technical and administrative assistance. Students that have provided valuable input include Mark Wallace, Jemma Marris (2008), Esther Kow (2010), Sarah Paul, Cameron Mounsey (2009), Liann Smithson (2009) and Kim Nguyen, while the contribution of Sacha Ruoss has been particularly significant.

Externally, Dr Pieter Poot (UWA) and Dr David Lubertazi (Harvard) provided important advice and assistance. Dr Brian Hederick and Dr Aaron Gove (Curtin University) assisted with ant identification. Dave Atkins at DEC Midwest Fire Branch and his crew are thanked for managing the experimental fire. Ben Croxford at Nuts About Natives is thanked for propagating and supplying stock for experimental and translocation work. Paul Sauter of Sauter geological is thanked for his assistance with the preparation of data for species distribution modelling, and his involvement was supported separately by Extension Hill. Extension Hill is also thanked for providing additional air photo and contour data as well as access to drill cores and geological mapping. We acknowledge ATA / Coffey consultants, in particular Shaun Grein who provided excellent distribution data for both species and Martine Scheltema who played an important role in the establishment and initial direction of the project. Finally, we thank both Extension Hill and Mt Gibson for their support, and specifically Peter Jones, Phil Davidson, Harry Goff, David Milton, and Jess Sackman for their individual contributions.

2 EXECUTIVE SUMMARY

Summary of results

Conservation genetics

- *Darwinia purpurea*, and *D.* sp. Chiddarcooping are identified as the taxa most closely related to *D. masonii*.
- *Lepidosperma gibsonii* was described as a new species and formally named, with its Rare conservation status transferred from *L.* sp Mt Gibson and is most closely related to nearby populations of the *L. costale*.
- While between population genetic structuring in *Darwinia masonii* is low, some populations do not mate randomly with other populations – suggesting that there are some weak barriers to gene flow across the Mt Gibson range.
- There is very low genetic structuring between populations of *L. gibsonii*, but tests show that there are some barriers to complete gene flow across the Mt Gibson range system.
- The current population size of *L. gibsonii* is estimated to be 1.25 times greater than the current census, due to multiple genetic individuals within some clumps. Some measures of survival may over-estimate by up to 25% due to unobserved loss of genetic individuals from clumps.

Population Demography

- *Darwinia masonii* are long lived (likely to ca. 100 years) and fire-killed. Most individuals recruit from long-lived soil-stored seedbanks in a single cohort following fire. Limited inter-fire recruitment may occur in older populations.
- Plant size data and known population ages suggest that *D. masonii* stem diameter growth averages 0.4 $mm.yr^{-1}$ and height growth averages 2.9 $cm.yr^{-1}$. Negative height growth recorded for tagged mature plants reflects poor growth conditions in measured years.
- Post-fire seedling recruitment is high in *D. masonii*, with as many as 3.2 seedlings per pre-fire adult, although ~90% of seedlings died over their 1^{st} summer (albeit in a dry season).

- While mortality is rare among mature *D. masonii* plants, drought over the winter of 2010 contributed to a significant level of mortality (>10% in one site). Mortality among 4-6 year old seedlings was recorded at 2.5-15% per year.

- Reproduction commences in *D. masonii* seedlings as young as six years, but increases with plant size, in both proportion of plants flowering, and flowers per plant.

- *Lepidosperma gibsonii* individuals recruit from long-lived soil-stored seedbanks in a single post-fire cohort. There is no evidence for inter-fire recruitment. Plants are long-lived (perhaps to ca. 100 years) and about half of plants exposed to fire appear to survive and resprout.

- Plant size data and known population ages suggest that *L. gibsonii* basal diameter growth averages 2 – 2.5 mm per year for seedlings and adults. Surveys of tagged plants identified mean negative growth rates between 2007 and 2010, possibly reflecting growth conditions in these years.

- Post-fire *L. gibsonii* recruitment averaged 4.2 seedlings produced per pre-fire adult, but ~75% did not survive to 2 years. Mortality among 4-6 year old seedlings averaged 3% per year.

- Reproduction commences in *L. gibsonii* seedlings as young as six years, but increases in terms of proportion of plants flowering, and flowers per plant as plant size increases.

Seed production and seed biology

- *Darwinia masonii* is predominantly pollinated by a single species of Honeyeater. *D. masonii* is capable of producing low-viability, selfed seeds but the production of outcrossed seed is a critical requirement for self-sustaining populations, as there is weak evidence that selfed seed is less fit than outcrossed seed.

- *Darwinia masonii* flowering and seed production takes place over a long period in spring and early summer with the peak of ripe seed production occurring around mid November. Seed fill rates varied between years from 15 to 30% and predation rates from 6 to 22%. Seed dispersal occurs by ants. *Darwinia masonii* seed production is moderately low, varying between years from 9 to 59 seeds per plant in mature populations. Inbreeding and predation by moth larvae contribute to reduced seed quality.

- *Lepidosperma gibsonii* reproduction takes place over multiple years, with inflorescence production occurring in one year and flowering and fruit ripening occurring in the next. Pollination is via wind. If seed is produced, the period for which ripe seed can be collected from *L. gibsonii* plants is brief (one to two weeks in mid October) as good seeds fall soon after ripening.

Seed germination and dormancy

- Large scale production of seedlings of either species via germination of fresh or stored seed involves physical manipulation of small seeds for seed coat nicking or removal, or retrieval of seed buried for months or years.

- Germination of fresh *D. masonii* is low but can be improved by a combination of detailed physical treatments and smoke application. Germination rates of 90% have been achieved with filled seed exhumed after 9 months of burial and treated with smoke water.

- *Lepidosperma gibsonii* seed germination remains unsolved, however indications of small positive, effects of seed burial, fruit wall breakdown/removal, smoke and heat treatments are apparent. Manual seed coat removal followed by a heat treatment resulted in 60% germination.

- Seed bank demography trials established for both species are ongoing. Buried seed is in place with experiments designed to continue for up to 5 years. Results to date indicate complex germination / dormancy strategies for both species, combining a requirement for physical degradation of the seed coat, environmental (seasonal temperature) cuing – with seeds cycling in and out of dormancy, and heat- and smoke-related physiological responses.

Environmental adaptations

- *D. masonii* and *L. gibsonii* share with co-occurring species the drought avoiding strategy of closing down transpiration and photosynthetic function to enter a period of physiological dormancy through summer drought with the capacity to restore tissues as soils wet.

- Roots of both *D. masonii* and *L. gibsonii* have a capacity to enter large cracks, pores and fissures in regolith and may achieve considerable root depths (perhaps to >10m), but neither species showed root growth adaptations that were significantly different from close relatives from non-BIF habitats.

Threats

- Grazing – presumed to be by goats and rabbits – can have a significant impact on growth and reproduction of *L. gibsonii* but has a negligible impact on *D. masonii*

- Predation of *D. masonii* seed (by larvae of an unidentified moth species) can be significant. This moth, and a gall forming insect observed on *D. masonii*, are both potentially specific to *D. masonii* and may therefore be rare and threatened species.

Propagation, Restoration and Translocation

- Techniques for the successful propagation of both *D. masonii* and *L. gibsonii* have been proven at both BGPA and an independent specialist nursery and involve greenstock production from cuttings (*D. masonii*) or separated clumps (*L. gibsonii*).

- Propagation from collected seed may be preferable for genetic diversity reasons and is possible for *D. masonii*, although at this stage requires some time for treatments to take place. As seed germination remains difficult for *L. gibsonii*, propagation from plant collections is the best viable option, however methods to grow plants from seed embryos in tissue culture have been developed, and provide another, more time-consuming solution.

- Species distribution models for *D. masonii* and *L. gibsonii* were able to provide good descriptions of the species' respective distributions and identified different habitat attributes for each. These models also identify localities for possible translocation sites.

- Distribution models indicate a preference of *L. gibsonii* for cooler sites and suggest that restoration surfaces should be sloped to minimise solar radiation receipt for this species. Similar models indicate broad habitat requirements for *D. masonii* (BIF rocky loam soils) but may possibly mask an association with unmapped sub-surface features.

- Translocation trials of both species utilised unmanipulated, naturally occurring substrate variation and demonstrated that both *D. masonii* and *L. gibsonii* have the ability to be planted and survive in restoration sites although this is effectively limited to BIF rock and BIF gravel substrate sites.

- Survival of transplanted *D. masonii* greenstock averaged under 40% (at 9 months) at the best performing site (BIF rocky loam). An additional pilot trial suggests that irrigation may improve *D. masonii* survival and growth rates.

- Transplanted *L. gibsonii* survival was greatest on BIF gravel sites (70%) but was also high on BIF rock sites

- Translocation sites differed in several soil properties, of which texture, gravel/rock content, patterns of moisture content and total Nitrogen may be the most critical.

***Ex Situ* Conservation**

- Batches of 1000 filled seeds of each of *D. masonii* and *L. gibsonii* have been deposited at three (Australian and international) conservation seed storage facilities. In addition genotypes of both species are stored as live plants at two locations off-site and as seed at three secure locations off-site.

- *in vitro* culture has been achieved with both *D. masonii* and *L. gibsonii* and cryostorage is an option for long-term storage of key clonal germplasm if required.

Summary of Recommendations

Conservation genetics

- Investigations requiring complete mapping of individuals (e.g. mating studies) for *L. gibsonii* requires exhaustive genetic sampling within clumps to identify all individuals.
- The precautionary principle should apply to avoid mixing genotypes in restoration between respective populations of *D. masonii* or *L. gibsonii*.

Population Demography

- Monitoring of tagged plants in plots established in this program, including post-fire plots should, continue. The monitoring program may require expansion in order to meet ministerial requirements for numbers of plants.
- Population survey should take place annually in October or November. All plants in selected, permanently marked plots should be individually tagged and measured.
- Key variables to measure in marked plots include: survival, recruitment (new plants should be tagged and recorded as found), health, herbivory, infructescence production (and seed production for *L. gibsonii*) and growth of seedlings and smaller plants.
- Annual collection of a sample of (>10) infructescences of both species from each major population to assess rates of seed predation and seed fill are also recommended.
- Established seed burial and retrieval trials with associated germination treatments should continue for at least several further years.
- Seed collection should be timed closely to ensure that collected fruits contain viable filled and un-predated seed. Ideal times appear to be mid November for *D. masonii* and mid October (in fruiting years) for *L. gibsonii*. Seed counts should take into account the low number of filled seeds per fruit, known selfing rates, and assess seed predation rates.

Environmental Interactions

- Mapping of soil or regolith data for the region is suggested to refine distribution models to improve understanding and predictions of the habitat and restoration requirements for *D. masonii*

- Root systems could be examined in mining pit walls as they are constructed, to determine rooting depth of *D. masonii* and *L. gibsonii* and their use of surficial versus deeper layers in the soil profile. Results would inform requirements for restoration substrates.

Threats and *Ex Situ* Conservation

- Manage populations of goats and rabbits, and monitor herbivory impacts of macropods on *L. gibsonii*.

- Ensure habitat requirements for key *D. masonii* pollinators are retained.

- Identify the seed-eating moth species and survey for its occurrence in co-occurring species and related *Darwinia* species.

- *Ex situ* collections of live plant and seed material and multiple (>100 for live plants) genotypes should be maintained, monitored and supplemented as required

Restoration / Translocation

- Samples of large numbers of filled seed can be assembled for *D. masonii* and *L. gibsonii* (in years in which it produces seed) with careful attention to timing of seed maturation, predation rates and seed screening and cleaning.

- Propagation of live plant material from wild collections and nursery stock are likely the most cost effective approach for the short-medium term storage and production of plants for restoration purposes.

- For *D. masonii*, further research into seedling production under lab, glasshouse or field conditions appears promising and may provide a preferable approach to providing a genetically diverse and numerous source of restoration plants.

- Experiments manipulating restoration substrates using mine waste components or other available and appropriate materials are recommended as mining construction commences. Record plant growth and survival.

- Sand and clay materials may not be effective restoration materials for *D. masonii* and *L. gibsonii*, although mixing clays with rock and/or gravel may be worth trialling. Final restored structure surface must incorporate a large proportion of BIF rock or gravel for successful restoration of both species.

- Trials in which *D. masonii* and *L. gibsonii* are translocated into restoration substrates designed and constructed with varying amounts of rock and gravels, and with rocks at varying depths are recommended.

- Restoration areas for *L. gibsonii* should be shaped as slopes or gullies oriented with lower radiation receipt. Restoration trials for *L. gibsonii* should include treatments varying shade and moisture.

- Restoration areas for *D. masonii* may not require particular topographies, but attention to soil requirements may be important. Restoration trials for *D. masonii* should include treatments varying degrees of soil depth and rockiness.

- Restoration efforts must include adequate community context e.g. ensuring adequate habitat for White-fronted Honeyeaters and seed dispersing ant species.

3 PROJECT BACKGROUND

Mount Gibson and the adjoining ridges lie 350 km north east of Perth in Western Australia. The range is largely composed of banded ironstone (BIF), with significant deposits of both hematite and magnetite. The range has been investigated for many years with the view to extracting iron ore.

The project was assessed as a Public Environmental Review (PER) under Part IV of the Western Australian *Environmental Protection Act* 1986. In addition the proposal is considered to be a controlled action under the Commonwealth *Environmental Protection and Biodiversity Conservation Act* 1999

The PER was released for public review from 18 April to 30 May 2006. The Environmental Protection Authority (EPA) released its Report and Recommendations on the Mt Gibson Iron Ore Mine and Infrastructure Project (Bulletin 1242) on 27 November 2006.

The EPA recommended that the project be given approval subject to a number of conditions. The Mt Gibson Iron Ore Mine and infrastructure Project was approved by the Western Australian Minister for the Environment on 24 October 2007 (Ministerial Statement 753). The project received approval to undertake a controlled action under the *Environmental Protection and Biodiversity Conservation Act 1999* on the 18 December 2007.

During the assessment process, a species of Declared Rare Flora (*Darwinia masonii*) was known to be endemic to the Mt Gibson Range, and the then project proponent, Mount Gibson Mining Limited contracted ATA Environmental to survey the plants, and BGPA to investigate critical biological factors relating to the rarity and reproductive potential of the species.

In early 2006, a second species endemic to the range was discovered, which was referred to in the EPA Bulletin 1242 as *Lepidosperma* sp. Mt Gibson, which has since been described as *Lepidosperma gibsonii* R.L. Barrett (Barrett, 2007). ATA Environmental (now Coffey Environments) and BGPA were again contracted to conduct similar preliminary research for *Lepidosperma gibsonii* as previously done for *Darwinia masonii*.

In August 2006, Mount Gibson Mining Limited sold Asia Iron Holdings Limited and Extension Hill Pty Ltd including the mining tenements and overall project to Sinom Investments but retained the rights to mine hematite ores verses the magnetite ores that were to be mined by the new independent company.

Since this time and following State Ministerial approval (24 October 2007) and Commonwealth Approval (18 December 2007), Mount Gibson Mining Limited (MGM) and Extension Hill Pty Ltd (EHPL) have become joint proponents in the Mount Gibson Iron Ore Mine and Infrastructure Project defined by Ministerial Statement 753 (WA Environmental Protection Act, 1986) and the Commonwealth approval under the Environmental Protection and Biodiversity Conservation Act, 1999. The proponents are now developing an iron ore mine at the Extension Hill deposit in the northern part of the Mt Gibson ranges consisting of both hematite and magnetite mining infrastructure (MGM and EHPL respectively). Expansions of the project's footprint were approved 20 February 2008.

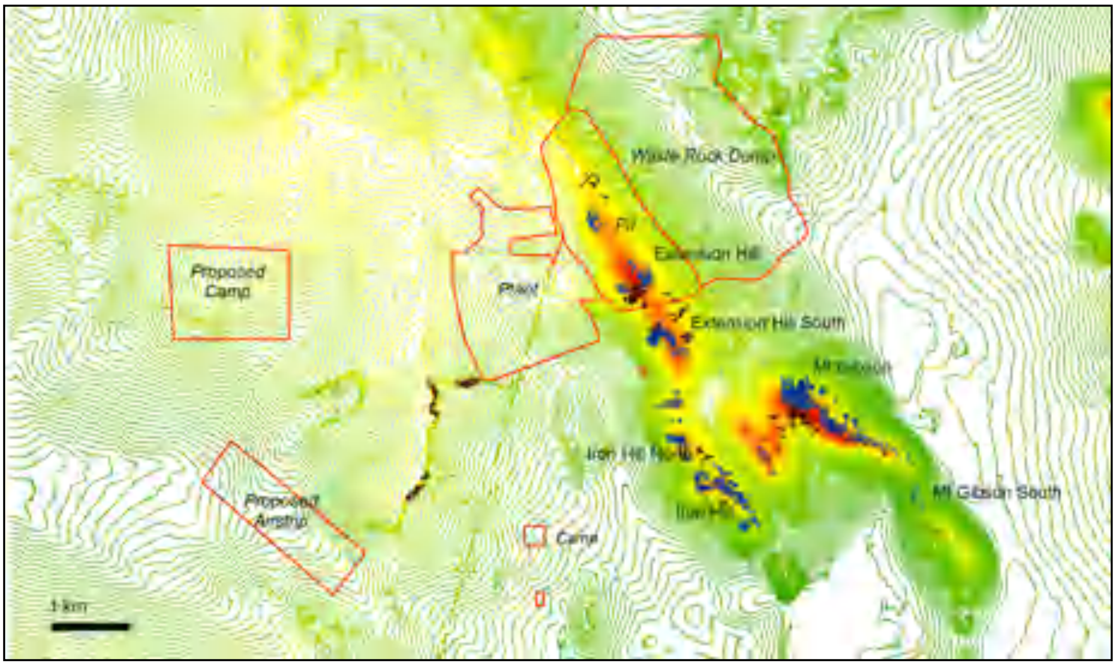

Figure 1 Major features of the study area including proposed (approved) mining project footprint, topography (1m contours), major peaks and the distribution of *L. gibsonii* (brown dots) and *D. masonii* (blue dots)

3.1 RELATED DOCUMENTS

Interim Recovery Plans (IRP's) have been prepared for *Darwinia masonii* and *Lepidosperma gibsonii* which detail the recovery actions and the monitoring to be undertaken for each species as required by Conditions 6.1.1, 6.2, 7.1.1 and 7.2 of Ministerial Statement 753.

An Environmental Management Plan has been prepared for the Mt Gibson Iron Ore Mine and Infrastructure Project that details management measures to minimize the direct and indirect impacts of mining on significant flora including

Darwinia masonii and *Lepidosperma gibsonii* as required by Condition 8 of Ministerial Statement 753.

3.2 OTHER RESEARCH

The research program reported here is devoted specifically to the Declared Rare Flora (DRF) species *Darwinia masonii* and *Lepidosperma gibsonii.* However, other research initiatives are required to meet Conditions 6.1.5 and 7.1.5 (other impacts on DRF, including from dust) and 14 (Closure) of Ministerial Statement 753. In response to these requirements, BGPA has prepared and submitted a **Proposal for research into the restoration of plant communities in the Extension Hill – Mt Gibson iron ore mining project** (submitted February 2008, updated February 2010) as well as a **Proposal for research into the affects of dust on rare plants** (submitted July 2008) to EHPL and MGM. Funding of a 2008 version of the restoration research plan was agreed by both EHPL and MGM subject to final approval of mining and the (subsequently delayed) commencement of operations. This community restoration research was specifically noted in the ***Darwinia masonii* and *Lepidosperma gibsonii* Conservation and Restoration Research Plan** (i.e. the plan outlining the research presented here and signed-off by DEC) as a necessary research component additional to the work covered in the plan.

The results of the research program presented here show that some research areas require ongoing investigation for satisfactory conclusion in relation to Conditions 6.1.1, 6.2, 7.1.1 and 7.2 of Ministerial Statement 753. In particular, the strong inter-annual variation observed in key population parameters (i.e. growth, survival and seed production rates) means that long-term population monitoring is required for determination of their average values and patterns of variability. This long-term monitoring is essential in order to determine whether future observed fluctuations result from mining impacts or natural variation. The same data are also essential for tests of population viability and extinction likelihoods in response to impacts such as fire, herbivory or continued drought (or similar climatic extreme), or mining impacts such as population loss, or augmentation through restoration. A program for continuation of the DRF research presented here – ***Proposal for continuation of Extension Hill – Mt Gibson DRF Research Program*** (January 2010, updated May 2010) – has been prepared by BGPA and submitted to EHPL and MGM.

Details of requirements for monitoring of the health of, and mining impacts on, DRF populations (including a specified proportion of individuals) are given in

Ministerial Statement 753. As this monitoring does not constitute research per se, it was never an objective of the BGPA research program to meet these requirements. Nevertheless, monitoring of these parameters for research objectives has been a component of the work presented here, although not to the requirements (in terms of number of individuals represented) of the Ministerial Statement in several details. Additional monitoring will be required by EHPL and MGM to meet these requirements.

4 FINDINGS

4.1 CONSERVATION GENETICS

4.1a Phylogenetic context

Darwinia masonii

Charles Gardner, when describing *Darwinia masonii* in 1964, noted the pendulous flower heads and long marginal bracts, and concluded that it was closely related to the Stirling Range species *Darwinia leiostyla*. No analysis of relationships within *Darwinia* has been undertaken since that time (other than speculations on the relationships of a few individual species).

In order to identify appropriate comparisons for the assessment of genetic diversity and comparative ecology in *D. masonii*, a thorough analysis of phylogenetic relationships in the genus *Darwinia* was undertaken, including most species of *Darwinia* in south-west WA, and several species of the disjunct "*D. fascicularis*-group" in New South Wales and South Australia. Two gene regions were used in order to detect incongruent signal resulting from gene trees vs species trees: the nuclear ribosomal External Transcribed Spacer (ETS), and the chloroplast trnK intron (including the *mat*K gene).

Analysis of chloroplast and nuclear genes showed significant incongruence at many of the upper nodes in the tree (suggesting either incomplete lineage sorting or ancient hybridisation), however most species-groups identified had identical composition. In particular, the position of *D. masonii* clearly resolved with neither the (monophyletic) Stirling Range Bells, nor the group around *D. helichrysoides*/*D. neildiana*, but rather with a group of unassuming *Darwinia* species of the WA Northern Sandplain and Wheatbelt regions, including *D. purpurea, D. acerosa*, and the undescribed species *D.* sp. Chiddarcooping (S.D. Hopper 6944). Each of these three species is a spreading shrub with upright to sub-pendulous flower heads and short bracts and styles, unlike *D. masonii* which is upright, with pendulous flower heads and long bracts and styles. Optimising morphological characters on the phylogeny, it is clear that both pendulous flowers and long styles and bracts have evolved several times independently in the genus *Darwinia*, presumably to improve pollination success by honeyeaters. *Darwinia masonii* has thus evolved its defining floral characteristics from less specialised forms like *D. purpurea*. Relationships between *D. masonii*, *D. purpurea, D. acerosa*, and *D.* sp. Chiddarcooping were unresolved by either phylogenetic marker, indicating that they are closely related, and possibly speciated allopatrically, through isolation and subsequent adaptation of a previously widespread species.

Summary

- *Darwinia purpurea*, *D. acerosa* and *D.* sp. Chiddarcooping were identified as the taxa most closely related to *D. masonii* and have subsequently been employed as comparison species for several studies in later sections, including genetic diversity analyses and root adaptations.

Lepidosperma gibsonii

Lepidosperma gibsonii was first identified from collected material from Extension Hill. From its discovery in 2006 the taxa was informally named as *Lepidosperma* sp. Mt Gibson (R. Meissner & Y. Caruso 3), but in late 2007 was formally described and published as the new species, *Lepidosperma gibsonii* R.L.Barrett, in a special edition of the journal *Nuytsia* devoted to new BIF associated species (Barrett 2007).

Lepidosperma gibsonii belongs to a morphologically depauperate group of grass-like plants, whose relationships are especially difficult to discern due to the lack of morphological variation. Genetic methods are therefore critical to identify related taxa. *Lepidosperma* species with similar morphology were sampled across south-west WA, focussing on populations within 200 km of MT Gibson. Two genes were used to assess relationships, the nuclear ribosomal External Transcribed Spacer (ETS) and the chloroplast *trn*L inton + *trn*L-*trn*F spacer. The latter proved to be less variable than ETS, and so sampling was less comprehensive for that region, with ETS being used only for subsets of taxa within clades.

The molecular analyses found that *L. gibsonii* was clearly closely related to a group of taxa around *L. costale*, and only more distantly related to the morphologically similar species *L. ferricola*. Further sampling by BGPA has identified populations of the *L. costale* complex from Mullewa and Mt Karara to Paynes Find, south to York and east to near Southern Cross. Both between- and within-population diversity in this species complex can be considerable, and further studies are required to full elucidate their taxonomy. Only *L. gibsonii* can be easily distinguished, being the only member of the complex with rounded, terete (or sub-terete) culms; all other populations have sharply angled stems. A separately-funded project at BGPA has investigated ploidy-level differences within the *L. costale* complex, demonstrating that most populations are tetraploid, some populations are of allopolyploid-hybrid origin, and that diploids are almost entirely restricted to the semi-arid interzone between Mt Gibson, Mt Karara and Wubin (Figure 2). Due to different breeding systems in the tetraploid populations (wholly or partly agamospermous, producing seeds without recombination), only the diploid populations are useful for comparative genetic diversity in *L. gibsonii*.

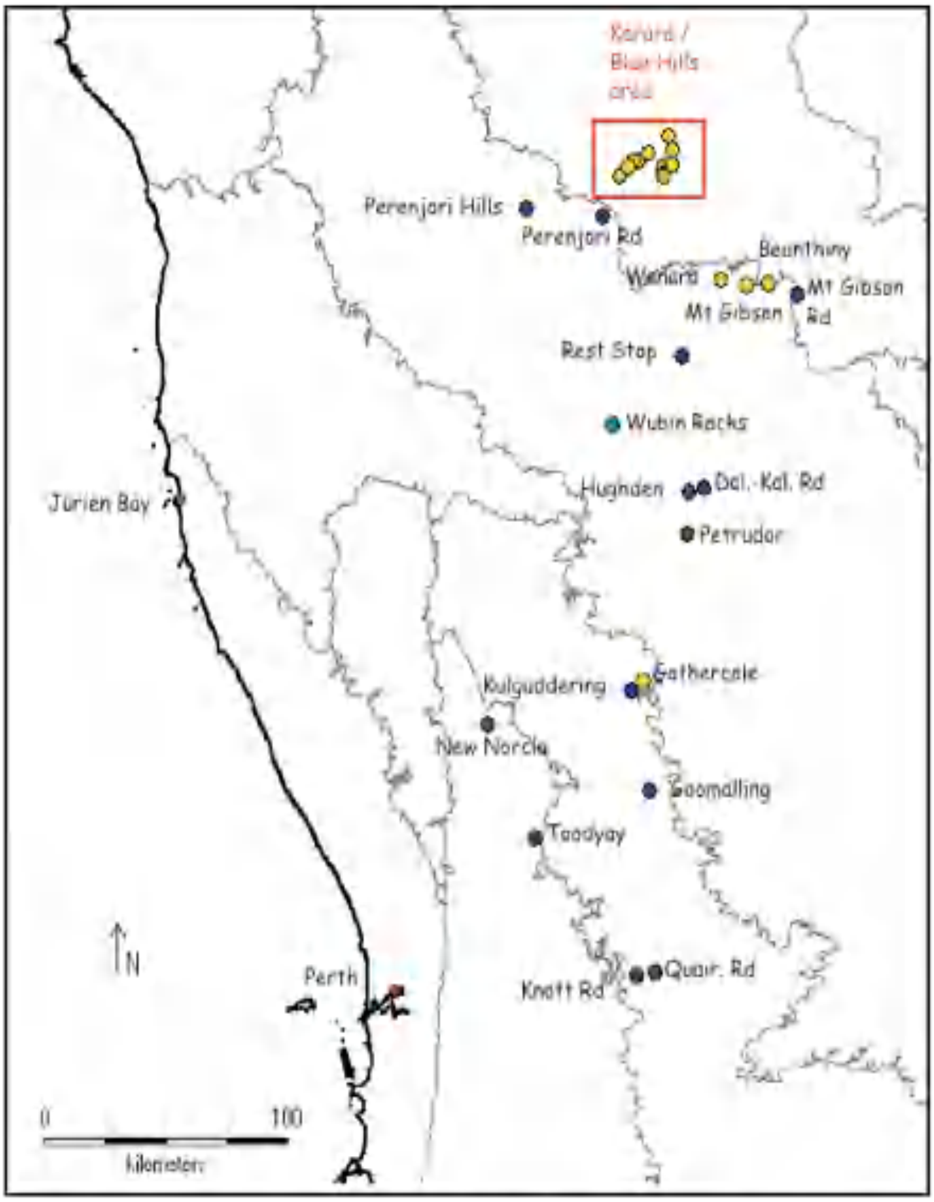

Figure 2. Map of genome content levels within the *Lepidosperma costale* complex. Yellow circles indicate populations with normal (diploid) DNA content. Blue indicates populations containing only individuals with double the normal DNA content per cell (tetraploid). The green circle (Wubin population) contains both diploid and tetraploid plants – extensive study of this population indicates that diploids and tetraploids are physically separated, and only a single triploid ‘hybrid’ was located. Diploid populations presumably gave rise to the now widespread tetraploid lineages, but are now almost confined to the driest area of the distribution of the species-complex. Some populations wholly or partly reproduce by agamospery (producing seeds without recombination). Other tetraploid populations are allotetraploid hybrids, with half the genome having come from a species outside of the *L. costale*-complex (at least two other species have contributed to this process in different locations).

Summary

- *Lepidosperma gibsonii* was described as a new species and formally named, with the conservation status of rare transferred to it from *L.* sp Mt Gibson.

- *Lepidosperma gibsonii* is most closely related genetically to populations of the *L. costale* complex around Mt Karara, Beanthiny Hill and Wubin. Comparisons of genetic diversity and adaptations were concentrated on these species.

4.1b Landscape scale genetic structure

Darwinia masonii

The initial genetic survey of *Darwinia masonii* (BGPA 2005, following a 6-month initial genetic survey) was based on 75 samples from four populations on the Mt Gibson range system, using the AFLP (Amplified Fragment Length Polymorphism) fingerprinting technique. This study found both limited diversity (with 50.6% of markers polymorphic, very low for AFLP), and low population differentiation (AMOVA found that 94% of genetic variation was contained within populations, and just 6% between populations). As recognised in the report, and also raised subsequently by reviewers from the Dept. of Environment and Conservation (DEC), the low variability observed in the AFLP markers lowered the power to test for population differentiation in this species, which was further hampered by insufficient sample size in the preliminary study, both in number of samples and number of populations. As a result, a more powerful genetic fingerprinting technique, simple-sequence repeats (SSR), more commonly known as microsatellites was employed following development of the marker system; this is the same type of genetic marker as used for *Lepidosperma gibsonii*.

SSR (Microsatellite) marker Development

Genomic DNA was extracted in bulk (100 ug of DNA total), and sent to Genetic Identification Services in the US for cutting, inserting into bacterial libraries, cloned, enriched for microsatellite-containing sequences, and sequenced. Microsatellite-containing sequences were then screened for the most appropriate microsatellite motifs (including a range of di- and tri-nucleotide motifs, while avoiding flanking regions containing long mono-nucleotide repeats as they can confound scoring). Primers were developed from the sequences to amplify the target loci, and these primers were screened for amplification reliability, copy number, and degree of stutter (an artefact that can prevent accurate scoring). A total of 14 microsatellite loci were finally produced, which were used in various analyses of genetic diversity and mating system in *D. masonii*.

Population genetic structure

A total of 179 samples from seven populations of *D. masonii* on the Mt Gibson range (Figure 3) were taken from young leaf tips and stored at -178°C in a liquid-nitrogen dry-shipper in the field, then placed in a -80°C freezer awaiting extraction. DNA was extracted following the Carlson-Qiagen extraction procedure as outlined in the Phase One study (BGPA 2005).

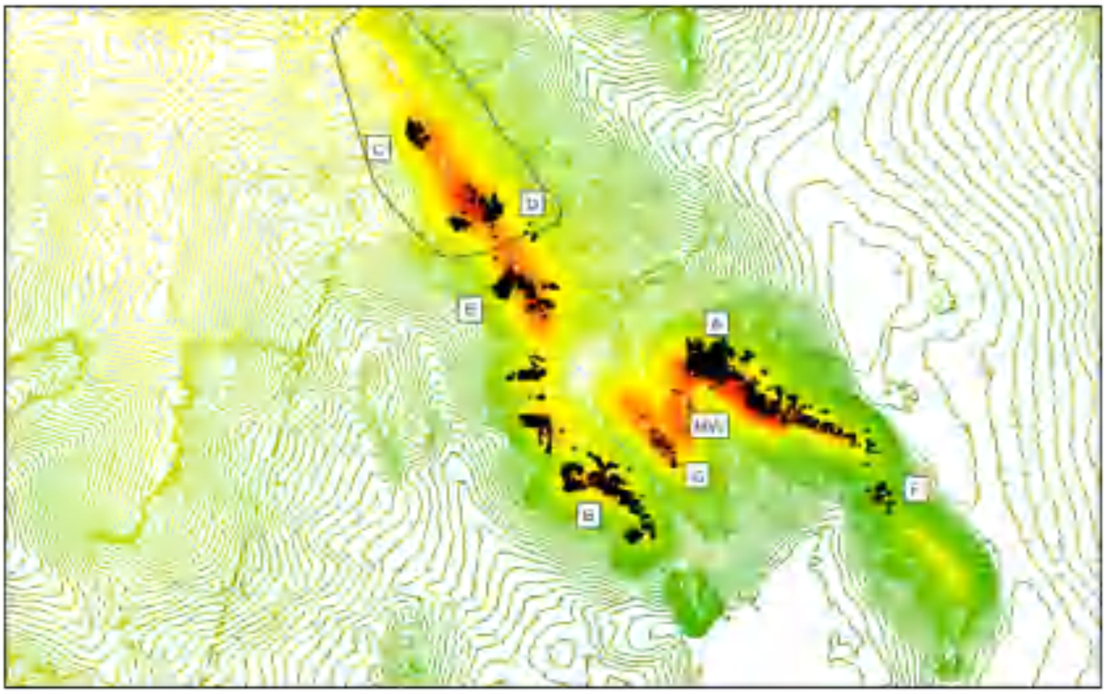

Figure 3. Distribution of *Darwinia masonii* (black dots) on the Mt Gibson range, and collection localities labelled by population code. Codes – A: Mt Gibson, B: Iron Hill, D: Extension Hill, E: Extension Hill South, F: Mt Gibson South, G: Iron Hill East, MW: between Mt Gibson and Iron Hill East. Black line shows approximate position of the pit.

Analysis of Molecular variance partitioned 94% of variation within populations, and 6% between populations, indicating weak population structure (as can be seen graphically in Figure 4, where samples from different populations do not group together, but are instead completely intermixed). This is the same result (6% between-population variation) obtained with AFLP data from fewer populations. In contrast to the previous AFLP study, which showed no significantly genetically distinct populations, pairwise permutation tests (

Table 1) between all populations show that two populations (on Extension Hill South and Mt Gibson South – E and F respectively in Figure 1) are statistically supported (at p< 0.001) as being genetically 'isolated' from each other and all remaining populations. In this context, 'isolated' means not mating randomly with other populations, with number of possible explanations. Aside from these two populations, other populations are scarcely significantly different from a single panmictic, interbreeding population.

Possible causes of divergence within populations: The population Mt Gibson South ("F") is somewhat disjunct and at the southern end of the range, as expected for a population diverging in isolation; however, the population has clearly not been burnt for > 50 years, unlike most other populations, and as a result the observed non-random mating could be an artefact of sampling different generations. The population on Extension Hill South ("E") is close to that the population on Extension Hill, occupies an intermediate position on the western ridge, and the observed result is surprising. The observed weak departure from non-random mating could be due to differences in population age, or some populations could be experiencing differential selection at loci linked to some microsatellite markers. Sampled plants came from a variety of plant ages, fire history, and substrate, as this population extends from almost bare BIF cliffs to laterite at the range base.

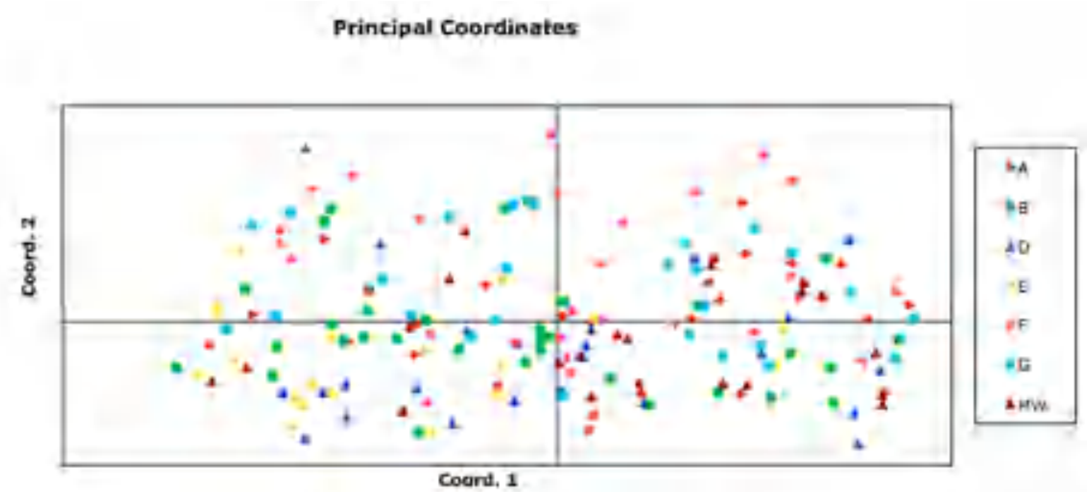

Figure 4 Principal Co-ordinates analyses of samples from seven populations of *D. masonii* showing weak differentiation between localities. Codes as previous figure. In this figure, samples placed close together are more closely related. The figure shows no strong clustering of individuals within populations; formal statistical tests demonstrated that only a few pairwise population comparisons are statistically distinct, with no geographic pattern.

Table 1. Pairwise permutation test of population differentiation. **Bold**: significant at p < 0.001, *italics* significant at p <0.005. Codes – A: Mt Gibson, B: Iron Hill, D: Extension Hill, E: Extension Hill South, F: Mt Gibson South, G: Iron Hill East, MW: between Mt Gibson and Iron Hill East. Populations E and F are significantly supported as departing from random mating with other populations; occasional other pairwise comparisons are also significant.

A	B	D	E	F	G	MW	
	0.001	*0.004*	**0.001**	*0.002*	0.076	0.425	**A**
		0.087	**0.001**	**0.001**	0.048	0.017	**B**
			0.002	**0.001**	*0.002*	0.119	**D**
				0.001	**0.001**	**0.001**	**E**
					0.004	**0.001**	**F**
						0.071	**G**
							MW

Population genetic diversity – within D. masonii

Expected heterozygosity, and fixation Index was estimated for all seven sampled *D. masonii* populations (Table 2). All were very similar in levels of diversity (Unbiased Heterozygosity estimates vary between 0.600-0.657). Fixation index for the species was 0.105 ± 0.024, indicating a low but significant level of inbreeding. This result is further corroborated below (section **4.3e Breeding and Mating systems**).

Table 2. Heterozygosity and fixation index estimates from populations of *Darwinia masonii.* Population codes as previous tables and figures.

Pop	Ho	He	UHe	F
A	0.487 ± 0.09	0.593 ± 0.115	0.605 ± 0.117	0.144 ± 0.041
B	0.59 ± 0.102	0.647 ± 0.109	0.657 ± 0.111	0.066 ± 0.048
D	0.474 ± 0.106	0.601 ± 0.123	0.614 ± 0.126	0.216 ± 0.057
E	0.657 ± 0.092	0.625 ± 0.088	0.642 ± 0.091	-0.067 ± 0.056
F	0.537 ± 0.094	0.629 ± 0.089	0.64 ± 0.091	0.172 ± 0.076
G	0.566 ± 0.126	0.63 ± 0.104	0.642 ± 0.106	0.149 ± 0.089
MW	0.533 ± 0.11	0.586 ± 0.117	0.6 ± 0.12	0.077 ± 0.031
Total	0.549 ± 0.037	0.616 ± 0.037	0.629 ± 0.038	0.105 ± 0.024

Population genetic diversity – comparison with other species

The preliminary genetic survey was unable to adequately reference the “low” AFLP variation due to the lack of a comparable study in *Darwinia*. It has been suggested that low chromosome number can decrease genetic variability (e.g. Diuris, Indsto et al 2009); since *Darwinia* species are known to show a dysploid chromosome-reduction series (Rye 1981, Rye & James 1990), this is one possible reason for the low observed diversity; the alternative hypothesis is a past low population size (population bottleneck) which caused loss of genetic diversity. The inability to distinguish between these scenarios was raised as a significant concern by DEC reviewers of the preliminary report. It was therefore necessary to reference the diversity in *D. masonii* with another species. Following the discovery through the phylogenetic research above, it was decided to use the closest relative of *D. masonii*, *D. purpurea*, as the comparative species. *Darwinia purpurea* is a relatively widespread species of sandplain and gravel soils, extending from near Perenjori and Mt Gibson South-East to about Warralakin (with a single disjunct population c. 80 km north of Mt Gibson at Kirkalocka Station on an isolated yellow sand lens). The potentially distinct species known by the informal phrase-name "*Darwinia* sp. Chiddarcooping (S.D. Hopper 6944)" was also included, due to apparent intergrades between it and *D. purpurea*, and the tendency for it to grow in isolated populations on granite rocks, and might therefore be a more appropriate comparison for *D. masonii* than the less habitat-constricted *D. purpurea*. The relative distribution of these species, and the related *D. acerosa*, is shown in Figure 5

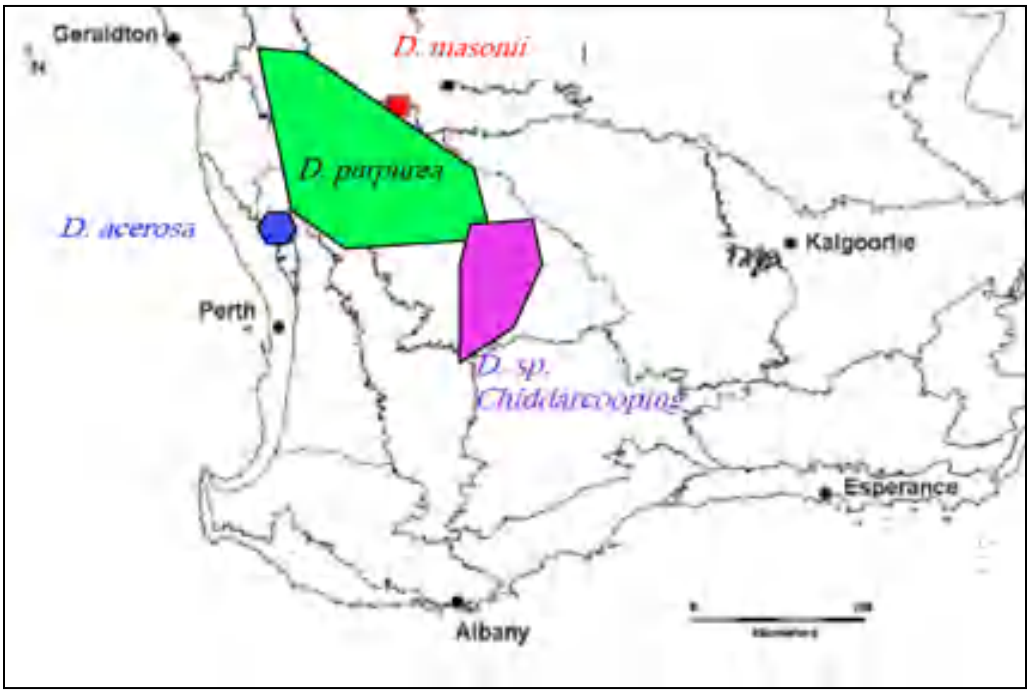

Figure 5. Distribution of *Darwinia masonii* and closely related species: *D. purpurea, D. acerosa* and *D.* sp. Chiddarcooping.

A total of 401 plants from thirteen populations of the *D. purpurea* / *D*. sp. Chiddarcooping species-group were sampled (Table 3), and genotyped using the microsatellite loci described above. Genetic diversity within and between these populations were compared to the diversity in all sampled *D. masonii* populations (as referred to above). Only one population of *D. masonii* (Iron

Hill) was used in the all-taxa population structure analysis (PCA) to allow comparisons of similar sampling numbers and sampling density (Figure 6).

Table 3 Average genetic diversity within sampled populations of *Darwinia masonii*, *D. purpurea* and *D. sp.* Chiddarcooping.

Population	Ho	He	UHe	F
		***D. sp. Chiddarcooping* populations**		
Corrigin	0.111 ± 0.049	0.214 ± 0.093	0.217 ± 0.094	0.365 ± 0.116
Billy	0.693 ± 0.058	0.750 ± 0.055	0.762 ± 0.056	0.077 ± 0.028
Chidd	0.670 ± 0.063	0.661 ± 0.058	0.672 ± 0.059	-0.020 ± 0.054
Wara	0.498 ± 0.093	0.651 ± 0.047	0.662 ± 0.048	0.243 ± 0.128
		***Darwinia purpurea* populations**		
Yorkrak	0.583 ± 0.059	0.670 ± 0.051	0.684 ± 0.052	0.109 ± 0.094
Burakin	0.722 ± 0.024	0.794 ± 0.024	0.807 ± 0.024	0.088 ± 0.035
Koorda	0.674 ± 0.093	0.762 ± 0.081	0.775 ± 0.082	0.103 ± 0.082
Korakadine	0.566 ± 0.086	0.577 ± 0.088	0.587 ± 0.090	0.007 ± 0.030
Ballidu	0.722 ± 0.027	0.775 ± 0.050	0.791 ± 0.051	0.056 ± 0.045
Dal-Kal	0.741 ± 0.069	0.758 ± 0.057	0.775 ± 0.058	0.029 ± 0.030
Bunjil	0.396 ± 0.090	0.434 ± 0.084	0.444 ± 0.087	0.184 ± 0.180
Latham	0.645 ± 0.080	0.684 ± 0.071	0.696 ± 0.072	0.066 ± 0.039
Wubin	0.806 ± 0.027	0.801 ± 0.034	0.822 ± 0.035	-0.008 ± 0.019
		***Darwinia masonii* populations**		
A	0.487 ± 0.09	0.593 ± 0.115	0.605 ± 0.117	0.144 ± 0.041
B	0.590 ± 0.102	0.647 ± 0.109	0.657 ± 0.111	0.066 ± 0.048
D	0.474 ± 0.106	0.601 ± 0.123	0.614 ± 0.126	0.216 ± 0.057
E	0.657 ± 0.092	0.625 ± 0.088	0.642 ± 0.091	-0.067 ± 0.056
F	0.537 ± 0.094	0.629 ± 0.089	0.640 ± 0.091	0.172 ± 0.076
G	0.566 ± 0.126	0.630 ± 0.104	0.642 ± 0.106	0.149 ± 0.089
MW	0.533 ± 0.110	0.586 ± 0.117	0.600 ± 0.120	0.077 ± 0.031
Total	0.549 ± 0.037	0.616 ± 0.037	0.629 ± 0.038	0.105 ± 0.024

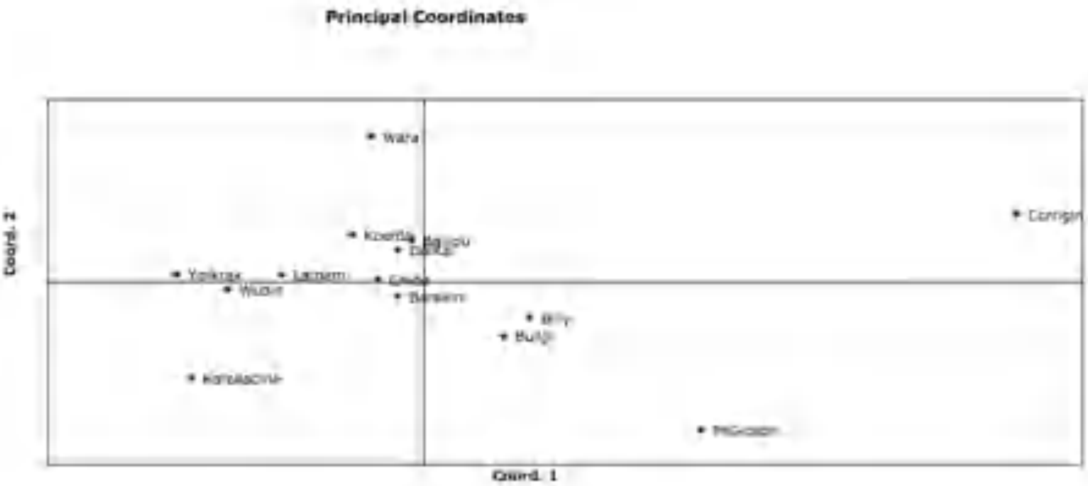

Figure 6 PCA analysis showing genetic relationships among sampled populations of *Darwinia purpurea*, *D. sp.* Chiddarcooping and *D. masonii* (as “Mt Gibson“), using Nei’s genetic distance as a measure of divergence between populations. In this figure, sites located close together are more closely related. The two most divergent populations are the Corrigin population, which may represent a distinct species, and

D. masonii, with the *D. purpurea* and *D.* sp. Chiddarcooping populations forming a cluster, with little differentiation between the two species.

Results: Darwinia masonii contains comparable (but slightly lower than average) microsatellite diversity relative to other populations in this species-group (Table 3). For example unbiased heterozygosity estimates in *D. masonii* range between 0.600 and 0.657, compared with 0.587-0.807 for *D. purpurea / D.* sp. Chiddarcooping populations, (excluding two populations with abnormally low diversity discussed next). The only two populations showing a significant reduction in genetic diversity were the Corrigin and Bunjil populations. The Bunjil population is in a small, highly disturbed patch of remnant vegetation with only a few scattered plants, and has presumably lost some of its diversity through recent reduction in population size. The Corrigin population is restricted to a small area on a single granite rock, contains less than 100 plants, and is geographically disjunct from other members of the *D. purpurea / D.* sp. Chiddarcooping complex. It also shows morphological differences to all other populations and species of *Darwinia*, and may warrant recognition as a distinct species. In the context of this study it serves as a reference comparison as a population that has presumably lost much of its genetic diversity though inbreeding due to small population size (an alternative hypothesis is that a rare long-distance dispersal event occurred, and that the Corrigin population is showing the effects of a recent founder population; however, given the number of unique alleles in this population, and the divergent morphology of its individuals, it is more likely to be a in isolated relictual population).

Darwinia masonii shows no indication of recent inbreeding depression, unlike the Bunjil and Corrigin populations discussed above.

Summary

- The more powerful tests of population-genetic structure carried out here (relative to the earlier study) is mostly in agreement with the preliminary result using a different marker technique, especially in the level of population differentiation observed.

- In general, there appears to be little genetic structuring between populations of *Darwinia masonii*, (94% of genetic variation is partitioned within populations) . However pairwise tests show that some populations are statistically supported as non-randomly mating with other populations with the more powerful microsatellite analysis. This suggests that there are some barriers to complete gene flow across the Mt Gibson range system, and that the precautionary principle should apply to avoid mixing genotypes between populations without careful consideration of consequences.

Lepidosperma gibsonii

The initial genetic survey of *Lepidosperma gibsonii* (BGPA 2006, following a 3-month initial genetic survey using microsatellites developed for that study) was based on 145 samples from seven populations on the Mt Gibson range system. This study found high levels of microsatellite variation, and low population differentiation (AMOVA analyses partitioned 98% of genetic variation within populations, and just 2% between populations).

Subsequently to that report, several populations of *Lepidosperma* were found by BGPA staff, and surveyed by ATA environmental / Coffey Environments (populations EFN, EFS, WC, WD and MGS in Figure 7). These populations were off the Mt Gibson Range, except in the case of the population on Mt Gibson South, at the extreme southern end of the range; all were in habitats not initially recognised as being suitable for *L. gibsonii*, and so were not discovered in the initial, extensive but time-limited survey.

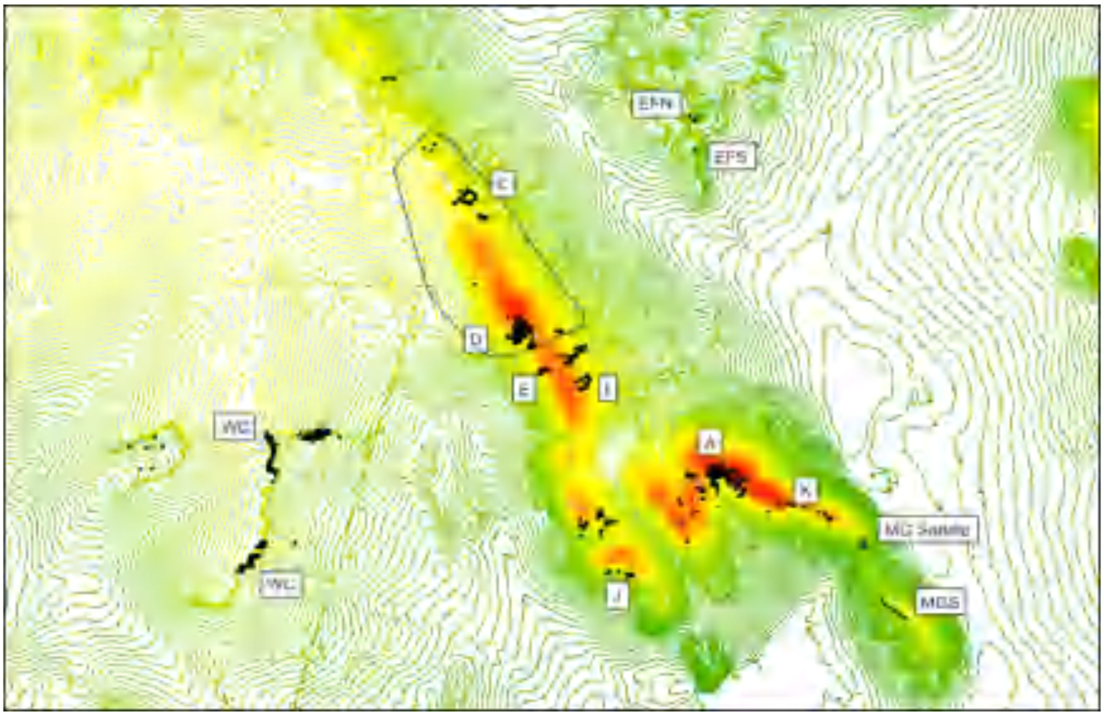

Figure 7. Distribution of *Lepidosperma gibsonii* (black dots), showing populations sampled in the genetic survey, and population codes: A - Mt Gibson, C- Extension Hill North, D – Extension Hill, E – Extension Hill South (west side), I - Extension Hill South (east side), J – Iron Hill, K – Mt Gibson (south end), MG Saddle – Saddle between Mt Gibson and Mt Gibson South, MGS – Mt Gibson South, EFN – Emu Fence North, EFS – Emu Fence south, WC – western breakaway north end, WD – western breakaway south end. Black line shows approximate position of the pit.

Samples from an additional six populations were collected, and genotyped using the procedure developed earlier. A total of 292 samples from 13 populations were analysed for population genetic structure (the degree of differentiation between populations, indicating the degree of dispersal of pollen and pores between populations), and diversity.

Population structure

Analysis of Molecular variance partitioned 96% of variation within populations, and 4% between populations, indicating weak population structure (as can be seen graphically in Figure 8, where samples belonging to the same population do not group together, but are instead completely intermixed, ie. individuals are just as closely related to individuals in other populations as they are to individuals in the same population). In contrast to the previous study, which examined half the number of populations and showed no significantly genetically distinct populations, pairwise permutation tests between populations (Table 4) show a few significant comparisons, in particular from that population on Mt Gibson Saddle, (MGSaddle respectively in Figure 7) which is statistically supported (at $p< 0.001$) as being genetically 'isolated' from nearly all remaining populations. In this context, 'isolated' means not mating randomly with other populations, due to a number of possible explanations. The most likely explanations are physical isolation, inbreeding in small populations, or strong selection at one or more linked loci. The population at the Mt Gibson Saddle is only moderately isolated from other populations, and geographically intermediate between populations that are genetically uniform. Neither of the populations (C and D) to be impacted by the pit on Extension Hill are supported as genetically distinct from other populations (except the Mt Gibson Saddle population as previously discussed, and also the population on the southern end of Extension hill from populations at the extreme end of the range (Mt Gibson and Mt Gibson South).

Table 4 Pairwise permutation test of population differentiation. **Bold**: significant at $p < 0.001$. Codes – MG - Mt Gibson, C- Extension Hill North, D – Extension Hill, E – Extension Hill South (west side), I - Extension Hill South (east side), J – Iron Hill, K – Mt Gibson (south end), MG Saddle – Saddle between Mt Gibson and Mt Gibson South, MGS – Mt Gibson South, EFN – Emu Fence North, EFS – Emu Fence south, WC – western breakaway north end, WD – western breakaway south end.

EFN	EFS	D	C	I	J	K	MG	MGS	MGSaddle	WC	WD	
0.001	0.012	0.002	0.004	0.109	0.165	0.257	0.038	0.005	**0.001**	0.007	0.050	**E**
	0.193	0.003	0.031	0.005	0.029	0.066	0.002	0.010	**0.001**	0.001	0.023	**EFN**
		0.004	0.007	0.022	0.038	0.098	0.082	0.020	**0.001**	0.010	0.079	**EFS**
			0.045	0.082	0.004	0.156	**0.001**	**0.001**	**0.001**	0.005	0.074	**D**
				0.055	0.026	0.282	0.025	0.008	**0.001**	0.044	0.239	**C**
					0.047	0.435	0.065	0.012	**0.001**	0.068	0.301	**I**
						0.435	0.422	0.374	**0.001**	0.289	0.430	**J**
							0.450	0.412	0.002	0.424	0.409	**K**
								0.138	**0.001**	0.127	0.288	**MG**
									0.001	0.023	0.085	**MGS**
										0.001	**0.001**	**MGSaddle**
											0.422	**WC**

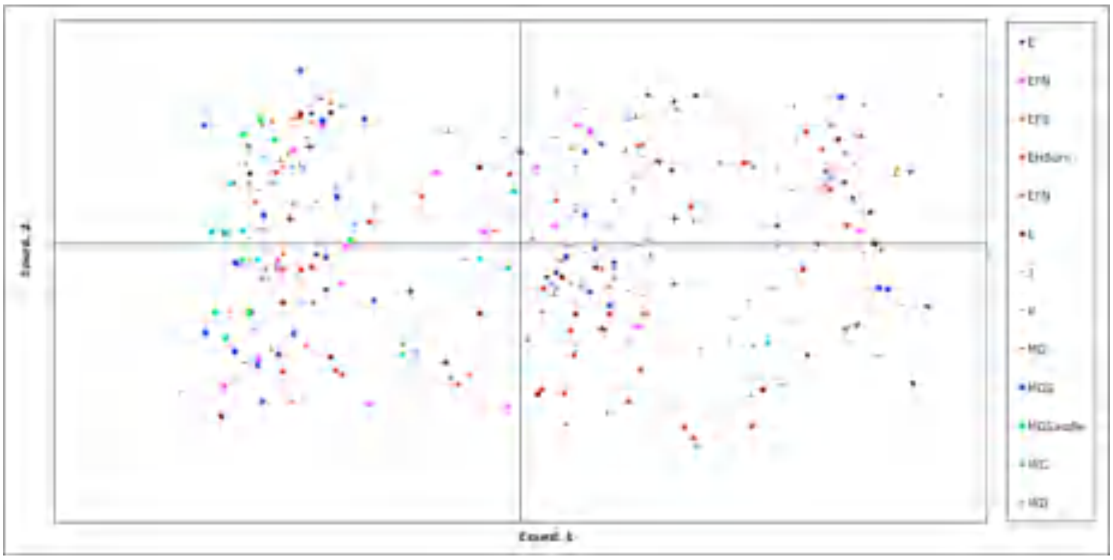

Figure 8. Principle coordinates analysis of samples from 13 populations of *Lepidosperma gibsonii*. Population codes as for the map in Figure 7. In this figure, samples placed close together are more closely related. The figure shows no strong clustering of individuals within populations; formal statistical tests demonstrated that only a few pairwise population comparisons are statistically distinct, with no geographic pattern.

Population genetic diversity and comparison with other species

Observed and expected heterozygosity, and fixation Index was estimated for all sampled *L. gibsonii* populations (Table 4). All were very similar in levels of diversity (Unbiased Heterozygosity estimates vary between 0.507-0.759). Fixation index for the species was 0.175 ± 0.026, suggesting a low but significant level of inbreeding.

In order to have a baseline comparison for the level of genetic diversity in L. gibsonii, several populations belonging to the *Lepidosperma costale* complex were sampled. A total of 88 plants from four populations of the *L. costale* complex were obtained, and confirmed as diploid in order to allow comparison of microsatellite data (tetraploids, with double the normal DNA content, are difficult to compare with diploid species, since they have four rather than 2 alleles per locus; in addition, tetraploid *Lepidosperma* have been shown to reproduce partly or wholly by agamospermy, and so show very different mating patterns to diploid populations). Several measures of heterozygosity and fixation index are reported in (Table 3). Genetic diversity within and between these populations/species is comparable with that observed in populations of *L. gibsonii*. Since sampled populations of both L. gibsonii and *L. costale* sens. lat. were sometimes quite small (e.g. populations EFN and Beanthiny Hill, where the c. 25 sampled plants represent most or a significant portion of the entire population), it is surprising that there is not greater evidence of inbreeding and population bottlenecks, suggesting either that gene flow is high over the scale of these population (quite possible given the wind-dispersed pollen), or that the current small populations are relicts of past populations, and their observed diversity is due to persistence of plants dating from a period of greater population size.

Table 5. Average genetic diversity within sampled populations of *Darwinia masonii*, *D. purpurea* and *D. sp.* Chiddarcooping.

Population	Ho	He	UHe	F
	***Lepidosperma gibsonii* populations**			
E	0.547 ± 0.076	0.713 ± 0.043	0.731 ± 0.045	0.240 ± 0.079
EFN	0.590 ± 0.082	0.621 ± 0.070	0.635 ± 0.072	0.044 ± 0.072
EFS	0.535 ± 0.113	0.649 ± 0.045	0.673 ± 0.046	0.182 ± 0.163
D	0.528 ± 0.080	0.692 ± 0.038	0.701 ± 0.038	0.242 ± 0.090
C	0.541 ± 0.085	0.652 ± 0.058	0.668 ± 0.060	0.170 ± 0.095
I	0.638 ± 0.083	0.733 ± 0.033	0.749 ± 0.033	0.135 ± 0.096
J	0.583 ± 0.090	0.638 ± 0.052	0.657 ± 0.053	0.108 ± 0.097
K	0.625 ± 0.100	0.727 ± 0.039	0.759 ± 0.041	0.149 ± 0.116
MG	0.587 ± 0.090	0.643 ± 0.058	0.660 ± 0.059	0.102 ± 0.102
MGS	0.501 ± 0.085	0.642 ± 0.068	0.655 ± 0.069	0.244 ± 0.088
MGSaddle	0.407 ± 0.072	0.493 ± 0.076	0.507 ± 0.079	0.185 ± 0.034
WC	0.542 ± 0.069	0.688 ± 0.024	0.701 ± 0.025	0.212 ± 0.096
WD	0.508 ± 0.072	0.684 ± 0.037	0.696 ± 0.037	0.261 ± 0.098
Total	*0.549 ± 0.022*	*0.660 ± 0.014*	*0.676 ± 0.015*	*0.175 ± 0.026*
	***Lepidosperma costale* complex**			
Blue Hills 1	0.454 ± 0.117	0.565 ± 0.098	0.576 ± 0.100	0.243 ± 0.114
Blue Hills 2	0.548 ± 0.159	0.626 ± 0.112	0.640 ± 0.114	0.088 ± 0.173
Beanthiny Hill	0.595 ± 0.107	0.699 ± 0.040	0.715 ± 0.041	0.176 ± 0.109
Wanara Rd	0.535 ± 0.134	0.609 ± 0.096	0.638 ± 0.101	0.239 ± 0.180

Clonality

Clumps of *L. gibsonii* are not necessarily a single genetic individual. The density of seedlings as reported elsewhere in this document raises the possibility of coalescence and intermingling of individuals as they clonally spread laterally by rhizomes. In order to determine the extent of clump coalescence, and the effect on census vs actual population size, a total of 213 samples were taken from 39 clumps of random sizes (excluding very small clumps clearly composed of ramets from a single individual), from 3 separate populations and genotyped using the microsatellite loci described above.

Results: A total of 49 individuals were detected amongst the 39 clumps, assuming correct assignment of individuals (which seems likely, as all 'individuals' recognised had at least 2 differences from other genotypes). Each clump was composed of between 1-3 individuals, with an average 1.25 individuals per clump.

Conclusions: The current population census of *Lepidosperma gibsonii* is approximately 1.25 times greater than currently estimated, assuming the observed ratio of intermingled clumps is similar in unsampled populations. Any investigations requiring complete mapping of individuals (e.g. mating studies) requires exhaustive genetic sampling within clumps to identify all individuals.

Partial clump death, after fire or drought, which has been observed in some individuals, may kill one or more genetic individuals, without complete death of the 'clump'. It is therefore likely that *Lepidosperma* death rates from fire and drought are underestimates (by 0-25%), since even a single resprouting ramet (and therefore a single individual) may be scored as survival of the clump, overlooking potential death of co-habiting individuals.

Summary and recommendations

- The increased population sampling (due to the discovery of more populations of *L. gibsonii* since the preliminary study) largely agrees with the preliminary results, although a slightly higher level of genetic population structure was observed (94% variation within populations vs 985 variation within populations).

- While there is little genetic structuring between populations of *L. gibsonii*, pairwise tests show that some populations are statistically supported as non-randomly mating with other populations. This suggests that there are some barriers to complete gene flow across the Mt Gibson range system, and that the precautionary principle should apply to avoid mixing genotypes between populations without careful consideration of consequences.

- The current population size of *L. gibsonii* is estimated to be 1.25 times greater than the current census, due to multiple genetic individuals within some clumps.

- Some measures of survival (e.g. from fire or drought) could be over-estimates by up to 25% due to unobserved loss of multiple genetic individuals from compound clumps.

- Any investigations requiring complete mapping of individuals (e.g. mating studies) requires exhaustive genetic sampling within clumps to identify all individuals.

4.1c Monitoring genetic threats

Baseline data on levels of genetic diversity within populations, relatedness among populations, the extent of inbreeding observed in populations, the processes contributing to inbreeding and the fitness costs of inbreeding was obtained and is described in sections **4.1b** and **4.3e**. These results do not indicate any level of inbreeding depression due to past bottlenecks. This data can be compared to future population (e.g. following translocation, regeneration after fire or catastrophic events) to detect departures from "normal" processes, e.g. pollinator effectiveness in reduced or translocated populations, or lowered outcrossing rate in small, isolated populations.

4.2 POPULATION DEMOGRAPHY

The demography of populations of *D. masonii* and *L. gibsonii* was studied by monitoring tagged plants in permanently marked plots. The initial tagging and measuring of plants for survey commenced in June/July 2007 and surveys were repeated in subsequent winters. Four extra plots were added in May 2009 within the boundary of a small experimental fire (12 May 2009) at the northern end of Extension Hill South. New seedlings observed in plots over the course of monitoring were mapped, tagged and measured in the same way as other plants. In each plot, plants were labelled with uniquely numbered aluminium tags and mapped to 1-5cm accuracy within an x-y system in each plot. Site factor data associated with plots was also recorded: GPS locality, estimated slope and aspect (later confirmed from GIS - DEM derived maps), estimated fire age (later confirmed from air photo analysis), landscape position (gully, ridge, slope..), mean vegetation height, community composition, estimated vegetation cover (subsequently confirmed by hemispheric photo image analysis), surface % cover of litter, rock, gravel, bare ground, soil crusts (lichen, algae, mosses). Soil samples were also collected for chemical analysis tests, performed at the WA Chem Lab, included electrical conductivity, pH, % organic Carbon, total N and 18 other major elements (of which, Mo, Cd, Se and As concentrations were at or below the limit of reporting and are therefore not presented)

Survey plots were located at six principal locations; both species were surveyed on Mt Gibson, Iron Hill and Extension Hill South, while plots for *Lepidosperma gibsonii* were additionally located at Iron Hill North and close to the Emu Fence (on duricrust; the only non-BIF locality surveyed) and three *D. masonii* plots were placed on Mt Gibson South (Figure 11).

The June/July census date was initiated to commence data collection soon after project startup and to enable 3 years of data collection within the project period, running from May 2007 to June 2010. In addition to the midwinter demography survey this program necessitated an early summer survey for seed production. However, as winter is the main growing season, a census in winter is not ideal as it means each census period, while incorporating one full summer, includes parts of two different winter growing periods. It is suggested that for future monitoring, the census date is moved to late spring. This would clarify the interpretation of the census year (to include all of one growth season not halves of two) and to reduce field survey effort (by combining seed and demography surveys). Three midwinter censuses have been completed from 2007, and the 2101 census is proposed for early summer.

Fire history

A fire history map was constructed for the region from air photo runs from 1968, 1974, 1990, 1996, 2000 and 2005. These were of varying scales, but mostly of high quality. Also utilised, were medium-low resolution satellite images from 1965-67, 1972, 1989, 2000 and 2004 and the high quality recent imagery from Google Earth (http://earth.google.com/). Other sources of fire history data used include Sentinel (MODIS hotpot data from Geosciences Australia, from 2003; http://sentinel.ga.gov.au), DEC preliminary fire mapping (1970-2005 – based on Landsat imagery), Landgate (from 1997: http://firewatch.landgate.wa.gov.au/), as well as personal observations of various workers, notes from literature and photographs. Each of these sources fails in at least one respect be either not recording all fires, accurately mapping boundaries or correctly identifying fire dates.

While these sources do not always agree, the best model of fire history since the mid 1960’s (Figure 10) describes just four major fires on the Mt Gibson range and several others nearby. Scars for the two recent fires are clearly visible on images dating from 2004 and 2005, and these can be accurately dated from Sentinel to 7-10th February 2003 and from personal communications to December 2005. The two previous fires are attributed to 1972 and 1969 are visible on high resolution images up to the present, and dating back to 1972. Evidence supporting the dates of these fires include their absence from the 1968 photo, presence in 1972 and relative freshness apparent in the two fire scars in the 1972 and 1974 images (Figure 9). While it is recognised that this dating may be imprecise, variation of a year or two is relatively insignificant relative to the subsequent 40 years of growth of plants subsequently. In fact only one of these fires appears to have burnt surveyed populations of *D. masonii* or *L. gibsonii*, although the 1972 fire may have burnt populations of *L. gibsonii* to the west of the Mt Gibson range.

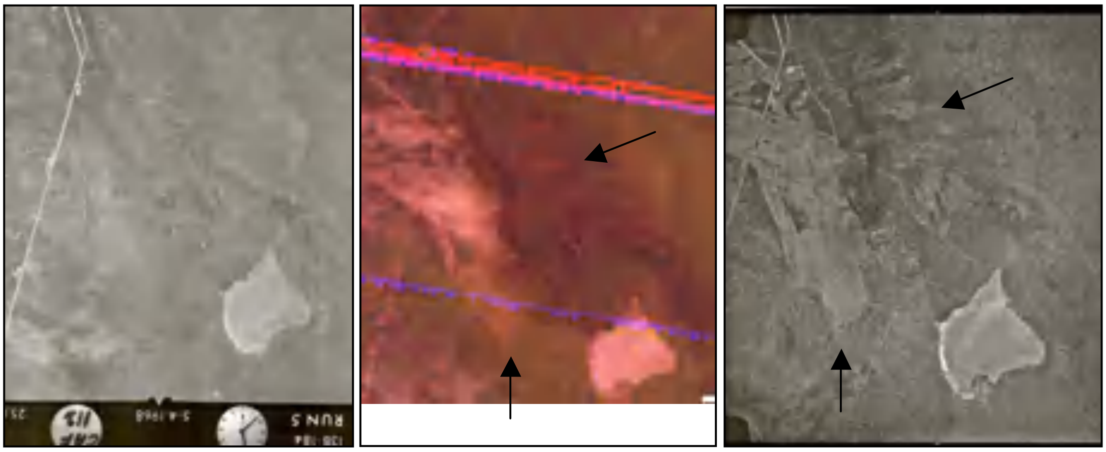

Figure 9. Air photo images from April 1968 (left) and December 1974 (right) with a LandSat image from 1972 (middle). Major identifiable features include the salt playa to the south of Mt Gibson in the bottom right of each image, the Great Northern Highway in the west, with the airstrip, built between 1968 and 1972 in the north west. No nearby fire scars are apparent on the 1962 image, but two are apparent on both the 1972 image: the '1972' fire is indicated by the lower arrow, and the '1969' fire scar by the upper arrow). The outlines of both fires are clearer in the 1974 image, with the '1972' fire most apparent.

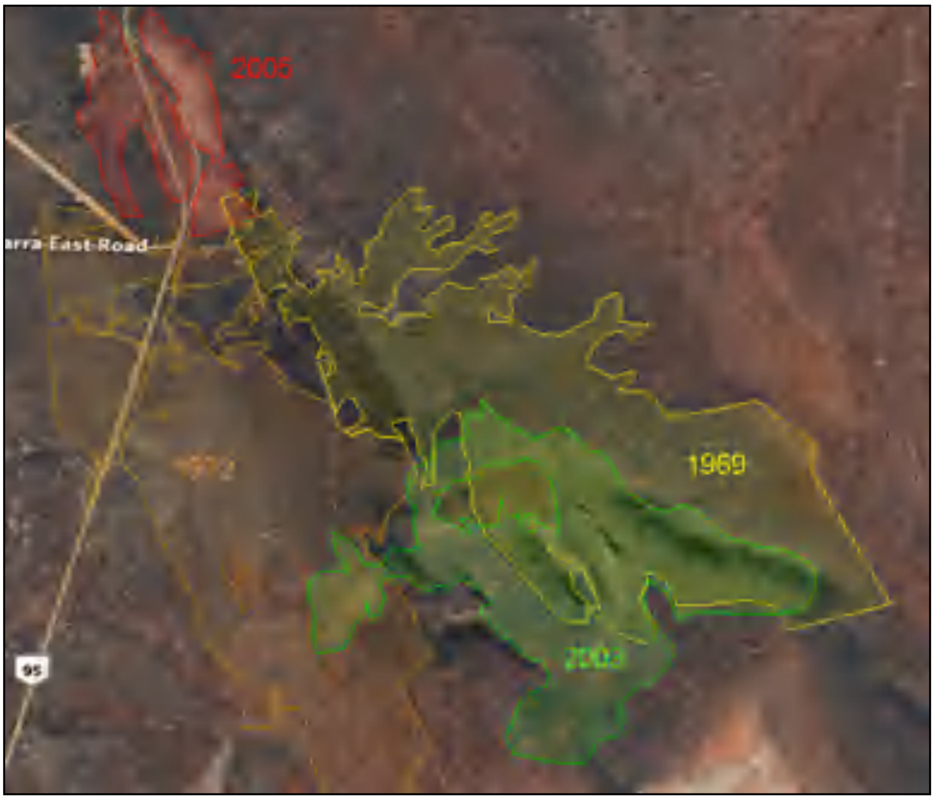

Figure 10. Mt Gibson-Extension Hill fire history; 1968-2010

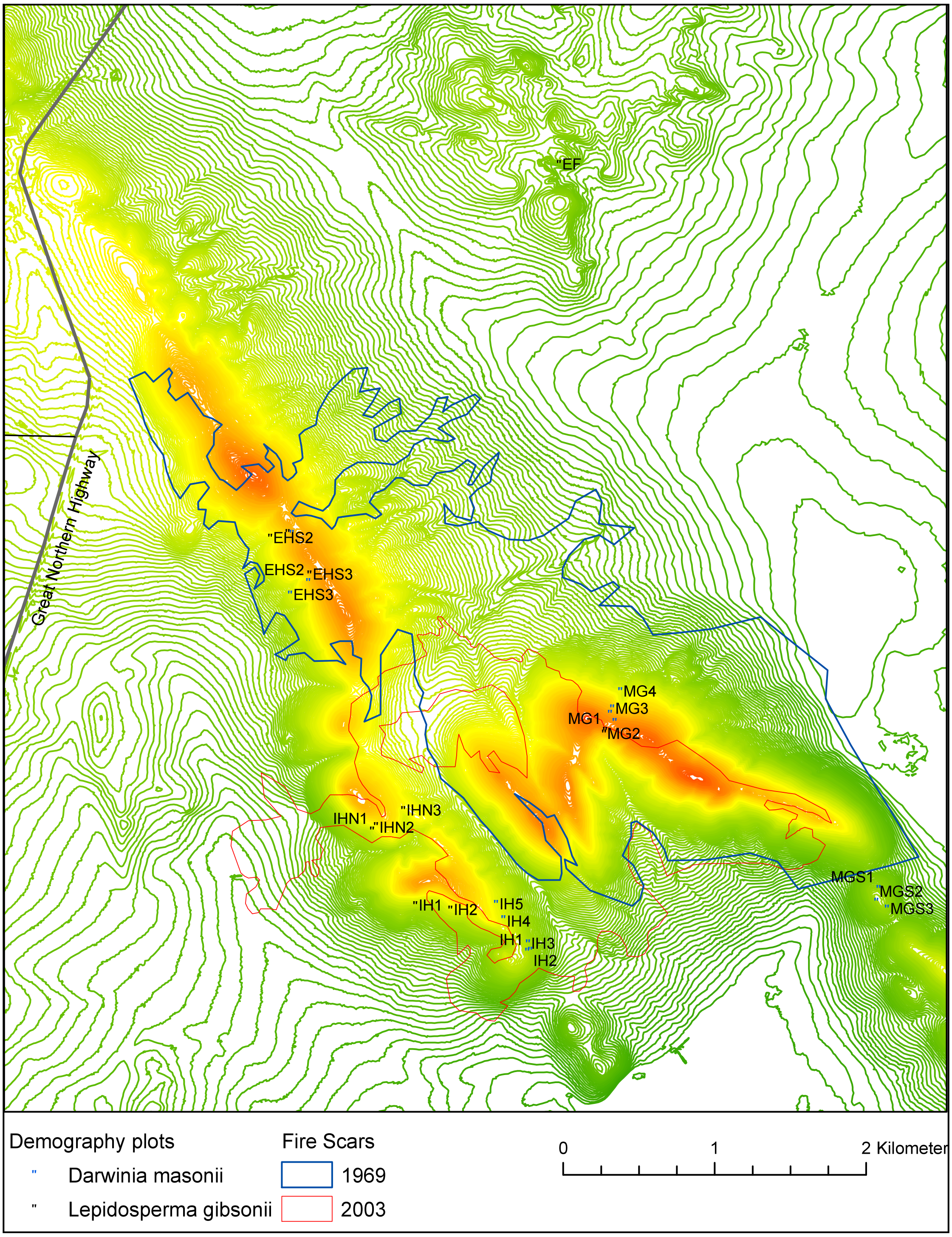

Figure 11 Location of permanent population demography monitoring plots in relation to fire history and topography (contours at 1m intervals).

Thus, fires on the Mt Gibson range fall into two periods, ‘recent’ (2003/2005), when the north of Extension Hill and the South West part of the range burnt, and older (1969/1972), when the central and western parts of the range burnt. As a result, most of the range was last burnt either 2 or 5 years prior to the project’s start in 2007, or ~35-40 years prior, or long unburnt (parts of

Extension Hill and Iron Hill). As there is little overlap in fire scars, fire interval cannot be calculated for most of the range: the main exception is for a region between Mt Gibson and Iron Hill East which burnt in 2003 after an interval of ~ 34 years. All other areas have had fire intervals of not less than 42-35 years, but as no scars are visible on the 1968 image, and with a conservative estimate of the period for which scars are visible, this minimum previous interval estimate is more likely >50 years. Evidence from demographic studies (below) suggest a much longer period.

Some important issues in this fire history analysis must be noted. Firstly, the map focuses on the range itself and there is some uncertainty at the range's extremities, with evidence that some of the mapped fires may have extended to areas of Mt Gibson South and Extension Hill North that are not fully mapped. Some smaller areas within mapped fire boundaries are known or suspected to have not burnt. Finally, notes from various workers in the mid 1990s report inference of fires from the previous 1 – 10 years, but these inferences are not borne out in the 1996 (or subsequent) air photo series. These notes derive from observations of the state of development of vegetation, which our own experience reveals to be misleading – our initial fire age estimates were proven to underestimate fire dates by as much as 50%.Demographic results are described in terms of the fire histories as indicated in Figure 11. The fire history of the Emu Fence and Mt Gibson South plots is unknown, but presumably these sites are long unburnt. Similarly the *L. gibsonii* plots on Iron Hill are not known to have burnt since the late 1960s at the earliest (the LIH2 plot is located in a small, clearly unburnt patch embedded in the 2003 fire). These sites are described as 'old', or 'long-unburnt'.

All Extension Hill South and Mt Gibson plots occur within the 1969 fire boundary, but two of these – *D. masonii* DMG2 and DMG3 – have a population structure, including very large stem sizes, which are taken to indicate that these rocky and open sites did not burn in that fire. As well as burning in the 1969 fire, the two Mt Gibson *L. gibsonii* plots were additionally burnt in 2003. The five remaining *D. masonii* and three *L. gibsonii* sites (Iron Hill and Iron Hill North) were also all burnt in the 2003 fire and were therefore 4 years old at the time of their first survey (into their fifth growing season).

The two oldest fire ages (i.e. 1969 and <1968) are collectively described as 'older' or 'mature' sites, while the 2003 fire sites may be described as 'young' or (in the case of *D. masonii*, 'seedling') sites.

Climate history

Climate data (chiefly rainfall) exists for several weather stations in the region of the Extension Hill – Mt Gibson Range (Figure 12a). Several stations have very long records (e.g. Ninghan, to 1905), others have opened and closed at different times, and many have missing data for various periods (e.g. Ninghan in 1909, 1968, 1971 and 1972). One rainfall record operated between 1970 and 1972 at ‘Mt Gibson’, possibly at Iron Hill while the adit there was being worked. The closest operating rainfall records are from Ninghan Station, while Mt Gibson Station (distinct from ‘Mt Gibson’) records missed parts of 2009 and 2010. In 2009, BGPA purchased and installed an automated climate station near the summit of Mt Gibson close to monitored populations of *D. masonii* and *L. gibsonii*. The closest current (non-BOM) records are from the Mt Gibson gold mine camp, which indicate a mean of 240 mm in the decade from 1999. Regionally, rainfall averages between 350 mm (at Dalwallinu) and 284 mm (Paynes Find) - (Figure 12b).

Regional rainfall over the study period (Figure 13) included two years of average to above average rainfall (2008 and 2009) and two below average years (2007 and 2010). While 2010 still has some months remaining, rainfall totals to October are, for a number of nearby stations, amongst the lowest on record. By October 2010, BGPA’s Mt Gibson weather station had recorded <100 mm since January, < 50% of the regional annual average. The study was preceded by four years of approximately average rainfall.

While the exact date of fire events around 1969 are not certain, it may be worth noting rainfall over the period 1967-1971 during which the fire and the post-fire population regeneration is likely to have occurred. Regional rainfall over these years was average, high, very low (1969 was the driest recorded year for 4 of the 6 then-active stations), above average, and average respectively. Thus, if fires did occur in 1969, they occurred during a period of severe drought and were followed by several years with good growing conditions.

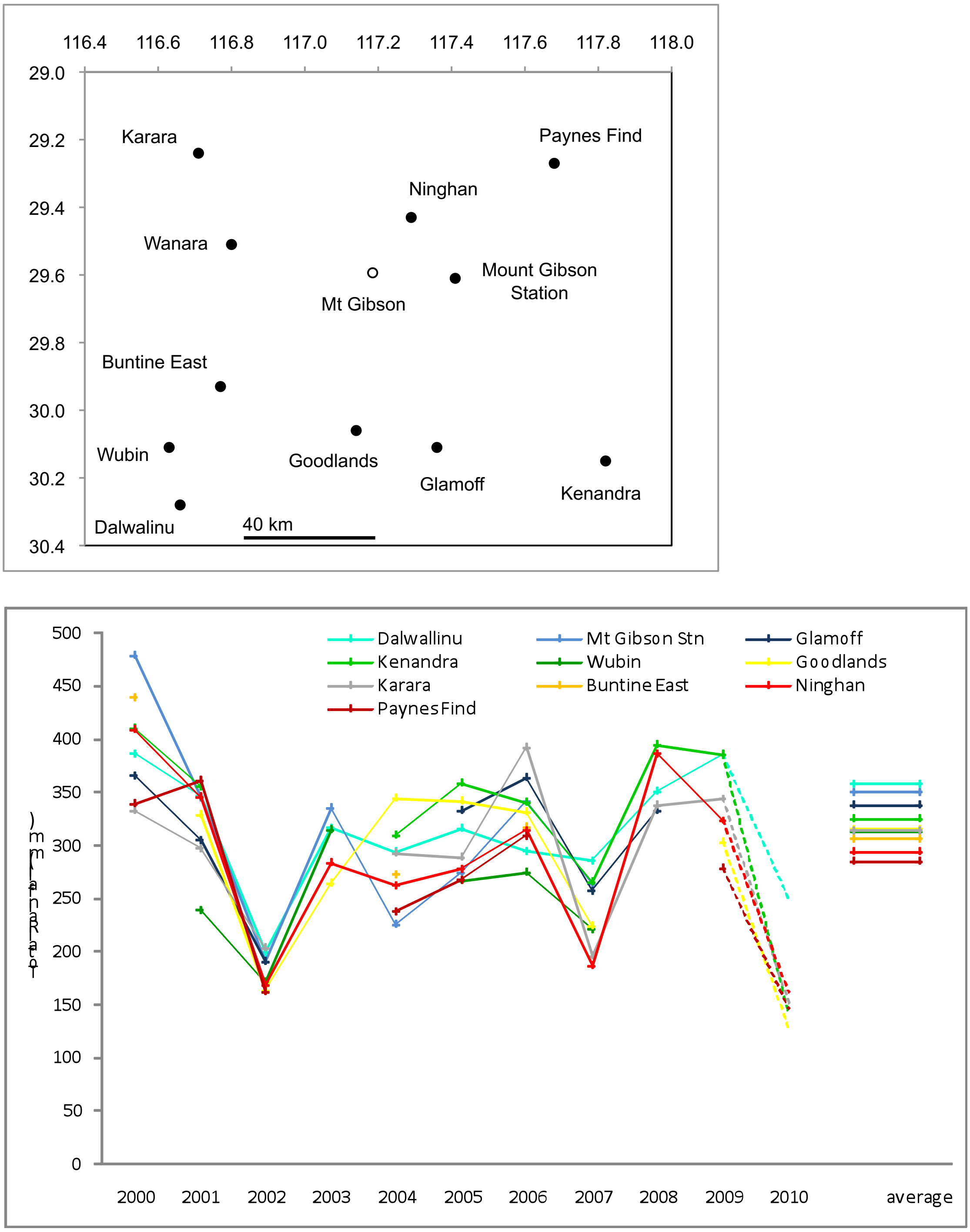

Figure 12 a) Locality of climate stations relative to BGPA's Mount Gibson climate station (open diamond). **b)** Annual rainfall for 2000 to 2009, to October 2010 (dashed) and for the long term average for nearby rainfall/climate stations (www.bom.gov.au).

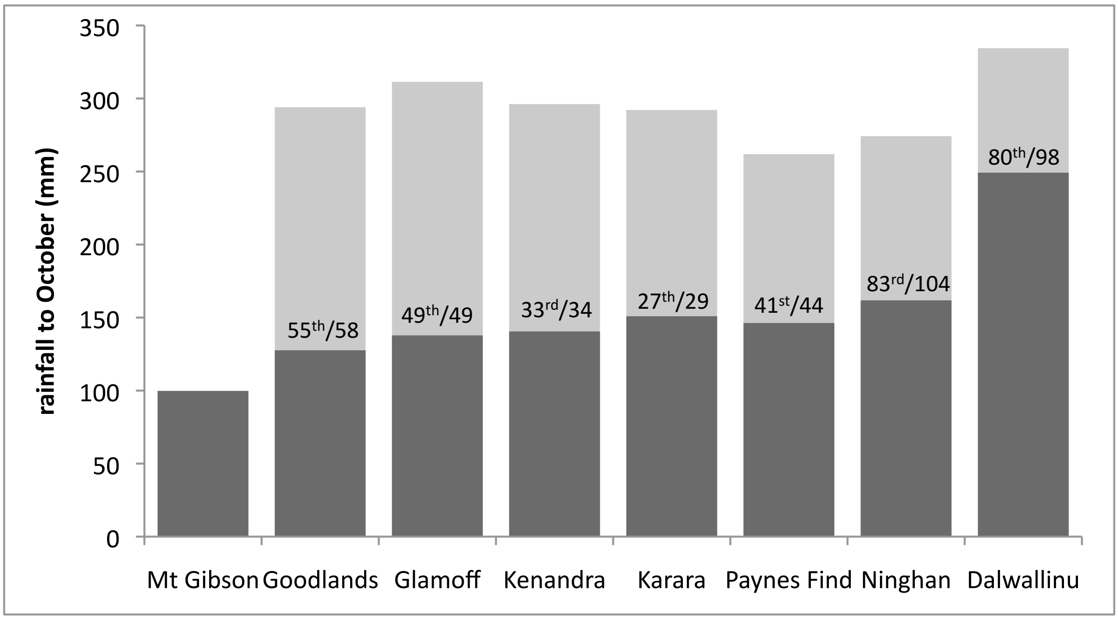

Figure 13 Cumulative rainfall to October, for 2010 (dark bars) and the long-term average (light bars) for the BGPA climate station on Mt Gibson (average not known), and for nearby stations with complete records (www.bom.gov.au). The rank of the 2010 record relative to the size of the record (number of years complete to October) also given. On average, rainfall to October accounts for 89% of annual rainfall for these stations.

Darwinia masonii

Darwinia masonii populations were monitored in 15 10×10 m plots on Extension Hill, Iron Hill, Mt Gibson and Mt Gibson South, with sites last burnt in 2003, 1969, or some time prior to 1968 (Figure 11, Table 6). In each plot, all live plants, including seedlings, were tagged, mapped and measured. Plots had between 13 and 57 plants each, and a total of 378 plants were measured. Stem density varied between 0.13 and 0.57 plants.m^{-2} and averaged 0.25 plants.m^{-2}. Plots were established in July 2007 and remeasured annually.

Table 6 Midpoints and fire histories of the *Darwinia masonii* 10×10m demographic survey plots.

Plot	Population	LAT	LONG	Last burnt
DEHS1	Extension Hill South	29°34.953	117°09.940	1969
DEHS2	Extension Hill South	29°35.124	117°09.999	1969
DEHS3	Extension Hill South	29°35.169	117°09.934	1969
DIS1	Iron Hill south	29°36.437	117°10.779	2003
DIS2	Iron Hill south	29°36.433	117°10.789	2003
DIS3	Iron Hill south	29°36.407	117°10.781	2003
DIS4	Iron Hill south	29°36.321	117°10.694	2003
DIS5	Iron Hill south	29°36.267	117°10.668	2003
DMG1	Mt Gibson	29°35.621	117°11.090	1969
DMG2	Mt Gibson	29°35.592	117°11.073	Older
DMG3	Mt Gibson	29°35.573	117°11.081	Older
DMG4	Mt Gibson	29°35.512	117°11.110	1969
DMGS1	Mt Gibson South	29°36.214	117°12.030	Older
DMGS2	Mt Gibson South	29°36.259	117°12.022	Older
DMGS3	Mt Gibson South	29°36.284	117°12.060	Older

For all tagged *D. masonii* plants in each plot height was measured as the vertical distance from the highest living tissue in the canopy to level at which the stem emerges from the ground. However, as plants were occasionally prostrate or reclining, and many grew on slopes, this measure often did not adequately describe plant size. In these cases, the equivalent ‘length’ was recorded as distance from the base of the stem on the ground, to the furthest edge of the canopy. ‘Canopy diameter’ was also measured for all plants as the longest horizontal distance across the canopy, and secondly (‘diameter 2’) as the horizontal distance across the canopy in the direction orthogonal to the first. Stem basal diameter also was measured in initial surveys for all plants. This was measured, using digital callipers, as the diameter of the stem and bark close to the plant base, but above any immediate swellings or corky areas. For non cylindrical stems, this was recorded in two horizontal dimension following the same principals as per canopy diameter measurements. Inflorescence numbers were counted, and a subjective 'health' score using a 5 point scale (Table 7) was also given for all plants. The health score was determined on the basis of relative foliage colour (noting that colour changes through the year – see **4.5e Plant Health**) and on inspection of vegetative bud activity.

Table 7 Qualitative health score for *Darwinia masonii*.

Score	Plant vigour	Canopy	Leaf colour	New growth
0) Near death	Dead or nearly	Absent or nearly	Yellow/ brown	absent
1) Very poor	Very low	Thin	Yellow / brown	absent
2) Poor	Moderate	Moderate-full	Grey - green some yellow-brown	absent
3) Fine	Good	Full	Blue green	present
4) Very good	Precocious seedling reproduction	Full	Dark green	vigorous

The slow, irregular and modular growth form of *D. masonii* means that neither plant height nor canopy diameter is ideal for measuring the 'growth' of mature plants at the year-to-year scale. In any year, branchlets at the top or furthest extent of a plant's canopy may die-back, while at the same time, strongly growing branchlets not at the canopy extremes would not contribute to an increase in measured plant size. Basal stem diameter may be a preferable measure of plant growth, but as plants (older ones particularly) have irregularly shaped stems – which may often crack, split or swell or lose or gain spongy bark – this measure also proved not ideal. However, seedling growth forms are more regular and their increase in height and diameter is also more amenable to meaningful measurement. As a result, data on plant population structures and growth rates are presented in a number of metrics.

Population structure

When surveyed in 2007, plant size ranged up to 240cm in height and 2.5m in canopy width and stem basal diameters varied from 1 to 74 mm.

Plant size varied in a clear pattern with population age (time since last fire) but stem densities did not (Table 8). The frequency distribution of plant size in plots (Figure 14, Figure 15) includes distinct peaks and narrow size ranges in the 2003 and 1969 plots and broader and flatter distributions in older sites. These patterns indicate that plants are killed in fire, and that the majority of plants arise in a single cohort following fire. Older site size distributions suggest that a small number of seedlings may recruit at infrequent intervals in the absence of fire.

Table 8. Attributes of *Darwinia masonii* populations and plants assessed in sites last burnt at in 2003, 1969, and prior to 1968 as assessed in 2007.

		Year last burnt		
		2003	1969	<1968
Sites (n)		5	5	5
Age (years at 2007)		4	38	>40
N		128	149	100
Density (stems.m^{-2})		26	30	20
Height 2007 (cm)	Min-Max	11-72	36-202	26-240
	Mean	37	110	119
Corresponding growth rate	(cm.yr^{-1})	9	2.9	
Canopy diameter 2007 (cm)	Mean	15	59	110
Corresponding growth rate	(cm.yr^{-1})	3.8	1.5	
Extrapolated age	years)			73
Stem diameter 2007 (mm)	Min-Max	1.1-9.2	2.9-37	2.1-120
	Mean	3.8	15	33
Corresponding growth rate	(mm.yr^{-1})	0.95	0.39	
Extrapolated age	(years)			85

Plants growing in sites burnt in 2003 (i.e. 4 year old seedlings), averaged 37cm in height, 15 cm in diameter and 3.8 mm in stem diameter when measured in 2007 (Table 8). These sizes represent mean growth rates of approximately 9 cm.yr^{-1} in height, 4 cm.yr^{-1} in diameter and 1 mm.yr^{-1} in stem diameter over their 4-year lifetimes. These growth rates are between 2 and 4 times greater than those observed in the next two years of survey (below), suggesting considerable year-to-year variation in growth rates.

Extrapolating the mean growth rates for canopy diameter and stem diameter from plants in sites last burnt in 1969 to the average dimensions of the older sites, suggests a mean ages of plants in these older sites of 73 and 85 years respectively. As well as assuming that the assessed mean canopy and stem diameters and their growth rates for this period are correct, representative and unvarying through time, this calculation assumes that all of the older plots were all burnt in the same previous fire, and that all plants date from the last fire. These assumptions suggest that the estimated age of these older populations 73-85 years may be underestimate their actual age. Taking the value of 85 years suggests a fire in these areas in 1922 (with 162 mm, 1922 was the 8th driest year on record at Ninghan, 1924 was almost identical).

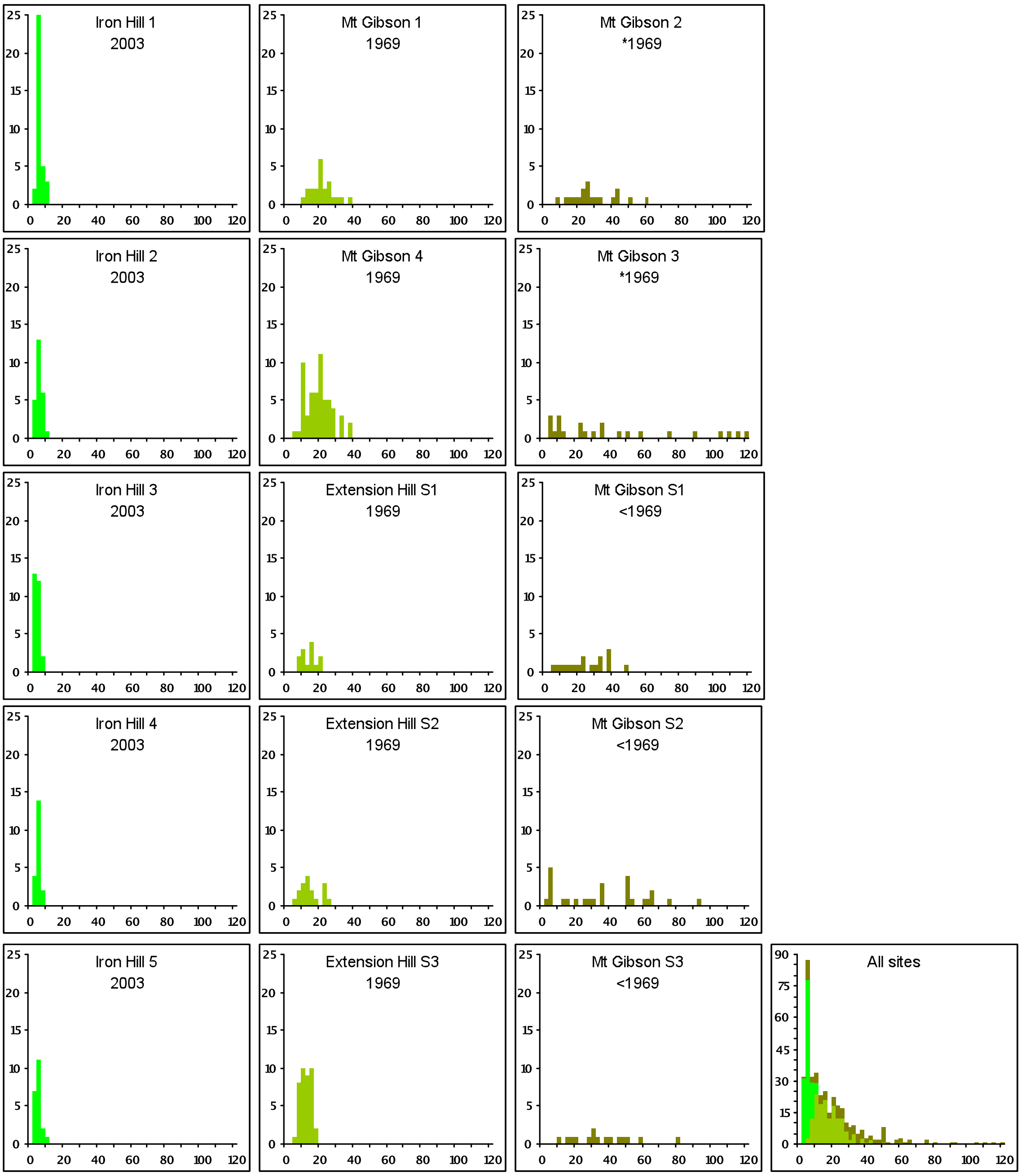

Figure 14. *Darwinia masonii* population structure: number of plants (Y-axis) classified by size (X-axis: Stem diameter close to ground level, 2.5 cm increments). Data from 2007 survey of fifteen 10×10m plots. Colour codes correspond to date of last fire (2003, 1969, <1969; *1969 = within the 1969 boundary but appears to have escaped that fire and hence is also <1969)

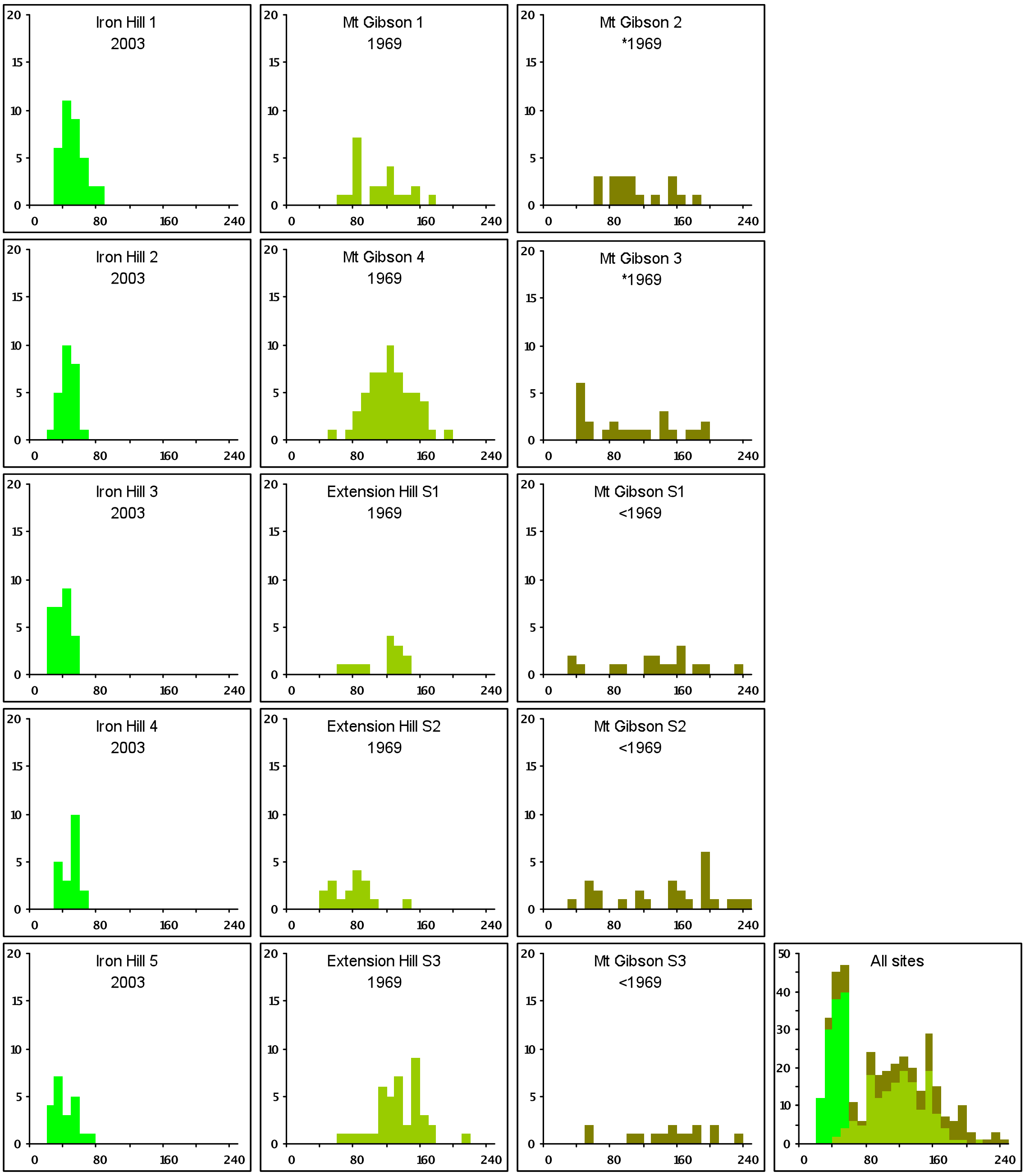

Figure 15. *Darwinia masonii* population structure: number of *Darwinia masonii* plants (Y-axis) classified by size (X-axis: plant height in 10 cm increments). Data from 2007 survey of fifteen 10 × 10m plots. Colour codes correspond to date of last fire (2003, 1969, <1969; *1969 = within the 1969 boundary but appears to have escaped that fire and hence is also <1969)

Recruitment

Just one new seedling was found in the 15 unburnt survey plots over the course of the study, this in July 2009 at the Mt Gibson South plot 2, a long unburnt site. The seedling was 9 cm tall, suggesting that it may have germinated in the previous winter (the preceding survey was July 2008). For what it is worth, this represents a mean interfire recruitment rate of 0.0023 new seedlings per adult per year in older plots.

In contrast, 233 seedlings were counted in the four plots (total area = 250 m^2) surveyed following the May 2009 experimental fire. This indicates a mean density of *D. masonii* seedlings of 0.9 m^{-2}. There were 93 pre-fire adults in the same area – equivalent to 0.37 m^{-2} and 1.2-1.9 times the density of adults in the unburnt survey plots. This would represent an average seedling production rate of 2.5 seedlings per pre-fire adult. However, the experimental fire was patchy and did not burn the entirety of the four plots, such that 20 (22%) of the 93 pre-fire adults did not burn. If we use this same proportion to represent the area of plots that did not burn, and assume that seedlings only germinated in burnt areas, it may be more appropriate to record a seedling density of 1.2 seedlings.m^{-2} of burnt area and 3.2 seedlings per adult.

Survival / Mortality

Of the 277 seedlings tagged at the end of the winter following the May 2009 experimental fire, just 9% were refound and alive one year later in October 2010. In addition, 79% were refound and dead, and 11% could not be found. Thus mortality rates of *D. masonii* seedlings over their 1st summer was 88-91%. This low survival rate may partly result from the drought experienced over the 2010 winter at Mt Gibson, as well as a likely high failure rate of establishing young seedlings.

Three of the 373 *D. masonii* plants tagged in demography plots in July 2007 died over the following 12 months: all were seedlings, and two were from one plot (Iron Hill South 5: DIHS5). A further 14 seedlings from this plot died over the following 12 months as did two smaller individuals (53 and 62 cm tall) from long unburnt populations on Mt Gibson and Mt Gibson South. The 5 remaining DIHS5 seedlings were still alive in November 2009, but a further 16 seedlings from other 2003-fire area plots had died. These deaths indicate a mean seedling mortality rate of 9.8% per year over the study period (Table 9), but also significant spatial and temporal variation in seedling survival (Figure 16).

Table 9 Number and proportion of tagged *Darwinia masonii* plants dying in each year 2007-2010; comparing seedlings from 2003 fire and older plots.

	2003 seedlings		1969 + older	
	N	%	N	%
2007-2008	3	2.5	0	
2008-2009	14	11.7	2	1.6
2009-2010	16	15.2	0	
average	33	9.8	2	0.5

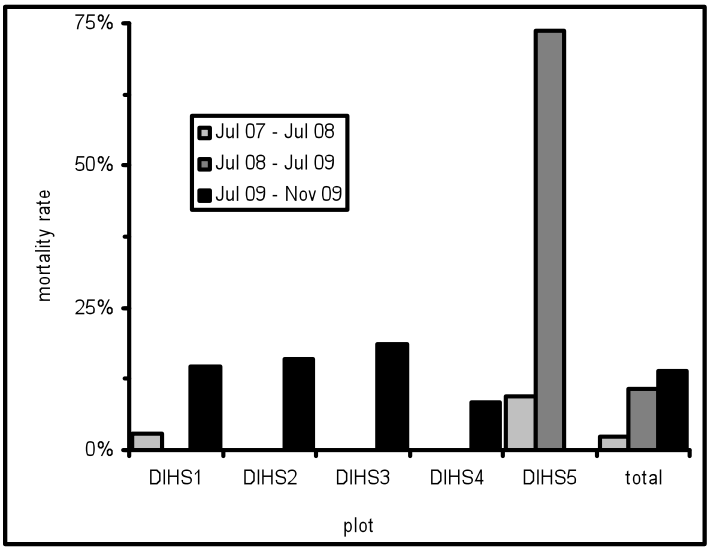

Figure 16 Proportion of *D. masonii* plants dying in five Iron Hill South seedling plots (burnt Feb 2003) at three sample times (the last not representing a full year).

The 16 deaths in DIHS5 represent a major population collapse for this locality over the two years to July 2009: in one year, 74% of remaining plants died. Skeletons of a further 21 seedlings were counted at the establishment of the plot, suggesting that poor survival is endemic at the site. It is unclear what the cause of this death is at this and other 2003 plots. The DIHS5 plot is the hottest of the five seedling plots in terms of solar radiation receipt (with an aspect of 65° versus 73-86°) and among the steepest (10° versus 8-10°). It is also mapped as a distinct geology: undifferentiated “white rock” versus cavernous Limonite and Breccia “(only hematite debris cemented by limonitic material)”, although only a short distance down-slope from the mapped contact with these. These differences may well suggest important differences in soil water holding capacity and micro-climate. But the fact that *D. masonii* seedlings occur there at all suggests that a number of adult individuals must have survived and reproduced on the site or very nearby prior to the fire.

Whether the increase in mortality of seedlings in the remaining plots through spring of 2009 is an indication of the commencement of a similar period of mortality in the other sites remains to be seen.

With just two recorded deaths in the older plots, the mortality rate in these areas between 2007 and 2009 averaged 0.5% per year (Table 9). Tagged plants are yet to be resurveyed in 2010 at time of writing, but a sample of 261 plants adjoining plot DMGS1 on Mt Gibson South (last burnt <1969) and marked in the pollination study were re-surveyed. These plants had a population-wide mortality rate of 10.3%, much higher than that observed in previous years in survey plots. This mortality also seems likely attributable to drought, but is of concern both for its magnitude with a significant impact on population sizes, and if projected climate change does lead to increased drying, or increased frequency of dry years in the region.

Health scores

Most (75-99%) of the plants in older sites had good health scores (i.e. scores of 3 or 4, Figure 17). Just one and two individuals had low health scores (0 or 1) in 2007 and 2008 respectively (i.e. ≤ 1%). Each of these three plants had recovered to a score of 3 by 2009. The proportion of plants with a poor health score (2) varied from 0-25%. The only two plants from these older sites that died in the survey period (both by July 2009) had scores of 2 and 3 in 2008, and 3 in 2007.

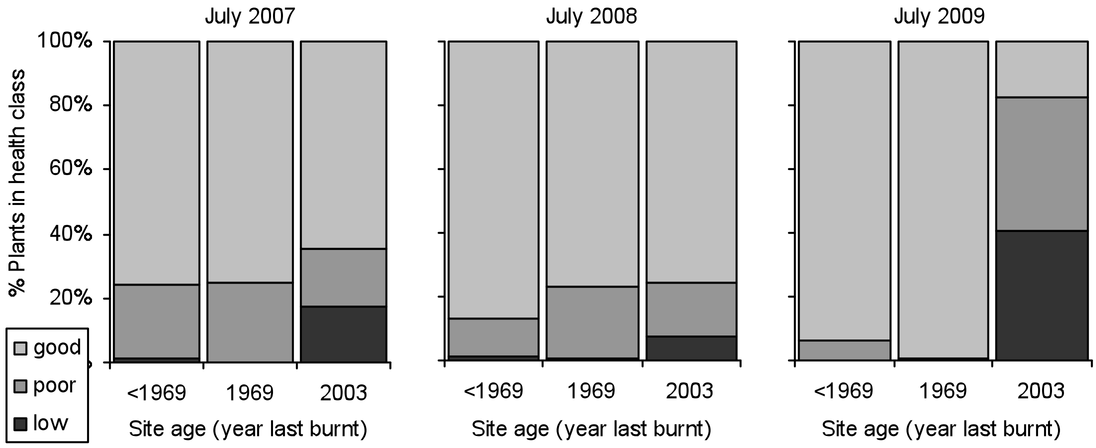

Figure 17 Variation in health scores for tagged Darwinia masonii plants varying between years and site age.

Examining patterns of annual change in health (Table 10) indicates greater fluctuation of apparent health among seedlings than in adults. Three quarters of plants in older plots did not change health score (most were 3), 20% improved in their health score and 4% declined, and very few moved more than one score class. In contrast, seedlings maintaining a constant health score across years were in the minority (18 - 51%). 82% of seedlings declined in health (26% by two or more scores) or died in 2007-2008, while 25% improved and 24% declined or died in the following year.

Averaging across years, 0.3% of seedlings with good health scores (3 or 4) died within the next 12 months, 20% of those with poor health (2) died and, 11% of individual seedlings with very poor or worse scores (1 or 0) were dead within 12 months. The proportion of live seedlings with low health scores has fluctuated between years and was highest in July 2009, suggesting that greater mortality of seedlings may be expected subsequently.

Table 10 Year to year variation in health status of *Darwinia masonii*

Site age	older			2003		
Period	2007-2008	2008-2009	2007-2009	2007-2008	2008-2009	2007-2009
improved	19%	14%	21%		25%	6%
>1 score	1%		0.4%		3%	
1 score	18%	14%	20%		21%	6%
no change	76%	75%	75%	18%	51%	19%
declined	4%	11%	4%	67%	22%	61%
1 score	3%	11%	3%	40%	22%	31%
> 1 score	0.5%	0.4%	0.4%	26%		31%
died	1%		1%	15%	2%	14%
Total	220	231	236	121	122	121

Live plants given a health score of 0 (near death) in 2007 mostly did eventually die, although all survived for more than one year before doing so (Figure 18). All but one of the 19 plants with a very poor health score (1) in 2007 were seedlings: four were dead by July 2008 and eight more (all seedlings) died by November 2009. Some of these plants regained health to a good standard within a year, but even so, some of these later died, and none had scores > 2 (poor) at last survey.

Figure 18. Two plants from plot DIHS4 photographed in July 2009. Both had experienced complete leaf loss and had health scores of 0, or 1 in the preceding two years, indicating that they had persisted with no canopy and only the leaf buds like those visible here on the stem for at least a few years. Their continued survival seems unlikely.

Growth

The growth of older plants appears to be slow relative to measurement errors and diffuse across their canopies – not necessarily resulting in an increase in maximum height – and confounded by both a pattern of shoot die-back and the datum problems described previously. Significant shoot die-back was recorded in 11% of measured *D. masonii* individuals. This occurred when the uppermost branchlet or shoot died such that subsequent measurement, from the ground to the highest growing point were lower than previous measurements, and resulted in reduced, or negative height growth. No specific factor appeared to be responsible for this process, other than the normal process of branchlet longevity interacting with overall poor plant vigour. The health score of plants that died back averaged 1.5, while the average score for the other plants in the plots where die-back was observed was 2.6.

Across all sites and sample years, growth averaged 0.6 $cm.yr^{-1}$ among all plants (Table 11), but there was considerable annual and site-based variation, as well as between plants that died back or and those that did not. At 3.4 $cm.yr^{-1}$, mean seedling growth across both years was 6 times higher than the average for all plants. Seedlings which died-back grew at less than half this rate. In 2007-2008, when Iron Hill seedlings were five years old, their growth averaged 4.1 cm.yr-1, but this declined to 2.7 $cm.yr^{-1}$ in the following year. Height growth of plants in older sites followed a similar pattern, being lower in 2008-09 than 2007-08, and lower in plants with stem die-back. Overall, height growth of older plants was slightly negative (-0.8 and -1.0 $cm.yr^{-1}$). Only 2007-08 growth in the oldest (burnt <1969) sites had a positive mean value (2 $cm.yr^{-1}$).

Table 11 Plant height growth rate (cm.yr-1; with ± SD and n) for tagged *Darwinia masonii* plants with varying time periods, time since fire and whether canopy die-back was recorded or not.

Year last burnt	2003	1969	<1968	Total older
2007-2008	4.1 ± 5.5 (121)	-0.1 ± 15.0 (129)	2.0 ± 6.6 (85)	0.6 ± 12.1 (228)
2008-2009	2.7 ± 9.5 (121)	-3.1 ± 13.8 (128)	-3.6 ± 7.7 (85)	-3.3 ± 11.7 (213)
mean 2007-2009	3.4 ± 5.0 (121)	-1.0 ± 4.1 (130)	-0.8 ± 2.8 (85)	-0.9 ± 3.7 (235)
Died back 07-09	1.5 ± 3.9 (21)	-2.5 ± 5.2 (12)	-4.1 ± 4.2 (4)	-2.9 ± 4.9 (16)
No d.b 07-09	3.8 ± 5.1 (100)	-0.8 ± 4.0 (118)	-0.7 ± 2.6 (81)	-0.8 ± 3.5 (219)

The difference between positive height growth in seedlings and neutral or negative height growth in mature plants reflects the details of their growth form. Seedling growth focuses on the extension of a single erect shoot, whose growth direction, and growing tip persists from year to year. This results in strong and sustained vertical growth – until plants reach maturity and flower, or the growing tip becomes damaged or dies. As flowering is terminal (occurs at the end of growing shoots) in *D. masonii,* reproduction means that shoot axes terminate and new growth develops laterally following reproduction. In older plants, new growth occurs via many dispersed branchlets growing in many different directions. This growth form does not encourage vertical growth, in fact, as branchlets die when they flower, and re-shoot laterally the canopy surface has a dynamism which may result in a fluctuating canopy height, with perhaps more net height growth in years of better growth conditions.

The pattern of variation in height with canopy width in *D. masonii* (Figure 7) shows increasing variation in canopy size with plant height once plants exceed 50-70cm in height, indicating the slower or more irregular nature of vertical growth in mature plants, as well as the propensity for older individuals to recline. That seedling growth was higher in 2007-08 than 2008-09 in seedlings and adults suggest better growth conditions in the earlier season.

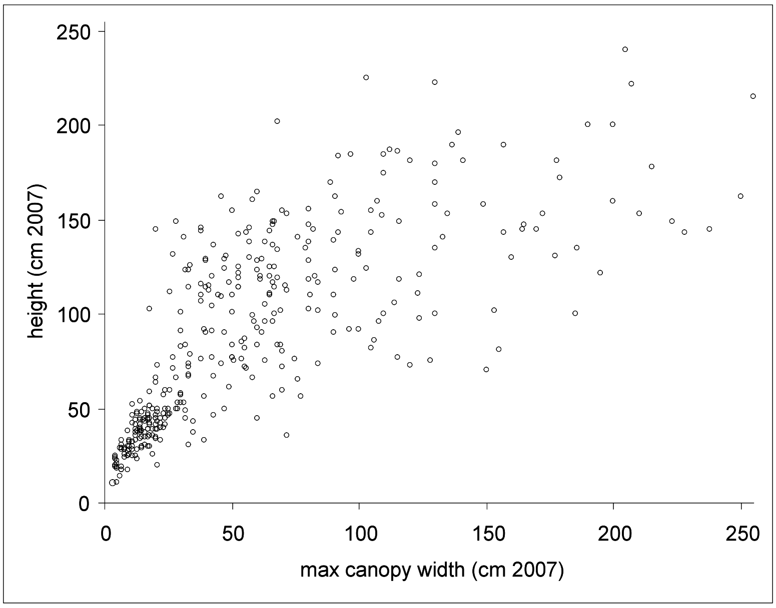

Figure 7 Maximum canopy diameter varying with plant height in tagged *Darwinia masonii* individuals (2007).

The 12 May 2009 experimental fire enabled assessment of seedling growth at their initial stages. The first rains after the fire occurred May 21-22 (with 22 mm recorded at the Mt Gibson Oroya camp), and seedling germination can most conveniently be dated from this time. Seedlings were measured after 4 months, 6 months and 17 months. In late September 2009, four months after the fire, seedlings averaged 2.8 cm in height, by November they averaged 3.3

cm. Assuming negligible growth over the summer period, this provides an average growth rate of 7.2 cm.yr^{-1}. By October 2010, surviving seedlings averaged 5.9 cm, suggesting a much lower 2nd year growth rate of 2.7 cm.yr^{-1}. As rainfall in the winter of 2010 was well below average, this low growth rate may reflect a water limitation of growth, as much as an inherently slow 2nd year growth.

The mean measured rate of growth of tagged plants is considerably less than the mean rate of growth derived from their population structure and known fire ages (Table 8). The population structure data suggest a mean height growth rate of 9 cm.yr^{-1} for seedlings up to 4 years old, and 2.9 cm.yr^{-1} for plants up to 38 years. Our results indicate annual variation in growth rates, suggesting that the sample size (in terms of numbers of years) is not sufficient to accurately assess mean annual growth rates for this species. The estimate of growth rate to 38 years includes a period of growth as a mature plant, but also a juvenile period of higher growth. As a result, 2.9 cm.yr^{-1} must be an overestimate of annual growth of mature plants. The length of the juvenile period is as yet unknown (but see *Fecundity* below).

Stem diameters were recorded for all plants in 2007 surveys, providing useful data on population structures, and then again for all plants in the 2003 fire areas and selected other individuals elsewhere in subsequent surveys. At the second survey, it became clear that slow growth rates, together with complications associated with remeasuring stems for older plants – due to bark swelling and sloughing, low branches and irregular cross-section shape – meant that the accuracy of stem diameter measurements was not sufficient for assessing individual growth rates on an annual basis. While 94 (of 247) of older plants were remeasured in 2008, remeasurement accuracy was such that 25% of these were not deemed adequate for comparison. Considerable variation in measured diameter growth rate was observed in the remaining 69 individuals (Table 12), and it is unclear to what extent measurement errors are responsible. The reported rate of 1.4 ± 2.6 mm.yr^{-1} should be treated with some caution.

Table 12 Plant stem diameter growth rate (mm.yr-1; with ± SD and n) for tagged *Darwinia masonii* plants with varying time periods and time since fire.

Year last burnt	1969	2003
2007-2008	1.38 ± 2.57 (69)	0.14 ± 0.55 (87)
2008-2009		0.55 ± 0.58 (86)
2007-2009		0.34 ± 0.43 (112)

Seedling stems have few of the problems listed for mature plants, and the measured mean rates and variation measured are more likely to reflect true growth patterns. Stem basal diameter growth of 4-6 year old seedlings averaged 0.34 $mm.yr^{-1}$ over the study, and was four times higher in 2008-09 than in the previous year (Table 12). Mean measured stem growth in these seedlings in their 6 and 7th years is about two thirds less than their mean growth in the preceding 5 years – as suggested by their mean diameters in 2007 (Table 8). The stem diameter of seedlings 17 months after the experimental fire averaged 0.84 mm, indicating a growth rate of 0.58 $mm.yr^{-1}$.

Fecundity

No tagged seedlings growing from the 2003 fire flowered in 2007 or 2008, but 6 of 115 (5%) surviving plants flowered in 2009. With heights of 51 to 95 cm these plants were all above average for seedlings of this age (45 cm), but made up just 13% of plants on this size range. It seems reasonable to suggest that 6 years is therefore the minimum age of reproduction for *D. masonii*, but to note that the proportion of plants flowering increases with plant size. The proportion of flowering plants also varies considerably between years, with 62% of all plants in older sites flowering in 2007, 36% in 2008 and 90% in 2009. In 2009, 93% of plants over 1m tall flowered.

The mean number of inflorescences per flowering plant also varied between years: averaging 29 in 2007, 5.6 in 2008 and 33 in 2009 (the 6 flowering seedlings averaged 2.3 inflorescences; Figure 19). This pattern reflects less flowering among smaller than larger plants and variation in the number of inflorescences produced by plants of different sizes (Figure 20).

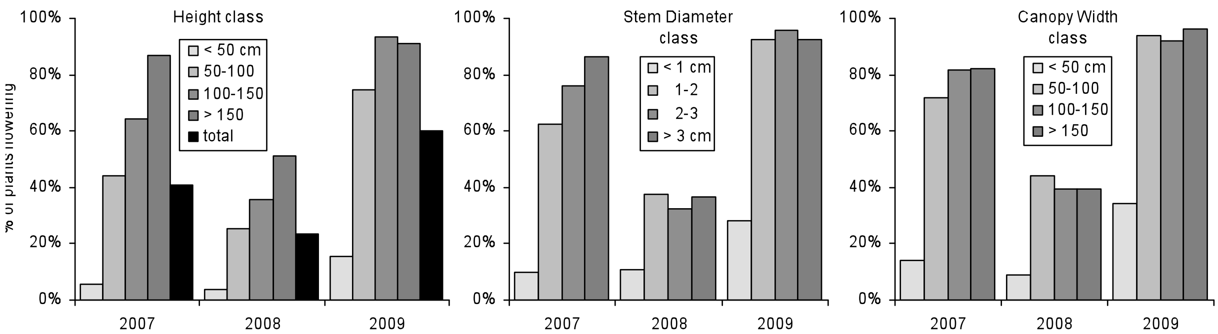

Figure 19 Proportion of *Darwinia masonii* plants flowering / fruiting varying by size class and year: Stem height (cm), Stem diameter (mm) and Canopy width (cm) as measured in 2007.

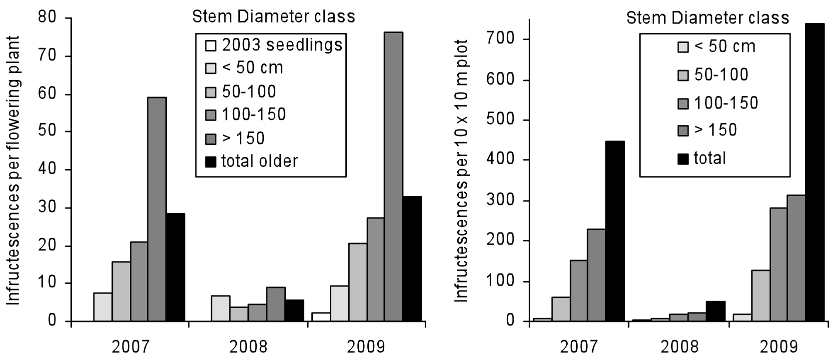

Figure 20. Inflorescence production per flowering plant (left) and per 10×10 m plot (right) varying by year and size class (canopy diameter) in older sites, as well as for seedlings from the 2003 fire.

The outcome of fewer flowering plants and fewer inflorescences per flowering plants is of course many fewer inflorescences per plot. In 2008, plants in the 10 older sites produced an average of 50 inflorescences per plot, but in 2007 and 2009 inflorescence production was 9 to 15 times higher (446 and 739 inflorescences per plot respectively; Table 13)

Table 13 Mean number of *Darwinia masonii* inflorescences per flowering plant and per 10×10 m plot varying between years and height class.

	Height	per flowering plant			per plot		
site age	class(cm)	2007	2008	2009	2007	2008	2009
	< 50	7.6	6.8	9.4	6.1	3.4	17.0
1969 +	50 - 100	15.6	3.9	20.7	59.2	8.6	128.5
Older	100 - 150	21.1	4.5	27.3	149.8	17.6	280.8
	> 150	59.1	8.9	76.2	230.4	20.4	312.5
	Total	28.6	5.6	33.0	445.5	50.0	738.8
2003	all	-	-	2.3	0	0	2.8

Summary – *Darwinia masonii*:

- The population structure of *D. masonii* indicates that most individuals recruit in a single cohort post-fire, with minimal inter-fire recruitment until populations age to (perhaps substantially) > 40 years. The oldest populations were more evenly structured, suggestive of infrequent inter-fire recruitment.

- Evidence from population structure suggests a mean stem diameter growth rate of 0.4 mm per year and a height growth rate of 2.9 cm.yr-1. Extrapolating these rates suggests that the oldest populations studied (‘<1968’) may have last burnt early in the 20th century, this estimation is crude, but suggests a fire around 1922.

- The survey of tagged plants confirms that interfire seedling recruitment is rare: just one new recruit was observed in the 15 survey plots over the 3 year period of the study, and that in an older site.

- Post-fire seedling recruitment is high, with as many as 3.2 seedlings produced per pre-fire adult. But mortality of these seedlings over the 1st summer following experimental fire was high, with 89-91% dying.

- Mortality among 4-6 year old seedlings was high, with 2.5-15% of seedlings dying each year.

- Death among 4-6 year old seedlings was highest among plants with low health scores, while the older plants that died were previously scored as healthy. Health scores varied considerably among seedlings, but little among older plants.

- Averaging 0.5% per year, mortality appears rare among plants in older sites in the absence of fire or extreme drought. The few deaths observed among plants in older sites were small plants, indicating an even lower mortality rate among older plants.

- Drought over 2010 appears to have contributed to a significant level of mortality of adult plants 10% in the Mt Gibson south population.

- Measured growth rates varied between years and younger and older sites. Negative height growth recorded for plants in older sites, may reflect poor growth conditions in measured years, but also difficulties in assessing plant size.

- Mean height growth averaged 7.2 and 2.1 $cm.yr^{-1}$ for 1 and 2 year old seedlings, 3.4 $cm.yr^{-1}$ for 4-6 year old seedlings. Mean height growth for older plants was close to zero or negative.

- Reproduction commences in seedlings as young as six years, but increases in terms of proportion of plants flowering, and flowers per plant as plant size increases.

- Total inflorescence production varied between years by more than an order of magnitude.

Lepidosperma gibsonii

Eleven 5×5 m plots were established for demographic monitoring of *Lepidosperma gibsonii* (Figure 11, Table 14), within which live plants, including seedlings, were tagged with uniquely numbered aluminium tags. All clumps found were tagged and measured in most plots, in plots where seedling density was very high, all plants were counted, but a large subsample of seedlings were tagged and measured. Plots had between 13 and 311 plants each, and a total of 549 plants were measured and 862 enumerated. Five plots contained seedlings, and 36% of tagged plants were deemed to be seedlings at the start of the survey. All of the plots with seedlings had been burnt in the February 2003 Mt Gibson-Iron Hill fire.

Table 14 Localities (midpoints) and fire ages of *Lepidosperma gibsonii* 5×5m demographic survey plots.

Plot	Population	LAT	LONG	Fire history
LEHS1	Extension Hill South	29°34.950	117°09.925	1969
LEHS2	Extension Hill South	29°34.967	117°09.863	1969
LEHS3	Extension Hill South	29°35.083	117°10.000	1969
LIH1	Iron Hill	29°36.272	117°10.380	Older
LIH2	Iron Hill	29°36.287	117°10.505	Older
LIHN1	Iron Hill North	29°36.007	117°10.226	2003
LIHN2	Iron Hill North	29°35.991	117°10.240	2003
LIHN3	Iron Hill North	29°35.934	117°10.337	2003
LMTG1	Mt Gibson	29°35.652	117°11.056	1969, 2003
LMTG2	Mt Gibson	29°35.662	117°11.052	1969, 2003
LEF1	Emu fence N	29°33.640	117°10.883	Older

For each tagged *L. gibsonii* individual, we measured 'clump diameter' using digital callipers as the distance across the collected live leaf and culm bases – at 0-1cm from ground level. For each clump this was measured for both the longest and perpendicular dimensions. Inflorescence counts were made for all plants, and health was assessed using a 3-point subjective 'health' scale (Table 15). This was largely determined on the basis of relative foliage colour (noting that colour changes through the year – see below), growth and reproductive activity.

Table 15 Qualitative health score for *Lepidosperma gibsonii.*

Score	Plant vigour	New growth	Reproduction	Leaf colour
0)	Dead or nearly	Absent	Little or none	Yellow-grey
1)	Poor	Little	Few inflorescences	Green-yellow

2)	Good	Vigorous	Many inflorescences	Green

Population structure

Population structure – the distribution of individuals across size classes – provides information on population processes and recruitment dynamics. The surveyed populations of *Lepidosperma gibsonii* varied considerably in their structure, with a number of distinct patterns distinguishable (Figure 21). Three of the five sites in areas burnt in 2003 showed a clear pulse of seedling recruitment following that wire, with the majority of individuals being seedlings. Seedlings were also found in the two remaining burnt plots, but not in abundance. No plant in any recently burnt area exceeded 20cm in diameter (Table 16). Two plots on Extension Hill South had a strong peak in plant sizes around 10cm and 14 cms respectively and both were probably last burnt in the 1969 fire, again few plants in these sites exceeded 20cm in diameter.

The remaining sites were last burnt at some time prior to 1968 and had fewer individuals but these did include all of the largest plants in the study. Two of these sites have a flat size distribution – indicating either a long period in which plants grew at varying rates or during which occasional recruitment contributed individuals at different times which now represent of a variety of ages. The smallest plants in these sites were 4-5cm and the largest 40-48 cm across at the base. The last site – Iron Hill N1 – had the lowest density of individuals and is therefore harder to interpret, however all individuals at this site were >9 cm and the largest was 32 cm.

Table 16 *Lepidosperma gibsonii* mean plant size in relation to fire history

plot	code	fire history	mean base diam (cm)	no of plants	Seedlings	Mature <20cm	>20cm
Emu Fence	EF	<?1969	26	14	none	few	few
Iron Hill 1	IH1	<?1969	15	15	none	few	few
Iron Hill 2	IH2	<?1969	18	23	none	few	few
Extension Hill South 1	EHS1	1969	7	66	none	many	few
Extension Hill South 2	EHS2	1969	10	19	none	some	none
Extension Hill South 3	EHS3	1969	8	77	none	many	few
Iron Hill North 1	IHN1	2003	11	13	few	few	none
Iron Hill North 2	IHN2	2003	6	15	few	few	none
Iron Hill North 3	IHN3	2003	2	67	many	few	none
Mt Gibson 1	MG1	1969, 2003	2	45	many	some	none
Mt Gibson 2	MG2	1969, 2003	2	127	many	some	none

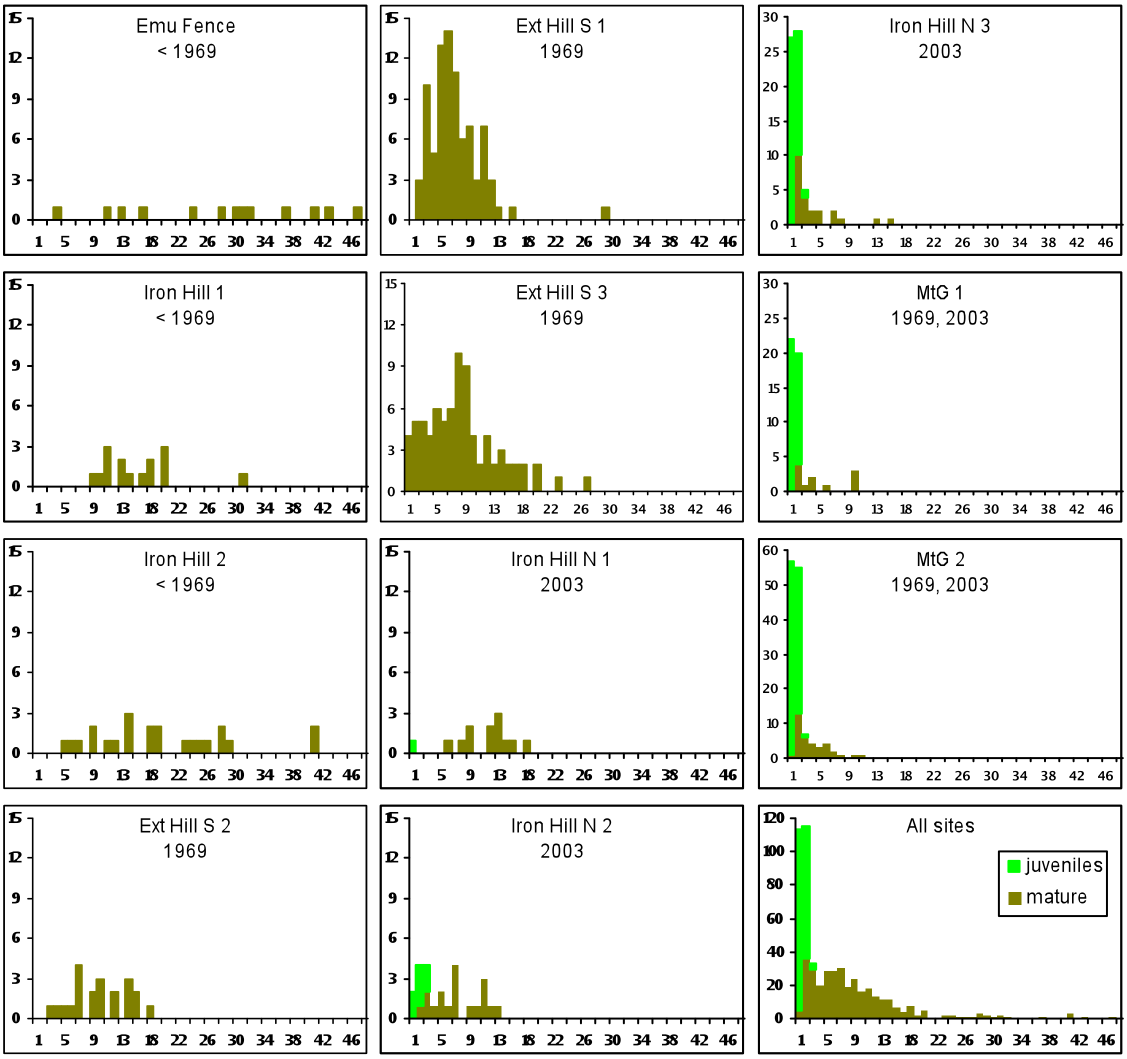

Figure 21. Population structure of surveyed Lepidosperma gibsonii plots. Number of Lepidosperma gibsonii plants (Y-axis) classified by size (X-axis: maximal clump diameter at ground level, 1cm increments). Data from 2007 survey of eleven 5×5m plots. Plots with seedlings were all burnt in a 2003 wildfire, other sites unburnt since prior to 1970 – year given.

These results indicate an important role for fire in determining the population structure and population dynamics of *L. gibsonii*. Firstly, the presence of both adults and seedlings in the most recently burnt sites indicates that at least some mature plants can survive wildfires but also that fires stimulate a large number of soil-stored seeds to germinate. The absence of seedlings in other sites suggests that fire is actually required for seedling recruitment, however the flat population structures of the oldest sites suggest that inter-fire recruitment might also occur. The high population densities, peaked population structures and smaller mean plant sizes in areas burnt only in 1969 suggest strong post-fire recruitment with few individuals surviving from the previous fire period. If that is so, with a mean plant size of 7-10cm and population age of 38 years would suggest a mean growth rate of ~ 2 mm per year. Seedlings deriving from the 2003 fire averaged 1.02 cm diameters and therefore a comparable 2.5 mm base diameter expansion per year. If these mean growth rates are consistent between sites, then the emu fence population could be 100 years old.

Recruitment

No *Lepidosperma gibsonii* seedlings were observed in study plots outside of areas burnt in 2003 or 2009. It is assumed that effectively all seedling recruitment occurs following fire. Seedling recruitment in areas burnt in 2003 was spatially very variable, with counts in 5 × 5 m plots burnt in 2003 of 1 to 261 seedlings (Table 17). This variation was equivalent to around 0.1 – 5.2 seedlings per pre-fire adult and post fire seedling densities from 0.04 to 10.4 per m^2. The extremes all occurred among Iron Hill North sites: two, both facing SW and respectively at the top and bottom of one shallow gully had very low recruitment rates, while the third site with high recruitment had a similar aspect but was in a protected site on the side of a deeper canyon. If mortality among pre-fire individuals (determined from counts of burnt clumps still visible as blackened leaf bases in 2007) is an indicator of fire intensity, the two sites with the lowest post-fire recruitment had both the highest and the lowest fire intensities.

Table 17 *Lepidosperma gibsonii* fire survival and recruitment data (2003 wildfire).

Plot	IHN1	IHN2	IHN3	MG1	MG2	all
pre-fire density (/m2)	0.5	2.8	2.0	0.4	2.0	1.5
% killed in fire	0	74	18	0	24	38
seedlings per pre-fire adult	0.1	0.1	5.2	3.5	2.0	2.1
seedling density (/m2)	0.04	0.3	10.4	1.5	4.0	3.2
Pop. growth (2003 - 2007)	1.1	0.4	6.0	4.5	2.7	2.7

In the spring following the May 2009 experimental fire, 229 seedlings were counted in three marked plots (Table 18). No new *L. gibsonii* seedlings were found in the fourth plot, which contained just one adult (and many *Darwinia masonii*). The density of seedlings ranged from 0.5 to 7.9 per m^2 and averaged 2/ m^2 (discounting plot four). The number of new seedlings per adult averaged 4.2 and varied from 1.3 to 12.8 among the three plots.

Table 18 *Lepidosperma gibsonii* fire survival and recruitment data (experimental fire in May 2009, seedlings assessed October 2009).

Plot	#	1	2	3	4	All*
	area m^2	100 m^2	25 m^2	25 m^2	100 m^2	250 m^2
Adults	no.	4	28	44	1	77
	% killed	50%	48%	56%	0%	54%
Seedlings	no.	51	197	53	0	229
	density /m^2	0.5	7.9	2.1	0	1.2
	per / adult	12.8	7.9	1.3	0	4.2

Survival / Mortality

Survival of *L. gibsonii* individuals was spatially and temporally variable, and differed between adults and seedlings. While plants are killed in fire, a proportion also survives fire. Mortality of pre-fire adults ranged from 0 to 74 % (Table 17) in the 2003 wildfire, while 54% of the 77 pre-fire adults burnt in the 2009 experimental fire were killed (Table 18). The mortality estimate from the 2003 fire is derived from counts of both resprouting individuals and observed burnt and non-resprouting plants. Burnt and non-resprouting plants are visible for some years post-fire as blackened leaf bases, but it is possible that a number of these were missed in the survey as they can be harder to find, and others may have degraded post-fire or were burnt to an extent that no evidence exists. Hence, the proportion given here of plants killed in the 2003 fire is likely an underestimate. Nonetheless, it is clear that this value is quite variable.

Mortality of older seedlings (i.e. of plants surveyed 2007-2010, emerging following the 2003 wildfire) averaged 3% per year (Table 19), but varied between years within sites. Among adult plants, mortality varied from 1 to 5% per year across all sites and also averaged 3% per year. However, most mortality occurred in a single plot. Of the 26 older plants observed to die over the course of the study 19 were in the EHS1 plot where 20% of plants died in one year (Table 19). This plot was first surveyed with 66 live plants: a comment noting 17 dead plants recorded at that time suggests a history of population decline at this site. Examination of dead plants revealed no clear cause of death. This site is not notable for any unusual environmental features. It quite high on the slope, and has relatively little catchment area above, although as *L. gibsonii* individuals do occur higher up the slope, it is not at the upper limit for the population.

Survival of seedlings that emerged following the experimental fire was markedly lower. Of the 230 seedlings marked in the first winter following the fire, the plant or tag of all but 12% was refound after the following winter. Of the 2020 refound plants 72% had died. If the not-found plants are assumed to have died, the mortality rate would be 76%. Wire mesh cage was placed over 37 seedlings to exclude vertebrate herbivores: 73% of these plants died.

Table 19 *Lepidosperma gibsonii* mortality data for plots burnt in 2003 (IHN, MG) and in older plots (EHS, EMN IH).

Plot	IHN1	IHN2	IHN3	MG1	MG2
count	1	7	257	38	99
% dying: seedlings 2007/08	0	14.3	0.8	7.9	7.1
% dying: seedlings 2008/09	0	0	4.7	0	0
count	12	18	41	11	38
% dying: adults 2007/08	0	0	0	0	7.9
% dying: adults 2008/09	0	0	0	0	0

Plot	EHS1	EHS2	EHS3	EMN1	IH1	IH2
count	103	21	87	16	15	23
% dying: adults 2007/08	1.2	0	0	0	0	0
% dying: adults 2008/09	20.2	0	2.3	0	0	0

Health scores

It proved difficult to determine a subjective, quantitative health score for *L. gibsonii* to more than three classes - based on apparent plant vigour, colour, and inflorescences production. With one of these classes representing dead or dying plants, the majority of scored individuals fell into the healthiest class, with very few or none scored as 0. The proportion of healthy plants varied from 66% of surveyed adults in 2008 to 99% of seedlings in 2009 (Table 20).

Table 20 Proportion of surveyed seedling and adult *Lepidosperma gibsonii* individuals with a health score of 2 (i.e. maximal).

	2007	2008	2009
Adults	89%	66%	95%
Seedlings	89%	85%	99%

Growth

The indeterminate and modular growth form of *L. gibsonii* clumps means that clumps can expand and contract in size, and this was observed (Figure 22). Older clumps often consist of live and dead sections, with measurements made across the longest dimension of the base between live parts. If one distant live section died then a clump could show a sudden large decrease in size. Over the period July 2007 – July 2009 the basal diameter growth rate of seedlings averaged 0.35 mm / year, while that of adults averaged -2.4 mm / year (Table 21). Seedlings averaged 6.3 mm growth in the first surveyed year and -5.0 mm in the next. Adult growth averaged -1.2 mm in -4.7 mm across consecutive years.

Table 21. Growth rate of *Lepidosperma gibsonii* clumps (of basal diameter, in longest dimension and perpendicular) in mm per year.

	2007-2008	2008-2009	2007-2009
Longest dimension			
adult	-1.2	-4.7	-2.4
seedling	6.3	-5.0	0.3
Perpendicular to longest dimension			
adult	3.0	-3.8	-1.8
seedling	5.3	-4.3	0.1

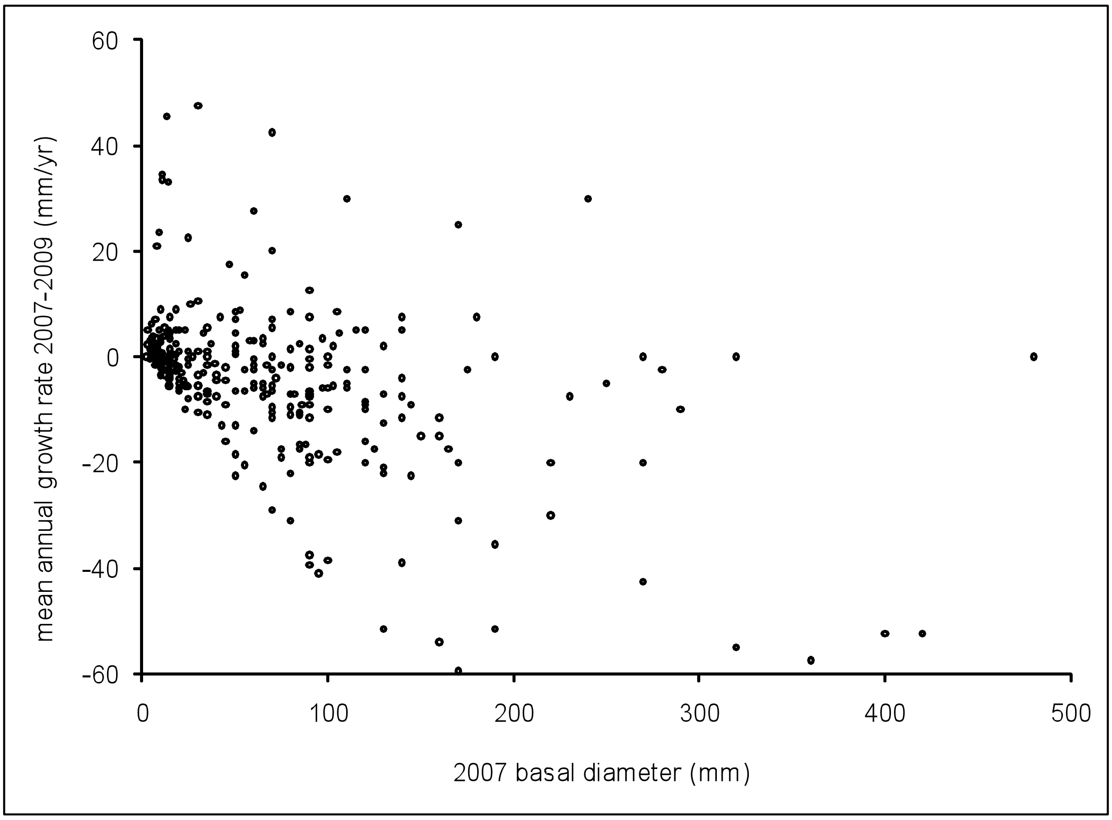

Figure 22 *Lepidosperma gibsonii* mean annual growth in relation to initial plant size (both of base diameter)

Fecundity

In 2007 57% of plants with a base diameter (bd) over 8 cm had infructescences indicating fruit production in 2006 and 39% of plants over 8cm bd had inflorescences ready for flowering in 2007. Flower and fruit production was observed among even the smallest individuals, with 7% of those < 1cm bd flowering and 4% fruiting. The proportion of reproductive plants increased through to 60 mm (for flowering) and 100 mm (for fruiting), and there was some evidence for reduced reproduction in the largest plants (Figure 23).

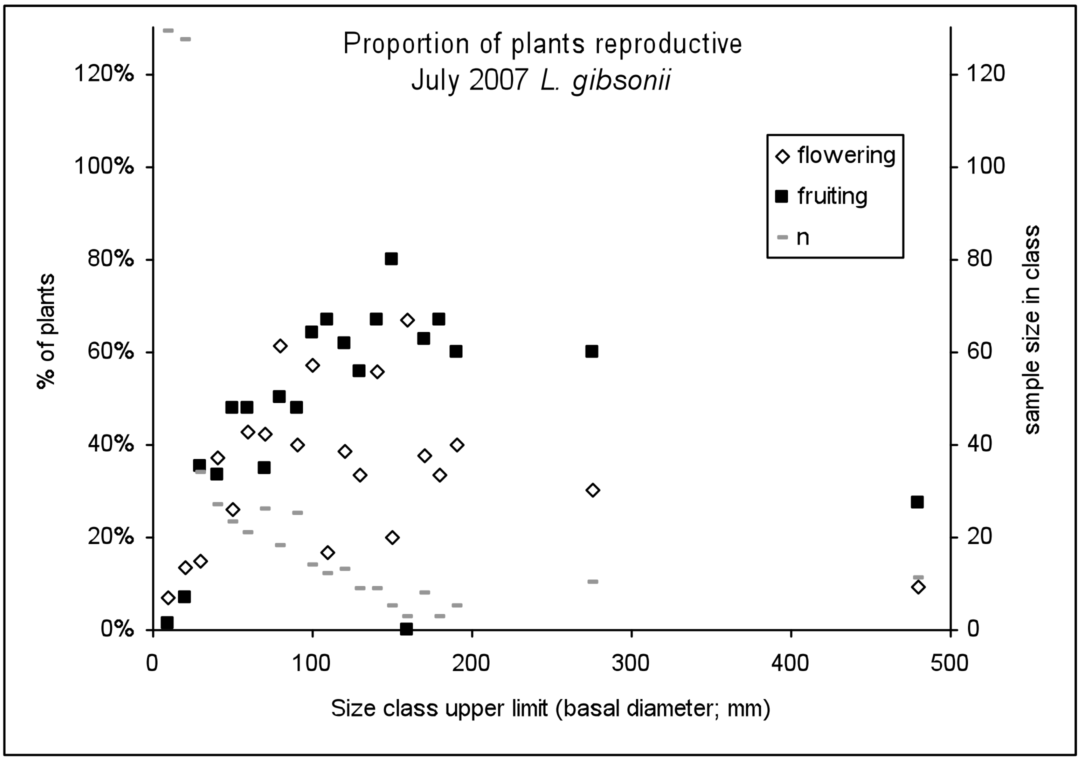

Figure 23 Proportion of plants in 2007 with flowers developing (for fruit production later in the year), or with evidence of fruits from 2006 varying with clump size.

Summary – *Lepidosperma gibsonii*:

- Population structure of *L. gibsonii* indicates that individuals recruit in a single cohort post-fire, with no evidence for inter-fire recruitment observed. That older populations were evenly structured, may suggest infrequent inter-fire recruitment, but are more likely to indicate varying growth rate and the coalescence and splitting of clumps through time.

- Evidence from population structure suggests a mean basal diameter growth rate of 2 – 2.5 mm per year for seedlings and adults.

- Extrapolating growth rates from population structure suggests that the oldest populations studied ("Emu Fence") may have last burnt early in the 20th century, perhaps around 1910.

- Post-fire recruitment was higher, with an average of 4.2 seedlings produced per pre-fire adult.

- Considerable spatial variability in post-fire seedling recruitment was observed following both wildfire and experimental fires, with burnt sites recording 0.1 – 12.1 seedlings per pre-fire adult.
- Approximately 50% of plants are killed in fire, the remainder produce new leaves from buds surviving among burnt leaf bases
- Mortality is variable among plants in older sites, averaging 3% per year overall, but largely due to 20% mortality observed in one year in one plot.
- Mortality among 4-6 year old seedlings was similar, with an average of 3% of seedlings dying each year.
- Mortality among seedlings over the first summer and winters following fire (and germination) was much higher; 72-76%.
- Measured growth rates varied between years and smaller and larger plants. Negative growth recorded for many plants, reflects poor conditions in measured years, but also difficulties in assessing plant size.
- Mean measured seedling basal diameter growth averaged 0.3 mm / year, while mean growth for older plants was -2.4 mm / year.
- Reproduction commences in seedlings as young as six years, but increases in terms of proportion of plants flowering, and flowers per plant as plant size increases.
- Total inflorescence production varied between years by more than an order of magnitude.

4.3 BREEDING BIOLOGY

4.3a Phenology

We divided the reproductive cycle of each species into discreet stages based on non-invasive observable measures, and monitored numbers of inflorescences per plant at each stage over an entire reproductive season in 2009. For each species, five plants in each of four populations were visited at 2-3 week intervals, and the number of flowers at each developmental stage was recorded.

Darwinia masonii

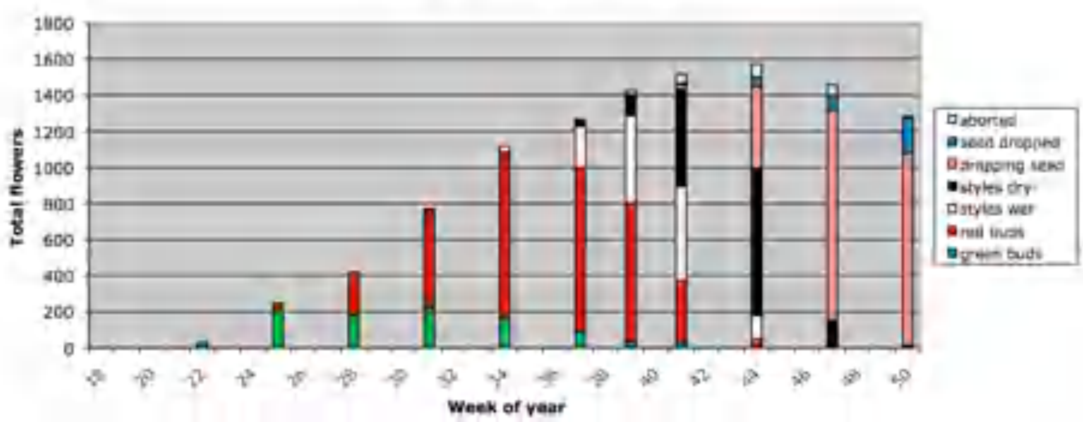

Figure 24 Phenology of developmental stages in *D. masonii*. Total of 20 plants assessed, 2009.

Table 22 Categories employed for assessing the phenology of *D. masonii* populations.

Green buds	New buds initiated (counted when clearly differentiated from leaves)
Red buds	Buds swollen but flowers not yet open (bud development stage)
Styles wet	Flowers at anthesis – actively donating and receiving pollen
Styles dry	Flowers with shrivelled styles but seed unripe (seeds maturing)
Seed ripe	Infructescences (flower heads) dropping seed
Seed dropped	All seeds dropped
Aborted	Development ceased at some stage prior to complete ripening

Floral initiation commences at the start of winter, with flowers opening from late August through to late October. Ripe seeds are first apparent in mid to late October and continue to ripen through to late November. Peak flowering (anthesis) in 2009 occurred about week 40 (first week of October). The 2009 season started late (no rain until late May), and was clearly extended by good late rains in October. In a more "normal" season plants have open flowers about 2 weeks earlier.

Optimal seed collection time is about when about number of infructescences yet to drop seeds = number with dropping seed. In 2009, this occurred around mid November. Note the broad initiation time (May-September) means that there are some flowers at all stages of development until the very end of the season, so the presence of *some* undeveloped seed is not a good indication of maximum seed availability. Seeds also drop rapidly, often with the bracts following quickly behind, so that it is then difficult to estimate the amount of seed already gone. Ants quickly remove seeds from around plants, so seed cannot be easily collected from the ground (see **4.3f Dispersal**). The most effective method of seed collection is from the plant, by hand during November – in most seasons at least some seed can be collected throughout the month (by agitating seeds within the drier flower-heads when still on the plant, and collecting seed that easily falls out). Note also that seed quality will probably depend on competing factors: earlier-developed seed is more likely to have been effectively pollinated (rather than inbred) because lower temperatures keep nectar liquid and attract more pollinators; styles are also less likely to be heat-damaged). However, predation by seed-eating moth larva (**4.3b Seed production**) may also be more prevalent earlier in the season, although this affect has not been quantified, and seems to vary considerably between population and season.

Seed drop is also progressive, with an average of around 10% of seed fallen from seed heads in late October, 50% by mid November and 90% fallen by December. A few (probably unfertilised) flowers remain attached to the inflorescence to late in the season, so the average percentage of seed dropped is a more accurate measure of seed maturity than number of heads with all seed dropped. Moth larvae in some infructescences prevent developed seeds from falling by attaching them to the infructescence-base (technically, the disk or receptacle) with silk threads. As fruits fall from un-infested infructescences through summer, the proportion of remaining infructescences that are predated by moth larvae increases: so some infructescences may appear to still be holding ripe fruits later in the season, but these may be predated and empty (Figure 25).

A small percentage of buds aborted, with a peak around late October as increasing daytime temperatures cause damage to buds and fresh flowers.

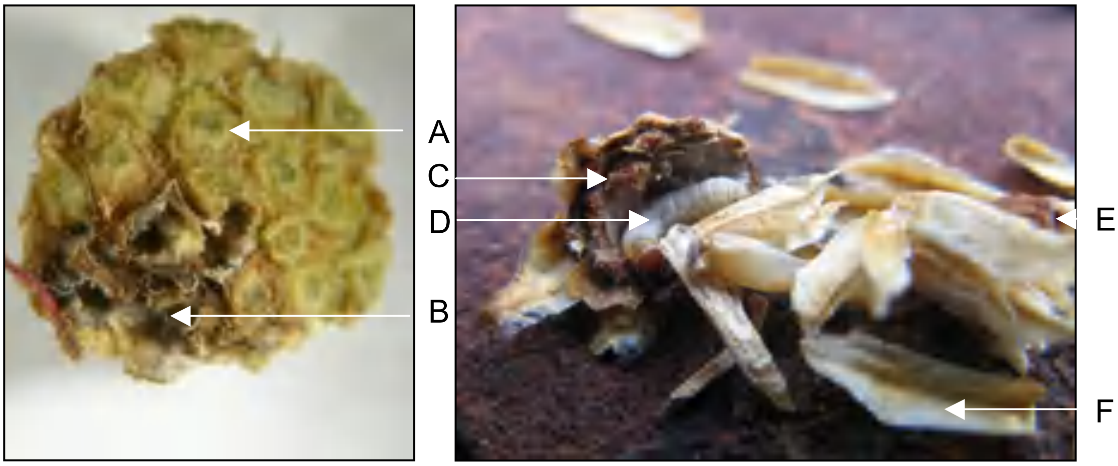

Figure 25 Left: The disk (or receptacle) of a *Darwinia masonii* inflorescence with flowers/fruits and bracts removed showing ~23 insertion sites for flowers/fruits (**A**), including a number which have been hollowed out by a moth larva (**B**). Right (April 2008): a receptacle (**C**) opened showing moth larva (**D**) with dried bracts (**E**) and fruit (**F**) retained.

Lepidosperma gibsonii

Flowering and fruit production in *Lepidosperma gibsonii* is a process which takes almost 18 months from initiation to seed release (

Table 23). Flower initiation commences with the initiation and extension of reproductive inflorescences or culms in late winter / early spring, culms cease development as they reach a length similar to or slightly longer than that of existing leaves, and then remain dormant over summer. Flower development is complete in April or May of the next year and the wind dispersed pollen is released in a synchronised burst correlated with stigma elongation, lasting only a couple of weeks (occasional flowers are still receptive for another couple of weeks; Figure 26).

Under ideal conditions, fruit development of pollinated flowers continues through winter and ripe seeds are released from infructescences during a brief period in late September-October (

Table 23). Undeveloped fruits and old infructescences usually remain on the plant over the following summer and into the next growing season. Thus successful seed development requires suitable conditions (i.e. sufficient soil moisture) for inflorescence development in spring of one year and suitable conditions again over the winter and spring of the next year. At any one time, evidence of two or three annual reproductive sequences may be visible on plants. Depending on the progress of their respective development and ageing, distinguishing between these is sometimes easy and sometimes difficult. It is particularly difficult to distinguish current year's inflorescences from the previous season's inflorescences after about July. It is therefore necessary to remove all inflorescence apices over summer to be able to score the number of new inflorescences produced each year (leaving the green part of the culm to prevent loss of photosynthetic area).

Table 23 Timing of reproductive events in *L. gibsonii.*

Event	Time	Duration	Dependence
Anthesis (pollen release and pollination)	late April to mid June	2-4 weeks	Presence and number of inflorescences depends on the previous season (may be very low). Timing of anthesis depends on heavy autumn dew and break of winter rains. Effective pollen release and stigma receptivity dependent on humid conditions. Anthesis is rapid and highly synchronised, with few flowers at anthesis outside of a 2-week period.
Gradual development of seed	Following anthesis to Nov	4 months	Depends on onset of anthesis and spring rains (which prolong development)
Emergence of new inflorescences for the break of the following season	August -November	1-4 months	Prolonged and increased numbers with spring rainfall
Seed release of viable seed (inviable seeds held on plant)	September-November	1-2 months	Seeds released more rapidly in drier conditions
Optimal seed collection (only 1 year observed with sufficient seed production)	Late September - Early October	c. 2 weeks	Seeds released more rapidly in drier conditions. NOTE: Post seed-release, inviable seeds are held on the plant and give false impression of seed availability.

By mid October in 2009, previously green seed (actually the fruit, a tiny thin-walled nut that contains one seed) had become brown and could be caused to fall by lightly running one's hands along the inflorescence. This was later confirmed, via X-ray analysis, to be the ideal time for seed collection – in terms of % of seeds filled. Examination of X-ray photographs of seeds in a Faxitron X-ray Corporation v1.2 (exposure 21kV for 10 seconds) camera reveals wether fruits contain filled seeds or not (Figure 27). *Lepidosperma gibsonii* fruits may be retained on infructescences for some time, but it the proportion of filled seed among retained fruits is much lower than among fruits which fall from the plant (Figure 28).

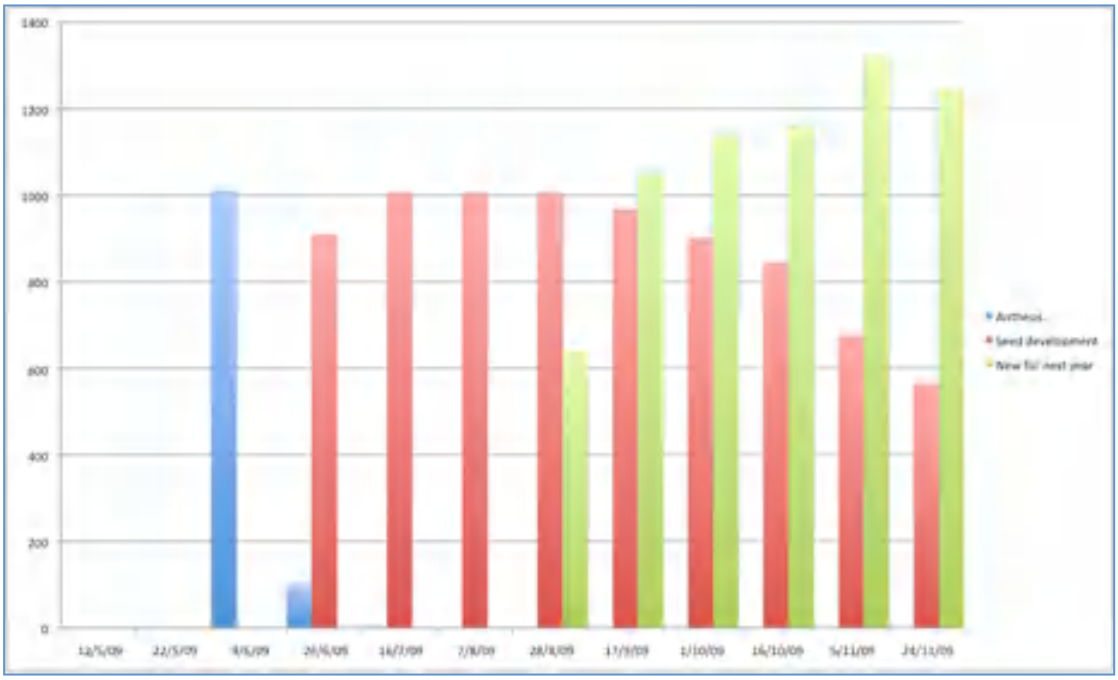

Figure 26. Relative number of inflorescences at differing development stages during 2009, showing rapid burst of anther release (and stigma receptivity), inflorescences developing seed, and production of new inflorescences for the following year. The y – axis is a total count of inflorescences at each stage, summed over 40 plants from 4 populations, as observed every 2-3 weeks over the growing season.

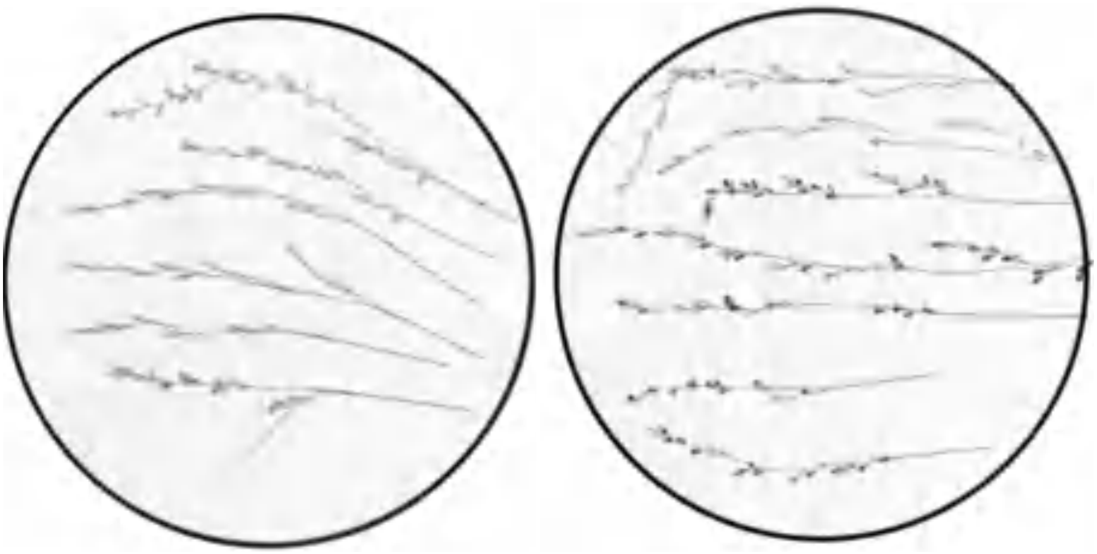

Figure 27. X-ray images of *L. gibsonii*, showing (left) developing seed from earlier in the season, unfilled and x-ray transparent; (right) developed seed from early October clearly showing developed seed (dark and x-ray opaque), and non-viable seed (pale, x-ray transparent. The darker seeds in the second image are ready to drop, while the non-viable seeds will remain on the plant, presumably to confound seed predators (and seed collectors).

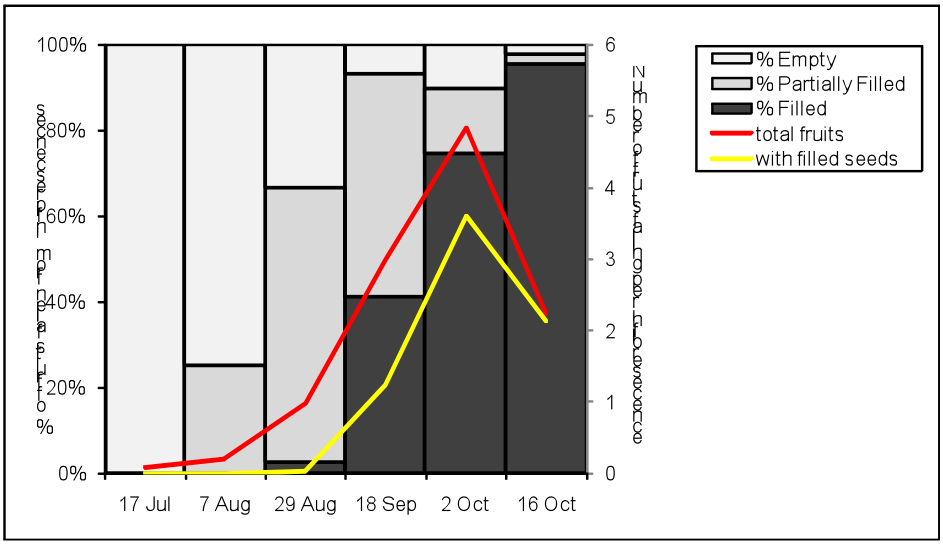

Figure 28. Proportion (bars) and number (lines) of filled fruits falling from *L. gibsonii* inflorescences (mean of ten inflorescence from each of four sites). Proportions are of fruits fallen at the sample time. Seed collection during late Sept-early Oct is possible, but the peak seed production (yellow line) is relatively short, as filled seed drop rapidly. In the field ripe seed can be detected by lightly running fingers along an inflorescence and counting the number of seed thus released.

Summary

- *Darwinia masonii* flowering and seed production takes place over a long period in spring and early summer.

- The peak period for *D. masonii* seed collection depends on the relative rates of seed development and seed drop, and may vary between years and localities, but in 2009 occurred around mid November.

- *Lepidosperma gibsonii* reproduction takes place over multiple years, with inflorescence production occurring in one year and flowering and fruit ripening occurring in the next.

- The seed collection window for *L. gibsonii* is brief (one to two weeks) as filled seeds fall soon after ripening. In this study mid October was found to be the ideal time for seed collection.

Recommendations

- Seed collection is timed closely to ensure that collected material contains viable filled seed.

- Ideal collection times appear to be mid November for *D. masonii* and mid October (in fruiting years) for *L. gibsonii*.

4.3b Seed production

Darwinia masonii

Seed production was assessed by counting the number of fruits in each of 30 infructescences collected from plants in the vicinity of each survey plot in each year. Seed fill rate was assessed by X-ray photography, and fruits with visible signs of external damage were counted as predated. Seed production per plant was calculated using these numbers together with the data on mean infructescences per plant and proportion of flowering plants reported previously (Table 13).

Table 24 Number of *D. masonii* fruits produced, number of filled seeds and number of predated seeds per infructescence (infr), as well as total seed production per plant for 2007-2009.

	2007	2008	2009
Flowers / infructescence	–	–	22.1
Fruits / infructescence	17.3	14.7	10.4
Filled seeds / infr (% of total)	2.6 (15%)	4.5 (30%)	2.0 (19%)
Predated seeds / infr (%of total)	1.1 (6%)	1.8 (11%)	2.3 (22%)
Uneaten seeds / flowering plant	75	25	66
Uneaten seeds per plant	47	9	59

Each flower in a *D. masonii* inflorescence has the potential to develop into a single fruit, each of which may in turn hold a single seed. However, when assessed in 2009, the number of developed fruits per infructescence was just under half the mean number of flowers per inflorescence (Table 24). Slightly fewer fruits developed per infructescence in 2009 (10.4) than in previous years (14.7 in 2008 and 17.3 in 2007). Externally indistinguishable, empty fruits (i.e. not containing developed seed), outnumbered filled fruits (containing developed seeds) in each year surveyed. With 70 - 85% of developed fruits not containing filled seeds, and the rate of seed predation varying between 6 and 22% per year, the mean number of good seeds that escaped predation varied from 2 to 4.5 per infructescence. Multiplying seeds per infructescence by the number of infructescences produced per flowering plants and the proportion of flowering plants in each year indicates that on average, between 25 and 75 good seeds are produced per flowering plant. Including non-flowering plants, this means an average of 9 – 59 seeds per plant per year in older plots.

Predated seeds are almost entirely all eaten by larvae of an unknown moth species. The moth prevents fruits from dispersing from infructescences by sewing them together with silk, and these are then retained on the plant for months after the fruits of non-predated infructescences have dispersed. The moth appears to survive summer in its larval stage, and has been observed in April living inside the hollowed out floral disk or inside a sewn-on fruit.

In 2008, filled fruits weighed an average of 6.4 ± 0.6 mg each (n = 976).

Lepidosperma gibsonii

The production of inflorescences and infructescences varies between plants in *L. gibsonii* as well as between plots and years. As described above (4.3a) *L. gibsonii* inflorescences develop over winter, become dormant over summer and flower and ripen seeds in the next winter. These inflorescences (which have green stems, i.e. photosynthesise) may also be held for a third year following seed production with the old reproductive parts still attached. Thus at any one survey time, plants may support evidence for reproduction across three years. At most seasons it can be difficult to distinguish old from developing infructescences.

As seed production requires two consecutive years of good rainfall for both culm initiation and development in one year, and flowering and fruit ripening in the next, and although it is not known what the threshold rainfall requirement is for these processes, it is possible to model seed production through time. With the exception of 3 years (1968, 1971 and 1972) the Ninghan annual rainfall record is continuous back to 1905. (Regionally, 1968 was above average, 1971 was average and 1972 below average). Seed production was observed in 2009, and rainfall at Ninghan in 2008 and 2009 was 130% and 110% of the average respectively. 2006 and 2007 had 63% and 107% of average rainfall, but seed production was not observed in 2007, suggesting that the minimum rain must be >63%. Thus the rainfall threshold is likely to be between 63% and 110% of the annual average.

Modelling of the sequence of years with rainfall receipt above a threshold percentage of the Ninghan long term average and reporting the years which are themselves both above the threshold and preceded by an equal or better year indicates that potential years of seed production are infrequent and clustered. If the limiting threshold for seed production is the same for both years of development and equal to (i.e. 100% of) the long term average rainfall, then seed production could occur in 22% of years, if this threshold is 110% of the mean rainfall, then fruit production would only have occurred in 10% of years. While these scenarios indicate an average of one year of seed production every 4.5 years and one per 10.5 years respectively, the actual run of years without seed production is very different. The 106-year Ninghan record indicates one period of 17 years without seed production (1944-1960) under a mean rainfall threshold, and a period of 49 years (1935-1983) without seed production if the threshold is 110% of average rainfall. If the threshold is as low as 65% (i.e. just exceeding that of 2007) then reproduction may occur in as many as 60% of years with 2 years being the longest run of consecutive years with reproductive failure.

This modelling does not account for possible effects of the seasonal distribution of rainfall (e.g. cyclonic summer rainfall may not assist in production of fruits if the following winter is dry), nor the possibility that inflorescence production and seed production have different minimum rainfall requirements.

Summary

- *Darwinia masonii* seed production is moderately low, varying between years from 9 to 59 seeds per plant in mature populations.

- Variation in production results from (in declining order of importance) variation in inflorescence production per flowering plant, seed predation rate, % of plants flowering, and % of fruits containing seed.

- *Lepidosperma gibsonii* seed production is limited by a requirement for sufficient rainfall in consecutive years. The amount of this rainfall is unknown but appears to lie in the range of 65-110% of the average. Applying these thresholds to the Ninghan rainfall record suggests that the frequency of *L. gibsonii* reproduction may vary between 60% and 22% of years, with likely historic runs of no seed production varying from 2 to 49 years.

Recommendations:

- Seed counts should take into account the low number of filled seeds per fruit.

- Seed collection should focus early in the season (November) before moth predation and seed dispersal lead to the loss of most seeds. Later collections will likely contain few uneaten seeds.

- Studies of the identity and habits of the *Darwinia* seed eating moth are recommended.

- Ongoing monitoring of *L. gibsonii* seed production each year, together correlation with rainfall data, will enable refinement of estimates of reproductive frequency.

4.3c Seed germination requirements

Darwinia masonii

Experiments on 2,700 *Darwinia masonii* stored and X-ray screened seed, collected in three different years (2004, 2007 and 2008) and using a variety of physical and chemical treatments were performed in 2009. Samples included 5 replicates of 10 or 20 seed (depending on availability) treated with smoke water or fresh water, light and dark storage, and excision (seed manually removed from fruit coat), nicking of fruit coats (allows water penetration to seed) or no physical treatment. In this experiment, the highest germination rate, 30%, resulted from dark storage of nicked seed, collected in 2007 and treated with smoke water. Insufficient seed was available to test all combinations, so physical treatments were tested only for dark treatments. In light treatments no germination was observed with H_2O, but 3% germinated with smoke (Table 25). In dark treatments, the best germination resulted from nicking or removal of seed coats. For excised seed, H_2O was as effective as smoke water, but in nicked fruits and those with no physical treatment, smoke water had a positive effect. The age of stored seed (up to 5 years old) appeared to have no clear (positive or negative) effect on results.

Table 25 Percent of fresh *Darwinia masonii* seed germinating from samples stored in with light or in dark conditions, treated with smoke or filtered water (SW v. H_2O) and with seed excised, from fruit coats, coats nicked, or no physical treatment (results include different seed batches pooled). nt = not tested.

	Dark		Light	
	H_2O	SW	H_2O	SW
Excised	18%	18%	nt	nt
Nicked	4%	19%	nt	nt
None	0%	6%	0%	3%
Grand Total	3%	13%	0%	3%

These results suggest that *D. masonii* seeds have both physical and a physiological dormancy processes, the former requiring the removal or breakdown of fruit walls, and the latter indicating a stimulatory effect of smoke chemicals. That smoke had limited effect on germination of fresh seeds also indicates an increased sensitivity to smoke with age. Further details on *D. masonii* germination are given in **4.3d Seed bank demography**.

Lepidosperma gibsonii

Due to the absence of seed production in previous years, experiments with fresh *L. gibsonii* seed were delayed until after late 2009. Results from germination experiments with fresh, X-rayed nuts (i.e. known to contain filled seed) using ± heat × ± smoke/ TC water × ± GA treatments, each with 5 replicates of 25 seeds, resulted in zero germinants. A small number of germinants were observed following burial for 3 and 6 months however (see 4.3d below).

Experiments with *L. gibsonii* seeds manually manipulated under a microscope to remove their external (i.e. fruit wall or nut) casing resulted in levels of germination: up to 60% of excised seeds treated with a heat (100°C) pulse germinated (4.7b see Germplasm storage).

Seed of *Lepidosperma* species are generally difficult to germinate. Recent work at BGPA by Shane Turner and others on other *Lepidosperma* species report the absence of germination without nicking of fruit coats or excision of seed (e.g. Kodym *et al*. 2010, Panaia *et al*. 2009). Turner (unpubl.) also reports a positive role for 80° and 100°C (but not 120°C) heat treatments in germination of previously buried *Lepidosperma leptostachyum* seed. Smoke water and gibberellic acid had independent and interactive positive effects, but maximal germination still did not exceed 25%.

These collected results indicate a physical dormancy process in *Lepidosperma* which may require the break-down of the fruit coat over time through weathering in the soil, and which can be replicated by the somewhat onerous process of seed excision.

Summary

- *Darwinia masonii* seed germination is low in experimental treatments on fresh and stored seed, but can be improved by a combination of physical treatments and smoke application.
- *Lepidosperma gibsonii* seed germination remains unsolved, however indications of positive, but still small, effects of seed burial, fruit wall breakdown (or removal), smoke and heat treatments can be derived from related studies and early results from burial experiments.

Recommendations

- Large scale production of seedlings of either species via germination of fresh or stored seed is possible, but inefficient, and involves physical manipulation of small seeds for seed coat nicking or removal, or retrieval of seed buried for months or years.

4.3d Seed bank demography

The significant soil seedbank germination response observed following experimental fire, described under 'recruitment' in section 4.2 above, indicates the presence of a significant soil seedbank for both species.

An experimental program was established to investigate the longevity and seasonal and longer-term patterns in germinability of seed buried in the soil. The *D. masonii* burial trial commenced in January 2009, and that of *L. gibsonii* as sufficient seed became available a year later. Collected seed was initially x-ray screened to ensure that only filled fruits were used in experiments. These were then counted into nylon mesh bags, with a total of 55 bags of 250 *D. masonii* seeds and 70 bags of 120 *L. gibsonii* seeds created. These were buried in 5 caches each for *D. masonii* and *L. gibsonii*, located on 100m transects running down the north (*D. masonii*) and south (*L. gibsonii*) slopes of Mount Gibson. Soil temperature sensors attached to battery operated data-loggers were placed with each collection which was covered with 2-5 cm of soil. Rocks and litter removed prior to burial was replaced, and a wire cage to exclude vertebrate disturbance was positioned over the top.

The experimental design incorporated provision for retrieval of one bag from each site, i.e. 5 replicate bags per sample period, for 11 (*D. masonii*) / 14 (*L. gibsonii*) sample periods. The retrieval schedule planned was 3 month intervals for two years, followed by annual (*D. masonii*) and biannual (*L. gibsonii*) intervals up to 5 years. This design allows for flexibility in sampling number or interval if early results suggest it may be required.

Prior to treatment, retrieved seeds were x-rayed and scored for internal and external signs of germination, predation or degradation. The five groups of intact seeds (one per retrieval site) were then split into groups of 100 (*D. masonii*) and 25 (*L. gibsonii*) for treatment. On retrieval, as well as (for control samples) at the time of burial (i.e. at time = 0) the five replicate samples were treated, plated out on filter paper in petri dishes and stored in the dark at 15°. Seeds were examined and the number of germinants counted fortnightly until germination ceased at approximately 150 days. *Darwinia masonii* seeds were treated with either smoke water or filtered water, while *L. gibsonii* seeds were treated to a crossed design of smoke water or filtered water and application of heat / no heat. Heat treatment was 100° for 10 minutes. Heat treatments were not applied for *D. masonii* as preliminary tests showed that heat (applied for 10 minutes or 30 minutes) did not enhance germination.

Darwinia masonii seed responded to smoke water (SW) at all periods, improving germination by 20-70% over fresh water only (Figure 29a).

Germination was low to negligible with fresh water except in spring (at 9 months) when it peaked at 29%. Smoke-water treated seeds germinated at all times, but at a much higher rate in spring and the second summer. The largest germination response (90%) was to smoke water after 9 months of burial (i.e. in spring). Germinability at 15 months was close to identical with that observed at 3 months and 6 months, suggesting no significant decline in seed viability with age over 2 years, and tight control over the germination process.

a) **b)**

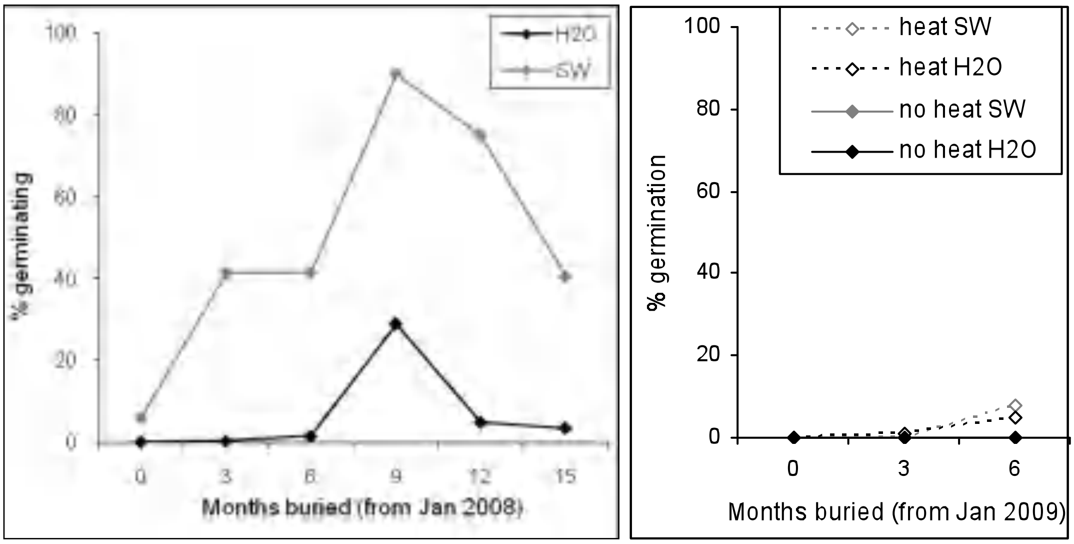

Figure 29. a) Germination rate of *Darwinia masonii* seed buried in the field and retrieved after 3-15 months. Results show average of 5 samples of 100 seeds, as well as smoke (SW) and filtered (H_2O) water treatments. **b)** Germination rate of *Lepidosperma gibsonii* seed buried in the field and retrieved after 3-6 months. Results show average of 5 samples of 25 seeds, as well as smoke and filtered water treatments crossed with ± heat (100° C for 10 minutes) treatments.

No seeds germinated for *L. gibsonii* in the absence of physical treatment, just one germinated after 3 months of burial (heat + SW treatment) and 16 germinated after 6 months of burial (Figure 29b). These were all in the heat treated samples and represented 8% of the SW and 4.8% of the H_2O only treated samples.

The seasonal pattern observed is common in species with long-lived seedbanks from areas with seasonal climates and indicates that seeds are cycling in and out of dormancy in relation to environmental cues. Soil temperature and moisture are likely to control the induction and loss of dormancy. The incomplete germination with smoke also shows that smoke does not break dormancy, but rather it acts as an additional cue.

Summary

- Seed bank trials have been established for both species, and are ongoing. The lack of availability of seed in previous years meant that *Lepidosperma gibsonii* trials had only had 6 months to run by the end of the project.

- Buried seed is still in place with experiments designed to continue for up to 5 years.

- Preliminary results indicate complex germination / dormancy strategies for both species, combining a requirement for physical degradation of the seed coat, environmental (seasonal temperature) cuing – with seeds cycling in and out of dormancy, and heat- and smoke-related physiological responses.

- Germination rates peaked for *D. masonii* at 90% with seed which had been exhumed after 9 months of burial and treated with smoke water

- Smoke water treatments of *L. gibsonii* seed buried for 6 months and exhumed in winter showed a small, but non-zero rate of germination. For this notoriously recalcitrant genus this result is encouraging.

Recommendations

- Established seed burial / retrieval trials should continue for at least several further years.

4.3e Breeding and mating systems

For most species, self-sustaining populations require both a large pool of genetic variation, and the ability to breed successfully with a wide pool of mates. Patterns of mating determine the level of homozygosity in the next generation, and thus affect reproductive success, fitness of offspring, genetic diversity and genome evolution. Relatively few inbreeding species have evolved mechanisms, or sufficiently purged their genome to withstand the deleterious effects of inbreeding over evolutionary timescales (hundreds of generation).

Knowledge of breeding and mating systems in rare plants is important for several reasons: (1) it gives basic information on the critical factors in maintaining mating patterns and seed production, (2) it gives baseline information which can then be monitored over time to detect changes in population sustainability (e.g. detecting lowered genetic variation in the seed rain before a fire event that might irrevocably kill off diversity not maintained in the seedbank), and (3) provides information on the critical factors for creating a self-sustaining population in translocation and restoration efforts.

Following Neal & Anderson (2005), Breeding system refers to the physical and physiological aspects of plant mating: (e.g. sex of flowers, relative timing of development of different organs, self-compatibility mechanisms etc). Mating system refers to the relatedness of mating gametes, and spatial relationships of parents (e.g. inbreeding, outcrossing, correlated paternity).

Darwinia masonii

Breeding system

Like most other species in Myrtaceae tribe subtribe Chamelaucineae (sensu Rye in press), the flowers of *D. masonii* exhibit *pollen presentation*. This specialised mechanism facilitates more accurate deposition and removal of pollen, or in some cases increase rates of self-fertilisation (for specific discussion of pollen presentation in Myrtaceae see Slater & Beardsell, 1991 and Beardsell et al., 1993). The pollen of *D. masonii* exudes from the anthers while the flower buds are still closed, it then becomes soaked in an oily pollenkitt which is excreted from a terminal gland on the anther. This pollenkitt and pollen attaches to a band of hairs just below the tip of the central style. As the flower opens and the enclosing bracteoles are pushed away, the style rapidly elongates to its full length, carrying the fresh, wet pollen with it just below the apex of the style. The timing of stigmatic receptivity has not been studied in *D. masonii*, however in the related species *Chamelaucium uncinatum*, the stigma is initially small and unreceptive at anthesis, but increases in size and becomes fully receptive 7 days after anthesis. (O'Brien 1996). In other species of *Darwinia* studied at Kings Park, the stigma is also initially unreceptive for many days after anthesis, but the stigma does not enlarge on becoming receptive; the only indication that the stigma has become receptive is a slight "wetting" of the style as a sugar-rich solution is released to simulate germination of pollen tubes. *D. masonii* is almost certainly very similar to other WA *Darwinia* species in its stigmatic development.

Pollen presentation has the potential to be very efficient at depositing and collecting pollen at a single area on a pollinator's body, but also increase the likelihood of *self-pollination* due to the close proximity of pollen to the stigma. An assessment is therefore necessary to determine (1) whether plants can and do self-pollinate, (2) what percentage of inbred seeds are produced, (3) do plants preferentially select outcross pollen, and (4) do outcrossed seeds germinate and survive better than selfed seeds? These factors are critical to allow accurate population-viability measures to be recorded and modelled; for instance, if most seeds are selfed, but selfed seed survive significantly worse than outcrossed seed, then effective seed production may be far lower than that measured crudely by seed fill rates. These questions are addressed below.

Pollinators: A total of 20 hours (x 2 people) was spent bird watching, initially at 2 hour intervals per day over 3 days, subsequently at times of peak bird activity between 0830 and 1100. Each observation point had a more-or less unrestricted view of 12 or more reproductive *D. masonii* plants. A total of 10 hours was spend watching insects on 1-3 plants at a time, initially in 15-minute blocks at 4-hour intervals over 3 days, subsequently at times of peak insect activity between 0930-1100. Each observation consisted information on: species, time spent feeding, number of plants visited, number of flowers visited per plant and destination after initial visitation.

Results:

A total of 26 bird visitations was observed, with all identifications (n=18) of a single species, the White-fronted Honeyeater (*Phylidonyris albifrons*). At least five other species of honeyeater have been observed at Mt Gibson, but none were observed visiting *D. masonii*. White-fronted Honeyeaters landed on the branches of *Darwinia* plants (or rarely the ground) and probed upward into the flower head to reach the copious nectar produced by recently-opened flowers. Birds were observed physically contacting styles. On one occasion a bird was seen vigorously wiping its beak on branches immediately after a visit to *D. masonii*, presumably to remove a build-up of sticky pollenkitt received from styles. Birds fed for 10 seconds to 2.5 minutes at a time, and visited single flowers on single plants, up to numerous flowers on at least 6 plants; most consecutive visits were between neighbouring plants, before flying away out of sight. Pollen longevity is not known, neither are honeyeater movements on larger temporal and spatial scales.

Although native bees and wasps were observed visiting other plant species around *Darwinia* plants, the only insect activity seen on *D. masonii* was very rare (n=2; total of 10 flowers) visitations of introduced honeybees, and one of a large native wasp. Visitations involved bees/wasps attempting to reach the nectar from the base of flower heads, and not attempting to collect the (wet) pollen held on styles [In contrast, numerous bees were observed combing plants of *Calycopeplus collinus* nearby for their dry pollen]. Most attempts by bees / wasps to reach nectar of *D. masonii* failed due to the angle of the head, and the insects usually left without touching the styles. Only twice was an insect (1 bee, 1 wasp) observed to reach the nectar, on a flower head held laterally and by the insects reaching in from the perimeter past the red bracts, without contacting pollen or the stigma. Only once was a bee observed contacting the style and stigma, during an unsuccessful attempt to squeeze through the mass of styles.

Conclusion: while both insect and bird visitation both occurs, by far the dominant (potential) pollinators are White-Fronted Honeyeaters, with insect visitation at best rare and ineffectual.

Pollinator dependence and inbreeding rate: The effective dispersal of pollen in most plants relies on the activity of pollinators. Some plants, however, have evolved strategies to avoid the need for outcrossing, and instead self. Other plants show a mixed mating system, with the ability to self-pollinate in the absence of pollinators. In this study, the ability of *D. masonii* to produce seed, and the effect of types of pollinators on total seed production was studied.

Sixteen plants in a single population were divided into three groups:

- Complete pollinator exclusion (caged with fine mesh to exclude all insects and birds); N=4.
- Partial exclusion (with 1 cm gap mesh to allow insect pollination but exclude birds); N=4.
- Open pollinated (uncaged); N=8.

Cages were erected to be self supporting and completely enclose plants, but provide minimal shade, and were placed over plants prior to anthesis of the first flowers (Figure 30).

Figure 30. Exclusion cages for *D. masonii* pollination study. Left: Bird and insect exclusion, Right: Bird exclusion.

Mature fruits (each fruit contains a sing (rarely two) seeds) were X-rayed in Faxitron X-ray Corporation v1.2 (exposure 21kV for 10 seconds) to determine whether a viable seed had developed. Seeds with filled ovaries (from the enlarged hypocotyl which forms the bulk of the seed in *D. masonii* (Prakash, 1969) were recorded (Figure 4). Seeds that are non-viable just show a cavity. A percentage of viable seeds out of the subset X-rayed were determined.

Mating system parameters was estimated using the MLTR program v3.2 (Ritland, 2002). MLTR estimates from progeny arrays the following parameters: 1) multilocus population outcrossing rate, 2) bi-parental inbreeding rate (mating among relatives) and 3) correlated paternity (fraction of siblings that share the same father).

Results: When all pollinators were completely excluded, seed set (6.6%) was significantly greater than zero (P<0.05; Figure 31). When birds were excluded but insects were allowed access to the plants, there was an increase of seed set to 14.8%, although this was not significantly greater than that following all pollinator exclusion (P>0.05). In contrast, plants given full access to pollinator showed a significant increase (23%, P<0.05) in seed set compared to complete pollinator exclusion; this result was however not significant when compared to the treatment excluding birds only (allowing insects).

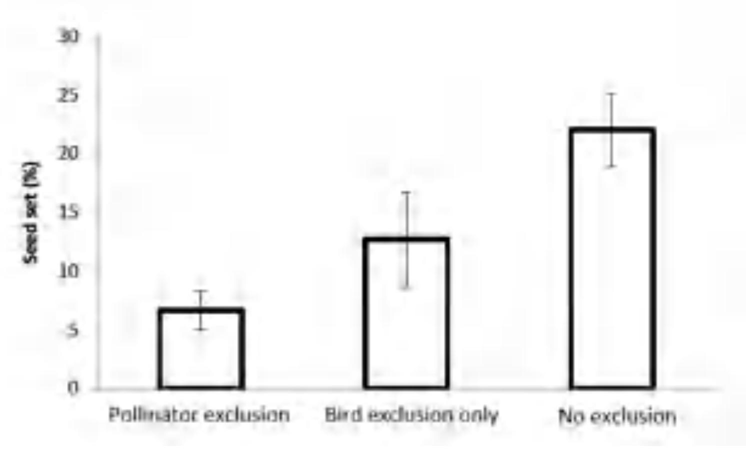

Figure 31. Percentage of flowers with filled seed from D. masonii plants allowed access to different classes of pollinators. In the control (no exclusion), seed set was relatively high (23%), compared to caged plants which excluded birds. The caged plants that excluded all pollinators (birds and insects) had the lowest seed set (7%), while the plants caged to exclude birds but not insects had an intermediate seed-set (13%). This data suggests that (1) plants can set a lowered level of self seed in the absence of pollinators, (2) that birds are significant pollinators, almost doubling the seed-fill rate compared to insect-only pollination, and (3) insect activity appears to have a weaker contribution (however the last result is not significantly different from zero).

Conclusion: *D. masonii* is able to self-pollinate at a low rate (6.6%) in the absence of pollinators, however pollinator activity significantly increases seed set. The study was not powerful enough to unambiguously separate the actions of pollinator classes, however the trend agrees well with pollinator observations: rare insect visitation increases the outcrossing rate (and seed set), however birds are much more effective pollinators and more common visitors, resulting in a higher seed set.

These results were further corroborated by an assessment of mating system parameters using MLTR (Ritland, 2002). Assignment of paternity using microsatellite genotypes (comparing maternal-only markers vs presence of non-maternal and therefore outcrossed markers) showed a multilocus outcrossing rate (tm) for the open pollinated plants (control) of 0.57 (0.09) (Table 26). This was greatly reduced, as expected, when all pollinators were excluded (tm = 0.17 ± 0.17, i.e. not significantly different from zero, as expected for complete selfing). The presence of insect pollinators only however increased the multilocus outcrossing rate to intermediate levels (tm = 0.45 ± 0.19; $P<0.05$), suggesting that insects can supply some pollen dispersal service in the absence of birds.

Table 26. Mating system parameters for pollinator exclusion experiment in *Darwinia masonii*. Multilocus outcrossing rate (tm), bi-parental inbreeding rate (tm-ts), and correlated paternity (rp) were estimated using MLTR (Ritland, 2002).

Treatment	tm (SD)	tm – ts (SD)	rp (SD)
Complete exclusion	0.17 (0.17)	0.08 (0.03)	-0.16 (0.71)
Bird exclusion	0.45 (0.19)	0.14 (0.04)	0.32 (0.43)
Control	0.57 (0.09)	0.03 (0.02)	0.09 (0.12)

Assessment of pollen limitation: The benefits of outcross mating over selfing can be expressed at several stages of development, including differential pollen germination, pollen tube growth rates, pollen tube growth in the style, fertilisation success (all pre-zygotic barriers to selfing), differential embryo development (in this case 2 ovules, usually only 1 develops), differential seed ripening, germination rate, seedling emergence, seedling survival and adult reproductive capacity (post-zygotic barriers). In this study we examined the effect of self vs outcross pollen up to seed maturation, by supplementing pollen over and above that received by plants from normal vectors. The three treatments were:

- Open pollinated plants with no supplemented pollen (control)
- Supplemented pollen from a known outcrossed plant, to determine whether there is an increase in reproductive success (seed fill rate)

over and above that observed from natural pollination – ie. is fertilisation *pollen limited* through scarcity of pollinators?

- Supplemented self-pollen (from other flowers on the same plant) to determine whether any observed increase in seed production is the result of *any* pollen limitation (e.g. physical or temporal separation of self-pollen transfer between the style hairs and the stigma), or whether it is *outcross-pollen* limited, implying pollen source is the controlling variable

Results: There was a significant increase of average percentage seed set over the control when outcross (+external) pollen was introduced but not when self-pollen was introduced (Figure 32). An ANOVA test showed $P<0.05$ when comparing no extra pollen (control) and external source of pollen. However, there is no significance increase of seed set when pollen was introduced from the same plant (+self pollen) compared to a control group.

Conclusion: Outcross pollen provides a significant improvement in seed-set rates over self-pollen; the addition of self pollen alone does not increase seed fill rates, suggesting that pollen presented near the style is able to self-fertilise plants effectively. The presence of external pollen, however implies a selection mechanism for outcross pollen – i.e. *D. masonii* is capable of selfing but is *preferentially outcrossing*, the same pattern reported in many eucalypt species.

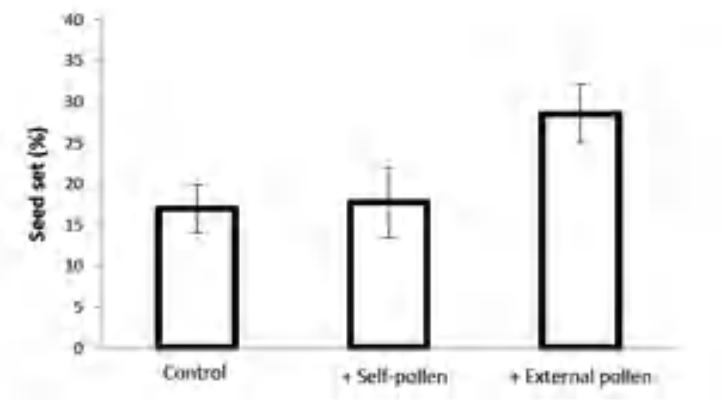

Figure 32. Seed fill rates (% of flowers with filled ovary cavity) when given access to natural pollinators (control), supplemented with self-pollen, and supplemented with outcross pollen.

Genetic diversity at different stages of the lifecycle:

Selfing is expected to lower the genetic diversity (especially observed heterozygosity and Fixation indices) of offspring relative to their parents. If left unchecked, this will result in a gradual decrease in genetic diversity, and loss of alleles until populations become almost uniform in genotype. Selection against homozygotes at different developmental stages can however result in maintenance of genetic diversity in the face of inbreeding.

We assessed genetic diversity at three stages of the lifecycle of *D. masonii*: adults, seeds and seedlings, by genotyping using microsatellite markers. Due to access constraints and the need for an experimental fire to generate seedlings under selection for their environment, two separate populations had to be used, (1) the adults and seedbank in the experimental burn are on Extension Hill, and (2) adults and their seed progeny in the Mt Gibson South population. A total of 220 adults and 113 seeds were analysed from Mt Gibson South, while a total of 77 adults and 146 seedlings were analysed from the Extension Hill experimental burn site.

As expected from the presence of inbreeding in *D. masonii*, seeds display reduced observed heterozygosity (Ho, table 27) compared to their parents (although the result is not statistically significant), and increased Fixation Index (a measure of homozygosity). Assuming both breeding system and selection processes are common between the two sites, the fact that parameters for seedlings are close to parent values is evidence for selection against inbred seeds / homozygotes, possibly through the action of lethal alleles.

Table 27. Comparative average diversity estimates for 2 adult populations of *D. masonii*, and their respective offspring: Pre-fire adults and post-fire seedling recruits at Extension Hill, and Adults and their seeds from Extension Hill south. Diversity measures are I (Information index), Ho (observed heterozygosity, He expected heterozygosity, and F fixation index; all values are means ± standard error). Seeds show a distinct decrease in observed heterozygosity and an increase in Fixation index (consistent with a percentage of inbreeding), while seedlings are more similar to adults, suggesting selection against inbred seeds in this species.

Averages:	**I**	**Ho**	**He**	**F**
EH Adults pre-burn	1.245 ± 0.290	0.557 ± 0.145	0.601 ± 0.128	0.106 ± 0.106
EH post-fire seedlings	1.251 ± 0.287	0.515 ± 0.133	0.597 ± 0.124	0.139 ± 0.099
MGS Adults	1.309 ± 0.307	0.571 ± 0.083	0.619 ± 0.094	0.070 ± 0.021
MGS seeds	1.209 ± 0.306	0.479 ± 0.095	0.587 ± 0.113	0.154 ± 0.047

A mating system in which plants can inbreed, but select against inbreed seed, ultimately producing mostly outcrossed offspring is termed *preferential* *outcrossing*, and is known to be the dominant system in *Eucalyptus* (also a member of the family Myrtaceae, like *Darwinia*) (House 1997).

Summary:

- *D. masonii* is predominantly pollinated by a single species of bird, the White-fronted Honeyeater.
- *D. masonii* is capable of selfing but selection for outcrossed seeds occurs at several levels, greatly reducing the number adult plants resulting from self-pollination, and the production of outcrossed seed is therefore a critical requirement for maintaining a self-sustaining population.
- Any restoration or translocation efforts must include the community context for *D. masonii*, especially in regard to ensuring adequate habitat for White-fronted Honeyeaters.

Lepidosperma gibsonii

Lepidosperma gibsonii is wind pollinated, and so does not have complex pollinator interactions as seen in *D. masonii*.

The mating system in *L. gibsonii* was investigated by sampling inflorescences from 12 plants and collecting the seed produced (total 48 seedlings). Embryos were extracted from seed using the protocol presented here, and left to grow into small seedlings on agar. Seedlings were then removed, DNA extracted, and genotyped using 11 microsatellite loci. Assignment of paternity using microsatellite genotypes (comparing maternal-only markers vs presence of non-maternal and therefore outcrossed markers) showed a multilocus outcrossing rate (tm) for the open pollinated plants of 91.7 %, demonstrating a very high rate of outcrossing compared to selfing, as expected for a wind-pollinated species, and as expected by the high genetic diversity and lower level of population structure observed in *L. gibsonii* (see section 4.1).

Population size and weather conditions are the likely factors affecting pollination success. Further research on the effect of population size (and therefore pollen abundance) on inbreeding rate would be beneficial.

Summary:

- *L. gibsonii* appears to have widespread, wind-assisted pollen dispersal and high rate of outcrossing.

4.3f Dispersal

Studies of dispersal took two forms: 1) inferences of possible seed dispersal patterns, vectors and distances from observations and experimental studies of dispersal agents and 2) measurements of patterns of actual dispersal of genetic material in both pollen and seeds, by using molecular techniques to identify the parents of seedlings observed following experimental fire.

Darwinia masonii

Pollen and seed dispersal

Pollen dispersal was studied by parental assignment of seed genotypes with known mothers to determine their most likely father (pollen donor). The program CERVUS (Kalinowski et al. 2007) was used to assign paternity to genotyped seeds collected from known, genotyped mother plants. A total of 200 seeds were genotyped and the most likely sire estimated from among 200 possible surrounding adult plants using likelihood assignment techniques. Effective Seed dispersal was studied by genetic assignment of seedlings within the surrounding pool of prospective parents. Since *D. masonii* seeds only rarely germinate in the absence of fire, an experimental fire was carried out in an area within the approved clearing footprint that contained a population of reproductively mature *D. masonii* (likely dating from the 1969 fire). Since adult plants are typically killed by fire, all adult plants in this population were genotyped prior to burning. The experimental fire was carried out in May 2009, just prior to the onset of winter rainfall, and seedlings were sampled at the end of spring, i.e. after the first season of growth but prior to the first summer. A total of 80 adult plants were genotyped, and a total of 230 seedlings were recovered and genotyped. Only the lowest leaves (senescing cotyledons) were sampled in order to track seedling survival (and genetic correlates with survival) through time. The program CERVUS (Kalinowski et al. 2007) was used to select the most likely parents (maternal and paternal) from among the 80 adult plants present before the fire. Results of this work are being prepared for publication.

Identity and behaviour of seed dispersal agents

Fruits of *Darwinia* species from NSW are reported by Auld (2009) as being dispersed by ants, and studies at Extension Hill confirm this behaviour with respect to *D. masonii*. Seed removal by ants was assessed in a baiting experiment, in which 14 piles of 5 *D. masonii* seed were observed between 9 am and 3 pm on December 2 2009, with seeds in baiting stations refreshed if any were seen to have been removed. The number and time of seed removal events was recorded and specimens of ant species observed removing seed were collected for identification (by Brian Hederick, Curtin University). The foraging behaviour by *R. violacea* ants (previously reported to be a key seed-dispersing species in SW WA; Gove *et al*. 2007) was examined on Extension Hill south (in December 2007 and May 2009). Foraging distances were assessed by offering randomly observed individuals food morsels (muesli bar fragments) and recording the distance back to their nest. Finally, to identify the interest of ants in *Darwinia* seeds, individually marked, weighed and photographed fruits were offered to captive *R. violacea* ants, which quickly removed the fruits below ground, but then later returned them to the surface. Returned seeds were rephotographed and weighed.

Six species of ant were observed removing *D. masonii* seeds in December 2009: *Iridomyrmex chasei*, *I. gracilis minor*, *Melophorus turneri perthensis*, *Rhytidoponera crassinoda*, *R. metallica* and *R. violacea*. Seed was removed from all 14 observed stations with an average of between 0.3 and 7.3 removals per station per hour, although at one station 41 seed were removed in a 1 hour period, including 18 in one 10 minute period, by *M. turneri perthenis* to a nest 2.5 m away.

A total of 30 *R. violacea* foraging distance observations were made at Extension Hill these indicate an average foraging distance of 3.7 m and a maximum of 10.8 m.

Auld (2009) suggests that ant dispersal of *Darwinia* fruits results from the attractiveness of *Darwinia* petals, however observations of *D. masonii* fruits collected and then returned to the surface by captive *R. violacea* ants with intact petals contradicts this idea. Instead, we suggest that ants are attracted to the highly concentrated but still-liquid nectar which coats the outside of *D. masonii* fruits. After processing by ants fruits weighed 10% less and had intact petals (n= 12 fruits). Before and after photographs also clearly show the removal of the external liquid coating.

Most offered fruits were disposed above ground by captive *R. violacea* ants, and 12 of 30 *R. violacea* nests discovered in the field had collections of up to 50 *D. masonii* fruits scattered at their entrance. However two observations of *D. masonii* seedlings emerging in groups of 4-6 individuals from buried ant garbage chambers at Extension Hill and Mt Gibson confirms the role of ants in the effective dispersal (and burial) of seed. It is possible that this dispersal process is responsible for the phenomenon of two or more *D. masonii* individuals growing in immediate proximity, with stems frequently observed abutting at their base.

Figure 33 An ant (*Melophorus turneri*) depositing fruits of *Darwinia masonii* on the soil surface close to a nest (left). (right) Four *D. masonii* seedlings germinating from a below-ground garbage chamber – note other seeds and parts of insects, including ants (identified as *Rhytidoponera violacea*).

Lepidosperma gibsonii

Pollen dispersal

Population genetic analyses of *Lepidosperma gibsonii* have shown that pollen dispersal must be extensive across all populations within the Mt Gibson area, due to the extremely low genetic differentiation between populations. This is almost certainly due to wind-dispersed pollen in this species (confirmed by field observations of dry pollen released in clouds at anthesis).

Seed dispersal

The small size, and abiotic dispersal vectors of *L. gibsonii* seed means that their dispersal is difficult to physically track – poor seed production also excluded the possibility of dispersal experiments which would be costly to limited seed stocks. The best method that could be constructed to measure seed dispersal was mapping actual dispersal distance by assignment of seedling genotype to its source plant. Since *L. gibsonii* seed only germinate after fire, this experiment made use of the May 2009 experimental fire to stimulate germination of seedlings. Three 5 x 5 m quadrats were marked out prior to burning, within which all adult plants were mapped, and then sampled and genotyped with 10 microsatellite loci. Plants were sampled exhaustively, with up to 11 samples per clump, since *Lepidosperma* clumps were previously shown to contain multiple intertwined clonal genotypes within larger clumps.

The experimental fire was carried out just prior to the onset of winter rainfall, and seedlings sampled at the end of spring, i.e. after the first season of growth but prior to the first summer. A total of 200 seedlings was collected and assigned to their most likely parents using the program CERVUS (Kalinowski et al. 2007). Results of this work are being prepared for publication.

Identity of seed dispersal agents

Insufficient seed was available for comprehensive studies of dispersal in *Lepidosperma gibsonii*; however seed have no apparent external dispersal adaptations. A small sample of fruits offered to captive seed-dispersing ants (*Rhytidoponera violacea*) collected from Extension Hill did not result in fruits been removed. The location of *L. gibsonii* seedlings, concentrated below rocks, in spouts and flow points on rocky slopes suggest that at least some seed is moved and concentrated by gravity (perhaps stimulated by scratching birds – e.g. Mallee Fowl), or flowing water.

Summary

- Effective pollen and seed dispersal distances were determined for both species.
- Experiments confirm the key role of ants in dispersal of *D. masonii* seed. Ants appear likely to collect and move nearly all fallen *D. masonii* seed, concentrating undamaged seeds in below-ground garbage chambers or surficial garbage piles. Predation of seeds by ants was not recorded.
- Observation suggests that water may be the primary dispersal vector of *L. gibsonii* seed.

Recommendations

- If collection of seed of *D. masonii* or *L. gibsonii* from the ground is to be attempted, allowance should be made for their dispersal processes i.e. – specifically where seeds might be concentrated.

4.4 PVA MODELLING

Population viability analysis (PVA) modelling of demographic processes in both species was proposed to assess population growth rates, and population (and species) extinction likelihoods, taking into account impacts of the loss or augmentation of populations, as well as variation in climate and fire regimes. This modelling would be based on demographic data derived from the demography and seed longevity programs (incorporating plant survival, growth, seed production, seed bank dynamics, fire response). The input data is required to be representative of the range of annual variation in each trait and associated with measured variation in climate (e.g. rainfall). With such data it is possible to model variation in population behaviour in relation to realistic climate data variation – manipulating the frequency or sequence of years of different types. The impact of fire can similarly be modelled by inserting fire years at varying intervals, varying the age and number of populations burnt. Soil seedbanks are an essential part of population dynamics of both DRF species, but add considerable complexity to models, and require accurate data to populate them.

The patterns of annual variation demonstrated through the period of the survey indicate that the data collected is not sufficient to construct worthwhile PVA analyses for either species. A greater number of years of data are required in order to capture sufficient natural variability for such models to make sense.

Examples of key processes inadequately represented by the three-year survey period include: growth rates of older *D. masonii* plants - which averaged negative growth; *L. gibsonii* seed production which occurred in only one of four observation years; and episodic mortality of *D. masonii* adults as observed in 2010. The longevity of seed in soil seed-banks of both species is equally important. Clearly *D. masonii* growth rates are not negative in the long term, the sample years have not captured anything like the mean rate of growth. Similarly it is unreasonable to assume that *L. gibsonii* reproduction occurs precisely once every three years. PVA modelling cannot be reliable without reasonable values of these (and other) parameters, including reliable estimates of both rates averages and variability (including correlates of this variability). It is clear that a longer period of sampling is required before confidence in the values for these two parameters (and many others) would be sufficient. For *L. gibsonii* two or three seasons with effective reproduction, and for *D. masonii*, enough years to give an average rate of plant growth that is at least positive, and ideally not dissimilar to the long term average derived tentatively from analysis of population structures. Soil seed-bank seed longevity is currently being examined in a program that was designed to monitor survival for ~5 years. For *L. gibsonii* this still has 4 years to run and for both species even a five year sample period may not fully indicate seed bank longevity. These complexities are inherent in species with slow and / or episodic growth dynamics, which are unfortunately common in semi-arid systems.

Without such data, PVA could be performed, but its results would be unreliable, unrealistic and likely unreasonable.

Summary:

- This component is incomplete due to the scale of annual variation in key demographic parameters relative to the project's running period.

Recommendations:

- Continued monitoring of plants in permanent plots and maintenance of seed burial experiments, including attention to regularity and timing of monitoring and adequate quality control and management and storage of data until confidence in key demographic parameters is confirmed and PVA can be performed.

4.5 ENVIRONMENTAL INTERACTIONS AND PLANT HEALTH

4.5a Abiotic associations

Two approaches to determining environmental associations of *D. masonii* and *L. gibsonii* were taken, one, an analysis of site factors assessed at locations where plants were surveyed, and the other modelling of species distributions against spatially mapped environmental data.

Site factors assessed at each demographic and physiological monitoring site are listed in Table 28. Canopy openness was assed via analysis of fish-eye photographs taken at 3 locations in each plot using a 180° angle lens adaptor to take full-sky hemispherical images (e.g. Figure 34). The camera was mounted on a tripod at 40 cm above the ground, levelled with a bubble level with the lens pointing directly upwards and oriented with north at the top of the image. Images were analysed using Gap Light Analyser (v 2.0, 1999) image analysis software for % canopy openness – the proportion of the vertical hemisphere that is not obscured by plants or surrounding hills. Site surface attributes estimated on the ground included % surface area covered by soil crusts (e.g. lichens), litter, gravels, outcropping rock, etc. and mean vegetation canopy height. Altitude, slope and curvature, together with solar radiation receipt were derived from a 1 m interval contour map (see this section below for details). Soils were collected from each site and analysed for pH, electrical conductivity, organic content and major plant minerals and other elements at the WA Chemistry Centre.

Several differences were determined between sites with *D. masonii* and sites with *L. gibsonii* (Table 28). Almost all soil elements analysed were less abundant in *D. masonii* than *L. gibsonii* sites, but only Ca, K and Ni were significantly lower. Sites with *D. masonii* also had significantly lower slopes and significantly greater solar radiation receipt at several times in the year, as well as large, but non-significant differences suggesting greater canopy openness and rock cover relative to sites with *L. gibsonii*. These results suggest that *D. masonii* typically occurs in flatter, hotter (drier), rockier and more open locations with poorer soils than does *L. gibsonii*.

Figure 34. Examples of hemispheric images used in estimation of % canopy openness at each site. Note the horizon visible around much of the perimeter of the right-hand image.

Table 28. Site factors assessed for demography survey, physiology survey and translocation sites, mean ± SE (n) within localities with *D. masonii*, *L. gibsonii* or neither (translocation and comparator species physiology sites). Asterisks indicate significant differences between *L. gibsonii* and *D. masonii*: sites * <0.005, ** <0.0005. To minimise type I errors due to the large number of tests an α of 0.005 is employed. Near-significant tests, *P* <0.05 are indicated '+'.

species	units	*L. gibsonii* sites	**sig.**	*D. masonii* sites	neither
canopy openness	%	62 ± 4 (7)	+	74 ± 4 (11)	
crust cover	%	13 ± 7 (10)		6 ± 3 (12)	
gravel cover	%	32 ± 5 (11)		27 ± 5 (15)	
rock cover	%	28 ± 6 (11)		44 ± 6 (16)	
bare soil	%	22 ± 3 (11)		19 ± 4 (16)	
litter cover	%	20 ± 6 (11)		19 ± 4 (16)	
debris >1cm cover	%	1.4 ± 0.5 (11)		1.8 ± 0.3 (16)	
vegetation cover	%	43 ± 5 (11)		36 ± 3 (16)	
vegetation height	m	2.5 ± 0.5 (11)		2.7 ± 0.5 (15)	
altitude	m asl	385 ± 7 (13)		385 ± 7 (19)	377 ± 6 (15)
slope	°	16.7 ± 1.9 (13)	**	9.4 ± 0.9 (19)	7.9 ± 1.2 (15)
curvature-profile	concave +	1.44 ± 0.59 (13)	+	0.01 ± 0.26 (19)	0.12 ± 0.11 (15)
curvature-plan	convex -	1.36 ± 0.72 (13)		-0.54 ± 0.44 (19)	0.24 ± 0.19 (15)
Solar Radiation					
July 10 am	$w.m^{-2}.hr^{-1}$	0.33 ± 0.05 (13)	**	0.83 ± 0.05 (19)	0.69 ± 0.04 (16)
July 12 pm	$w.m^{-2}.hr^{-1}$	0.91 ± 0.06 (13)		0.95 ± 0.03 (19)	0.93 ± 0.02 (16)
July 2 pm	$w.m^{-2}.hr^{-1}$	0.59 ± 0.05 (13)	**	0.82 ± 0.03 (19)	0.79 ± 0.03 (16)
July 4 pm	$w.m^{-2}.hr^{-1}$	0.24 ± 0.04 (13)		0.33 ± 0.04 (19)	0.27 ± 0.02 (16)
Equinox 10 am	$w.m^{-2}.hr^{-1}$	0.67 ± 0.05 (13)	**	1.11 ± 0.05 (19)	1.00 ± 0.03 (16)
Equinox 12 pm	$w.m^{-2}.hr^{-1}$	0.78 ± 0.05 (13)	**	1.12 ± 0.02 (19)	1.08 ± 0.03 (16)
Equinox 2 pm	$w.m^{-2}.hr^{-1}$	0.96 ± 0.04 (13)		0.97 ± 0.03 (19)	1.07 ± 0.02 (16)
Equinox 4 pm	$w.m^{-2}.hr^{-1}$	0.74 ± 0.05 (13)		0.67 ± 0.05 (19)	0.76 ± 0.02 (16)
December 10 am	$w.m^{-2}.hr^{-1}$	0.99 ± 0.06 (13)	+	1.17 ± 0.03 (19)	1.07 ± 0.02 (16)
December 12 pm	$w.m^{-2}.hr^{-1}$	0.79 ± 0.04 (13)	*	0.89 ± 0.01 (19)	0.90 ± 0.01 (16)
December 2 pm	$w.m^{-2}.hr^{-1}$	1.09 ± 0.03 (13)		1.03 ± 0.04 (19)	1.13 ± 0.01 (16)
December 4 pm	$w.m^{-2}.hr^{-1}$	1.07 ± 0.05 (13)	+	0.84 ± 0.05 (19)	1.01 ± 0.02 (16)
EC	(1:5) mS/m	7.6 ± 1.2 (12)		5.5 ± 0.5 (18)	6.6 ± 0.9 (20)
pH	($CaCl_2$)	5.1 ± 0.2 (12)		4.9 ± 0.1 (18)	4.8 ± 0.1 (20)
OrgC	(W/B) %	3.2 ± 0.3 (12)	+	2.4 ± 0.2 (18)	1.5 ± 0.2 (20)
N	(total) %	0.15 ± 0.01 (12)		0.11 ± 0.01 (18)	0.08 ± 0.01 (20)
P	PRI mL/g	41 ± 5 (12)		55 ± 6 (18)	44 ± 8 (20)
B	mg/kg	0.91 ± 0.08 (12)		1.01 ± 0.05 (18)	0.58 ± 0.09 (20)
Ca	mg/kg	1025 ± 169 (12)	*	578 ± 53 (18)	525 ± 79 (20)
Co	mg/kg	0.17 ± 0.02 (12)		0.19 ± 0.02 (18)	0.23 ± 0.06 (20)
Cu	mg/kg	1.33 ± 0.13 (12)		1.38 ± 0.12 (18)	0.89 ± 0.11 (20)
Fe	mg/kg	98 ± 21 (12)	+	59 ± 5 (18)	63 ± 5 (20)
K	mg/kg	151 ± 11 (12)	*	108 ± 8 (18)	86 ± 8 (20)
Mg	mg/kg	171 ± 17 (12)	+	110 ± 13 (18)	67 ± 10 (20)
Mn	mg/kg	72 ± 10 (12)		68 ± 5 (18)	30 ± 4 (20)
Na	mg/kg	34 ± 6 (12)		24 ± 3 (18)	15 ± 2 (20)
Ni	mg/kg	0.38 ± 0.05 (12)	*	0.20 ± 0.03 (18)	0.2 ± 0.02 (20)
S	mg/kg	12.7 ± 1.1 (12)		15.4 ± 1.6 (18)	15.9 ± 1.6 (20)
Zn	mg/kg	1.5 ± 0.2 (12)	+	1.0 ± 0.1 (18)	5.0 ± 2.3 (20)
Pb	mg/kg	0.79 ± 0.08 (12)		0.84 ± 0.04 (18)	1.19 ± 0.21 (20)

Modelling of species distributions was undertaken using presence records from our own data, together with that of consultant's surveys (ATA 2004, 2006) and some provided from Extension Hill Pty Ltd. These data were combined into a single GIS layer totalling 2534 presence records for *D. masonii* and 912 for *L. gibsonii*. Variation in the numerical resolution represented by the *L. gibsonii* data was extreme, with many location records representing single plants, other representing several or many plants, and a small number representing several thousand individuals each. This data was therefore transformed to a 20m grid, where a single point was located on the grid if one or more plants were recorded within the surrounding 20×20m area. Large populations delineated with two or more point on their margins only were extrapolated appropriately to include more grid points.

Models were constructed using MaxEnt software (V3.3.1; Phillips *et al*. 2006, 2008) which compares environmental data for points where species presences are recorded with equivalent environmental data a large sample (10,000 in this case) of randomly selected 'background' points from the sampled landscape. The MaxEnt routine then select the simplest set of transformations and interactions of the environmental layer data that provide a best fit to the recorded localities. This can then be reprojected onto the spatial maps of the environmental data to produce a map of presence likelihoods. Other MaxEnt outputs include response curves for the model, which show how modelled presence likelihoods change with each environmental variable, and a table indicating the relative significance of each variable to the total model fit. Finally, model fit is tested using AUC / ROC statistics. MaxEnt is increasingly used in ecological research and studies comparing this and other approaches generally find the performance of MaxEnt to be among the best, and often actually the best approach (e.g. Elith *et al*. 2006).

The environmental layer data employed in this study were derived from three sources: Mt Gibson Iron Deposit Geological Plan (Pickands 1967) for geology, satellite and air photo imagery from 1969 to 2007 for fire history (see Figure 10 and Figure 11 for the derived fire history), and the 1m interval contour map available from the region received from Extension Hill. A number of parameters were derived from the contour data – Solar radiation receipt, Aspect, Slope, Curvature, and Elevation – these were calculated (by Sauter Geological consulting) with a 5 m horizontal resolution. Solar radiation (SR) was calculated (following Coleman *et al*. 2009) for the specific latitude of the site on three specified dates (solar equinox and the winter and summer solstices), and for four times on these days (10 am, 12, 2 and 4pm). SR results take into account site shading from nearby topography, assume a constant solar influx and are expressed in $w.m^{-2}.hr^{-1}$. Slope, aspect and curvature were calculated from the 1m contour data in mapinfo's Discover>Surfaces utility.

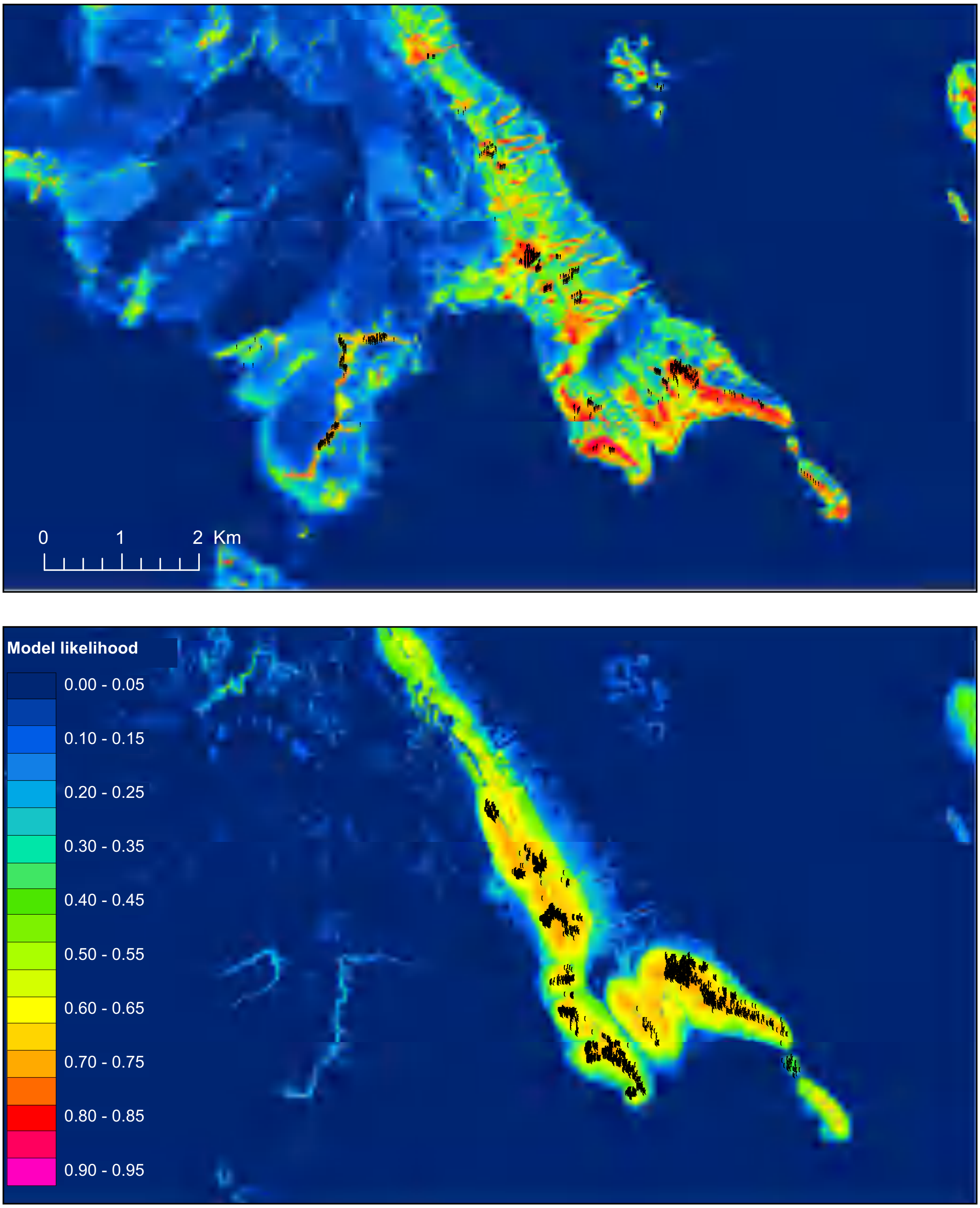

Figure 35 Maxent model outputs showing probabilities of presence (blue = low, red = high) for *Lepidosperma gibsonii* (top) and *Darwinia masonii*. Black dots indicate known localities.

A breakdown of parameters contributing to model predictions shows that, for *L. gibsonii*, winter 2 pm solar radiation contributed to 40% of the predictive model, with elevation and slope contributing most of the remainder (Table 29). For *Darwinia masonii*, slope alone makes an 80% relative contribution to model predictions, with elevation, geology and summer midday SR making up most of the rest. Fire history since 1969 did not contribute to model predictions.

Models for both species predicted their respective distributions well (AUC = 0.988 for both *D. masonii* and 0.98 for *L. gibsonii* species: the maximum possible value = 1). Models predicted a detailed pattern of presence probabilities for *L. gibsonii*, with many small areas identified with a >90% likelihood of presence, but a broader pattern of high (60-75%) probability of occurrence for most of the Mt Gibson range for *D. masonii* (Figure 35). Both models predicted few localities outside of the known range, with the exception of Yandanhoo Hill in the far east.

Table 29 Estimate of relative contributions of the environmental variables to Maxent models for *Lepidosperma gibsonii* and *Darwinia masonii*.

Lepidosperma gibsonii		***Darwinia masonii***	
variable	% contribution	variable	% contribution
Winter SR 2pm	40.3	slope	79.5
elevation	29.5	elevation	15.4
slope	13.6	geology	1.7
geology	4.6	summer SR noon	1.4
aspect	3.3	fire	1.0
fire	2.2		

The response curves from the model output indicate that the association of *L. gibsonii* distribution with SR is a negative one (Figure 36), with probabilities of *L. gibsonii* presence of 80% predicted for areas with <0.4 $w.m^{-2}.hr^{-1}$ and a rapid fall in likelihoods at around 0.7 $w.m^{-2}.hr^{-1}$.

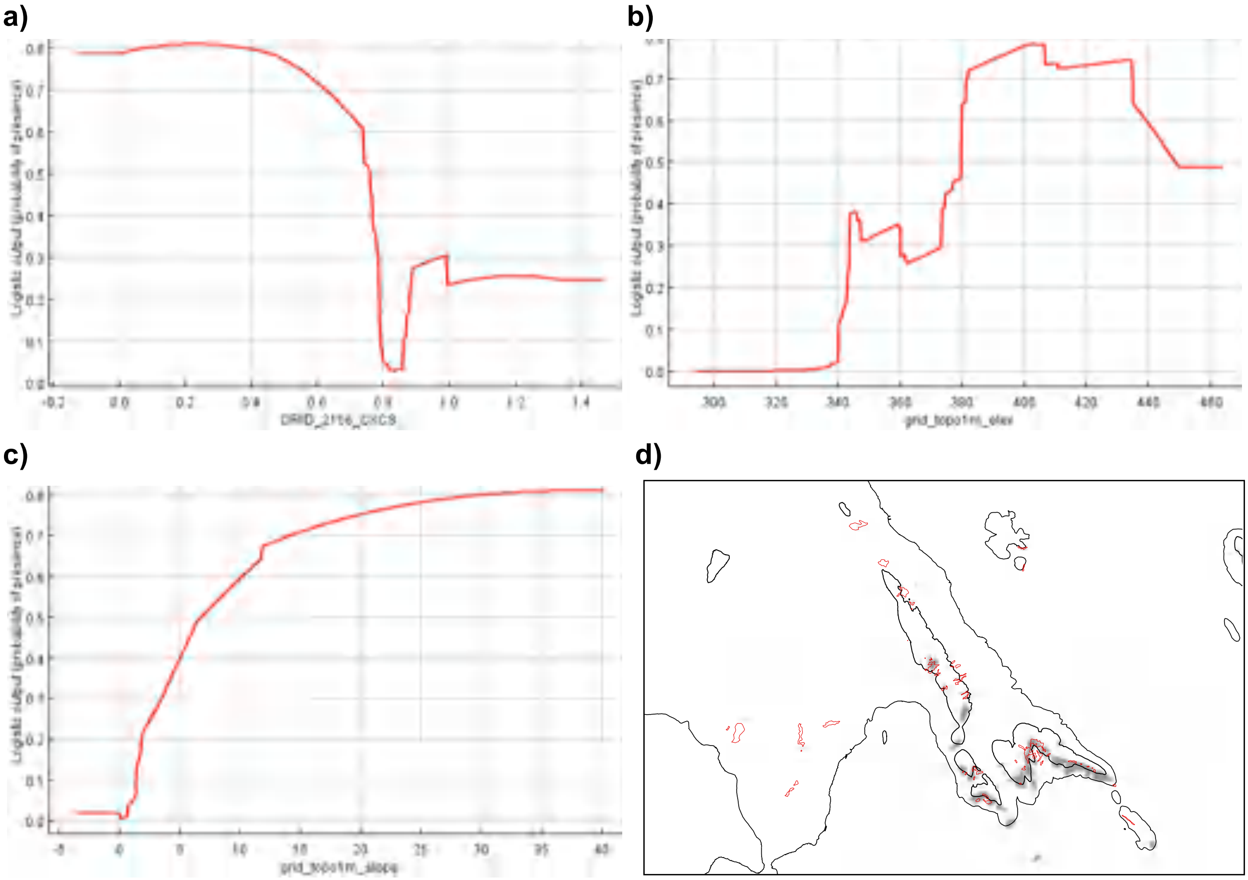

Figure 36 Response curves of the key variables influencing Maxent model predictions of *Lepidosperma gibsonii* showing presence probability estimates if the shown parameter is used alone as a model input. **a)** Winter 2 pm solar radiation receipt ($w.m^{-2}.hr^{-1}$), **b)** elevation (m) and **c)** slope (degrees). **d)** Distribution of *L. gibsonii* (red outline) in relation to winter 2 pm solar radiation <0.6 $w.m^{-2}.hr^{-1}$ (grey) and elevation (340 and 380 m contours)

The response curves of the principal environmental parameters predicting *Darwinia masonii* distribution – elevation, slope and geology – suggest that their contribution to the model is solely to select the Mt Gibson range (Figure 37). Slopes over 7-8°, elevation over 380 m and all geology types except for 14 and 99 have an associated probability of 50-60% if considered alone. Geology unit 99 represents areas not covered by the mapping. As mapping focussed on the ridges and slopes of the range, a negative association with this unit effectively identifies the range and foothills. Unit 14 is “White Rock (unclassified, including granite & its group, acidic dyke rocks, feldspar porphyry & meta-sediments phyllitic rock)” this captures the footslopes of the ranges and the saddles between major hills. Thus elevation, slope and geology parameters combine to indicate simply that *D. masonii* is associated with the slopes and ridges of the BIF range.

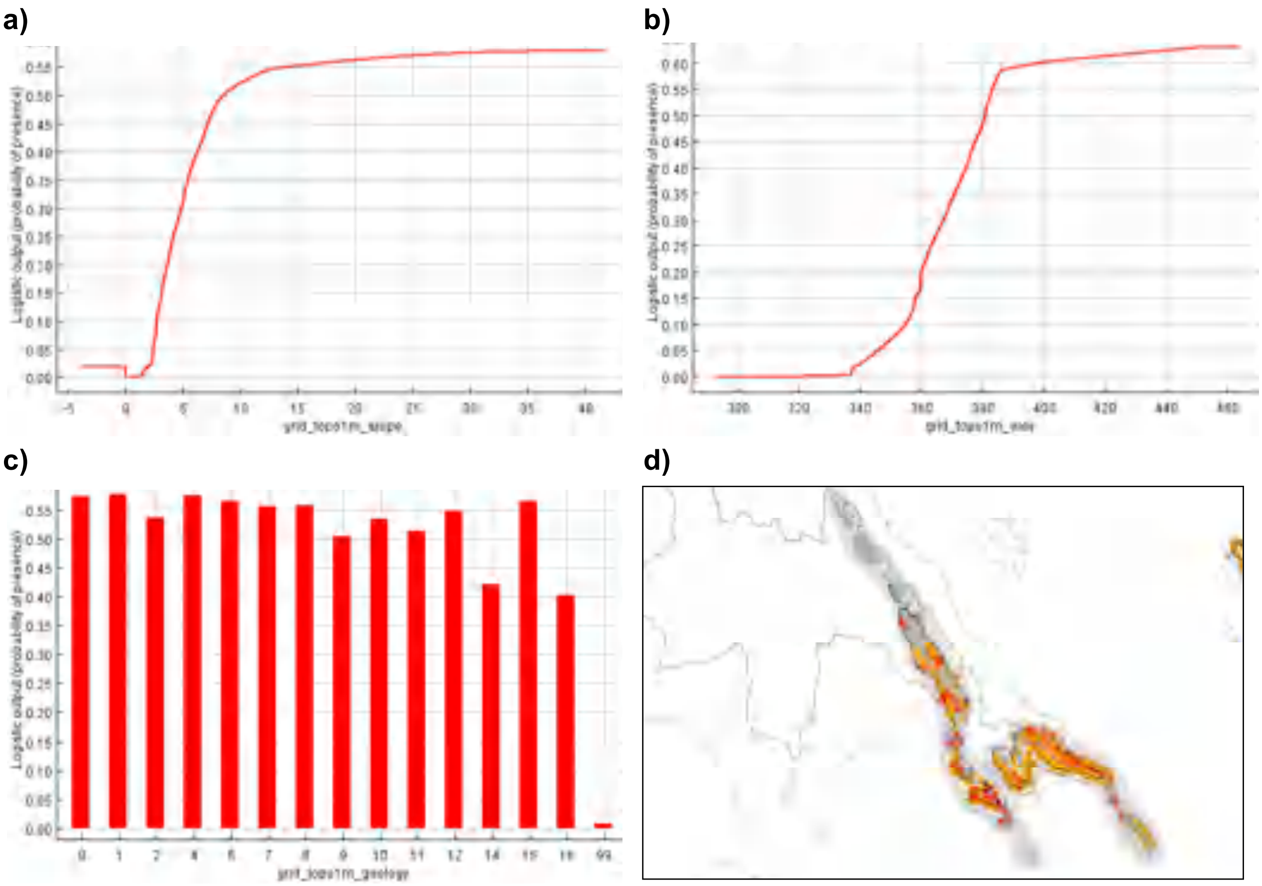

Figure 37 Response curves of the key variables influencing Maxent model predictions of *Darwinia masonii* showing presence probability estimates if the shown parameter is used alone as a model input. **a)** slope (degrees), **b)** elevation (m) and **c)** geology – see text for codes. **d**) distribution of *D. masonii* (red outline) in relation to slope >12° (orange), elevation (340, 360 and 385 m shown) and geology (white = 99, light grey = 14, all others, dark grey).

Implications

The maxent models for *D. masonii* and *L. gibsonii* identify the species' respective habitats with differing degrees of detail. The *L. gibsonii* model identifies locations which are the coolest part of the landscape. Low solar radiation means relatively low receipt of light and heat, which have differing implications for plant behaviour and plant environment. Plants require light for photosynthesise but, particularly if deficient in water or nutrients, too much light can damage plant tissues: during summer droughts, damage to plant photosystems from excess sunlight can lead to long-term damage. Heat loads associated with solar radiation receipt can also influence plant physiology, but more importantly, by promoting evaporation, soil moisture availability. Field-based manipulative experiments examining the interactions of heat, soil moisture and photoinhibition and photosystem damage would be required in order to disentangle the physiology reflected in the association of *L. gibsonii* with low radiation areas. However the strength of this association is clear. The habitat of *D. masonii*, on the other hand, is not so circumscribed and appears to be simply gravelly / rocky iron-rich loams.

Lepidosperma gibsonii is already known to occupy many of the areas that it is most strongly predicted to occupy. It is suspected that most of the remaining highly predicted areas will also contain populations if they were to be surveyed. In contrast, *D. masonii* is predicted to occur broadly across the ranges with a high likelihood but not predicted to occur anywhere with a very high likelihood. Many areas where populations are most highly predicted are known to not support *D. masonii* individuals. These results suggest three things. Firstly, that while the factors limiting the distribution of *L. gibsonii* are described by the environmental variables modelled, the distribution *D. masonii* may be limited by factors not included in the model inputs. Unincorporated factors might include attributes of the regolith – soil depth, underlying rock structure, etc – and longer-term fire-regime. Fire history since 1968 was included as a model input but did not contribute to model predictive capacity. On the other hand, it is likely that longer term fire history patterns not captured by the limited temporal coverage of the data may be important. It seems likely that some areas of the Mt Gibson range are more fire-prone than others – rocky open sites may be less able to carry fire and therefore burn less frequently, for instance.

Secondly, potential restoration and translocation areas for *L. gibsonii* need to be low SR and able to maintain higher soil moisture levels than the landscape average, but all such existing locations are likely to be already occupied. For *D. masonii*, models suggest that iron rich gravelly loams seem likely to be all that is required of a suitable translocation or restoration site, and there are many such areas available which are currently unoccupied if translocation was required. However further details of the substrate may still be important to ensure restoration success – for instance it is not known whether the key attributes of such substrates for *D. masonii* survival will be recreated in restoration.

The final implication, therefore, is that restoration trials for each species should include treatments addressing these uncertainties – i.e. shade and moisture for *L. gibsonii* and attributes of soil depth and rockiness for *D. masonii*.

Summary

- Species distribution models were constructed for *D. masonii* and *L. gibsonii* using the Maxent technique to assess the association of both species with key environmental variables.

- Models were able to provide good descriptions of the species' respective distributions, and identified different habitat attributes for each, consistent with different observed micro-site distributions of the two species.

- Results have implications – for survey for new populations, selection of potential translocation sites, construction of restoration areas and research into plant interactions with their environments – which are particular each species.

Recommendations

- Restoration areas for *L. gibsonii* should be shaped as slopes or gullies with lower radiation receipt.

- Restoration trials for *L. gibsonii* should include treatments varying shade and moisture.

- Mapping of soil or regolith data for the region to refine distribution models to improve understanding and predictions of the habitat and restoration requirements for *D. masonii*

- Restoration areas for *D. masonii* may not require particular topographies, but attention to soil requirements may be important.

- Restoration trials for *D. masonii* should include treatments varying degrees of soil depth and rockiness.

4.5b Translocation study of environmental boundaries

A pilot translocation trial was installed in May 2005 on a ripped drill pad on Iron Hill East. In this trial, 206 *Darwinia masonii* cuttings were planted in a grid connected to a drip feed irrigation system which supplied water for an hour at a time, twice a month over the first two summers. The irrigated plants were fenced to exclude herbivores. Twenty additional plants were planted outside of the fenced and irrigated area. Ten percent (2) of these unwatered plants survive to 2010, while 89% of the watered plants survive. The surviving irrigated plants have grown rapidly to a large size and (tripling in size in their first 18 months) and have flowered extensively and precociously (with half flowering in the first year).

A second restoration trial was established in the winter of 2009. This experiment included planting nursery stock of *D. masonii* and *L. gibsonii* – established respectively from cuttings and separated clumps, together with seedlings of *Acacia cerastes* (a local species with P1 conservation status).

Plantings occurred in four sites with differing field soil substrates which included 1) deep red loam/clay plains east of Extension Hill – a material potentially available in abundance for restoration as it underlies most of the planned waste rock dump, 2) white-yellow sands of sandplains west of Extension Hill and 3) gravelly and 4) rocky loams of the north Extension Hill slope and ridge (Table 30).

Three 10m x 10m replicate plots per site were cleared and fenced before planting (Table 30). A total of 780 plants of each species were planted in July/August 2009, with 65 per plot. Monitoring of these plants started after one month and is ongoing at 3 month intervals. Monitoring has included demographic (survival, health, height, fecundity) and ecophysiological parameters (leaf gas exchange and plant water status – measured via a Li-6400 gas analyser; LI-COR Inc, Lincoln, Nebraska, USA and a Scholander-type pressure chamber; Wescor Inc., Logan, UH, USA).

Table 30 Location of Translocation Sites on the Mt. Gibson Range.

Site	Substrate	Replicate	Locality	
1	BIF Rock	1	S29° 34' 03.9"	E117° 09' 21.9"
2	BIF Rock	2	S29° 34' 03.1"	E117° 09' 21.1"
3	BIF Rock	3	S29° 34' 04.1"	E117° 09' 21.1"
4	BIF Gravel	1	S29° 34' 04.2"	E117° 09' 20.5"
5	BIF Gravel	2	S29° 34' 03.5"	E117° 09' 19.8"
6	BIF Gravel	3	S29° 34' 04.3"	E117° 09' 19.6"
7	Sand	1	S29° 34' 04.8"	E117° 09' 17.8"
8	Sand	2	S29° 34' 04.2"	E117° 09' 17.3"
9	Sand	3	S29° 34' 04.7"	E117° 09' 16.6"
10	Clay	1	S29° 34' 19.1"	E117° 10' 29.4"
11	Clay	2	S29° 34' 18.3"	E117° 10' 30.4"
12	Clay	3	S29° 34' 17.2"	E117° 10' 30.3"

By April 2010 (9 months after planting), results showed clear differences among substrates. *Acacia cerastes* established on all of the four substrates, but least successfully at the Clay site (Figure 38). *Darwinia masonii* and *L. gibsonii* demonstrated a greater specificity for substrate type with survival successful only in the BIF Rock and BIF Gravel substrate. While occasional *L. gibsonii* plants persist on the other sites they show very limited vigour and survival prospects. In terms of mean plant health and height, plants of all three species performed better growing on BIF rock and BIF gravel loams than on the clay and sandy substrates. Measurement of the physiological attributes of these plants – rates of photosynthesis, transpiration and water potential – confirm the poor performance of *D. masonii* and *L. gibsonii* on sand and clay substrates, and indicate relatively poorer performance of *Acacia cerastes* on clay.

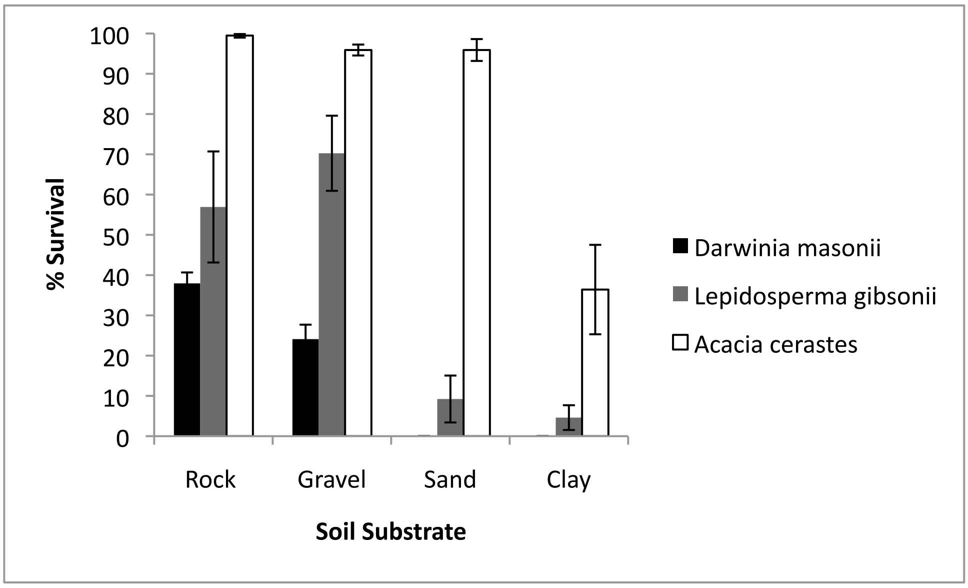

Figure 38 Survival rates of *D. masonii* and *L. gibsonii* planted together with *Acacia cerastes* on four differing soil substrates – nine months after planting.

Table 31. Chemical properties of translocation substrate soils. Significance (ANOVA) indicates *p<0.05, ***p<0.001

	units	rock	gravel	sand	clay	sig
EC	mS/m	7.00 ± 2.00	5.67 ± 2.08	5.33 ± 2.08	2.00 ± 0.00	*
pH	($CaCl_2$)	5.07 ± 0.15	4.5 ± 0.35	5.33 ± 0.38	4.33 ± 0.58	*
Organic C	%	1.91 ± 0.21	1.54 ± 0.32	0.98 ± 0.04	0.53 ± 0.12	***
Cu	mg/kg	0.77 ± 0.12	0.53 ± 0.25	0.23 ± 0.06	1.13 ± 0.15	***
Ca	mg/kg	610 ± 61	393 ± 250	393 ± 93	223 ± 170	
Fe	mg/kg	76.3 ± 8.7	74.0 ± 8.2	75.0 ± 2.6	27.7 ± 2.5	***
K	mg/kg	90.7 ± 8.5	74.3 ± 22.0	43.0 ± 4.4	76.7 ± 46.2	
Mg	mg/kg	66.3 ± 11.1	41.0 ± 21.5	36.0 ± 16.8	60.0 ± 52.0	
P	mL/g	48.3 ± 12.7	64.3 ± 28.9	11.0 ± 1.0	66.0 ± 33.8	
Mn	mg/kg	24.7 ± 3.8	13.3 ± 7.2	16.3 ± 1.2	39.3 ± 25.5	
Na	mg/kg	15.7 ± 6.1	14.0 ± 7.5	14.0 ± 4.6	7.7 ± 4.7	
S	mg/kg	17.0 ± 3.5	20.3 ± 8.0	12.7 ± 3.2	10.0 ± 3.5	
N total	%	0.10 ± 0.01	0.07 ± 0.02	0.05 ± 0.00	0.04 ± 0.01	***
B	mg/kg	1.00 ± 0.44	0.80 ± 0.52	0.57 ± 0.12	0.40 ± 0.17	
Co	mg/kg	0.08 ± 0.02	0.04 ± 0.01	0.08 ± 0.02	0.56 ± 0.35	*
Ni	mg/kg	0.17 ± 0.06	0.13 ± 0.12	0.17 ± 0.06	0.30 ± 0.10	
P	mg/kg	5.67 ± 2.08	3.67 ± 1.53	4.00 ± 0.00	5.33 ± 0.58	
Zn	mg/kg	1.00 ± 0.36	0.67 ± 0.23	0.5 ± 0.17	0.83 ± 0.23	
Pb	mg/kg	1.00 ± 0.00	0.87 ± 0.15	0.43 ± 0.06	0.87 ± 0.12	***

The properties of translocation site soils were assessed via chemical analysis (WA Chem Centre, one bulked sample of 5 subsamples of 0-10cm depth per plot) and soil moisture probes. Three moisture probes were installed in one plot of each substrate type: these were set to record every 10 minutes (Hobo microstation S-SMC-M003 ECH2O soil moisture probes: Onset Computer

Company). Soil chemistry differed several respects between sites, most significantly in C content, Fe, Cu, Pb and total N. Electrical conductivity, pH and Co also varied significantly (Table 31). pH was highest at the Sand site and lowest at Clay – although all were acid, and EC was much lower at the Clay site than any other (associated with lower Na and Ca). Organic C content and % total N were highest at the Gravel and Rocky loam sites. Fe was lowest, and Cu and Co highest at the Clay site. Of these differences, N is likely the most important for plant growth and survival.

Higher % organic C in Gravel and Rock site soils may be indicative of a simple, but significant, role of gravel and rock in these substrates. By excluding water and other inputs., the presence of gravel and rocks in soil means that identical rainfall inputs over a unit area of surface is concentrated into a smaller volume of soil so that in a uniform rainfall event, rocky soils receive and hold a greater volume of water than non-rocky soils. The same process occurs with other soil inputs sourced from above-ground, such as organic C.

In seasonal and low rainfall regions, soil water availability is usually more limiting to plant growth than soil nutrition. Soil probe outputs show that while soils attain similar maximum and minimum soil moisture concentrations, the Sand, and Clay site soils appear to dry out more rapidly than those at the Rock and Gravel sites (Figure 39). Clay site soils appear to wet more quickly, or more responsively to smaller rain events, but the Gravel and Rock site soils also reached slightly higher maximum water contents than the other sites (27-28% v 24-25%). Soils of different composition and texture bind water with different potentials, so that water in soils of differing texture but similar water content may, from a plant's point of view, differ in the availability of water and the ease with which it can be extracted. Also important for plant survival is the period for which plants experience water availability levels above or below key thresholds (e.g. wilting point). While observed soil dry-down rates may not appear to differ markedly, the slightly slower drying curves of the Gravel and Rock sites may lead to plants experiencing significantly longer periods of favourable water availability in these sites.

The pattern of soil moisture with depth in the soil profile is also unknown and may differ between sites. Rock and gravel cover effectively reduce the area of exposed soil surface and thereby act to limit surface evaporative losses on a volume basis.

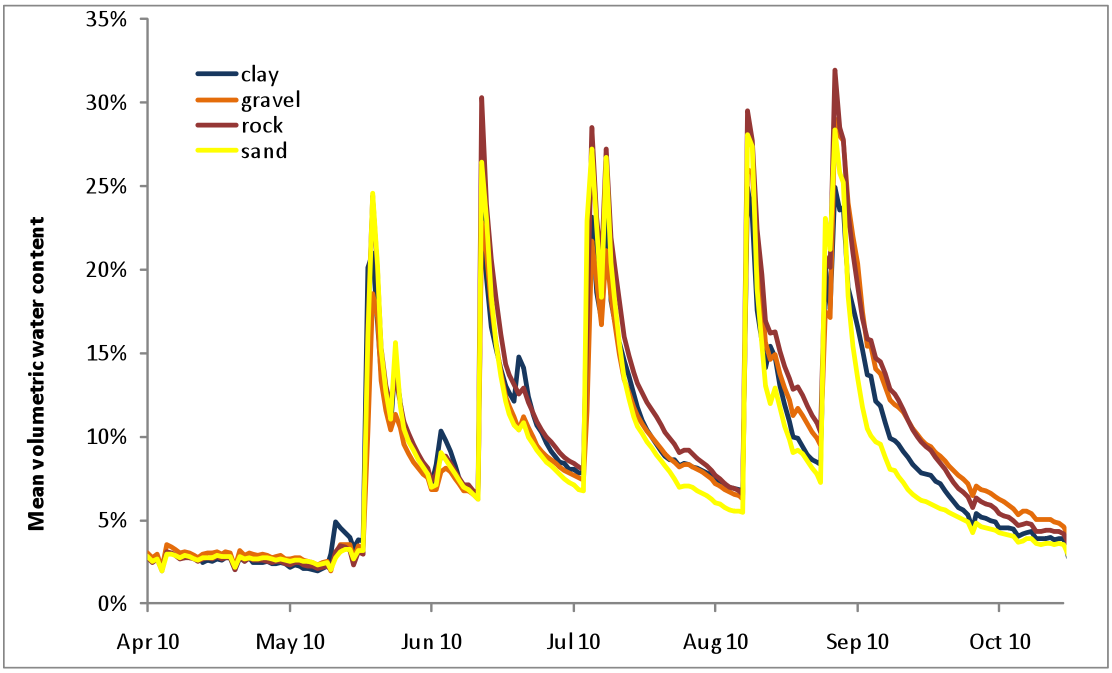

Figure 39 Mean daily maximum soil moisture content at 5cm depth for translocation trial sites on differing substrates (average of three Hobo microstation S-SMC-M003 ECH2O soil moisture probes, Onset Computer Company). Winter 2010

Summary

- Both *D. masonii* and *L. gibsonii* have the ability to be planted and survive in restoration sites
- Survival and establishment of translocated *D. masonii* and *L. gibsonii* individuals was effectively limited to BIF rock and BIF gravel sites
- Survival to 9 months of transplanted *D. masonii* greenstock averaged under 40% at its best performing site (BIF rock)
- Transplanted *L. gibsonii* survival (to 9 months) was greatest on BIF gravel sites (~70%) but was also high (>50%) on BIF rock sites
- Translocation sites differed in several soil properties, of which patterns of moisture content and total Nitrogen may be the most critical.

Recommendations

- Sand and clay substrates may not be effective restoration materials for *D. masonii* and *L. gibsonii*, although mixing clays with quantities of rock and/or gravel may be worth trialling.

- Final restored structure surface should incorporate a large proportion of BIF rock or gravel for successful restoration of both *Darwinia masonii* and *Lepidosperma gibsonii*.

- Field studies in which *D. masonii* and *L. gibsonii* are translocated into restoration substrates designed with varying amounts of rock and gravels, and with rocks at varying depths are recommended to ensure optimal restoration success.

4.5c Drought study

Many of the studies in this and the next section are comparative, with the target species studied in comparison with a range of other taxa. Comparator species included 2-4 of the most closely related taxa (*Darwinia acerosa*, *D. purpurea*, *Lepidosperma* sp. 'costale' Wanara, *L.* sp. 'costale' Beanthiny, *L.* sp. Wubin biconvex, *L.* sp Wubin scabrid) as well as species which are less closely related but co-occur with *D. masonii* and *L. gibsonii* at Mt Gibson but are also common / widespread across a range of habitat types – *Gahnia drummondii* (Cyperaceae) and *Amphipogon caricinus* var. *caricinus* (Poaceae) and *Aluta aspera* subsp. *aspera* (Myrtaceae). The purpose of comparisons with related species is to identify if observed traits are adaptations specific to the target species or shared among close relatives, and therefore pre-dating the evolution of the modern species and excluding specific adaptation to their modern habitats. Comparisons with widespread species indicate the extent to which observed traits are shared with other species in the same habitat.

Drought studies were performed under controlled glasshouse conditions and involved comparisons with several closely related *Lepidosperma* and *Darwinia* taxa. These experiments took two forms, one investigating root growth and biomass accumulation under drought conditions and the other measuring physiological response to declining water availability.

In the root growth and biomass accumulation study 80 individuals from each species were transplanted into free draining custom-made PVC tubes (1 m deep and 0.1 m diameter). Soils were white sands with addition of 59 mL of diluted nutrient solution (200μM $Ca(NO_3)_2$, 100 μM K_2SO_4, 4 μM KH_2PO_4, 54 μM $MgSO_4$, 0.24 μM $MnSO_4$, 0.10 μM $ZnSO_4$, 0.018 μM $CuSO_4$, 2.4 μM H_3BO_3, 0.030 μM Na_2MoO_4, 40 μM Fe-EDTA – following Poot and Lambers 2008). Tubes were held upright in a metal frame and watered twice daily from overhead sprinklers during an establishment period (2 months) prior to drought treatment. Plants were subsequently exposed to drought (no watering) and control (250 mL of water twice a week) treatments over a period of four months.

After 72 days, droughted plants had significantly higher root growth and lower stem growth (ANOVA $p<0.05$) than non-droughted plants in both species (Figure 40). Examination of the distribution of dry mass down the profile in the tube-pots showed that this extra root growth occurred at all depths.

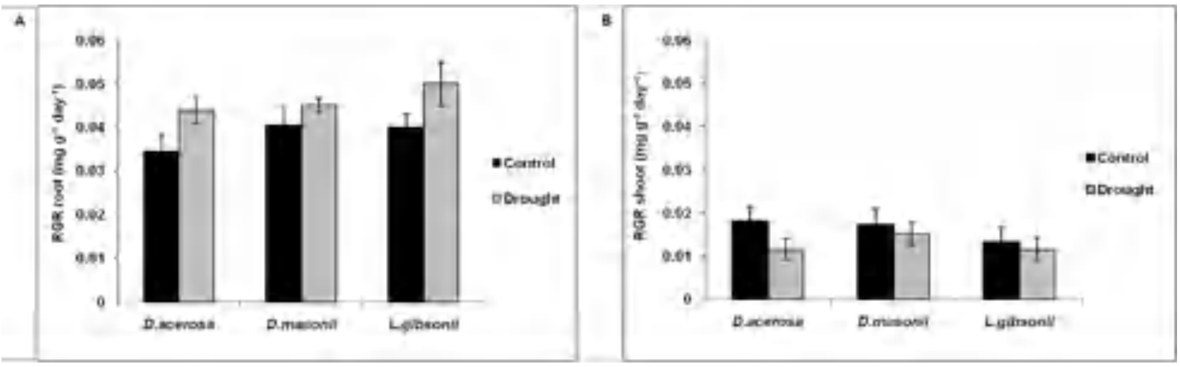

Figure 40. Relative growth rates (RGR) of shoot dry mass (A) and root dry mass (B) over a 72 day period. Comparison of control (black bars) and drought plants (grey bars) *Darwinia acerosa, D. masonii* and *Lepidosperma gibsonii* respectively. Bars represent means ± SE (n=8 per harvest).

In this experiment, *D. masonii* plants had greater total leaf surface area than did *L. gibsonii* (likely simply a result of plant selection), but *L. gibsonii* had a significantly larger difference in total leaf area between control and droughted plants (drought plants had 50% of the area of watered plants) than did *D. masonii* (10% difference).

Treated plants in this study were also examined for their plant water status and photosynthetic activity. Water status was assessed via measurement of both pre-dawn and midday xylem pressure potential using a Scholander-type pressure chamber (Wescor Inc., Logan, UH, USA). Midday plant water potential reflects both the level of soil water potential and the transpiration activity of the plant during the day. The absence of photosynthetic activity during the night means that pre-dawn plant water potential are generally in equilibrium with the soil water potential. Photosynthesis, C-assimilation and transpiration rates were measured for each plant in the study using a portable infrared gas analyser (Li-6400, LI-COR Inc, Lincoln, Nebraska, USA).

The difference between midday and pre-dawn water potential of drought plants was greater for drought plants than controls in *L. gibsonii* but less so for *D. masonii.* There was little difference between species in their rates of photosynthesis and transpiration, although *L. gibsonii* did have slightly lower rates than *D. masonii* at 72 days.

In a second study, 15 plants of each of *D. masonii* and *L. gibsonii* were grown, together with closely relative taxa *D. purpurea*, *D. acerosa*, *L.* sp Wubin bi-convex and *L.* sp Wubin scabrid, in free draining 25 cm diameter × 40 cm deep pots. This study was designed in order to control soil moisture conditions as closely as possible and to ensure that samples of each species were exposed to identical soil moisture conditions. Pots were lined with a fine nylon fabric prevent soil loss and filled with a known weight of oven dried, commercial loamy sand. All materials were weighed in initial dry conditions and then watered to field capacity. Pots were subsequently weighed at intervals to determine soil gravimetric water content. Pots were then watered in controlled volumes to maintain or manipulate water content at desired levels for testing over a period of 85 days. Plant physiology was measured using the Li-6400 as described above and plant drought response curves based on soil water potential were assembled for each species. The relationship between gravimetric water content and soil water potential was established for the experimental soil using an inverse van Genuchten Equation (van Genuchten 1980). This equation was constructed from measurements of the two parameters made using the pressure plate method (Wild 1988) ($n = 3$) at -0.01, -0.10, -0.3, -1 and -1.5 MPa as well as using the vacuum desiccator method (Bulut 1996) at -39, -98, and -316 MPa.

Water potential is expressed in units of pressure required to remove water from the target material. Its units are negative as the process requires a vacuum to extract water. Values of water potential close to 0 indicate water can be extracted with little effort, while larger negative values indicate dryer conditions.

Plants were exposed to soil water potentials between -0.00052 to -1.3 MPa. Establishing the point at which plant function ceased is a delicate matter as a small change in soil water content corresponded to a large change in soil water potential in very dry soils so that the critical soil water potential when the gas exchange of the plants ceased occurred over a narrow range (a few hours to a few days). Results identify the lowest soil water potential under which plants were measured to be functioning and the next lowest measurement when they were not. *Lepidosperma* sp Wubin scabrid appeared to cease gas exchange at a higher water potential (between -0.6 and -0.7 MPa) than the other *Lepidosperma* species (-1.0 and -1.1 MPa for both *L. gibsonii* and *L.* sp Wubin bi-convex). Differences between the *Darwinia* species were less clear (all between -0.8 and -1.3 MPa) but encompass the range of the *Lepidosperma* species (Figure 41).

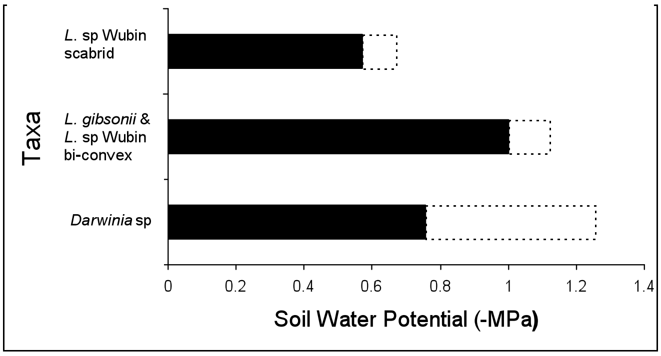

Figure 41 The soil water potential at which measured photosynthesis rate (A) became zero or negative. Black bars are based on last time of measurement when A was still positive, dotted ranges are based on the next time of measurement when A was zero or negative.

Drought response curves differed between genera as *Lepidosperma* species had lower rates of photosynthesis at maximum water potentials than the *Darwinia* species did. *Darwinia masonii* recorded among the highest rates of photosynthetic activity in the study, and *Lepidosperma gibsonii* recorded the lowest even when well watered (Figure 42).

Water use efficiency (WUE) was calculated for examined plants – on the basis of ratio of Carbon assimilated per water lost – across the range of soil water potentials (Figure 43). *Darwinia* species were able to maintain their WUE with declining water availability, while *Lepidosperma* species were able to increase their efficiency. Both *D. masonii* and *L. gibsonii* had relatively low and broadly similar WUE. *Darwinia acerosa*, a DRF species from granite areas closer to Perth, had significantly higher WUE than other *Darwinia* (and *Lepidosperma*) species (t_{78} = 3.64, P <0.001). This habitat of this species has higher mean rainfall than that of any other tested.

It is important to note that the soil water potentials that were able to be imposed in these experiments – and which were ultimately lethal at their lowest levels – were all considerably wetter than the levels that are frequently recorded in the field (e.g. Figure 44). This illustrates the difficulty of transferring glasshouse experimental results to field conditions, but also identifies the key strategy employed by most of the experimental species, including *D. masonii* and *L. gibsonii*, which is to avoid drought. Drought avoidance, as opposed to drought tolerance is a strategy whereby, plants do not function under drought conditions, but instead cease photosynthetic function and try to conserve water and survive through to a time when soils become moist again. The implication of this strategy is that plant tissues must have the capacity to desiccate to a very high degree, remain alive under such conditions and then regain metabolic function when soils rewet.

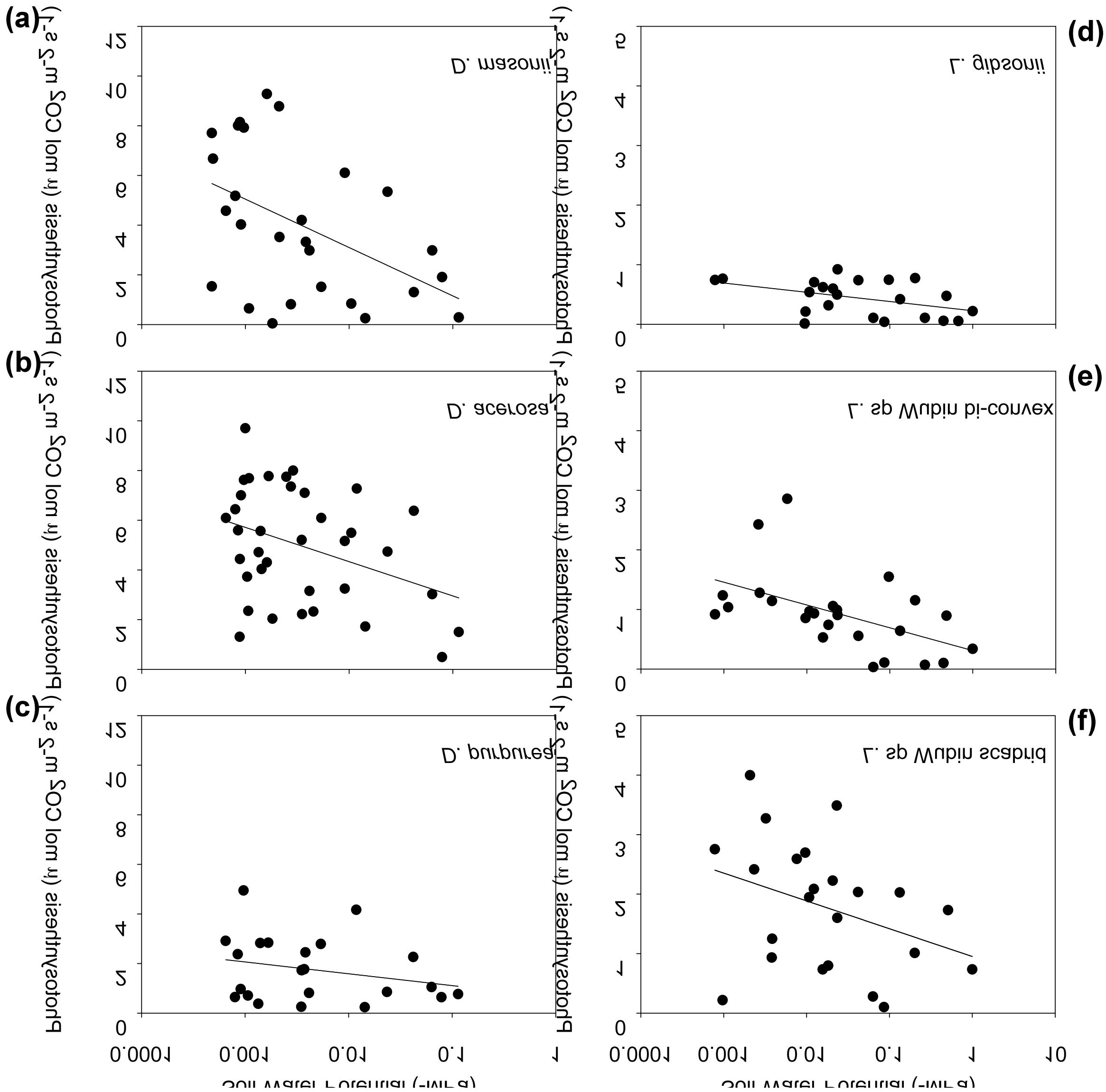

Figure 42. The response of photosynthesis to varying soil water potential for the target species (a) & (d) and their respective congeners. Points are multiple measurements of individual plants taken at various points through time. Note different Y-axes for each genus and log X-axis scale. Linear regressions fitted to the log transformed soil water potential data are significant for *Darwinia masonii*, *D. acerosa*, *Lepidosperma gibsonii* and *L.* sp Wubin bi-convex ($p<0.05$)

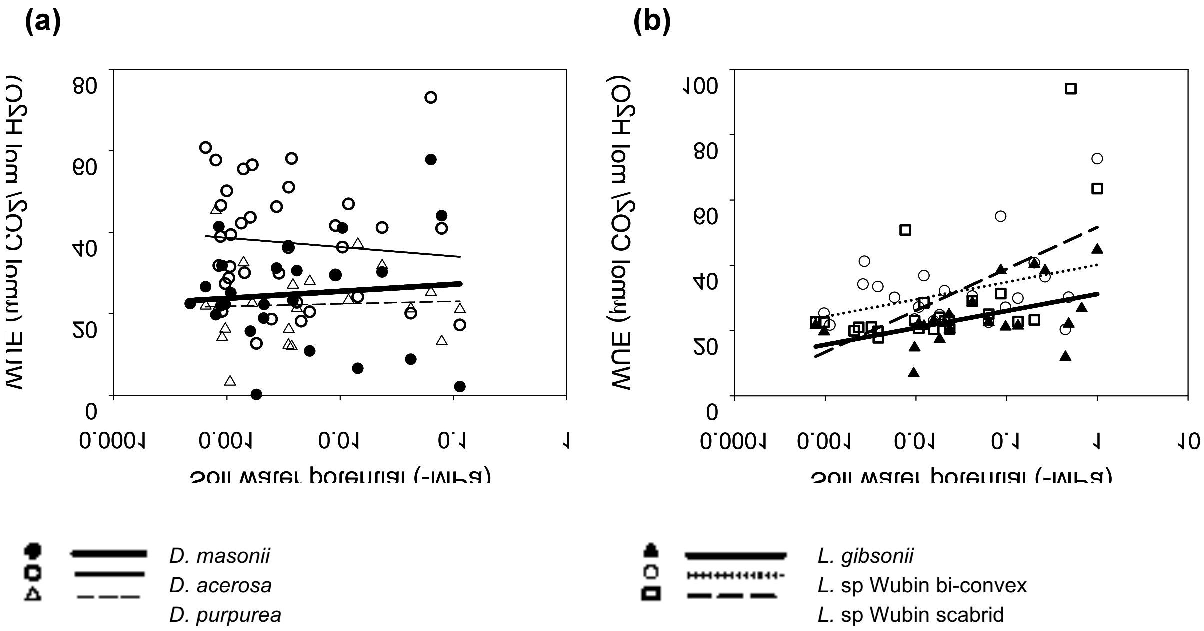

Figure 43. Intrinsic water use efficiency (WUE) of (a) the *Darwinia* species and (b) the *Lepidosperma* species with varying soil water potential. Intrinsic water use efficiency is photosynthesis/ stomatal conductance.

Both species have relatively low water use efficiency when they are functioning, and respond to lower soil mater availability by increasing root growth at the expense of reduced shoot growth. *Lepidosperma gibsonii* has low maximum photosynthetic rates, lower WUE, a greater root growth response to dryer conditions. *Darwinia masonii* on the other hand has high maximum rates of photosynthesis

Summary:

- Comparative studies of *D. masonii* and *L. gibsonii* and related species of other environments demonstrate that the target taxa do not possess unique capacity to function or use water at lower levels of water availability.
- Both species do respond to declining soil moisture levels by increasing root growth at the expense of investment in leaves and shoots.
- *D. masonii* and *L. gibsonii* appear to persist over the arid summer period by closing down plant function and maintaining a dormant state through to next winter.

4.5d Plant response to environmental variation

The environment experienced by *D. masonii* and *L. gibsonii* has been investigated via assessment of site factors, soil and surface properties and modelling of distributions in respect of environmental variables (**4.5a Abiotic associations**). The role of fire in the mortality and recruitment of plants has been examined in section 4.2 Population Demography, and the role of climatic variation – as much as was possible within the study period (section **4.2** and **4.3b Seed production**). The response of *D. masonii* and *L. gibsonii* to experimentally induced drought conditions is described in section **4.5c** above. This section presents addition studies of the physiological behaviour of *D. masonii* and *L. gibsonii* under field conditions.

Seasonal monitoring of plant ecophysiology has been ongoing at Mt. Gibson since 2008. This survey (of 145 plants of 5 species) characterises ecophysiological strategies in terms of seasonal variation in leaf gas exchange and plant water status, comparing *D. masonii*, *L. gibsonii* and *A. cerastes* with common/widespread relatives (*Aluta aspera* subsp. *aspera* and *Amphipogon caricinus* var. *caricinus*. 8-11 plants are monitored every three months at each site.

Table 32. Location of sites used in ecophysiological monitoring.

Site	Species	Location	Age Class	Locality	n
1	*D. m.*	Mt Gibson	Adult	S29 35 37.4 E117 11 03.7	11
2	*D. m.*	Iron Hill	Seedling	S29 36 25.4 E117 10 46.4	8
3	*D. m.*	Mt Gibson South	Adult	S29 36 12.9 E117 12 00.6	11
4	*D. m.*	Extension Hill South	Adult	S29 35 04.4 E117 10 00.7	11
5	*L. g.*	Iron Hill	Adult	S29 36 16.8 E117 10 23.4	11
6	*L. g.*	Iron Hill North	Adult	S29 35 59.3 E117 10 14.6	10
7	*L. g.*	Extension Hill South	Adult	S29 35 04.9 E117 10 00.0	11
8	*L. g.*	Mt Gibson	Adult	S29 35 39.1 E117 11 03.7	11
9	*L. g.*	Mt Gibson	Seedling	S29 35 39.1 E117 11 03.6	11

Ecophysiological monitoring indicates that there are no differences in mean water potential or leaf gas exchange attributes (photosynthesis and stomatal conductance) between *D. masonii* and *L. gibsonii* and non BIF-endemic species from all sites (e.g. Figure 44 – gas exchange parameters, and other sites show similar patterns). All species examined show the same diurnal and seasonal patterns, with both gas exchange and water potential parameters indicating active growth and C-uptake during winter, but an almost complete cessation of growth over summer and autumn. These results do not support the theory that *D. masonii* and *L. gibsonii* have root foraging (or other) strategies which enable their access to water that other species are not – but which may cause them to be limited to the BIF substrate. They are, however, very drought tolerant through the simple drought avoidance strategy of shutting down function completely over summer and autumn. The process of this shut down is illustrated in Figure 45 and Figure 46.

These physiological measurements (e.g. Figure 44) additionally illustrate the effect of winter drought, with pre-dawn water potentials in winter of 2010 much higher than the levels measured exactly 12 months previously, and approaching those observed in the summer of 2008/09.

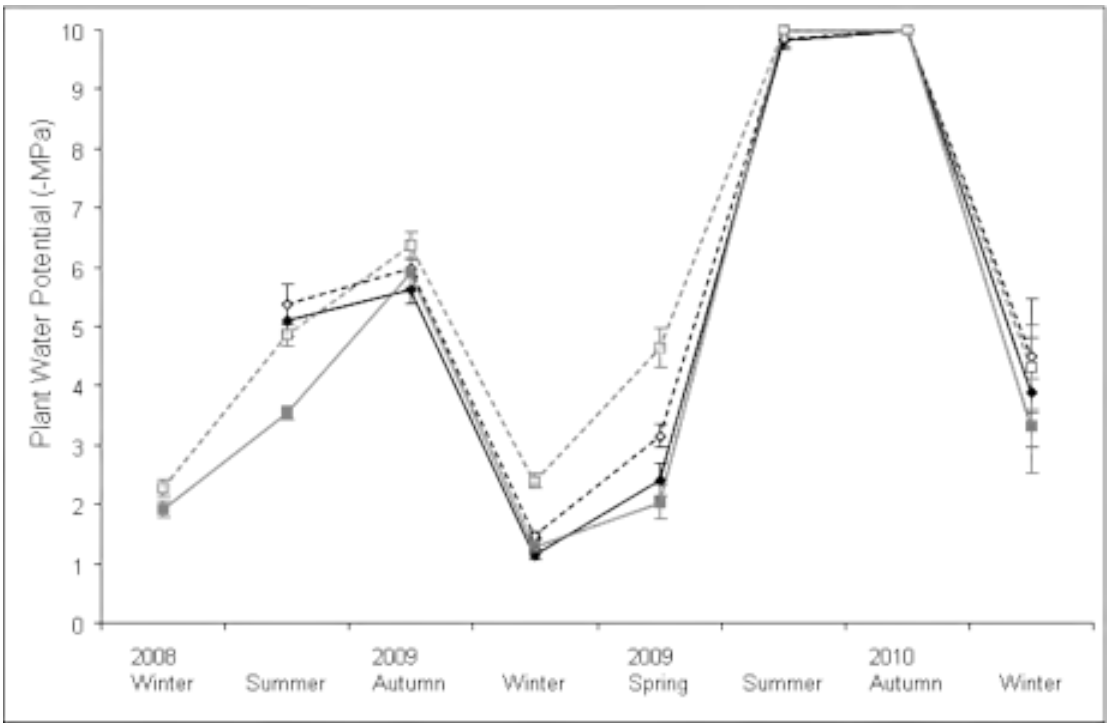

Figure 44. Mean (± SE) Water potential of Mt Gibson *Darwinia masonii* (grey) and Iron Hill *Lepidosperma gibsonii* (black) populations from mid 2008 to mid 2010. Water potential readings observed pre-dawn (dashed: 0400-0600hrs) and PM (solid: 1200-1400hrs).

4.5e Plant health

Plant health scores have been discussed previously under **Population demography** (**4.2**), interactions with predators and parasites are described under **Biotic Interactions** (**4.5g**, below) and plant physiological behaviour is discussed above (**4.5c, 4.5d**).

Figure 45. *Darwinia masonii* foliage passing through seasonal changes. Leaves and stem are produced in autumn and winter and function through to spring. They enter a dormant state over summer, and regain their green colour and photosynthetic function with the onset of rains. Most leaves survive through one or two summers and function through two or three winters. Left (July): Previous season's leaves re-greened and new season growth commenced. Centre left (December): last season's growth lost, showing much bare stem. Centre right (January) and Right (April): last season's growth yellow-grey in drought mode.

Figure 46. *Lepidosperma gibsonii* leaf growth commences with onset of rains and continues through winter (left). Growth ceases in late spring and leaves change colour through December (centre left) and January (right).

A quantitative health score based on comparing foliage colour with colour tables was trialled for both species, with the aims of reducing the subjectivity of scoring, and of deriving further information on plant vigour. However, foliar colour is observed to change seasonally in both species, with even the healthiest plants attaining a colour in early autumn comparable with that of the least healthy plants in early spring. This coloration is likely an adaptive mechanism which protects leaf photo-systems from damage due to excess light and heat during the period when they are unable to repair themselves, or make use of available light, due to the lack of water. Photosynthesis ceases as soils dry during over summer and leaves remain yellow or orange through until rains return, whereupon leaves re-green and start photosynthesis and growth again. Leaves of both species appear capable of surviving through one or two summers, although, in more sheltered positions they may survive longer. Leaves therefore function through 2-3 winters. Any quantitative colour score would need to be finely calibrated for season and soil moisture content.

4.5f Below ground adaptations

The root growth and foraging abilities of both species were examined in experimental studies investigating root vertical and horizontal growth capacities, and in their ability to penetrate small pore spaces and fissures. Excavation of the root systems of *D. masonii* seedlings and *L. gibsonii* clumps was also undertaken in the field. The response of root mass growth of both species to experimentally imposed drought has been described previously (section 4.5c).

Vertical root growth was relatively rapid in glasshouse experiments. Root extension was determined by comparing root depths among plants of each species grown from cuttings (*D. masonii*) and clump separation (*L. gibsonii*) in white sand in 1 m deep and 0.1 m diameter PVC tubes (as detailed in 4.5c) when harvested at 28 days versus 72 days after planting. Eight individuals of each species were harvested at each period. Over this 44 day period, roots of well watered plants of both species when harvested at 72 days, were on average 24 and 25 cm deeper than those of plants harvested at 28 days. These measurements suggest a rate of vertical growth of 5.5 and 5.7 $mm.day^{-1}$ for *D. masonii* and *L. gibsonii* respectively. Under drought conditions, *D. masonii* root growth was similar (6.1 mm.day-1) but *L. gibsonii* root extension declined (to 3.0 $mm.day^{-1}$). As the experimental plants of *L. gibsonii* were initially larger than those of *Darwinia masonii*, and plant growth often increases with size, it may be more appropriate to compare the ratio of root growth rate relative to initial size (relative growth rate), which would then be 0.4 and 0.9 over this 44 day period. By the end of the study program, the root systems of many individuals of both species had reached the bottom of the 1 m pots.

A second glasshouse study examined rates of horizontal root extension by growing cuttings transplanted into custom made containers (1.8 m long, 0.2 m wide and 0.15 m deep) filled with course white sand to a depth of 0.1 m. These long pots had transparent polycarbonate bases covered externally with black plastic to maintain humidity and shield roots from light. Plants were flushed once a fortnight with approximately 500 ml of the standard nutrient solution and grown in well-watered conditions. Root growth was periodically examined by observing the transparent base of each pot, and all pots were harvested and root distributions assessed after five months when the first roots were observed to have reached the end of the 1.8 m long pots. In this study five individuals of each of six species (*D. masonii* and *L. gibsonii* and two closely related taxa) were compared. In this study horizontal root growth was measured at around 1.5 mm.day-1 for *D. masonii*, slower than its close relative, the sandplain species *D. purpurea*, but similar to another shallow soil endemic species (*D. acerosa*, which occurs on granites). *Lepidosperma gibsonii* horizontal root extension rates averaged 3.5 mm.day^{-1}.

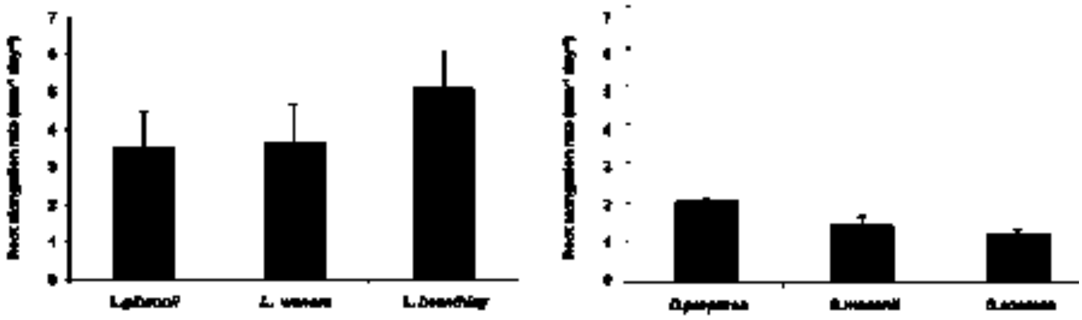

Figure 47. Horizontal root extension over the bottom of 1.8 m-long containers over a period of 44 days of three *Darwinia*, and three *Lepidosperma* taxa, once the roots reached the bottom. Error bars indicate standard errors (n=5)

A final study examined the capacity of roots of target species, and of two near relatives per genus, to explore soil areas by entering into small apertures such as pores and cracks in rocks. This study utilised plants grown in climate controlled glasshouse in 550mm x 90mm diameter PVC tubes with soils and nutrient additions (as above) and watered daily. Five replicate control plants of each species were grown in 55cm tubes without any restrictions, and another five replicates were grown in a sealed stack of six 5cm high sections, each of which had a sheet of stainless steel woven wire mesh (Metalmesh) siliconed to its base. A 15 cm top segment with a mesh bottom was attached upon the top of the stack to accommodate the planting of seedlings. Mesh sizes were based on the measured diameters of roots for each species and ranged from 34 to 530 µm. Plants were harvested when roots from control plants were observed to have reached the bottom of their pots (at 5 months). Sections were carefully separated on harvesting with root dry mass and root length measured and the number of root mesh penetrations counted. Controls were also cut into sections corresponding to the sections of the treatments, in order to provide comparison with an unobstructed root profile. Each section of roots (both treatments and controls) was scanned at high resolution, using the WinRhizo Pro 2007d software package (Regent Instruments, Quebec, Canada) and an Epson Perfection 4990 photo scanner.

Sections of fine roots taken from free growing plants were also examined under a microscope to identify elements of their anatomic structure (Figure 48). Of key significance is the diameter of the root itself, and of the root stele. Previous work (Zwieniecki and Newton 1995) had identified the root stele diameter as the major factor limiting pore entry of roots of shallow soil species. The stele occupies the centre of the root section and consists of the bundled vascular cells which transport water, nutrients and sugars around the plant. Stele diameters did not vary within genera but larger among *Lepidosperma* species (averaging 223 μm, relative to the average of 102 μm for *Darwinia* species). Root diameters were more variable, averaging 3-5 times that of the stele.

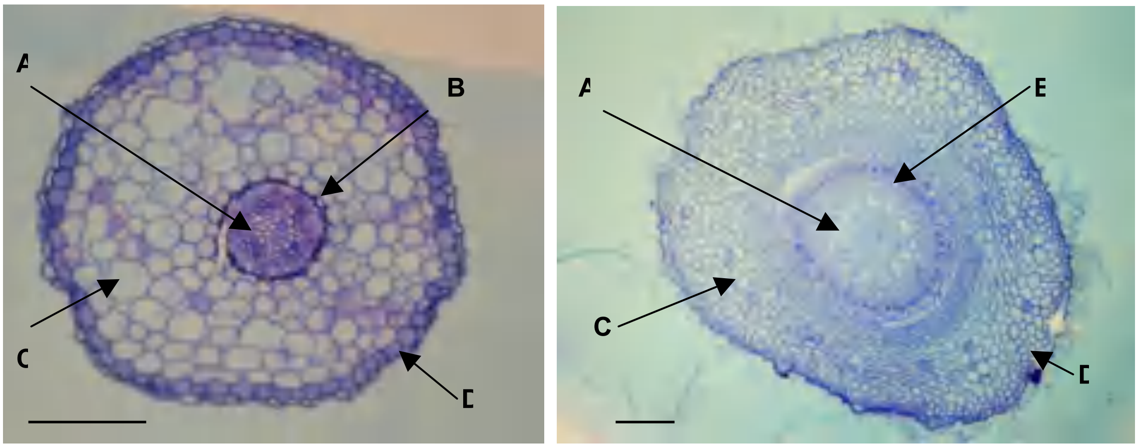

Figure 48. Root sections of *Darwinia masonii* (left) and *Lepidosperma gibsonii* (right). Root samples were imbedded in resin using biowave technology, sectioned, and stained with toluidine blue. Letters indicate the root stele (a), endodermis (b), cortex (c) and epidermis (d). Bars represent 100 μm.

Examination of number of root penetrations, root mass and total root length below mesh barriers identified differences between species within genera, as well as between genera. *Darwinia* root penetration was severely limited at the 100 μm mesh barrier and effectively prevented at a 63 μm mesh. Root penetration by *Lepidosperma* species was reduced at the 260 μm mesh, and no *Lepidosperma* species penetrated the 150 μm mesh.

Root excavations were performed in the field using brushes and a compressed air jet. Two *D. masonii* seedlings and one *L. gibsonii* clump were excavated from within the mining footprint on Extension Hill. In both cases, root systems were successfully traced up to the point when roots passed into, or beneath larger, immovable rocks. Unfortunately, in each case this occurred within 10-15 cm and roots passed into rock and regolith which could not be excavated with the tools available.

In the case of *D. Masonii*, plants were 5 months old and 5-6cm tall. They were each found to be emerging from seeds (still attached) buried at 3-4 depth, and with root systems traced a further 6 cm, to a total depth of ~10 cm (Figure 49). In the case of *L. gibsonii*, the excavated plant was a small sized mature individual likely dating from the 1969 fire. It had a well developed root system, with ~30-40 individual roots emerging from the clump base. These spread diagonally downwards, but could be traced for only 10-15cm before entering crack and pore spaces in rock-like regolith material (Figure 50).

Figure 49. Excavated *Darwinia masonii* seedling from within the mining footprint on Extension Hill; October 2009, following May 2009 experimental fire. Seedling height 5 cm, seed depth 3 cm, roots excavated to 10 cm depth – and continuing into rock cracks. Arrows show seed attached to stem (below) and ground level (above).

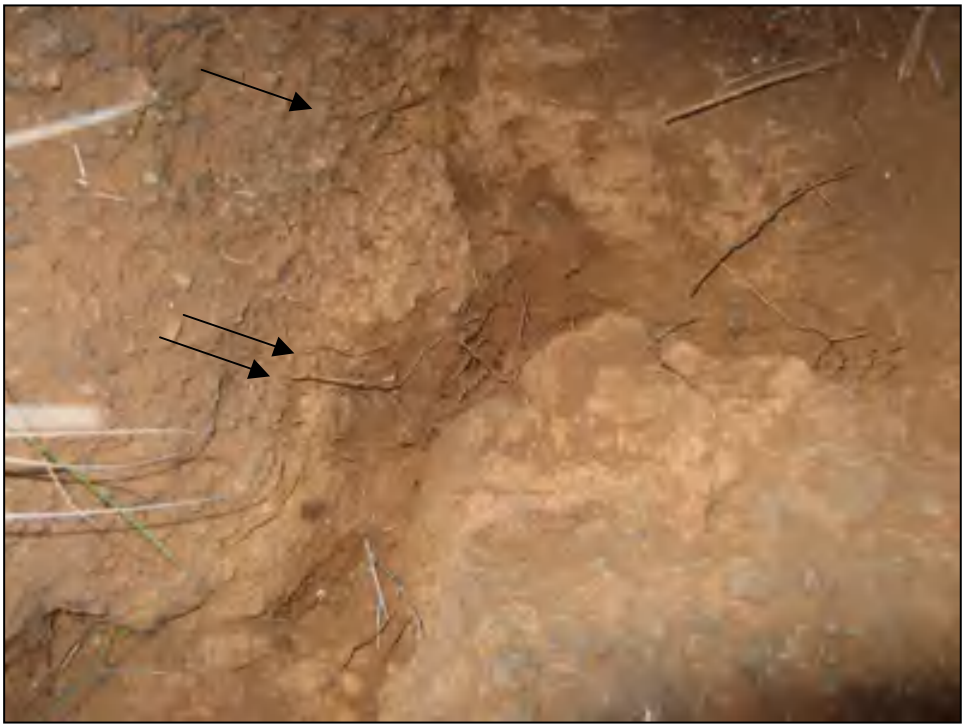

Figure 50. Site from which the root system of a *Lepidosperma gibsonii* plant was excavated from within the mining footprint on Extension Hill. The roots of the excavated plant (basal diameter 80 mm) extended to 15 cm depth before terminating at, or entering hard regolith surfaces (several indicated with arrows).

Examination of seven mining drill cores from Extension Hill, including from localities close to individuals of *D. masonii* and *L. gibsonii* revealed extensive weathering of underlying regolith with abundant solution channels, large cracks and pores. Many of these cracks, including to depths below the surface much exceeding the height of the vegetation above ground, contained visible root material (Figure 51). While one core (with sand overlaying weathered rock) had no visible roots, and one had roots only to 1.1m others had roots extending to over to 10 m, one to 13 m (Figure 52). While it was not possible to identify the plant species, and there are a number of candidate species, it is feasible that either study species could possess root systems with the capacity to exploit weathered regolith to this depth.

Figure 51. Example of roots (lower white arrow) observed in a natural break in a rock core form Extension Hill, here at 2 m depth. Note also solution channels in rock above (upper white arrows)

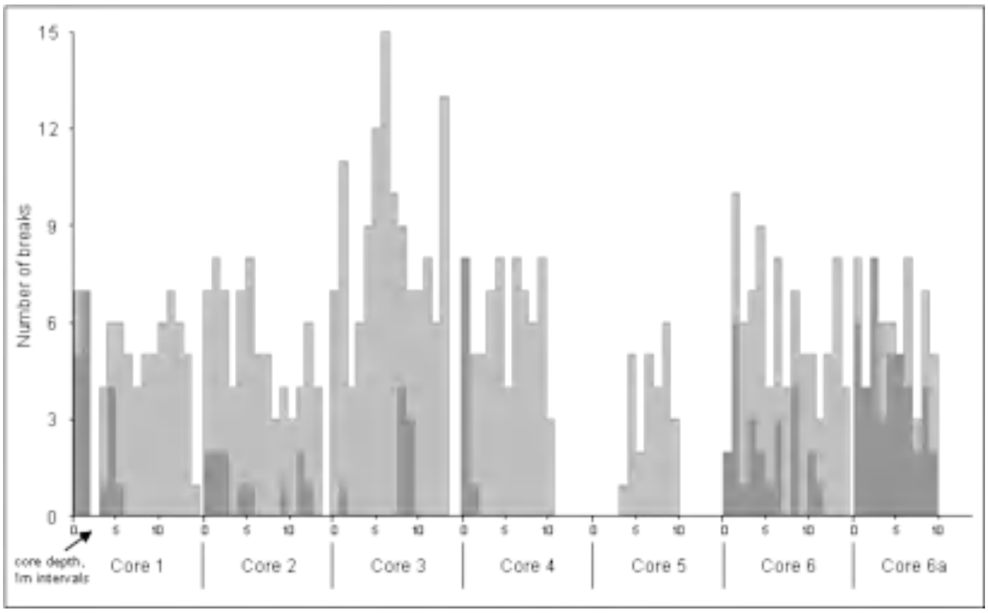

Figure 52. Frequency of root observations (dark grey) among breaks (fissures and cracks, light grey) in 1m sections of seven 50mm drill cores from Extension Hill.

Planned excavations of whole root systems with the aid of mining technology were not undertaken as mining development had not reached this stage during the period of the study.

Summary

- Results of these research programs show a capacity of both *D. masonii* and *L. gibsonii* for rapid horizontal and vertical root growth under good conditions and root growth is relatively increased in drying soils.

- Measured rates of root growth were faster for both species in vertical orientations than horizontally. Both species had similar rates of vertical growth (5-6 $mm.day^{-1}$), but *L. gibsonii* grew faster horizontally (3.5 v 1.5 $mm.day^{-1}$).

- Roots of both species grew to 1m depth and a similar horizontal extent over a period of a few months in glasshouse conditions.

- *Lepidosperma gibsonii* roots are generally larger than those of *D. masonii*, and are more restricted in the size of soil and root spaces that they can enter.

- Neither BIF species showed root growth adaptations that were significantly different from close relatives from non-BIF habitats.

- Excavations indicate a capacity of roots to enter large cracks, pores and fissures in regolith, and examination of drill cores show that the regolith is highly porous and that some plant species do achieve root depths exceeding 10m in the BIF system.

Recommendations

- Proposed examination of root systems in mine pit faces should proceed as mining commences through populations of *D. masonii* and *L. gibsonii*, but are likely to prove challenging as roots pass through solution channels and fissures in rock. These studies may help to determine rooting depth of *D. masonii* and *L. gibsonii* and their use of surficial versus deeper layers in the soil profile. Results would inform requirements for restoration substrates.

- Mapping of regolith may indicate a relationship with the distribution of *Darwinia masonii* around the range which may reveal an important but as yet unknown association of the species with particular fracture patterns or density.

4.5g Biotic interactions

Darwinia masonii

Vertebrate grazing impacts have been considered a possible threat for *Darwinia masonii* populations. However, mortality among seedlings protected from herbivory by a coarse (chicken wire) steel mesh was similar to that observed among uncaged seedlings (see **mortality/survival** under **4.2 Population Demography** above). Further, no evidence of mammalian herbivory was observed on any plant, seedling or adult in the demographic survey plots or outside of these (with the exception of a single cutting damaged by a presumed rabbit-bite, but not actually grazed, and therefore likely to be an isolated instance), and it is not considered to be a current threat. Four tagged flowering plants were observed to have had branch tips cut off (2007 only). Further evidence of this impact was observed elsewhere in 2007, and was presumed to result from the actions of parrots eating developing seeds or flowers.

Invertebrate herbivory. Galls were observed on a very small number of *Darwinia masonii* individuals (Figure 53), but other evidence for foliar loss or damage from insect attack was not noted.

Figure 53. *Darwinia gibsonii* leaf gall.

Termites were observed on stems of 15 of 357 tagged *Darwinia masonii* individuals. One of these individuals was from a site last burnt in 1969, the remaining 14 were from older sites: respectively this represents 0.7% and 15% of individuals in these site ages. Termites were observed with their trails ascending the stems of *D. masonii* plants, and in one case had hollowed out a dead stem, their impact never appeared significant, and the mean of growth rates and health scores of affected individuals did not vary greatly from the mean of termite-free individuals in the same areas.

Pollination experiments describing the role of birds (white cheeked honeyeaters) and insects in pollen transfer are described under section 4.3e. Extensive s**eed predation** by moth larvae and **seed dispersal** by various ant species are described under sections 4.3b and 4.3f respectively.

Mycorrhizal associations: Examined field-collected root-systems of *D. masonii* clearly showed Vesicular-Arbuscular mycorrhizal (VAM) colonisation, but no obvious Ectomycorrhizal (ECM) formation. VAM associations are ubiquitous in Myrtaceae, and ECM associations common in Myrtaceae. Few shrubby Myrtaceae have been investigated for ECM associations, but an ECM partnership between *Chamelaucium uncinatum* (a sister-genus of Darwinia) and *Pisolithus* sp. has been documented at Kalbarri. No evidence of fruiting of ECM fungi was observed in the vicinity of *Darwinia masonii* plants during this project; however, some ECM-forming fungi were observed fruiting elsewhere in the range (*Amanita* spp., *Torrendia inculta*, *Pisolithus* sp., *Entoloma* sp., which were probably associated with *Eucalyptus* and/or *Acacia* spp.). Mycorrhizal formation is potentially important for restoration success for *D. masonii* (e.g. for seeding survival and growth rate, as has been shown for a variety of VAM and ECM-forming species), and should be further investigated in comparative restoration trials, in particular whether restoration-planted seedling are spontaneously able to form mycorrhizal associations in restoration surfaces, or whether inoculation is required or beneficial.

Fungal infections: Only a single unidentified bracket fungus has been observed fruiting on *D. masonii* trunks during this study. Wood of dead or burnt *D. masonii* plants persists for many years after death, with no obvious indication of fungal rotting. In contrast, living *Melaleuca nematophylla* was frequently observed colonised by *Fulvifomes* sp., and numerous plant species had dead wood colonised by *Pycnoporus coccineus* and numerous corticioid wood-rotting species. It is likely that wood rots have a very minor impact on *D. masonii*.

Evidence for **competition or facilitation** (i.e. negative or positive interactions with neighbouring plants) was also not observed, however such interactions are best determined by manipulative experiments under field conditions. Such experiments are suggested for future restoration research.

Lepidosperma gibsonii

Vertebrate grazing Mortality among seedlings protected from herbivory by a coarse (chicken wire) steel mesh was identical to that observed among uncaged seedlings (see ***L. gibsonii*** **mortality/survival** under **4.2 Population**

Demography above). Nonetheless, significant herbivory was observed in a number of surveyed plots. Herbivory was recorded on 100% of individuals in three surveyed plots: one each at Iron Hill (IH1), Iron Hill North (IHN1) and the Emu Fence. Herbivory was assessed as estimated proportion of leaves or scapes which had been grazed (usually to close to the ground). In these plots, herbivory of individual *L. gibsonii* clumps represented 15 to 100% of foliar loss (Figure 54). Complete foliar loss (100% herbivory) was observed in 35 surveyed plants. One fifth of all surveyed *L. gibsonii* adults had >20% herbivory, 16% were at least half eaten. Herbivory among seedlings was not observed as frequently: 6% of tagged seedlings had 20% or more foliar loss.

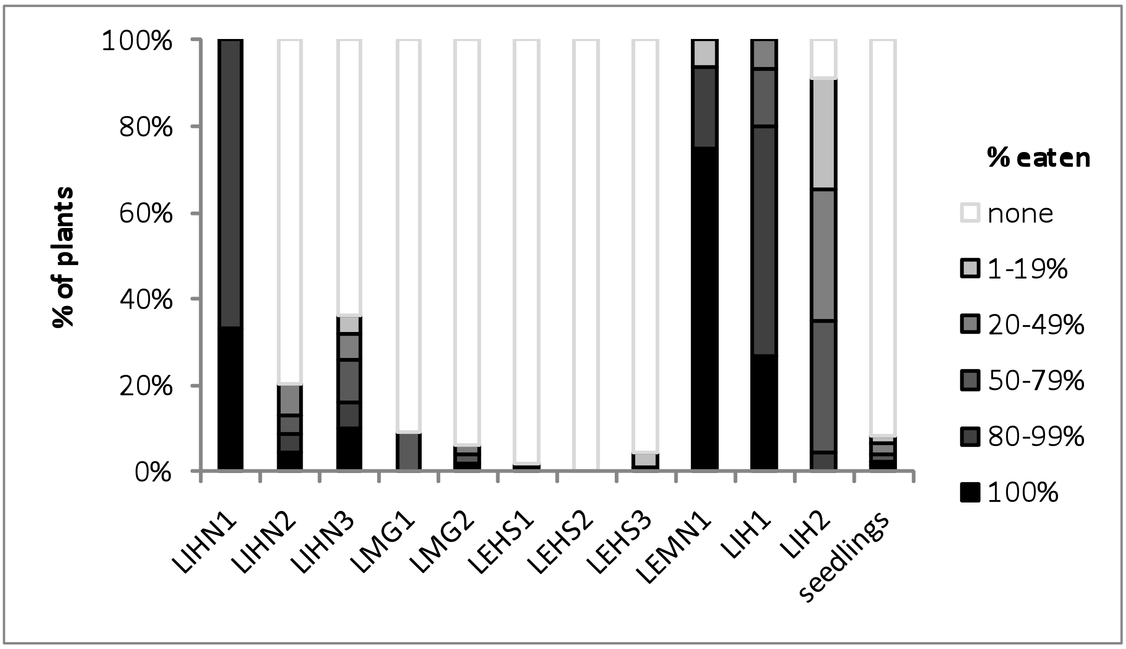

Figure 54. Frequency (number of plants) and intensity of maximum observed herbivory (% of foliage eaten) in mature *L. gibsonii* in each plot and in seedlings pooled across plots.

Sites with significant herbivory are located in the south and the north of the survey area, but are also lower on slopes (e.g. IH1, IHN1) or not on slopes (e.g. Emu Fence). Judging by the presence and abundance of nearby faecal scats, this grazing may be attributable to rabbits and / or goats. Macropods may also play a role.

Plants previously observed to have experienced herbivory often showed significant recovery on subsequent surveys, but sites with extensive herbivory seem to also experience frequent herbivory. While evidence for an impact of herbivory on survival rates is unclear, the evidence for an impact on reproductive output is clear. Grazed plants have their reproductive capacity reduced to exactly the same extent as they are eaten as leaves and culms are impacted to the same extent. That is to say, plants in the most heavily grazed sites may have their reproductive output reduced to close to zero through grazing.

Invertebrate herbivory An unidentified scale insect (Hemiptera: Coocoidea) was observed to be abundant on *L. gibsonii* culms. In some populations (e.g. near the Emu-proof fence) they covered a large areas of the available photosynthetic surface, and in such cases are likely to significantly affect the growth rate and reproductive potential due to the parasitic, sap-sucking lifestyle of the insect.

Fungal infections An unidentified rust fungus has been observed on the culms of *L. gibsonii* plants from most populations, albeit usually in small numbers (1-5 culms per clump). Infected culms have been observed successfully fruiting in 'good' years. Since culms only last 2-3 years, these rusts are potentially minor parasites of *L. gibsonii*, but could potentially have a stronger effect in poor seasons, or under increased infection rates. Five species of smut fungi (four *Moreaua*, one *Heterotolyposporium*) are known to infect inflorescences of *Lepidosperma*, and have been observed in populations of *L. costale sens.lat*. in the Midwest, but not yet on *L. gibsonii*. When abundant, *Lepidosperma* smuts can sometimes have a significant impact on reproductive output, as they are systemic and destroy all florets within an inflorescence.

Summary:

- Interactions with other organisms play an important role in the life-cycle of both *D. masonii* and *L. gibsonii*.

- Herbivores had a negligible impact on *Darwinia masonii* plants. Seed predation (by larvae of an unidentified moth species) can be significant, although is spatially and annually variable. Positive or neutral interactions with pollinators (chiefly white cheeked honeyeaters) and seed dispersers (a number of ant species) also play a major role in *Darwinia masonii* life history.

- In *L. gibsonii*, grazing – presumed to be by goats and rabbits – can have a significant impact on growth and reproduction but was observed in only a handful of localities. Other leaf parasites, notably a rust pathogen and a scale insect also occur infrequently (and often at these same sites).

- Both the seed-eating moth, and a gall forming insect observed on *Darwinia masonii* individuals are unidentified, likely unrecognised species and possibly specialist on *Darwinia masonii* and therefore also potentially rare and threatened species. The bract feeding beetle observed in collected *D. masonii* seed is less likely to be a specialist species.

Recommendations:

- Manage populations of goats and rabbits across the distribution of *L. gibsonii* and in restoration sites in particular, and monitor herbivory impacts of macropods on *L. gibsonii*.

- Ensure habitat requirements for key *D. masonii* pollinators are retained.

- Monitor and take into account the dynamics of moth impacts when collecting *Darwinia masonii* seed for restoration.

- Identify the seed-eating moth species and survey for its occurrence in co-occurring species and related *Darwinia* species.

4.6 RESTORATION AND TRANSLOCATION

4.6a Storage of propagation material for translocation

Cuttings were collected from 300 genotypes of *Darwinia masonii* and 250 genotypes of *Lepidosperma gibsonii*. All material was taken from within the mine footprint on Extension Hill and under the DRF collection permits of EHPL and BGPA. Collections were made at several times but established best when soils were moist and plant tissues were fresh and growing (i.e. mid-winter), material can then be stored and transported in cool and moist conditions. Collected material was delivered to Nuts About Natives (NAN), a specialist native plant nursery in October 2008. They reported that 385 *D. masonii* cuttings (12% of total cuttings) from 150 different genotypes (50% of genotypes) had successfully initiated after 3 months. At the same time, 815 (44%) of the 1846 pots of *L. gibsonii* divisions showed new root and shoot growth and could be considered successfully initiated. These represent 187 genotypes (75% of collected genotypes) and could be considered successfully initiated.

Both DRF species are able to be successfully initiated into cultivation, and are now stored in cultivation at NAN's nursery. These plants are maintained at NAN as an off-site genotype stock with the intention that they will be multiplied up (by taking further *D. masonii* cuttings and separating *L. gibsonii* clumps) to provide an off-site collection and perhaps ultimately to contribute to stock for population restoration. The nursery plants are maintained on unshaded external benches, regularly monitored, and watered at moderate intervals.

BGPA has made a number of additional collections, using the same techniques and keeps a small number of genotypes of both species in glasshouses at Kings Park for experimental purposes. Here, *L. gibsonii* grows vigorously, and flowers, under watered glasshouse conditions, and is easily split and repotted to create larger number of individuals (clones). *Darwinia masonii* cuttings survive and flower but have not shown the same degree of vigour in their growth, *Lepidosperma gibsonii* appears to be susceptible to a moth whose subterranean caterpillars (likely a native species and possibly present at Mt Gibson) consume dead and older live, leaf material. *Darwinia masonii* cuttings appear to prefer lower humidity levels than may often occur in glasshouse conditions. Seedlings established from *D. masonii* seeds derived from experimental studies are also potted up and growing in Kings Park glasshouses. These appear to grow with slightly greater vigour than cuttings.

Glasshouse plants of both species experimentally exposed to drought conditions do not appear to be able to enter or recover from a dormant, drought-mode state equivalent to that observed in field plants through late summer and autumn (see **4.5c Drought study**). Propagated plants planted in field translocation trials in winter did appear to achieve and recover from this dormant state in the following summer and winter periods.

While the use of nursery stock from cuttings or clump separation is a proven and suitable technique for population restoration, its drawbacks imply that investigation into the use of seed as a restoration resource for *D. masonii* and *L. gibsonii* are worth continuing. The drawbacks of greenstock include its infrastructure, resource and time demands (pots, potting media, glasshouse bench space, irrigation, pest management, time and expertise to establish cuttings, plant out, etc) as well as implications for genetic selection and diversity. Selection in propagation – i.e. with survival of plants better suited to glasshouse, but not necessarily field, conditions – can lead to a loss of genetic diversity and capacity. In terms of numbers, collection and establishment of genotypes numbering in the (low) hundreds is feasible and demonstrated, larger numbers may be possible but with diminishing returns in terms of required effort. Finally, the translocation of large and/or unbalanced numbers of genetic clones means that some genotypes may become grossly over-represented in restoration, which should ideally aim to replicate source levels of genetic diversity. The most effective way to ensure reinstallation of genetic diversity without creating artificial imbalances in genotype representation is to use seeds as a restoration source, either from collected seed or soil seedbanks.

In this area recommendations differ for *D. masonii* and *L. gibsonii*. Seed of *L. gibsonii* has proven difficult to collect and germinate and is likely to continue as such, however *D. masonii* seed is produced in larger numbers and more easily collected. As germination of treated fresh or standard stored seed of *D. masonii* is also low, this immediate approach is not recommended for restoration. However, germination of buried seed retrieved after 9 months of burial in field soils and then treated with smoke water reached 90% (see **4.3d Seed bank demography**). This suggests three possibilities: 1) It is technically feasible to explicitly follow this approach, exhuming bagged seeds after a period of burial in field soils, for germination in pots for planting as seedling greenstock; 2) Trialling a process of broadcasting of *D. masonii* seeds into field restoration areas, followed by application of smoke or smoke chemicals after some period, and which does seem likely to lead to the emergence of seedlings after some time; 3) Continued research into cues responsible for the pattern identified in burial trials may enable replication of these in seeds under lab conditions (e.g. by storing seeds under alternating warm/ hot temperatures and following this with a period of cool and moist conditions and the application of smoke) and cued seed could then be applied to restoration areas ready to germinate – at higher rates.

Summary:

- Techniques for the successful collection, establishment, maintenance and propagation of both *D. masonii* and *L. gibsonii* have been proven at both BGPA and an independent specialist nursery.

- Proven propagation techniques involve greenstock production from cuttings (*D. masonii*) or separated clumps (*L. gibsonii*).

- Both species can persist as tube-stock when stored outside in hygienic nursery conditions and watered through dry periods. *L. gibsonii* may show improved growth under more humid glasshouse conditions.

Recommendations:

- *ex situ* collections of live plant and seed material and multiple (>100 for live plants) genotypes should be monitored and maintained and supplemented as required.

- Seed collections made for restoration purposes should be viability checked and maintained in standard, pest-free, temperature and humidity controlled seed banks.

- Propagation of live plant material from wild collections and nursery stock likely pose the most cost effective approach for the short-medium term storage and production of plants for restoration purposes.

- Collection and storage of seed for restoration purposes may yet prove effective and is relatively cheap, however allowance must be made for the likely ultimate rate of seed germination, difficulty of collection (for *L. gibsonii*) and the potential cost (in time and money) of developing seedlings from seed.

- Uncertain and low seed production rates, and poor return in terms of demonstrated germination rates (to date) means that this approach is not yet recommended.

- For *D. masonii*, further research into seedling production under lab, glasshouse or field conditions appears promising and may provide a preferable approach to providing a genetically diverse and numerous source of restoration plants.

4.6b Translocation methods

Plants from the BGPA collection, supplemented by material previously cultivated at NAN (from BGPA collections) were used in translocation trials at Extension Hill with acceptable survival rates (as described in **4.5b Translocation study**). Evidence from the *D. masonii* pilot watering trial (also see 4.5b) indicates that *D. masonii* survival may be approximately doubled by irrigation in the initial years, although the two trials commenced in years differing markedly in their total rainfall receipt.

The trials performed demonstrate successful establishment and survival of both *D. masonii* and *L. gibsonii* in the rocky/gravelly loams of the Extension Hill range. While it is yet possible that some substrate attribute essential to growth and survival of these species may be missed in a regular replacement of gravel/rocky loam over waste rock, and these should be confirmed in restoration trials, the indications that this would succeed are good.

Potential localities for translocation (as opposed to restoration) of populations have been identified and mapped in section **4.5a** (**Abiotic associations**).

Plans for studies of plants planted into reconstructed substrates and designed to identify optimal soil and subsurface features for the growth and survival of *D. masonii* and *L. gibsonii* were contingent upon the commencement of mining and the provision of trial areas with trial substrate materials derived from the mining process. These are still to take place.

Summary:

- Trial translocation of propagated cuttings of *D. masonii* and split clumps of *L. gibsonii*, planted into field substrates in early winter and watered only at planting have proven successful.

- Attributes and localities of potential translocation sites within the Mt Gibson-Extension Hill range have been identified.

Recommendations:

- Experiments manipulating restoration substrates using mine waste components or other available and appropriate materials are recommended as mining construction commences.

4.7 *EX SITU* CONSERVATION

4.7a Seed storage

Batches of 1000 filled seeds of each of *Darwinia masonii* and *L. gibsonii* have been deposited at each of the WA Seed Technology Centre in the Botanic Gardens and Parks Authority at Kings Park, the DEC-operated Western Australian Threatened Flora Seed Centre, and Kew Garden's Millennium Seedbank at Wakehurst Place in the UK. These three facilities are premier global and national seed storage facilities.

Viability of long-term stored *L. gibsonii* seeds has not been tested due to its recent collection date, however *D. masonii* seed collected from 2004 and stored for three years appears to retain equivalent levels of viability when compared to seed collected (and simultaneously tested) in 2007. The soil seedbank strategy of both species strongly suggests that seed viability is likely to persist though storage under standard seed storage conditions for many years.

Summary:

- Batches of 1000 filled seeds of each of *Darwinia masonii* and *L. gibsonii* have been deposited at each of three, Australian and international, conservation seed storage facilities.

4.7b Germplasm storage

Germplasm storage techniques were investigated using standard approaches from excised seed embryos for both *D. masonii* and *L. gibsonii*, and shoot cuttings for *D. masonii*. The medium used for in vitro propagation was basal medium as per Bunn (2005) supplemented with BAP 0.15 μM, pH 6 and 6 gL-1 agar.

For *D. masonii*, shoot cutting material was trialled from 12 individuals representing 5 populations in a total of 35 separate 120 ml culture tubes. After a period of three months, all 35 tubes had initiated root and stem tissue and were growing well and multiplying (Figure 55). Culture lines are being maintained successfully in culture at room temperature with alternating cool storage (short to medium term storage).

Figure 55. *Darwinia masonii* in tissue culture (bar = 20 mm)

For *L. gibsonii*, tissue culture was attempted via embryo extraction in an experiment combining investigation into the role of heat shock on *L. gibsonii* seeds. Fruits were soaked in water for 24 hours to soften up the endosperm, then surface sterilised in 1% bleach for 20 minutes and rinsed in sterile water three times for approximately 3-5 minutes each. Embryos were then extracted under a binocular microscope in a laminar flow cabinet and plated on a special media of ½ MS + GA3 + Zeatin (6g per litre Agar & 20g per litre Sucrose). Prior to imbibing water, fruits were split into control and multiple heat treatment samples, with the latter exposed in a temperature controlled oven to 100°C for a period of 10 to 90 minutes for the heat shock treatment. Each of the seven treatments included a total of 16 embryos. Plated embryos were incubated @ 15°C in dark conditions examined for growth. Embryos with growing root and shoot systems were transferred to culture tubes and maintained under the same conditions as per *D. masonii* (above).

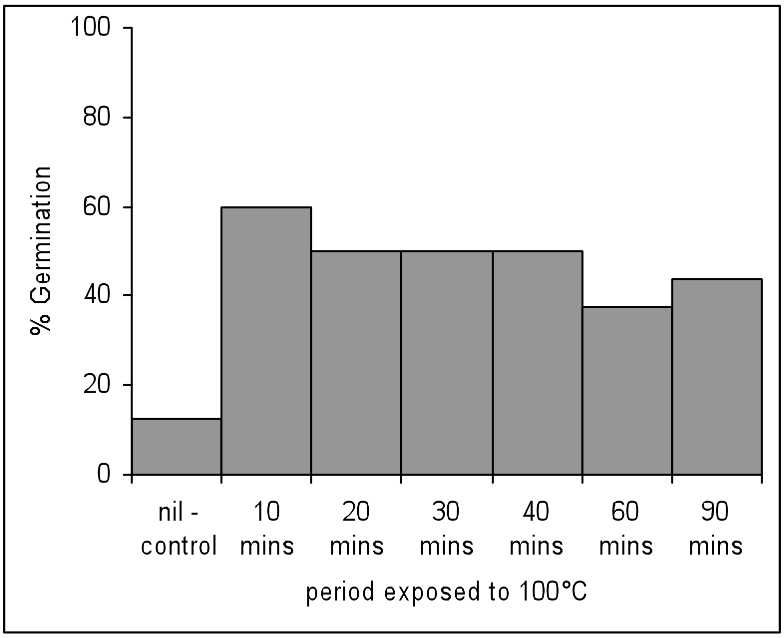

Figure 56. Germination rates (including to establishment of roots and leaf shoots) for seeds of *Lepidosperma gibsonii* exposed to varying periods of heat treatment.

An average of 49% of excised *L. gibsonii* embryos exposed to temps of 100°C produced roots and shoots and survived to establish successfully in tissue culture (Figure 56). Less than a quarter of this proportion of seeds not exposed to high temperatures germinated and established, and there is some limited indication that exposure to 100°C for longer periods may lead to lower establishment.

Summary:

- *in vitro* culture, with root initiation has been achieved with multiple genotypes of both *Darwinia masonii* and *Lepidosperma gibsonii*, using stem tissue and embryo extraction respectively.
- Culture lines can be maintained in culture with alternating room temperature / cool storage (for short to medium term storage).
- Cryostorage is an option for long-term storage of key clonal germplasm if required.
- Micropropagation is feasible should it be required as a propagation option for both species.
- Genotypes of both species are stored as live plants at two locations off-site (including a significant collection of Extension hill genotypes of both species)

- Genotypes of both species are additionally stored as seed at three secure locations off-site, representing a total of 3000 seeds of each species.

Recommendations:

- *ex situ* collections of live plant and seed material and multiple (>100 for live plants) genotypes should be monitored and maintained.

- The effectiveness of *ex situ* storage of germplasm in a variety of forms is demonstrated for both species, but live plant collections likely pose the most cost effective approach for the short-medium term.

- Collection and storage of seed as an *ex situ* conservation measure may also be effective, and is relatively cheap, however allowance must be made for the likely ultimate rate of seed germination, difficulty of collection (for *L. gibsonii*) and the potential cost (in time and money) of developing seedlings from seed.

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Appendix B Geochemical Characterisation of Soil, Regolith, Waste bedrock and low grade ore samples

MOUNT GIBSON MINING LIMITED

EXTENSION HILL
IRON-ORE PROJECT

GEOCHEMICAL CHARACTERISATION OF SOIL, REGOLITH, WASTE-BEDROCK AND LOW-GRADE-ORE SAMPLES

['STATIC-TESTWORK']

Implications for Mine-Waste Management

GRAEME CAMPBELL AND ASSOCIATES PTY LTD
(ACN 061 827674)
NOVEMBER 2005
Job No. 0503/1

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SUMMARY OF TECHNICAL TERMS EMPLOYED IN THIS REPORT

ACRONYM	PARAMETER	DEFINITION/DETERMINATION	UNIT
AFP	Acid-Formation Potential		
ARD	Acid-Rock Drainage		
Total-S	Total Sulphur	Analysis Result	% (w/w)
Sulphide-S	Sulphide Sulphur	Testwork Result [i.e. Sulphide-S = Total-S - Sulphate-S]	% (w/w)
ANC	Acid-Neutralisation Capacity	Testwork Result	kg H_2SO_4/tonne
MPA	Maximum-Potential Acidity	Calculation	kg H_2SO_4/tonne
NAPP	Net-Acid-Producing Potential	Calculation	kg H_2SO_4/tonne
NAG	Net-Acid Generation	Testwork Result	kg H_2SO_4/tonne
NAF	Non-Acid Forming	Calculation: • Sulphide-S < 0.3 % • Sulphide-S ≥ 0.3 %, and negative-NAPP value with ANC/MPA ≥ 2.0	kg H_2SO_4/tonne
PAF	Potentially-Acid Forming	Calculation: • Sulphide-S ≥ 0.3 %, and any positive-NAPP value • Sulphide-S ≥ 0.3 %, and a negative-NAPP value with ANC/MPA < 2.0	kg H_2SO_4/tonne
PAF-[SL]	PAF-[Short-Lag]	Estimation [e.g. inferred from 'kinetic' testing]	
PAF-[LL]	PAF-[Long-Lag]	Estimation [e.g. inferred from 'kinetic' testing]	
SOR	Sulphide-Oxidation Rate	Testwork Result [e.g. obtained from 'kinetic' testing]	mg SO_4/kg/week,

Notes:

The **PAF-[SL]** classification applies to (initially circum-neutral) PAF-materials that may acidify (viz. pH less than 5) within a matter of weeks-to-months when subjected to "aggressive-ambient-weathering", corresponding to periods of at least a few days during which unsaturated-conditions prevail (via drainage/evaporation processes) between successive inundations that, in turn, occur semi-regularly (e.g. weekly-to-fortnightly "on-average" during most of the annual hydrological-cycle).

The **PAF-[LL]** classification applies to PAF-materials where exposure to the atmosphere for years (even decades, or longer) may be needed before acidification develops. Circum-neutral-pH during the "lag-phase" for such lithotypes is chiefly due to buffering reactions involving carbonate-minerals.

Climate directly influences the duration of the "lag-phase", and a sulphide-gangue assemblage classified as PAF-[SL] in a "humid" environment where the SOR is controlled by O_2-**supply**, may instead be classified as PAF-[LL] in semi-arid/arid environments where the SOR is contolled by **water-supply** (viz. frequency of "flushing-episodes") [Campbell 2004]. The formation of "secondary-oxidation-products" (e.g. Fe-oxyhydroxides) as protective-coatings is generally enhanced during the "lag-phase-stage" of mine-waste weathering in semi-arid/arid environments, and so further curtails sulphide-oxidation rates.

1.0 INTRODUCTION

Mount Gibson Mining Limited is developing the Extension Hill Iron-Ore Project located between Wubin and Paynes Find, Western Australia.

Ore will be produced via open-pit mining, and the excavated waste-rock materials (viz. regoliths and waste-bedrocks) placed on waste-dumps in the vicinity of the Pit. Varieties of low-grade-ores will also be stockpiled for possible future processing, pending the outcome of metallurgical evaluation, and Project economics.

Graeme Campbell & Associates Pty Ltd (GCA) was commissioned to carry out geochemical testwork on a range of soil, regolith, waste-bedrock and low-grade-ore samples derived from the Extension Hill Deposit.

The 'Static-Testwork' Programme focused on Acid-Formation Potential (AFP), Multi-Element Composition, and Mineralogy.[1]

The testwork results are presented and discussed in this report, and implications for mine-waste management highlighted.[2]

[1] A 'Static-Testwork' Programme comprises "whole-rock" analyses and tests.
[2] Related testing on samples of process-tailings is the subject of the GCA (2005) report.

2.0 STUDY APPROACH

Details of the sampling and testwork programmes, and the calculations and criteria employed for classifying the soil, regolith, waste-bedrock and low-grade-ore samples into AFP categories, are presented and discussed in the following sections.

2.1 Testwork Programme

2.1.1 Samples

Details of the samples submitted for testing by GCA are presented in Appendix A.

The tested samples typically correspond to down-hole intervals of *c.* 0.1-0.5 m, and so allow assessment of mine-waste geochemistry at the "sub-metre-scale" in terms of sulphide-/carbonate-mineral abundance, and minor-element content.

The 27 samples tested in this study comprised:

- 2 samples of soil;[3]
- 6 samples of regoliths and weathered-rock materials;
- 15 samples of waste-bedrocks; and,
- 4 samples of low-grade-ores.

The predominant lithotypes making up the waste-bedrocks are Banded-Iron Formation (BIF), and varieties of tuffs and cherts.

[3] The two soil samples correspond to different depth-intervals of a gravelly *red-earth*.

It is assumed that the samples submitted for testing are representative of the major types of soil, regoliths, waste-bedrocks and low-grade-ores to be produced via open-pit mining of the Extension Hill Deposit.

2.1.2 Testwork

The samples were assigned GCA Sample-Numbers, and relevant details recorded in the GCA Sample-Register.

All samples were crushed (nominal 2 mm), and pulped (nominal 75 μm), for specific tests.

The testwork methods employed in this study are based on recognised procedures for the geochemical characterisation of mine-waste materials (e.g. AMIRA 2002; Morin and Hutt 1997; Smith 1992; Coastech Research 1991; BC AMD Task Force 1989).

Part of the testwork was carried out by SGS Environmental Service [SGS] (Welshpool), and Genalysis Laboratory Services [GLS] (Maddington). The analyses performed by SGS and GLS have NATA endorsement.[4]

Specialised testing (viz. auto-titrations and Net-Acid-Generation [NAG] Tests) was undertaken by Dr. Graeme Campbell in the GCA Testing-Laboratory (Bridgetown).

The mineralogical investigation was carried out by Dr. Roger Townend of Roger Townend & Associates (Malaga).

Details of the testwork methods are presented in Appendix B, and copies of the laboratory and mineralogical reports are presented in Appendix C.

[4] NATA = National Association of Testing Authorities.

2.2 Calculated Parameters

The Maximum-Potential-Acidity (MPA) values (in kg H_2SO_4/tonne) of the samples were calculated by multiplying the Sulphide-S values (in %) by 30.6. The multiplication-factor of 30.6 reflects both the reaction stoichiometry for the complete-oxidation of pyrite, by O_2 to "$Fe(OH)_3$" and H_2SO_4, and the different weight-based units of % and kg H_2SO_4/tonne. The stoichiometry of pyrite-oxidation is discussed further in Appendix B.

The Net-Acid-Producing-Potential (NAPP) values (in kg H_2SO_4/tonne) were calculated from the corresponding MPA and Acid-Neutralisation-Capacity (ANC) values (i.e. NAPP = MPA - ANC).[5]

2.3 Classification Criteria

In terms of AFP, mine-waste materials may be classified into one of the following categories, viz.

- Non-Acid Forming (NAF).

- Potentially-Acid Forming (PAF).

There are **no** unifying, "standard" criteria for classifying the AFP of mine-waste materials (Campbell 2002a,b; Smith 1992), and reflects the diversity of sulphide and gangue-mineral assemblages within (un)mineralised-lithotypes of varying weathering- and alteration-status. Rather, criteria for classifying AFP may need to be tailored to deposit-specific geochemistry, and mineralogy.

[5] NAPP values were not performed for sample with Sulphide-S contents less than 0.1 %.

The AFP-classification criteria often employed at mining-operations worldwide are:

- **NAF**: Sulphide-S < 0.3 %. For Sulphide-S ≥ 0.3 %, both a negative NAPP value, and an ANC/MPA ratio ≥ 2.0.

- **PAF**: For Sulphide-S ≥ 0.3 %, any positive-NAPP value; negative-NAPP value with an ANC/MPA ratio < 2.0.

In assessing the AFP of mine-waste materials, there is consensus (e.g. mining/environmental regulators in British Columbia, Canada) that lithotypes with Sulphide-S contents less than 0.3 % are unlikely to oxidise at rates fast enough to result in acidification (e.g. pH less than 4-5) [Soregaroli and Lawrence 1997]. This position assumes that the groundmass hosting such "trace-sulphides" is not simply quartz, and/or clays (Price *et al.* 1997), and that for a carbonate-deficient gangue, the sulphides are not unusually reactive (e.g. sulphide-oxidation rates [SORs] less than *c.* 20-40 mg SO_4/kg/week) [= *c.* 1-2 kg SO_4/tonne/year].[6] A "cut-off" of 0.3 % for Sulphide-S also accords with the findings of 'kinetic' testing conducted, since the late-1980s, by Dr. Graeme Campbell for mine-waste samples of diverse mineralogy in terms of AFP.

The ANC/MPA criteria for the NAF category reflects the need to compensate for "less-than-perfect" availability of alkalinity-forms (e.g. carbonate-minerals) for neutralisation of acid produced through sulphide-oxidation. A "less-than-perfect" availability of alkalinity-forms may arise from:

(a) Restricted accessibility of acid to carbonate-grains.

(b) Rate-limiting dissolution of carbonates-grains near pH=6-7.

[6] Although 'steady-state' SORs (at circum-neutral-pH) for Sulphide-S contents less than 0.3 % may indeed exceed 1-2 kg SO_4/tonne/year, such rates are generally restricted to either sedimentary forms (e.g. framboidal-pyrite), or hydrothermal-sulphides that are atypically reactive.

(c) Depletion of carbonate-minerals through rainfall-fed leaching within waste-dumps.[7]

Restricted accessibility of acid to the surfaces of carbonate-grains may occur at different spatial-scales (viz. at the "whole-rock-scale" in which Acid-Rock Drainage [ARD] "by-passes" carbonate-bearing materials via preferential-flow pathways within a waste-dump, and at the "grain-scale" in which the surfaces of individual carbonate-grains are "blinded/rimmed" by precipitates of Fe(III)-oxyhydroxides [e.g. ferrihydrite-type phases]). As shown by Li (1997), ferroan-carbonates (especially "Fe-rich" varieties) are especially prone to "surface-armouring/rimming": laboratory-weathering of tailings-solids containing pyrite, ankerites and Mg-siderites produced acidic leachates when less than one-third of the carbonate-grains had dissolved.

To compensate for the effects of (a) to (c) above, some authors advocate that, for a mine-waste sample to be classified as NAF, it must have an ANC/MPA ratio of at least 3.0 (see review of earlier literature by Smith [1992]). In recent years, fundamental-research (especially estimation of reaction-rates for diverse sulphide/gangue-mineral assemblages), and field-experience at mining operations world-wide, have shown that the potential for ARD production is very low for mine-waste materials with ANC/MPA ratios greater than 2.0 (AMIRA 2002; Price *et al.* 1997, Currey *et al.* 1997, and Murray *et al.* 1995).[8] This ANC/MPA ratio is employed in the present work.[9]

[7] Depletion of carbonate-minerals through dissolution in meteoric-waters is generally minimal in semi-arid settings, especially within the "hydrologically-active-zone" (e.g. top 2-3 m) of a waste-dump, since re-precipitation occurs during evapo-concentration when strongly-desiccating conditions soon return after "wet-spells".

[8] Such ANC/MPA ratios are consistent with those indicated from SORs, and carbonate-depletion rates, as reported in the International-Kinetic Database for mine-waste materials from around the world (Morin and Hutt 1997).

[9] It should be noted that mining-regulators in Nevada (USA) classify a mine-waste sample as NAF, if it is characterised by an ANC/MPA ratio greater than 1.2 (US EPA 1994). This lower ANC/MPA ratio reflects the semi-arid conditions typically encountered at mine-sites in Nevada. Although utilised in the early-1990s, it is understood that an ANC/MPA ratio of 1.2 is still entertained by regulators in Nevada for "screening" PAF and NAF varieties of mine-wastes in semi-arid settings.

The risk posed by handling PAF-lithotypes during the working of a deposit is governed primarily by the duration of the "lag-phase" (i.e. the period during which sulphide-oxidation occurs, but acidification does not develop, due to buffering near pH=7 by gangue-phases).[10] Although the "lag-phase" applicable to exposed mine-wastes at "field-scale" cannot be accurately predicted *a priori*, estimates (albeit approximate) are still needed to identify the exposure-times for the safe handling of PAF-lithotypes, and so reduce the risk for ARD production. Estimates of the "lag-phase" are invariably obtained through programmes of 'kinetic' testing (viz. Weathering-Columns). However, based on experience, "first-pass" estimates of the "lag-phase" may be made, and thereby used to further classify PAF-lithotypes into **PAF-[Short-Lag]** and **PAF-[Long-Lag]** sub-categories. Such "first-pass" estimates are necessarily provisional, and subject to revision, in the light of the outcomes of 'kinetic' testing, and field observations.

[10] SO_4 is still produced by sulphide-oxidation during the "lag-phase", and appreciable amounts of soluble-forms of certain minor-elements (e.g. As) may be released at circum-neutral-pH during the "within-lag-phase-stage" of mine-waste weathering.

3.0 ACID-BASE CHEMISTRY AND SALINITY OF SOIL, REGOLITH AND WASTE-BEDROCK SAMPLES

The testwork results on the acid-base chemistry and salinity of the soil, regolith, and waste-bedrock samples, are presented in Tables 3.1 and 3.2, and shown on Figure 1. These results are discussed in the following sections.

3.1 Soil and Regoliths

3.1.1 pH and Salinity

The samples had pH-(1:2) values of 4.7-8.0, and EC-(1:2) values of 0.15-1.9 mS/cm (Table 3.1).[11]

Although not tested, the soluble-salts should mainly comprise chlorides.

The testwork results indicate that the soil sample was mildly-acidic (viz. pH 4-5), whereas the regolith samples were neutral-to-alkaline (viz. pH 7-8). The soluble-salt contents were low-to-moderate.

3.1.2 Sulphur Forms

The samples had Total-S values of 0.01-0.04 % (Table 3.1).

The testwork results indicate that, as expected, all samples contained negligible amounts of sulphide-minerals (viz. Sulphide-S contents less than 0.05 %).

[11] EC= Electrical-Conductivity. The pH-(1:2) and EC-(1:2) Tests (and other testwork) are described in Appendix B

3.1.3 Acid-Consuming Properties

The samples had ANC values of 0.5-7.6 kg H_2SO_4/tonne (Table 3.1).[12]

The testwork results indicate that all samples had a low capacity to consume acid.

3.1.4 Acid-Formation Potential

The testwork results indicate that all samples were classified as NAF.

3.2 Waste-Bedrocks

3.2.1 pH and Salinity

The samples had pH-(1:2) values of 7.9-9.6, and EC-(1:2) values of 0.19-0.76 mS/cm (Table 3.2).

Although not tested, the soluble-salts should mainly comprise chlorides.

The testwork results indicate that the samples were mildly-alkaline (viz. pH 8-10), with low-to-moderate contents of soluble-salts.

3.2.2 Sulphur Forms

The samples had Total-S values of 0.01-1.8 %, and the samples tested for SO_4-S had SO_4-S values that ranged from less than 0.01 %, to 0.01 % (Table 3.2).

All samples, but two, had Sulphide-S values less than 0.2 %.

[12] ANC values of 0.5-7.6 kg H_2SO_4/tonne are equivalent to c. 0.05-0.76 % (as "$CaCO_3$")

Sample GCA5908 (viz. Chert/Chloritic-Tuff) stood out with a Sulphide-S value of 1.8 %.

The testwork results indicate that samples typically contained negligible amounts of sulphide-minerals (viz. Sulphide-S contents less than 0.1-0.2 %).

3.2.3 Acid-Consuming Properties

The samples had ANC values within the range 1.0-450 kg H_2SO_4/tonne (Table 3.2).[13]

The ANC values were typically less than 10-20 kg H_2SO_4/tonne.

The pH-Buffering properties of samples GCA5906 (viz. Magnetite-Chert) and GCA5915 (viz. BIF) were determined via auto-titration, and 0.05 M-H_2SO_4. The acid-addition rates employed during the auto-titrations were *c.* 10^3-10^4 kg H_2SO_4/tonne/year, and correspond to SORs up to 10^4-10^5 faster than those typically observed for the weathering (at circum-neutral-pH) of "trace-sulphides". The pH-buffering curves (Figure 1) exhibited a steady decrease in pH values with progressive acid-addition, although an "inflection-point" near pH=7 was shown by sample GCA5906. The presence of reactive carbonate-minerals (e.g. calcite) in the latter sample was inferred from the effervescence (i.e. "fizzing") recorded upon the addition ('in-the-cold') of dilute HCl in the ANC testwork. Traces of calcite in sample GCA5915 were identified in the mineralogical study (Table 4.3).

The testwork results indicate that the samples typically had a low capacity to consume acid, due to a paucity of carbonate-minerals. However, locally, some calcareous varieties of waste-bedrocks occur.

[13] ANC values of 1.0-450 kg H_2SO_4/tonne are equivalent to *c.* 0.1-45.0 % (as "$CaCO_3$")

3.2.4 Acid-Formation Potential

The samples had NAPP values that ranged from -420 kg H_2SO_4/tonne, to 45 kg H_2SO_4/tonne (Table 3.2).

The NAG-pH values were 2.6-7.8, and the NAG values ranged from less than 0.5 kg H_2SO_4/tonne, to 25 kg H_2SO_4/tonne.

The testwork results indicate that all samples, but one, were classified as NAF.

The sample of Chert/Chloritic-Tuff was classified as PAF.

4.0 MULTI-ELEMENT COMPOSITION AND MINERALOGY OF SOIL, REGOLITH AND WASTE-BEDROCK SAMPLES

The multi-element composition and mineralogy of selected samples is indicated by the data presented in Tables 4.1-4.3.[14] The corresponding element-enrichments, as indicated by the values of the Geochemical-Abundance Index (GAI), are also presented in Tables 4.1 and 4.2.[15] It should be noted that these element-enrichments are relative enrichments, based on the element contents typically recorded for unmineralised soils, regoliths and bedrocks (Bowen 1979).

The assayed samples generally had contents of major- and minor-elements below, or close to, those typically recorded for unmineralised soils, regoliths, and bedrocks (Tables 4.1-4.3). Slight-to-moderate enrichment in As, Sb and Se was apparent for certain samples. However, the contents of these chalcophyles were well within the range recorded for mine-waste materials at other local iron-ore mines.[16]

The waste-bedrock samples subjected to mineralogical assessment mainly comprised quartz, silicates and Fe-oxides, as expected (Table 4.3). Trace-to-accessory amounts of pyrite occurred, and the carbonate-mineral suite comprised mostly siderites.

The results indicate that, geochemically, the assayed samples of soils, regoliths and waste-bedrocks were "clean" (viz. low contents of environmentally-significant elements).

[14] The suite of elements listed in Tables 4.1 and 4.2 is grouped into (a) the major-elements (viz. Na, K, Mg, Ca, Al and Fe) making-up the lattices of primary-silicates, clays, sesquioxides and carbonates, and (b) minor-elements. A distinction is made between minor-elements which, under neutral-to-alkaline conditions, occur (i) as cationic-hydrolysis forms (e.g. Cu), and (ii) as anions/oxyanions (e.g. As). Anionic forms may exhibit moderate solubility under neutral-to-alkaline conditions.
[15] The GAI is defined in Appendix B.
[16] This statement is based on the experience of Dr. Graeme Campbell, since the 1980s, in related testing of mine-waste samples derived from a range of iron-ore deposits in the Pilbara.

5.0 GEOCHEMISTRY OF LOW-GRADE-ORES

The testwork results for the low-grade-ore samples are presented in Tables 5.1-5.3.

The low-grade-ore samples were characterised by (Table 5.1):

- pH-(1:2) values of 8.6-9.7, and EC-(1:2) values of 0.15-0.21 mS/cm;
- Total-S values of 0.02-0.14 %, and Sulphide-S values of 0.02-0.14 %;
- ANC values of 2.4-100 kg H_2SO_4/tonne;
- NAPP values that ranged from -14 kg H_2SO_4/tonne, to –7.7 kg H_2SO_4/tonne; and,
- NAG-pH values of 6.3-8.6, and NAG values that ranged from less than 0.5 kg H_2SO_4/tonne, to 1.1 kg H_2SO_4/tonne.

The assayed samples of low-grade-ores were slightly enriched in As, Sb and Se (Table 5.2).

The samples subjected to mineralogical assessment comprises mainly Fe-oxides, and quartz (Table 5.3).

The testwork results indicate that the low-grade-ore samples were classified as NAF, and had low contents of environmentally-significant elements.

6.0 CONCLUSIONS AND MANAGEMENT IMPLICATIONS

In the present study, samples of soil, regoliths, waste-bedrocks, and low-grade-ores derived from the Extension Hill Deposit have been geochemically characterised.

Details of the sampling programme, testwork methods employed in this study, and approach to classifying the samples into AFP categories, are presented in Section 2, and Appendices A and B.[17] All testwork results are presented, and fully interpreted, in Sections 3 to 5.

Based on the testwork results obtained in this study, implications for mine-waste management are outlined in the following sections.

6.1 Soils and Regoliths

The soils and regoliths to be produced during open-pit mining should be geochemically benign, and hospitable as a rooting-medium for the native-vegetation endemic to the mine-site. However, the revegetation aspects of the rehabilitation programmes need to be fully assessed and planned by others.

6.2 Waste-Bedrocks

Although the number of samples tested herein was by no means marked, the indications are that the waste-bedrocks to be produced during open-pit mining should typically be classified as NAF varieties. due to negligible amounts of sulphide-minerals.[18]

The Chert/Chloritic-Tuff is an exception, and is classified as PAF, due to trace-to-accessory amounts of sulphide-minerals (chiefly pyrite) in a groundmass devoid of

[17] AFP = Acid-Formation Potential
[18] NAF = Non-Acid Forming.

reactive carbonate-minerals (e.g. calcite).[19] Lithotypes of this kind will therefore need to be buried (preferably deeply) within the waste-dumps, and not located closer than 5-10 m from the outer-surfaces – of both dump-top and side-slopes – when the waste-dumps are decommissioned.

6.3 Low-Grade-Ores

The low-grade-ores should be geochemically benign.

[19] PAF = Potentially-Acid Forming. Although the Chert Chloritic-Tuff contains siderite, this carbonate-mineral is ineffective in consuming acid under circum-neutral conditions.

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TABLES

Table 3.1: Acid-Base-Analysis, Salinity and Net-Acid-Generation Results for Soil and Regolith Samples

GCA-SAMPLE NO.	SITE-SAMPLE NO.	DRILLHOLE & DOWN-HOLE INTERVAL (m)	LITHOTYPE	pH-(1:2)	EC-(1:2) [mS/cm]	TOTAL-S (%)	ANC	NAPP	NAG	NAG-pH	AFP CATEGORY
							kg H_2SO_4/tonne				
Samples of Topsoil											
GCA5898	Soil-001	0.0-0.1	*red-earth soil*	4.7	0.15	0.04	0.5	nc	<0.5	6.7	NAF
GCA5899	Soil-002	0.1-0.2	*red earth soil*	4.7	0.23	0.03	0.8	nc	<0.5	6.7	NAF
Samples of Regoliths											
GCA5900	Reg.-001	EHGT005, 3.8-4.0	Canga/Laterite-Canga	6.9	0.92	0.05	2.1	nc	<0.5	6.8	NAF
GCA5901	Reg.-002	EHGT011, 1.0-1.5	Laterite	8.0	0.79	0.01	7.6	nc	<0.5	7.3	NAF
Samples of Weathered-Rock Materials											
GCA5902	Weath.-001	EHGT012, 17.5-17.9	Pale-Yellow-Clays	7.6	1.9	0.02	0.5 (0.6)	nc	<0.5	7.0	NAF
GCA5903	Weath.-002	EHGT009, 17.00-17.25	Weathered-Mafic	7.7	1.3	0.02	1.1	nc	<0.5	6.9	NAF
GCA5904	Weath.-003	EHGT005, 20.15-20.30	Weathered-BIF	7.3	0.70	0.03	1.4	nc	<0.5	6.7	NAF
GCA5905	Weath.-004	EHGT005, 37.4-37.5	Weathered-BIF	7.4	0.44	0.03	1.1	nc	<0.5	6.5	NAF

Notes:
EC – Electrical Conductivity; ANC – Acid-Neutralisation Capacity; NAPP = Net-Acid-Producing Potential; AFP – Acid-Formation Potential; NAF – Non-Acid Forming; nc – not calculated.
pH-(1:2) and EC (1:2) values correspond to pH and EC measured on sample slurries prepared with deionised-water, and a solid:solution ratio of c. 1:2 (w/w).
All results expressed on a dry-weight basis, except for pH-(1:2), EC-(1:2), and NAG-pH.
Values in parentheses represent duplicates

Table 3.2: Acid-Base-Analysis, Salinity and Net-Acid-Generation Results for Waste-Bedrock Samples

GCA-SAMPLE NO.	SITE-SAMPLE NO.	DRILLHOLE & DOWN-HOLE INTERVAL (m)	LITHOTYPE	pH-(1:2)	EC-(1:2) [mS/cm]	TOTAL-S (%)	SO_4-S (%)	Sulphide-S (%)	CO_3-C (%)	ANC	NAPP	NAG	NAG-pH	AFP CATEGORY
										kg H_2SO_4/tonne				
GCA5906	Prim.-001	EHGT012, 17.5-17.9	Magnetite-Chert	9.0	0.20	0.18	<0.01	0.18	0.29	43*	-37	<0.5	6.8	NAF
GCA5910	Prim.-005	EHR048, 188.0-188.76	Banded-Chert/Magnetite	9.1	0.21	0.03	nm	0.03	nm	4.0	nc	<0.5	7.1	NAF
GCA5907	Prim.-002	EHR026, 222.67-223.35	Ca-Magnetite-Silicate	9.1 (9.0)	0.37 (0.36)	0.52	<0.01	0.52	7.6	450* (440*)	-420	<0.5	6.9	NAF
GCA5908	Prim.-003	EHR066, 231.78-232.50	Chert/Chlorite-Tuff	8.7	0.29	1.8	0.01	1.8	nm	11*	45	25	2.6	**PAF**
GCA5909	Prim.-004	EHR048, 189.50-190.50	Dark-Green-Tuff	8.8	0.22	0.04	nm	0.04	nm	6.0	nc	<0.5	7.3	NAF
GCA5918	Prim.-013	EHGT003, 190.30-190.50	Dark-Green-Tuff	9.8	0.31	0.17	<0.01	0.17	nm	16	-10	<0.5	6.6	NAF
GCA5917	Prim.-012	EHGT001, 209.05-209.30	Tuff	9.6 (9.5)	0.18 (0.18)	0.01	nm	0.01	0.19	13 (14)	nc	<0.5	7.8	NAF
GCA5920	Prim.-015	EHGT003, 133.85-137.05	Mafic/Tuff	9.6	0.19	0.02	nm	0.02	nm	8.4	nc	<0.5	7.4	NAF
GCA5911	Prim.-006	EHR003, 99.55-99.80	Basalt	8.6	0.42	0.03	nm	0.03	nm	10	nc	<0.5	6.9	NAF
GCA5913	Prim.-008	EHGT010, 44.6-44.7	Dolerite	8.5	0.53	0.03	nm	0.03	nm	6.2	nc	<0.5	6.8	NAF
GCA5912	Prim.-007	EHGT005, 64.8-65.0	BIF	7.9	0.20	0.02	nm	0.02	nm	1.0 (1.1)	nc	<0.5	6.7	NAF
GCA5914	Prim.-009	EHGT004, 75.4-75.6	BIF	8.2	0.76	0.02	nm	0.02	nm	6.9	nc	<0.5	7.0	NAF
GCA5915	Prim.-010	EHGT006, 77.1-77.5	BIF	9.1	0.29	0.13	<0.01	0.13	1.5	58	-54	<0.5	6.7	NAF
GCA5916	Prim.-011	EGHT005, 115.6-115.76	BIF	9.2	0.51	0.14	<0.01	0.14	nm	10*	-5.7	<0.5	6.3	NAF
GCA5919	Prim.-014	EHH081, 85.55-85.75	BIF	9.0	0.15	0.02	nm	0.02	nm	2.4	nc	<0.5	6.2	NAF

Notes:
EC = Electrical Conductivity; ANC = Acid-Neutralisation Capacity; NAPP = Net-Acid-Producing Potential; AFP = Acid-Formation Potential; NAF = Non-Acid Forming; PAF = Potentially-Acid Forming; nm = not measured; nc = not calculated.
pH-(1:2) and EC-(1:2) values correspond to pH and EC measured on sample slurries prepared with deionised-water, and a solid:solution ratio of c. 1:2 (w/w).
ANC values labelled with an asterisk signify that green suspensions were produced as the pH~7 end-point was approached in the ANC testwork, and indicates dissolution of ferroan-carbonates/silicates
All results expressed on a dry-weight basis, except for pH-(1:2), EC-(1:2), and NAG pH
Values in parentheses represent duplicates.

Table 4.1: **Multi-Element-Analysis Results for Soil and Regolith Samples**

Note: Refer Appendix B for the definition of the Geochemical-Abundance-Index (GAI) indicated in this table.

ELEMENT	TOTAL-ELEMENT CONTENT (mg/kg or %)			AV.-CRUSTAL-ABUNDANCE (mg/kg or %)	GEOCHEMICAL-ABUNDANCE INDEX (GAI)		
	Topsoil (GCA5899)	Laterite (GCA5901)	Weathered-BIF (GCA5904)		Topsoil (GCA5899)	Laterite (GCA5901)	Weathered-BIF (GCA5904)
Al	7.1%	9.5%	2.1%	8.2%	0	0	0
Fe	21.0%	25.2%	36.1%	4.1%	2	2	3
Na	0.03%	0.16%	0.05%	2.3%	0	0	0
K	0.38%	0.20%	0.07%	2.1%	0	0	0
Mg	0.08%	0.20%	0.08%	2.3%	0	0	0
Ca	0.06%	0.26%	0.04%	4.1%	0	0	0
Ag	0.2	0.2	0.5	0.07	1	1	2
Cu	24	20	34	50	0	0	0
Zn	39	25	13	75	0	0	0
Cd	<0.1	<0.1	<0.1	0.11	0	0	0
Pb	22	27	11	14	0	0	0
Cr	540	340	140	100	2	1	0
Ni	56	50	14	80	0	0	0
Co	6.4	9.1	4.1	20	0	0	0
Mn	210	120	35	950	0	0	0
Hg	<0.01	<0.01	0.03	0.05	0	0	0
Sn	2.0	2.1	1.2	2.2	0	0	0
Sr	13	29	6.9	370	0	0	0
Ba	88	70	22	500	0	0	0
Th	20	30	2.8	12	0	1	0
U	2.2	3.2	0.9	2.4	0	0	0
Tl	0.24	0.21	0.05	0.6	0	0	0
V	230	170	39	160	0	0	0
As	24	18	21	1.5	3	3	3
Bi	0.35	0.28	0.13	0.048	2	2	1
Sb	3.2	2.8	3.6	0.2	3	3	4
Se	0.88	0.73	0.47	0.05	4	3	3
Mo	2.7	2.9	2.7	1.5	0	0	0
B	<50	<50	<50	10	0	0	0
P	270	120	240	1,000	0	0	0
F	120	140	96	950	0	0	0

Note: Average-crustal abundance of elements based on Bowen (1979).

Table 4.2: Multi-Element-Analysis Results for Waste-Bedrock Samples

Note: Refer Appendix B for the definition of the Geochemical-Abundance-Index (GAI) indicated in this table.

ELEMENT	TOTAL-ELEMENT CONTENT (mg/kg or %)					AVERAGE-CRUSTAL-ABUNDANCE (mg/kg or %)	GEOCHEMICAL-ABUNDANCE INDEX (GAI)				
	Magnetite-Chert (GCA5906)	Chert/Chlor.-Tuff (GCA5908)	Tuff (GCA5917)	BIF (GCA5914)	BIF (GCA5915)		Magnetite-Chert (GCA5906)	Chert/Chlor.-Tuff (GCA5908)	Tuff (GCA5917)	BIF (GCA5914)	BIF (GCA5915)
Al	1.1%	2.8%	7.4%	0.42%	1.0%	8.2%	0	0	0	0	0
Fe	25.9%	23.2%	1.8%	38.5%	41.1%	4.1%	2	2	0	3	3
Na	0.01%	0.02%	0.34%	0.20%	0.04%	2.3%	0	0	0	0	0
K	0.71%	0.09%	3.6%	0.10%	0.05%	2.1%	0	0	0	0	0
Mg	1.6%	2.0%	0.60%	0.58%	2.1%	2.3%	0	0	0	0	0
Ca	0.83%	0.23%	1.3%	0.09%	0.31%	4.1%	0	0	0	0	0
Ag	0.1	0.2	0.1	<0.1	0.1	0.07	0	1	0	0	0
Cu	9	110	8	8	20	50	0	1	0	0	0
Zn	64	40	23	35	23	75	0	0	0	0	0
Cd	0.4	<0.1	<0.1	<0.1	<0.1	0.11	1	0	0	0	0
Pb	4	9	9	<2	3	14	0	0	0	0	0
Cr	58	200	43	34	45	100	0	0	0	0	0
Ni	10	91	20	20	11	80	0	0	0	0	0
Co	3.2	22	4.9	4.5	4.1	20	0	0	0	0	0
Mn	760	2,100	290	910	2,900	950	0	1	0	0	1
Hg	<0.01	<0.01	<0.01	<0.01	0.05	0.05	0	0	0	0	0
Sn	0.6	1.7	1.6	0.4	0.4	2.2	0	0	0	0	0
Sr	32	5.8	27	22	4.5	370	0	0	0	0	0
Ba	69	17	460	14	25	500	0	0	0	0	0
Th	1.8	2.6	12	0.25	1.6	12	0	0	0	0	0
U	0.37	0.55	4.6	0.07	0.42	2.4	0	0	0	0	0
Tl	0.19	0.12	0.49	<0.02	0.04	0.6	0	0	0	0	0
V	5	44	32	<2	2	160	0	0	0	0	0
As	300	96	<1	19	10	1.5	6	5	0	3	2
Bi	0.18	0.15	0.09	0.04	0.07	0.048	1	1	0	0	0
Sb	12	3.1	0.50	34	4.4	0.2	5	3	1	6	4
Se	0.13	0.85	<0.01	<0.01	0.19	0.05	1	4	0	0	1
Mo	2.8	8.0	3.0	0.9	14	1.5	0	2	0	0	3
B	<50	<50	<50	<50	<50	10	0	0	0	0	0
P	530	640	310	660	680	1,000	0	0	0	0	0
F	140	200	250	87	150	950	0	0	0	0	0

Note: Average-crustal abundance of elements based on Bowen (1979).

Table 4.3: Mineralogical Results for Waste-Bedrock Samples

Chert/Chloritic-Tuff (GCA5908)		Tuff (GCA5917)		BIF (GCA5915)	
Component	**Abundance**	**Component**	**Abundance**	**Component**	**Abundance**
				quartz	dominant
quartz Fe-chlorite magnetite	major	quartz magnetite	major	muscovite	major
		Fe-chlorite hematitic	minor		
pyrite **siderite**	accessory	**siderite** goethite	accessory	**siderite** **calcite** Fe-chlorite feldspars	accessory
		pyrite	trace	clinozoisite titanite	trace

Notes:

major – 20-50 %, minor – 20-50 %; accessory – 2-10 %; and, trace – less than 2 %.

See mineralogical report in Appendix C for further information.

Table 5.1: Acid-Base-Analysis, Salinity and Net-Acid-Generation Results for Low-Grade-Ore Samples

GCA-SAMPLE NO.	SITE-SAMPLE NO.	DRILLHOLE & DOWN-HOLE INTERVAL (m)	LITHOTYPE	pH-(1:2)	EC-(1:2) [mS/cm]	TOTAL-S (%)	SO_4-S (%)	Sulphide-S (%)	CO_3-C (%)	ANC	NAPP	NAG	NAG-pH	AFP CATEGORY
										kg H_2SO_4/tonne				
GCA5921	lg-001	EHR026, 222.67-223.35	Carbonate-Zone	9.5	0.16	0.14	<0.01	0.14	0.16	12	-7.7	<0.5	7.2	NAF
GCA5922	lg-002	EHR066, 231.78-232.50	Chloritic-Tuff	9.7	0.15	0.10	nm	0.10	0.23	18 (18)	-14	<0.5	7.3	NAF
GCA5923	lg-003	EHR048, 189.50-190.50	Tuff	9.4	0.16	0.03	nm	0.03	nm	100*	nc	<0.5	8.6	NAF
GCA5924	lg-004	EHR048, 188.00-188.76	Chert	8.6	0.21	0.02	nm	0.02	nm	2.4	nc	<0.5 (1.1)	6.6 (6.3)	NAF

Notes
EC - Electrical Conductivity; ANC - Acid-Neutralisation Capacity; NAPP - Net-Acid-Producing Potential; AFP - Acid-Formation Potential; NAF - Non-Acid Forming;
nm - not measured, nc - not calculated.
pH-(1:2) and EC-(1:2) values correspond to pH and EC measured on sample slurries prepared with deionised-water, and a solid:solution ratio of c. 1:2 (w/w).
ANC values labelled with an asterisk signify that green-suspensions were produced as the pH-7 end-point was approached in the ANC testwork, and indicates dissolution of ferroan-carbonates/silicates.
All results expressed on a dry-weight basis, except for pH-(1:2), EC-(1:2), and NAG-pH.
Values in parentheses represent duplicates.

Table 5.2: Multi-Element-Analysis Results for Low-Grade-Ore Samples

Note: Refer Appendix B for the definition of the Geochemical-Abundance-Index (GAI) indicated in this table.

ELEMENT	TOTAL-ELEMENT CONTENT (mg/kg or %)		AVERAGE-CRUSTAL ABUNDANCE (mg/kg or %)	GEOCHEMICAL-ABUNDANCE INDEX (GAI)	
	Carbonate-Zone (GCA5921)	Chert (GCA5924)		Carbonate-Zone (GCA5921)	Chert (GCA5924)
Al	0.47%	0.15%	8.2%	0	0
Fe	32.7%	35.5%	4.1%	2	3
Na	0.01%	0.02%	2.3%	0	0
K	0.36%	0.03%	2.1%	0	0
Mg	0.72%	0.16%	2.3%	0	0
Ca	0.41%	0.06%	4.1%	0	0
Ag	<0.1	0.1	0.07	0	0
Cu	13	23	50	0	0
Zn	66	18	75	0	0
Cd	0.2	<0.1	0.11	0	0
Pb	10	4	14	0	0
Cr	62	51	100	0	0
Ni	21	46	80	0	0
Co	3.3	5.2	20	0	0
Mn	440	1,100	950	0	0
Hg	<0.01	0.21	0.05	0	1
Sn	0.5	0.3	2.2	0	0
Sr	18	3.4	370	0	0
Ba	48	5.2	500	0	0
Th	0.58	0.16	12	0	0
U	0.14	0.09	2.4	0	0
Tl	0.07	<0.02	0.6	0	0
V	4	<2	160	0	0
As	27	3	1.5	**4**	0
Bi	0.03	0.02	0.048	0	0
Sb	9.1	1.1	0.2	**5**	2
Se	0.04	0.69	0.05	0	**3**
Mo	4.6	4.3	1.5	1	1
B	<50	<50	10	0	0
P	370	340	1,000	0	0
F	96	78	950	0	0

Note: Average-crustal abundance of elements based on Bowen (1979).

Table 5.3: Mineralogical Results for Low-Grade-Ore Samples

Carbonate-Zone (GCA5921)		Chert (GCA5924)	
Component	Abundance	Component	Abundance
quartz magnetite	major	quartz hematite	major
biotite grunerite	accessory	magnetite goethite	accessory
pyrite arsenopyrite	trace		

Notes:

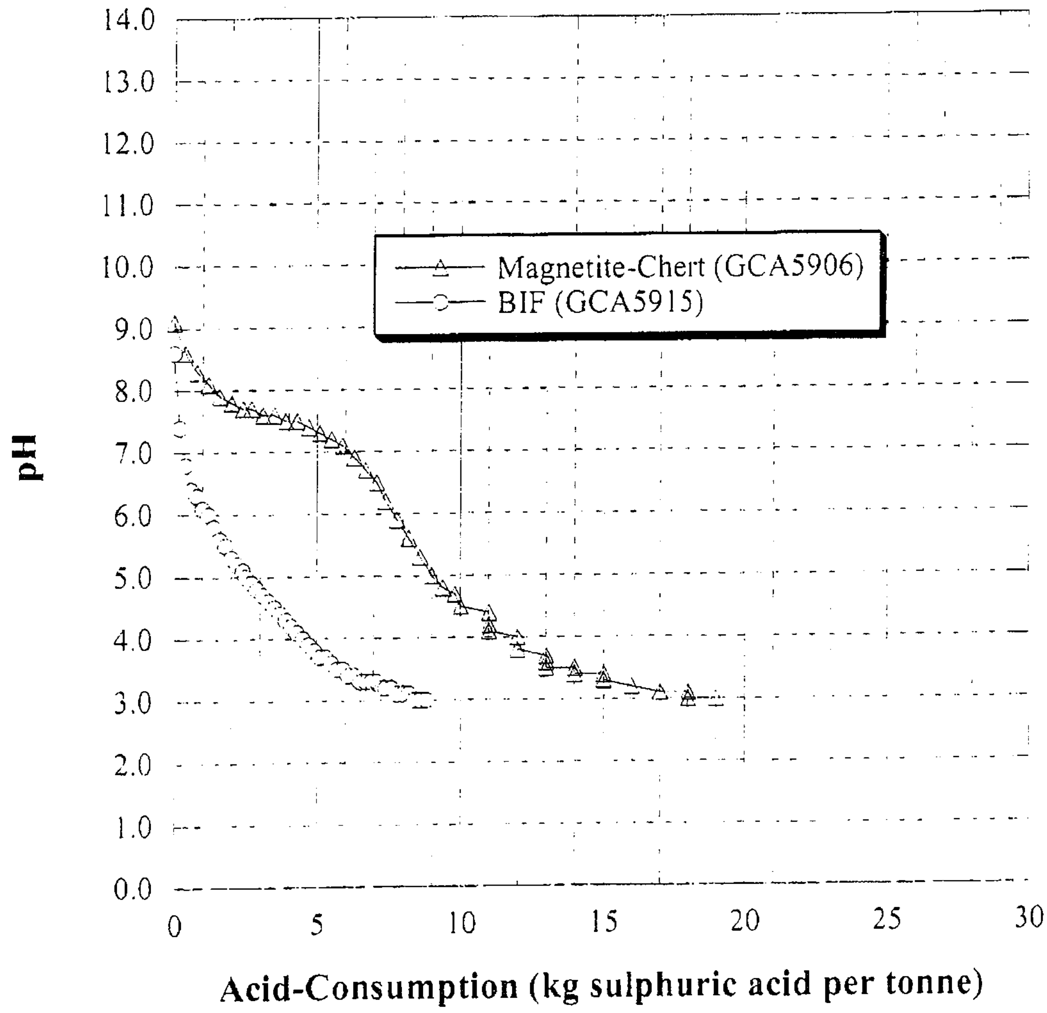
major = 20-50 %; accessory = 2-10 %; and, trace = less than 2 %.

See mineralogical report in Appendix C for further information.

FIGURE

Figure 1

pH-Buffering Curves for Waste-Bedrock Sampies



Note: The H_2SO_4-addition rates employed in the auto-titrations correspond to sulphide-oxidation rates (SORs) of *c.* 1-3 x 10^5 mg SO_4/kg.week (= *c.* 5-10 x 10^3 kg H_2SO_4 tonne year).

These SORs are therefore up to 10^4-10^5 **faster** than those typical for the weathering (at circum-neutral-pH) of mine-waste materials that contain "trace-sulphides".

APPENDIX A

DETAILS OF SAMPLING PROGRAMME

Acid Drainage Evaluation
Samples Submitted from Mount Gibson Extension Hill Project

Soil001 0.0 – 0.1m	
Soil002 0.1 – 0.2m	
Reg001 EHGT005 3.8 – 4.0m 2kg	Canga/Laterite Canga
Reg002 EHGT011 1.0 – 1.5m 2.0kg	Laterite, soil, hematite chips and clays.
Reg003 EHGT011 1.0 – 1.5m	Laterite soil
Weth001 EHGT012 17.5 – 17.9m	Pale yellow clays (after mafic?).
Weth002 EHGT009 17.0 – 17.25 1.9kg	Highly weathered mafic, foliated, possible zone of white sediment?
Weth003 EHGT005 20.15 – 20.3m 2.0kg	Highly weathered BIF.
Weth004 EHGT005 37.4 – 37.5m 1.9kg	Moderately to highly weathered BIF
Prim001 EHGT012 17.5 – 17.9m, 1.8kg	Magnetite Chert with schist (tuffaceous and chloritic).
LG01 - Prim002 EHR026 222.67 – 223.35 1.7kg	Carbonate rich zone. Ca rich magnetite silicate, contourted with Ca interstitial and in joints/fractures.
LG02 - Prim003 EHR066 231.78 – 232.50 1.7kg	Thick banded chert alternating with fine grained finely laminated tuff (chloritic tuff).
LG03 - Prim004 EHR048 189.50 – 190.50 2.1kg	Monotonous dark green tuff with few narrow bands 2cm wide bands of chert. Primarily tuff zone.
LG04 - Prim005 EHR048 188.0 – 188.76m 1.6kg	Thick banded chert with few thin banded magnetite. Primarily chert – low DTR recovery material.
Prim006 EHR003 99.55 – 99.80m 1.6kg	Weakly foliated mafic – basalt. Weakly to moderately weathered.
Prim007 EHGT005 64.8 – 65.0m 2.0kg	Moderately weathered (to highly weathered locally) BIF. Above transition zone.
Prim008 EHGT010 44.6 – 44.6m 2.0kg	Moderately weathered mafic (Dolerite).
Prim009 EHGT004 75.4 – 75.6m 2.0kg	Moderately weathered BIF. Banded magnetite chert with highly weathered chlorite? (epidote?) in joints.
Prim010 EHGT006 77.1 – 77.5m 1.5kg	BIF – Banded magnetite chert, weakly weathered with small broken 10cm wide of goethite rich BIF – transition zone.
Prim011 EGHT005 115.6 – 115.76m	Banded chert magnetite BIF – predominantly chert below foliated mafic/tuff interval.
Prim012 EHGT001 209.05 – 209.3m 2.0kg	Foliated mafic weakly carbonated. Possible tuff.
Prim013 EHGT003 190.30-190.50m 1.7kg	Dark green-grey black fine grained tuff? – possible sediment? Minor disseminated sulphide – pyrite.
Prim014 EHH081 85.55 – 85.75 1.8kg	Weakly weathered magnetite chert – BIF.
Prim015 EHGT003 133.85 – 137.05 1.6kg	Weakly carbonated foliated mafic or tuff.

APPENDIX B

TESTWORK METHODS

APPENDIX B

TESTWORK METHODS

B1.0 ACID-BASE-CHEMISTRY AND SALINITY TESTWORK

The acid-base chemistry and salinity of the soil, regolith, waste-bedrock and low-grade-ore samples was assessed by determining:

- pH and Electrical-Conductivity (EC) on sample slurries.
- Total-Sulphur (Total-S) and Sulphate-Sulphur (SO_4-S).
- Acid-Neutralisation-Capacity (ANC), Carbonate-Carbon (CO_3-C), and pH-Buffering properties.
- Net-Acid-Producing-Potential (NAPP).
- Net-Acid-Generation (NAG).

Relevant details of the testwork methods employed are discussed briefly below. Further details are presented in the laboratory reports (see Appendix C).

B1.1 pH-(1:2) and EC-(1:2) Tests

Measurements of pH and EC were performed on slurries prepared using deionised-water, and a solid:water ratio of *c.* 1:2 (w/w). The sample slurries were allowed to age in contact with the air for *c.* 24 hours, prior to measuring pH and EC.[1]

The resulting pH-(1:2) and EC-(1:2) values provide a measure of the inherent acidity/alkalinity and salinity of the samples.[2]

B1.2 Total-S and SO_4-S Tests

The Total-S values were measured by Leco combustion (@ 1300 °C) with detection of evolved $SO_{2(g)}$ by infra-red spectroscopy.

The SO_4-S values were determined by the Na_2CO_3-Extraction Method (Lenahan and Murray-Smith 1986).[3] The difference between the Total-S and SO_4-S values indicates the Sulphide-S (strictly Non-Sulphate-S) content.

B1.3 Acid-Consuming Properties

B1.3.1 ANC Tests

The ANC values of the samples were determined by a procedure based on that of Sobek *et al.* (1978). This procedure is essentially the "standard" method employed for

[1] The sample slurries were stirred at the beginning of the testwork, and once again immediately prior to measuring pH and EC.

[2] The pH-(1:2) values approximate the "Abrasion-pH" values employed for identifying minerals in the field (Stevens and Carron 1948).

[3] The Na_2CO_3-reagent extracts SO_4-S which occurs as soluble sulphates, and calcium sulphates (e.g. gypsum and anhydrite). It also extracts SO_4 sorbed to the surfaces of sesquioxides, clays and silicates. However, SO_4 present as barytes ($BaSO_4$) is not extracted, and SO_4 associated with jarositic-type and alunitic-type compounds are incompletely extracted.

estimating the ANC values of mine-waste materials (Morin and Hutt 1997; BC AMD Task Force 1989).

The samples were reacted with dilute HCl for *c.* 2 hours at 80-90 °C, followed by back-titration with NaOH to a pH=7 end-point to determine the amount of acid consumed.[4] The simmering step for *c.* 2 hours differs slightly from the heating treatment of the Sobek *et al.* procedure wherein the test mixtures are heated to near boiling until reaction is deemed to be complete (viz. gas evolution not visually apparent), followed by boiling for one minute. In terms of dissolution of carbonate, primary-silicate and oxyhydroxide minerals, this variation to the Sobek *et al.* method is inconsequential.

The Sobek *et al.* (1978) procedure exposes mine-waste samples to both strongly-acidic conditions (e.g. pH of 1-2), and a near-boiling temperature. Provided excess acid is added, this method ensures that carbonate-minerals (including ferroan and manganoan varieties) are dissolved quantitatively, and that at least traces of ferro-magnesian silicates (e.g. amphiboles, pyroxenes, chlorites, micas, etc.), and feldspars, are dissolved. However, under circum-neutral (viz. pH 6-8) conditions required for mine-waste and environmental management, the dissolution of ferro-magnesian silicates is kinetically extremely slow (e.g. see review-monograph by White and Brantley [1995]). Near pH=7, the dissolution rates (under 'steady-state' conditions, and in the absence of inhibiting alteration-rims) of mafic-silicates and feldspars generally correspond to H_2SO_4-consumption rates 'of-the-order' 10^{-11} 10^{-12} moles/m^2/s (White and Brantley 1995). As a guide, for minerals of sub-mm grading, such silicate-dissolution rates correspond to Sulphide-Oxidation Rates (SORs) ranging up to 'of-the-order' 1-10 mg

[4] Two drops of 30 % (w/w) H_2O_2 were added to the test mixtures as the pH=7 end-point was approached, so that any Fe(II) forms released by the acid-attack of ferroan-carbonates and -silicates are oxidised to Fe(III) forms (which then hydrolyse to "$Fe(OH)_3$"). This step ensures that the resulting ANC values are not unduly biased "on-the-high-side", due to the release of Fe(II) during the acidification digestion step. Such potential bias in ANC values may be marked for mine-waste samples in which "Fe-rich" ferroan-carbonates (e.g. siderite) dominate acid consumption. The addition of the H_2O_2 reagent is <u>not</u> part of the methodology described by Sobek *et al.* (1978).

SO_4/kg/week (= *c.* 0.1-1.0 kg H_2SO_4/tonne/year).[5] Maintenance of circum-neutral-pH through dissolution/hydrolysis of primary-silicates is therefore restricted to both "mineral-fines", and slow rates of pyrite weathering.

Despite the aggressive-digestion conditions employed, the ANC values determined by the Sobek *et al.* (1978) method allow an informed, initial "screening" of mine-waste materials in terms of acid-consuming and pH-buffering properties, especially when due account is taken of gangue mineralogy (Morin and Hutt 1997). Jambor *et al.* (2000, 2002) have presented a compendium of 'Sobek-ANC' values for specific classes of primary-silicates, and assists interpretation of the ANC values recorded for mine-waste materials of varying mineralogy.

B1.3.2 CO_3-C Values

The CO_3-C value is the difference between the Total-C and Total-Organic-C (TOC) values.

The Total-C was measured by Leco combustion (@ 1300 °C) with detection of evolved $CO_{2(g)}$ by infra-red spectroscopy. The TOC was determined by Leco combustion on a sub-sample which had been treated with strong HCl to decompose carbonate-minerals.

Calcite was the only carbonate-mineral identified in the waste-bedrock samples characterised in the mineralogical study (Table 4.5).

B1.3.3 pH-Buffering Properties

The pH-Buffering properties of selected samples were determined via a Metrohm® 736 Titrino auto-titrator, and 0.05 M-H_2SO_4.

[5] SORs of this magnitude (at circum-neutral-pH) would typically only be recorded for the oxidation of "trace-sulphides" (e.g. Sulphide-S contents less than 0.5 %).

The auto-titrations comprised regular addition of the H_2SO_4 reagent to monotonically decrease the pH values of the test-suspensions to 3.0.[6] The Start-pH values of the suspensions were *c.* 8-9. Under the testwork conditions employed, the H_2SO_4-addition rates correspond to SORs ranging up to 'of-the-order' 10^5 mg SO_4/kg/week (i.e. 'of-the-order' 10^4 kg H_2SO_4/tonne/year) , and so represent <u>very-rapid rates of acid addition</u>.

Further details of the auto-titrations are presented in the laboratory reports (Appendix C).

B1.4 NAPP Calculations

The NAPP values of the samples were calculated from the Total-S, SO_4-S and ANC values, assuming that <u>**all**</u> of the Non-Sulphate-S occurs in the form of pyrite.[7] NAPP calculations serve as a starting point in the assessment of the acid-formation potential of sulphide-bearing materials.

The complete oxidation of pyrite may be described by:

$$FeS_2 + 15/4\ O_2 + 7/2\ H_2O = 2SO_4^{2-} + 4H^+ + \text{"}Fe(OH)_3\text{"}$$

It may be shown that, if the Sulphide-S (in %S) occurs as pyrite, then the amount of acid (in kg H_2SO_4/tonne) produced through complete-oxidation is given by <u>**30.6 x %S**</u>.

<u>Note</u>: The above treatment of oxidation-reaction stoichiometry is restricted to oxidation by 'atmospheric-O_2' which is the dominant oxidant at circum-neutral-pH. A different

[6] It should be noted that, in titrating to a pH=3.0 end-point, any Fe(II) released through acid attack of ferroan-silicates and -carbonates is <u>not</u> quantitatively oxidised to Fe(III). Furthermore, under the conditions employed in the auto-titration, the equivalent of *c.* 0.5 kg H_2SO_4/tonne was required to decrease the pH of the "solution-only" (i.e. without waste-rock sample) to pH=3.0. <u>No</u> correction was made for such "electrolyte-consumption" of the 0.05 M-H_2SO_4 titrant.

[7] The sulphide-mineral suite in the waste-bedrock samples was generally characterised by a co-dominance of pyrite, and pyrrhotite (Table 4.5).

oxidation-stoichiometry applies under acidic conditions (e.g. pH less than 3-4) where soluble-Fe(III) forms prevail, and then function as the chief oxidant.

B1.5 NAG Tests

The NAG Test is a direct measure of a sample's potential to produce acid through sulphide oxidation, and also provides an indication of the reactivity of the sulphides, and the availability of the alkalinity-forms contributing to the ANC (AMIRA 2002; Miller *et al.* 1997, 1994).

In this test, the sample is reacted with H_2O_2 to rapidly oxidise contained sulphides, and allow the produced acid to react with the acid-neutralising materials (e.g. carbonates). The NAG Test supplements the NAPP-based assessment of the acid-formation potential of mine-waste materials (Morin and Hutt 1997).

The procedure employed in this study is based on that for the 'Static-NAG Test' (AMIRA 2002; Miller *et al.* 1994, 1997). The Start-pH of the 15 % (w/w) H_2O_2 solution (prepared from A.R.-grade H_2O_2) was adjusted to pH=4.5 using dilute NaOH. In addition, the boiling treatment to decompose residual, unreacted-H_2O_2 following overnight reaction was carried out in two stages (viz. boiling for *c.* 2 hours initially, cooling and addition of 1 mL of 0.02 M-$CuSO_4$ to the test mixtures, followed by boiling again for *c.* 2 hours). The addition of Cu(II) salts catalyses the decomposition of residual H_2O_2, and thereby prevents "positive-blank" values being obtained (O'Shay *et al.* 1990).[8] Pulped K-feldspar was employed for the blanks run for the NAG testwork.

Prior to the boiling steps, the pH values of the test-mixture suspensions are measured, and invariably correspond to an "overnight-period" of reaction. Such pH values reflect buffering under ambient conditions without accelerated dissolution of gangue-phases through boiling to decompose any unreacted-H_2O_2. In the interpretation of NAG-testwork data, it is important to take note of the pH values recorded prior to the boiling steps, especially for mine-waste samples that have both Sulphide-S contents less than 1 %, and ANC values less than *c.* 10 kg H_2SO_4/tonne (as typically recorded for a felsic/mafic-gangue that is void of carbonates). Furthermore, oxidation by H_2O_2 is generally at least 10^3 faster than the SORs recorded during 'kinetic' testing (e.g. Weathering-Columns) of mine-waste samples. If circum-neutral conditions are to prevail during NAG testwork, then the rate of acid consumption by gangue-phases must be proportionately faster (c.f. rates for 'ambient-weathering'), and is essentially restricted to pH-Buffering by carbonates (viz. calcites, dolomites and ankerites) that are not unduly ferroan. This aspect must also be borne in mind when interpreting NAG-testwork data, especially for mine-waste materials that contain "trace-sulphides" in a carbonate-void gangue, since the dissolution/hydrolysis kinetics of primary-silicates (both felsic- and mafic-silicates) are strongly pH-dependent.

B2.0 MULTI-ELEMENT ANALYSES

The total content of a wide range of major- and minor-elements in selected samples was determined through the use of various digestion and analytical techniques. The detection-limits employed in these analyses are appropriate for environmental investigations.

Element enrichments were identified using the *Geochemical Abundance Index (GAI)*.[9]

The GAI quantifies an assay result for a particular element in terms of the average-crustal-abundance of that element.[10]

[8] Where mine-waste samples contain sufficient Cu, then Cu(II) forms will be released to solution during the NAG Test, especially at low pH.

[9] The GAI was developed by Förstner *et al* (1993), and is defined as.

$$GAI = \log_2 [C_n / (1.5 \times B_n)]$$

where:

C_n = measured content of n-th element in the sample

B_n = "background" content of the n-th element in the sample.

The GAI (based on a log-2 scale) is expressed in 7 integer increments (viz. 0 to 6). A GAI of 0 indicates that the content of the element is less than, or similar to, the average-crustal-abundance; a GAI of 3 corresponds to a 12-fold enrichment above the average-crustal-abundance; and so forth, up to a GAI of 6 which corresponds to a 96-fold, or greater, enrichment above average-crustal-abundances.

[10] The average-crustal-abundances of the elements for the GAI calculations are based on the values listed in Bowen (1979).

APPENDIX C

LABORATORY REPORTS

Roger Townend and Associates

Consulting Mineralogists

GRAEME CAMPBELL AND ASSOC, 7-11-2005

PO BOX 247,

BRIDGETOWN

WA

OUR REF. 21469

YOUR REF. 0503/1

XRD/PLM/SEM ANALYSIS OF FIVE SAMPLES

(EXTENSION HILL)

R TOWNEND

Correspondence to Box 3129, Malaga D.C WA 6945
ACN 069 920 476 ABN 92 076 109 663

<CAMPBELL

No <214469

RESULTS. XRD/PLM/SEM

GCA	5908	5915	5917	5921	5924
QUARTZ	MAJOR	MAJOR	DOMINANT	MAJOR	MAJOR
FE CHLORITE	MAJOR	MINOR	ACCESSORY		
SIDERITE	ACCESS.	ACCESS.	ACCESS.		
CALCITE			ACCESSORY		
MUSCOVITE			MAJOR		
BIOTITE				ACCESS.	
CLINOZOISITE			TRACE		
FELDSPARS			ACCESSORY		
GRUNERITE				ACCESS.	.
TITANITE			TRACE		
MAGNETITE	MAJOR	MAJOR		MAJOR	ACCESS.
HEMATITE		MINOR			MAJOR
GOETHITE		ACCESS.			ACCESS.
PYRITE	ACCESS.	TRACE		TRACE	
ARSENOPYRITE				TRACE	

The siderite in GCA 5915 composition was 8.7% MgO, <0.5% CaO, 3.8% MnO, and 47.3% FeO. The pyrite is fresh.

Roger Townend and Associates

SGS

16 September, 2005

Graeme Campbell & Associates Pty Ltd
Attn: Dr G Campbell
PO Box 247
BRIDGETOWN WA 6255

Our Reference: 91040
Your Reference: GCA0503/1
NATA Accreditation: 2562(1705)

Dear Sir,

On the 22nd August 2005, you forwarded test work instructions for twenty-seven (27) mine waste samples that were received that day at our laboratory. As per your instructions samples were crushed and pulped. Approximately 100 grams of pulps were sent to Graeme Campbell and Associates.

Results of all test work performed follow:

Sample Number	pH (1:2) (pH Units)	Conductivity (1:2) (µs/cm)	Total Sulphur (%w/w)	Sulphate Sulphur, SO_4-S (Na_2CO_3)
GCA5898	4.7	150	0.033	NA
GCA5899	4.7	230	0.028	NA
GCA5900	6.9	920	0.045	NA
GCA5901	8.0	790	0.009	NA
GCA5902	7.6	1900	0.017	NA
GCA5903	7.7	1300	0.020	NA
GCA5904	7.3	700	0.021	NA
GCA5905	7.4	440	0.024	NA
GCA5906	9.0	200	0.18	<0.01
GCA5907	9.1	370	0.52	<0.01
Rpt GCA5907	9.0	360	-	-
GCA5908	8.7	290	1.78	0.01
GCA5909	8.8	220	0.036	NA
GCA5910	9.1	210	0.023	NA
GCA5911	8.6	420	0.026	NA
GCA5912	7.9	200	0.019	NA
GCA5913	8.5	530	0.028	NA
GCA5914	8.2	760	0.020	NA
GCA5915	9.1	290	0.13	<0.01
GCA5916	9.2	510	0.14	<0.01
GCA5917	9.6	180	0.007	NA
Rpt GCA5917	9.5	180	-	NA
GCA5918	9.8	310	0.17	<0.01
GCA5919	9.0	150	0.017	NA
GCA5920	9.6	190	0.020	NA
GCA5921	9.5	160	0.14	<0.01
GCA5922	9.7	150	0.098	NA
GCA5923	9.4	160	0.030	NA

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CLIENT: Graeme Campbell & Associates Pty Ltd **OUR REFERENCE: 91040**
PROJECT NO: GCA0503/1

Sample Number	pH (1:2) (pH Units)	Conductivity (1:2) (µs/cm)	Total Sulphur (%w/w)	Sulphate Sulphur, SO_4-S (Na_2CO_3)
GCA5924	8.6	210	0.020	NA

NOTES:

1. *Total sulphur was determined on dried pulped sample by LECO induction furnace, IR detection, and is reported on that basis. This test work was performed by SGS Minerals Services, Welshpool, report number WM088186 (NATA1936).*
2. *pH and conductivity were determined on a 1:2 w/w as received sample to deionised water extract after 24 hours ambient aging.*
3. *Sulphate sulphur was determined on an as received sample by Na_2CO_3 extraction, $BaSO_4$ precipitation with results reported back to the 105°C dried sample basis.*

Acid Neutralisation Capacity (ANC):

Sample Number	Fizz Rating	Sample Weight (g)	Titre NaOH (mL)	Normality HCl/NaOH (N)	Initial Effervescence	Effervescence on Warming	ANC Solution pH	ANC (kg H_2SO_4/tonne)
GCA5898	0	4.9818	24.70	0.1N	Nil	Nil	1.3	0.5
GCA5899	0	5.0079	24.40	0.1N	Nil	Nil	1.3	0.8
GCA5900	0	4.9709	23.00	0.1N	Nil	Nil	1.3	2.1
GCA5901	0	4.9501	17.50	0.1N	Nil	Nil	1.5	7.6
GCA5902	0	4.9231	24.70	0.5N	Nil	Nil	1.2	0.5
Rpt GCA5902	0	5.0972	24.60	0.5N	Nil	Nil	1.3	0.6
GCA5903	0	4.9790	24.10	0.1N	Nil	Nil	1.3	1.1
GCA5904	0	4.9155	23.80	0.1N	Nil	Nil	1.4	1.4
GCA5905	0	5.0532	24.10	0.1N	Nil	Nil	1.3	1.1
GCA5906	3	2.1674	21.30	0.5N	Moderate	Nil	0.9	43*
GCA5907	3	1.0813	15.10	1N	Moderate	Nil	0.7	450*
Rpt GCA5907	3	1.1647	14.50	1N	Moderate	Nil	0.7	440*
GCA5908	0	2.0427	20.20	0.1N	Slight	Nil	2.0	11*
GCA5909	0	4.9866	19.00	0.1N	Nil	Nil	2.1	6.0
GCA5910	0	5.1016	21.00	0.1N	Nil	Nil	1.5	4.0
GCA5911	0	5.0388	14.20	0.1N	Nil	Nil	1.8	10
GCA5912	0	5.0383	24.20	0.1N	Nil	Nil	1.4	1.0
Rpt GCA5912	0	5.0559	24.10	0.1N	Nil	Nil	1.4	1.1
GCA5913	0	5.1350	18.60	0.1N	Nil	Nil	1.5	6.2
GCA5914	0	4.9093	18.20	0.1N	Nil	Nil	1.6	6.9
GCA5915	1	2.0173	20.30	0.5N	Moderate	Nil	1.0	58
GCA5916	0	2.0953	20.70	0.1N	Nil	Nil	1.6	10*
GCA5917	2	2.3835	18.50	0.1N	Slight	Nil	1.5	13
Rpt GCA5917	2	2.1548	18.70	0.1N	Slight	Nil	1.5	14
GCA5918	1	2.0264	18.20	0.1N	Nil	Nil	2.0	16
GCA5919	0	4.9936	22.70	0.1N	Nil	Nil	1.4	2.4
GCA5920	1	5.0507	16.50	0.1N	Nil	Nil	2.1	8.4
GCA5921	2	2.2105	19.40	0.1N	Slight	Nil	1.5	12
GCA5922	2	2.2126	17.00	0.1N	Slight	Nil	1.7	18
Rpt GCA5922	2	2.0760	17.20	0.1N	Slight	Nil	1.7	18

SGS

CLIENT: Graeme Campbell & Associates Pty Ltd **OUR REFERENCE: 91040**
PROJECT NO: GCA0503/1

Sample Number	Fizz Rating	Sample Weight (g)	Titre NaOH (mL)	Normality HCl/NaOH (N)	Initial Effervescence	Effervescence on Warming	ANC Solution pH	ANC (kg H_2SO_4/tonne)
GCA5923	2	2.1148	15.80	0.5N	Moderate	Nil	0.9	100*
GCA5924	0	4.8557	22.80	0.1N	Nil	Nil	1.4	2.4
Std20	-	2.0715	16.30	0.1N	-	-	1.5	20.9
Std200	-	1.2756	15.20	0.5N	-	-	0.9	189.4

NOTES:

1. *Acid neutralisation capacity was determined on the nominal 2mm crushed sample. Unless otherwise stated, 25mL of HCl is used. Reagent blank titre of 0.1N NaOH was 25.20mL.*
2. **Indicates the appearance of a green colouration as the pH=7 endpoint was approached. Two drops of hydrogen peroxide are added to each sample as the pH =7 endpoint is approached to oxidise any ferrous iron.*
3. *ANC Std20and Std200 are internally produced standards of $CaCO_3$ and quartz pulped to a nominal 75µm particle size which have nominal ANC of 20kg and 200kg H_2SO_4/tonne, respectively.*
4. *This procedure is based on Sobek et al, 1978.*

Yours faithfully,

Steven Edmett.

STEVEN EDMETT
Project Manager

J. Venning

JANICE VENNING
Manager, Perth

This report supersedes our preliminary results sent by facsimile on the 14th September 2005.

NATA Endorsed Test Report

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NATA Accredited Laboratory No 2562

SGS

5 October, 2005

Graeme Campbell & Associates Pty Ltd
Attn: Dr G Campbell
PO Box 247
BRIDGETOWN WA 6255

Our Reference: 91040A
Your Reference: GCA0503/1
NATA Accreditation: 2562(1705)

Dear Sir

On the 20th of September 2005 you forwarded testwork instructions for additional analysis on six (6) mine waste samples which were received on 23rd of August at our laboratory.

Results of all testwork performed follow:

Sample Number	Total Carbon (% w/w)	Total Organic Carbon (% w/w)	Carbonate Carbon CO_3-C (% w/w)
GCA5906	0.29	<0.05	0.29
GCA5907	7.94	0.25	7.69
GCA5915	1.57	0.07	1.50
GCA5917	0.19	<0.05	0.19
GCA5921	0.16	<0.05	0.16
GCA5922	0.23	<0.05	0.23

NOTES:

1. *Total carbon and total organic carbon (noncarbonate or acid insoluble carbon) were determined on dried pulped sample by LECO induction furnace. IR detection, and is reported on that basis. This test work was performed by SGS Minerals Services, Welshpool, report number WM088827 (NATA1936).*
2. *Carbonate-Carbon is determined as the difference between Total Carbon and Total Organic Carbon where Total Organic Carbon is acid insoluble Carbon (theoretically non-Carbonate-Carbon).*

Yours faithfully,

Steven Edmett.

STEVEN EDMETT
Project Manager

J.Venning

JANICE VENNING
Manager, Perth

This report supersedes our preliminary results sent by facsimile on the 3rd of October 2005.

NATA Endorsed Test Report

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NATA Accredited Laboratory No 2562

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NET-ACID-GENERATION (NAG) TESTWORK

Sample Number	Sample Weight (g)	Comments	pH of Test Mixture Before Boiling Step	Test Mixture After Boiling Step		Titre [0.1 M-NaOH] (mL)	NAG (kg H_2SO_4/ tonne)
				pH	EC (µS/cm)		
GCA5898	5.5		4.7	6.7	300	-	<0.5
GCA5899	5.8		4.6	6.7	330	-	<0.5
GCA5900	6.1		5.6	6.8	320	-	<0.5
GCA5901	6.5		6.3	7.3	340	-	<0.5
GCA5902	4.2		5.2	7.0	280	-	<0.5
GCA5903	4.5		4.7	6.9	310	-	<0.5
GCA5904	6.7		4.7	6.7	260	-	<0.5
GCA5905	6.2		4.7	6.5	270	1.50	1.2
GCA5906	5.6		5.8	6.8	380	-	<0.5
GCA5907	6.3	Reaction peaked overnight	6.8	6.9	660	-	<0.5
GCA5908	6.4	Reaction peaked within 2 hrs	2.1	2.6	1,700	32.10	25
GCA5909	7.6	Reaction peaked overnight	6.3	7.3	300	-	<0.5
GCA5910	7.6		5.2	7.1	300	-	<0.5
GCA5911	5.7		6.5	6.9	320	-	<0.5
GCA5912	5.6		4.7	6.7	260	-	<0.5

Sample Number	Sample Weight (g)	Comments	pH of Test Mixture Before Boiling Step	Test Mixture After Boiling Step		Titre [0.1 M-NaOH] (mL)	NAG (kg H_2SO_4/ tonne)
				pH	EC (µS/cm)		
GCA5913	7.1		5.4	6.8	320	-	<0.5
GCA5914	6.6		5.6	7.0	330	-	<0.5
GCA5915	7.2	Reaction peaked overnight	5.3	6.7	380	-	<0.5
GCA5916	5.7		3.9	6.3	320	1.20	1.1
GCA5917	6.6		6.2	7.8	290	-	<0.5
GCA5918	5.4		5.9	6.6	380	-	<0.5
GCA5919	8.1	Reaction peaked overnight	5.5	6.2	270	1.50	1.0
GCA5920	8.8		6.2	7.4	310	-	<0.5
GCA5921	6.6		5.9	7.2	330	-	<0.5
GCA5922	6.5	Reaction peaked overnight	6.3	7.3	360	-	<0.5
GCA5923	6.4		6.8	8.6	290	-	<0.5
GCA5924	7.0		5.7	6.6	260	-	<0.5
GCA5924 (Repeat)	5.4		5.5	6.3	230	1.20	1.1
Blank	6.1		5.4	7.2	500	-	<0.5

Notes: Test conditions based on those described by Miller *et al.* (1997). The pH of the 15 % (v/v) H_2O_2 solution was adjusted to 4.5 using 0.1 M-NaOH prior to commencing the NAG Tests. Test mixtures boiled for *c.* 2 hours to accelerate reaction with H_2O_2. Then, after allowing the test mixtures to cool, 1.0 mL of 0.016 M-$CuSO_4$ solution was added, and the test mixtures again boiled for *c.* 2 hours. The addition of Cu(II) catalyses the decomposition of any residual, unreacted H_2O_2 in the test mixtures (O'Shay *et al.* 1990).
K-Feldspar was employed for the Blank. Note that Blank-EC is elevated, due to NaOH added to an "acidic" batch of H_2O_2 reagent.

Dr GD Campbell
24th September 2005

Graeme Campbell & Associates Pty Ltd

Laboratory Report

pH-BUFFERING TESTWORK (GCA5906)

Cumulative Volume of Acid Added (mL)	Cumulative Acid Consumption (kg H_2SO_4/tonne)	pH	Cumulative Volume of Acid Added (mL)	Cumulative Acid Consumption (kg H_2SO_4/tonne)	pH
0.00	0.0	9.1	14.40	14	3.4
0.40	0.4	8.6	14.80	15	3.4
0.80	0.8	8.3	15.20	15	3.3
1.20	1.2	8.1	15.60	15	3.3
1.60	1.6	7.9	16.00	16	3.2
2.00	2.0	7.8	16.40	16	3.2
2.40	2.4	7.7	16.80	16	3.2
2.80	2.7	7.7	17.20	17	3.1
3.20	3.1	7.6	17.60	17	3.1
3.60	3.5	7.6	18.00	18	3.1
4.00	3.9	7.5	18.40	18	3.0
4.40	4.3	7.5	18.80	18	3.0
4.80	4.7	7.4	19.20	19	3.0
5.20	5.1	7.3			
5.60	5.5	7.2			
6.00	5.9	7.1			
6.40	6.3	6.9			
6.80	6.7	6.7			
7.20	7.1	6.5			
7.60	7.4	6.2			
8.00	7.8	5.9			
8.40	8.2	5.6			
8.80	8.6	5.3			
9.20	9.0	5.0			
9.60	9.4	4.8			
10.00	9.8	4.7			
10.40	10	4.5			
10.80	11	4.4			
11.20	11	4.2			
11.60	11	4.1			
12.00	12	4.0			
12.40	12	3.8			
12.80	13	3.7			
13.20	13	3.6			
13.60	13	3.5			
14.00	14	3.5			

Note: Titration performed using a Metrohm® 736 Titrino auto-titrator, and 0.05 M-H_2SO_4. Equilibration time between titrant additions was 15 minutes. 5.0 g of pulped-rock initially dispersed in 150 mL of deionised-water

Test mixture in contact with air, at ambient temperature, and continuously stirred.

<u>Calibration of pH-Glass Electrode</u>:

Immediately prior to titration: asymmetry potential = -20 mV (pH=7.00); slope-point = 154 mV (pH=4.00); 98.3 % of Nernstian response for 25 °C

Immediately following titration: pH=7.00 buffer read pH=7.03 and pH=4.00 buffer read pH=4.02. These discrepancies represent drift in pH-Glass electrode response during course of auto-titration.

Dr GD Campbell **19th September 2005**

Graeme Campbell & Associates Pty Ltd

Laboratory Report

pH-BUFFERING TESTWORK (GCA5915)

Cumulative Volume of Acid Added (mL)	Cumulative Acid Consumption (kg H_2SO_4/tonne)	pH	Cumulative Volume of Acid Added (mL)	Cumulative Acid Consumption (kg H_2SO_4/tonne)	pH
0.00	0.0	8.6	14.40	7.1	3.3
0.40	0.2	7.4	14.80	7.3	3.2
0.80	0.4	6.8	15.20	7.4	3.2
1.20	0.6	6.4	15.60	7.6	3.2
1.60	0.8	6.3	16.00	7.8	3.1
2.00	1.0	6.1	16.40	8.0	3.1
2.40	1.2	6.0	16.80	8.2	3.1
2.80	1.4	5.8	17.20	8.4	3.0
3.20	1.6	5.6	17.60	8.6	3.0
3.60	1.8	5.5	18.00	8.8	3.0
4.00	2.0	5.3			
4.40	2.2	5.2			
4.80	2.4	5.1			
5.20	2.5	5.0			
5.60	2.7	4.9			
6.00	2.9	4.8			
6.40	3.1	4.7			
6.80	3.3	4.6			
7.20	3.5	4.5			
7.60	3.7	4.4			
8.00	3.9	4.3			
8.40	4.1	4.2			
8.80	4.3	4.1			
9.20	4.5	4.0			
9.60	4.7	3.9			
10.00	4.9	3.8			
10.40	5.1	3.7			
10.80	5.3	3.7			
11.20	5.5	3.6			
11.60	5.7	3.5			
12.00	5.9	3.5			
12.40	6.1	3.4			
12.80	6.3	3.4			
13.20	6.5	3.3			
13.60	6.7	3.3			
14.00	6.9	3.3			

Note: Titration performed using a Metrohm® 736 Titrino auto-titrator, and 0.05 M-H_2SO_4. Equilibration time between titrant additions was 15 minutes. 10.0 g of pulped-rock initially dispersed in 150 mL of deionised-water.
Test mixture in contact with air, at ambient temperature, and continuously stirred.
Calibration of pH-Glass Electrode:
Immediately prior to titration: asymmetry potential = -19 mV (pH=7.00); slope-point = 155 mV (pH=4.00); 98.6 % of Nernstian response for 25 °C
Immediately following titration: pH=7.00 buffer read pH=7.03 and pH=4.00 buffer read pH=4.02. These discrepancies represent drift in pH-Glass electrode response during course of auto-titration

Dr GD Campbell
24th September 2005

ANALYTICAL REPORT

Dr G. CAMPBELL
CAMPBELL, GRAEME and ASSOCIATES
PO Box 247
BRIDGETOWN, W.A. 6255
AUSTRALIA

JOB INFORMATION

JOB CODE	143.0/0508686
No. of SAMPLES	10
No. of ELEMENTS	32
CLIENT O/N	GCA0503/1
SAMPLE SUBMISSION No	
PROJECT	Extension Hill Iron-Ore Project
STATE	Solid
DATE RECEIVED	06/10/2005
DATE COMPLETED	01/11/2005
DATE PRINTED	01/11/2005

LEGEND

X	= Less than Detection Limit
N/R	= Sample Not Received
*	= Result Checked
( )	= Result still to come
I/S	= Insufficient Sample for Analysis
E6	= Result X 1,000,000
UA	= Unable to Assay
>	= Value beyond Limit of Method

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SAMPLE DETAILS

DISCLAIMER

Genalysis Laboratory Services Pty Ltd wishes to make the following disclaimer pertaining to the accompanying analytical results.

Genalysis Laboratory Services Pty Ltd disclaims any liability, legal or otherwise, for any inferences implied from this report relating to either the origin of, or the sampling technique employed in the collection of, the submitted samples.

SIGNIFICANT FIGURES

It is common practice to report data derived from analytical instrumentation to a maximum of two or three significant figures. Some data reported herein may show more figures than this. The reporting of more than two or three figures in no way implies that the third, fourth and subsequent figures may be real or significant.

Genalysis Laboratory Services Pty Ltd accepts no responsibility whatsoever for any interpretation by any party of any data where more than two or three significant figures have been reported.

SAMPLE STORAGE DETAILS

GENERAL CONDITIONS

SAMPLE STORAGE OF SOLIDS

Bulk Residues and Pulps will be stored for 60 DAYS without charge. After this time all Bulk Residues and Pulps will be stored at a rate of $1.95 per cubic metre per day until your written advice regarding collection or disposal is received. Expenses related to the return or disposal of samples will be charged to you at cost. Current disposal cost is charged at $50.00 per cubic metre.

SAMPLE STORAGE OF SOLUTIONS

Samples received as liquids, waters or solutions will be held for 60 DAYS free of charge then disposed of, unless written advice for return or collection is received

NOTES

*** NATA ENDORSED DOCUMENT ****

Company Accreditation Number 3244

The contents of this report have been prepared in accordance with the terms of NATA accreditation and as such should only be reproduced in full.

The analysis results reported herein have been obtained using the following methods and conditions:

The 10 samples, as listed on the report, were received as being waste rocks.

The samples required drying at 45 degrees Celcius prior to being fine pulverised in a zirconia bowl.

The results have been determined according to Genalysis methods codes : SL_W001 (A/), SL_W007 (BP/), ENV_W012 (DH/SIE), SL_W013 (D/) and SL_W012 (CM/) for the digests and ICP_W004 (/OES), ICP_W005 (/MS) and AAS_W004 (/CVAP).

The results included the assay of blanks and international reference standard SARM-1 and SO-2 and Genalysis in-house standards TKC4, AE12 and HgSTD-4.

The results are expressed as parts per million or percent by mass in the dried and prepared material.

NATA Signatory: T K Chan
Chief Chemist

Date 1st November 2005

ANALYSIS

ELEMENTS	Ag	Al	As	B	Ba	Bi	Ca	Cd	Co	Cr
UNITS	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
DETECTION	0.1	0.02	1	50	0.1	0.01	10	0.1	0.1	2
DIGEST	A/	D/	A/	D/	A/	A/	A/	A/	A/	A/
ANALYTICAL FINISH	MS	OES	MS	OES	MS	MS	OES	MS	MS	OES
SAMPLE NUMBERS										
0001 GCA5899	0.2	7.10	24	X	87.2	0.35	599	X	6.4	532
0002 GCA5901	0.2	9.45	18	X	69.5	0.28	2573	X	9.1	338
0003 GCA5904	0.5	2.07	21	X	21.5	0.13	312	X	4.1	132
0004 GCA5906	0.1	1.09	292	X	68.5	0.18	8283	0.4	3.2	58
0005 GCA5908	0.2	2.73	96	X	16.8	0.15	2291	X	21.5	191
0006 GCA5914	X	0.42	19	X	13.7	0.04	835	X	4.5	34
0007 GCA5915	0.1	1.00	10	X	24.2	0.07	3077	X	4.1	45
0008 GCA5917	0.1	7.35	X	X	455.9	0.09	1.26%	X	4.9	43
0009 GCA5921	X	0.47	27	X	47.6	0.03	4061	0.2	3.3	62
0010 GCA5924	0.1	0.15	3	X	5.2	0.02	549	X	5.2	51
CHECKS										
0001 GCA5899	0.2	6.85	25	X	95.0	0.37	604	X	6.3	543
STANDARDS										
0001 AE12										
0002 HgSTD-4										
0003 S0-2										
0004 SARM1		6.37		X						
0005 TKC4	18.7		581		1098.9	31.13	1.78%	5.3	143.1	811
BLANKS										
0001 Control Blank	X	X	X	X	X	0.01	X	X	X	X
0002 Control Blank	X		1		0.1	X	14	X	0.1	X
0003 Control Blank										
0004 Control Blank										
0005 Control Blank		X		X						
0006 Acid Blank	0.2		X		X	0.02	X	X	X	X
0007 Acid Blank										
0008 Acid Blank		X		X						
0009 Control Blank										

ANALYSIS

ELEMENTS	Cu	F	Fe	Hg	K	Mg	Mn	Mo	Na	Ni
UNITS	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm
DETECTION	1	50	0.01	0.01	20	20	1	0.1	20	1
DIGEST	A/	DH/	D/	CM/	A/	A/	A/	A/	A/	A/
ANALYTICAL FINISH	OES	SIE	OES	CVAP	OES	OES	OES	MS	OES	OES
SAMPLE NUMBERS										
0001 GCA5899	24	117	20.94	X	3763	753	202	2.7	281	56
0002 GCA5901	20	133	25.14	X	1924	1954	115	2.9	1542	50
0003 GCA5904	34	96	36.04	0.03	649	748	35	2.7	457	14
0004 GCA5906	9	132	25.81	X	7037	1.57%	755	2.8	97	10
0005 GCA5908	107	199	23.12	X	809	1.93%	2048	8.0	157	91
0006 GCA5914	8	87	38.42	X	951	5736	909	0.9	1928	20
0007 GCA5915	20	143	41.06	0.05	480	2.04%	2854	13.3	348	11
0008 GCA5917	8	249	1.80	X	3.59%	5936	286	3.0	3331	20
0009 GCA5921	13	96	32.65	X	3572	7200	432	4.6	69	21
0010 GCA5924	23	78	35.41	0.21	233	1522	1060	4.3	113	46
CHECKS										
0001 GCA5899	24	98	20.22	X	3823	737	196	2.7	284	55
STANDARDS										
0001 AE12										
0002 HgSTD-4				0.27						
0003 S0-2		462								
0004 SARM1			1.47							
0005 TKC4	2074				1.11%	1.54%	1822	55.5	1.67%	2158
BLANKS										
0001 Control Blank	X	X	X	X	X	X	X	0.1	X	1
0002 Control Blank	X				X	X	X	X	22	2
0003 Control Blank										
0004 Control Blank				X						
0005 Control Blank			X							
0006 Acid Blank	X				X	X	X	0.1	X	X
0007 Acid Blank				X						
0008 Acid Blank			X							
0009 Control Blank										

ANALYSIS

ELEMENTS	P	Pb	S	Sb	Se	Sn	Sr	Th	Tl	U
UNITS	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
DETECTION	20	2	10	0.05	0.01	0.1	0.05	0.01	0.02	0.01
DIGEST	A/	A/	A/	A/	BP/	A/	A/	A/	A/	A/
ANALYTICAL FINISH	OES	MS	OES	MS	MS	MS	MS	MS	MS	MS
SAMPLE NUMBERS										
0001 GCA5899	267	22	154	3.18	0.88	2.0	12.65	19.15	0.24	2.20
0002 GCA5901	116	27	135	2.71	0.73	2.1	28.98	29.74	0.21	3.19
0003 GCA5904	234	11	203	3.60	0.47	1.2	6.89	2.73	0.05	0.90
0004 GCA5906	524	4	1621	11.61	0.13	0.6	31.04	1.76	0.19	0.37
0005 GCA5908	631	9	1.84%	3.01	0.85	1.7	5.71	2.57	0.12	0.55
0006 GCA5914	660	X	121	33.17	X	0.4	21.58	0.25	X	0.07
0007 GCA5915	674	3	1070	4.38	0.19	0.4	4.42	1.58	0.04	0.42
0008 GCA5917	302	9	107	0.50	X	1.6	26.72	11.05	0.49	4.57
0009 GCA5921	369	10	491	9.10	0.04	0.5	17.84	0.58	0.07	0.14
0010 GCA5924	340	4	275	1.07	0.69	0.3	3.32	0.16	X	0.09
CHECKS										
0001 GCA5899	241	23	141	3.32	0.95	2.1	12.87	20.39	0.24	2.24
STANDARDS										
0001 AE12					0.60					
0002 HgSTD-4										
0003 S0-2										
0004 SARM1										
0005 TKC4	1458	1858	1.22%	176.39		9.5	508.67	162.41	15.06	16.79
BLANKS										
0001 Control Blank	21	X	12	X	X	0.1	X	X	X	X
0002 Control Blank	X	X	26	X		0.2	X	0.01	X	X
0003 Control Blank					X					
0004 Control Blank										
0005 Control Blank										
0006 Acid Blank	X	X	X	0.06		X	X	0.02	0.02	X
0007 Acid Blank										
0008 Acid Blank										
0009 Control Blank					X					

ANALYSIS

ELEMENTS	V	Zn
UNITS	ppm	ppm
DETECTION	2	1
DIGEST	A/	A/
ANALYTICAL FINISH	OES	OES
SAMPLE NUMBERS		
0001 GCA5899	221	39
0002 GCA5901	161	25
0003 GCA5904	39	13
0004 GCA5906	5	64
0005 GCA5908	44	40
0006 GCA5914	X	35
0007 GCA5915	2	23
0008 GCA5917	32	23
0009 GCA5921	4	66
0010 GCA5924	X	18
CHECKS		
0001 GCA5899	221	36
STANDARDS		
0001 AE12		
0002 HgSTD-4		
0003 S0-2		
0004 SARM1		
0005 TKC4	318	1126
BLANKS		
0001 Control Blank	X	1
0002 Control Blank	X	X
0003 Control Blank		
0004 Control Blank		
0005 Control Blank		
0006 Acid Blank	X	X
0007 Acid Blank		
0008 Acid Blank		
0009 Control Blank		

METHOD CODE DESCRIPTION

A/MS

Multi-acid digest including Hydrofluoric, Nitric, Perchloric and Hydrochloric acids in Teflon Beakers. Analysed by Inductively Coupled Plasma Mass Spectrometry.

A/OES

Muiti-acid digest including Hydrofluoric, Nitric, Perchloric and Hydrochloric acids in Tefion Beakers. Analysed by Inductively Coupled Plasma Optical (Atomic) Emission Spectrometry.

BP/MS

Aqua-Regia digest followed by Precipitation and Concentration. Specific for Selenium. Analysed by Inductively Coupled Plasma Mass Spectrometry.

D/OES

Sodium peroxide fusion (Zirconium crucibles) and Hydrochloric acid to dissolve the melt. Analysed by inductively Coupled Plasma Opticai (Atomic) Emission Spectrometry.

DH/SIE

Alkaiine fusion (Nickel crucible) specific for Fluorine. Analysed by Specific Ion Electrode.

CM/CVAP

Low temperature Perchloric acid digest specific for Mercury. Analysed by Cold Vapour Generation Atomic Absorption Spectrometry

Appendix C Design of the Hematite Waste Dump

Design of the Hematite Waste Dump

Extension Hill Operation

Mount Gibson Iron Limited

May 2012

Landloch Pty Ltd
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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Mount Gibson Mining Limited (MGM) proposes to mine and process hematite iron ore from Extension Hill and Extension Hill North (the Site). The Site is located within the Mt Gibson Range in the Mid-West region of Western Australia ~350km north east of Perth, ~70km south west of Paynes Find, and ~83km north east of Wubin. Approximately 6.2Mbcm (~8.1Mlcm) of waste rock will be generated and stored in the waste dump. The dump is expected to have a maximum final height of 40m, and have a footprint of 25ha.

Landloch was engaged by MGM to undertake erodibility studies and develop an erosionally stable final landform design. Rehabilitation guidelines, closure Key Performance Indicators and an operational surface water management plan were also required.

Soils at Extension Hill are dominated by sandy textured soil. Given that sandy soils tend to be highly erodible, rockier BIF waste was also supplied as potential armouring material. Three surfaces were assessed for their erodibility and infiltration characteristics:

1) Sandy soil.
2) 2:1 Weathered BIF/soil mixture.
3) 2:1 Fresh BIF/soil mixture.

The erodibility and infiltration characteristics derived included:

- Interrill erodibility (K_i);
- Rill erodibility (K_R);
- Critical shear for rill initiation (τ_c); and
- Effective hydraulic conductivity (K_e).

These parameters were used to model runoff and erosion using the Water Erosion Prediction Program (WEPP) runoff and erosion model. Site specific climate data was also used in performing the runoff and erosion simulations.

For the given slope profile, a surface sheeted with soil was predicted to have an erosion potential that exceeded the threshold values set for this project. Mixing the BIF (either the fresh or the weathered BIF) into the soil at a ratio of 2 parts rocky BIF to 1 part soil significantly reduced erosion potential.

A final landform batter design was developed using this 2:1 BIF/soil mixture. The profile developed had the following characteristics:

1. A linear batter profile without the use of a berm.
2. Maximum height of 40m at any point along the waste dump batter.
3. Batter gradient of 18°.
4. Same footprint as required for the originally proposed design that contained a berm.

5. Fertiliser applied at a rate of 100-150kg.ha of diammonium phosphate (DAP) with trace elements. Fertiliser to be incorporated into surface as outlined in section 9.1.
6. Waste dump top to be levelled as outlined in section 9.2.
7. Crest bunds installed as defined in section 9.2.1.
8. Cross bunds installed as defined in section 9.2.2.
9. Created rip lines to be horizontal (on contour) and no larger than 300mm (Section 9.3). Precision guidance equipment will be required.
10. Ripping should be performed with a triple tyne implement with tynes spaced at 1m. Use of a single tyne ripper is not recommended.
11. Constructed in 10m or 20m lifts rather than a single 40m lift. Costs of reshaping a single 40m high lift can be considerably higher than reshaping multiple smaller lifts (Section 9.4).
12. Surface sheeted with a 2:1 BIF/soil mixture with the rocky component (particles greater than 25mm) having a D_{50} of ~70-100 mm and a rock particle density >2.7 g/cm³. The sourced rock should have no more than 10% of the rock greater than 300mm, and no more than 10% of the rock less than 25mm in diameter (Section 9.5).
13. Sufficient rock should be added such that >30% contact cover is achieved (Section 9.5).
14. Rock/soil layer to be at least 0.5 m thick.
15. In plan view, landform footprint should not have sharp changes in batter direction (Section 9.6)
16. Landform shape should also consider rehabilitation cost. Section 9.6).
17. Monitoring programs for stability should be implemented (Section 9.7).

Operational surface water management is outlined in Section 8. A surface water management plan is given in Appendix B.

Rehabilitation Key Performance Indicators are provided in Section 10. KPIs for surface stability (not including those required for vegetation) have been developed for 5 stages of mining:

1. Planning;
2. Landform Construction;
3. Initial Rehabilitation Performance;
4. Monitored Rehabilitation Performance; and
5. Sustainability.

This is in recognition of the fact that actions taken during the planning and operational phases of mining have significant impacts on the potential success of rehabilitation efforts. KPIs associated to the planning and operational phases must be satisfactorily completed prior to any rehabilitation efforts being undertaken. Failure to complete KPIs at any stage will jeopardise the likelihood of successful rehabilitation of the waste dump and eventual mine closure.

1. BACKGROUND

1.1. Extension Hill Operation

Mount Gibson Mining Limited (MGM) proposes to mine and process hematite iron ore from Extension Hill and Extension Hill North (the Site). The Site is located within the Mt Gibson Range in the Mid-West region of Western Australia ~350km north east of Perth, ~70km south west of Paynes Find, and ~83km north east of Wubin. The site is immediately adjacent to Great Northern Highway, within the Shire of Yalgoo.

The hematite and associated waste rock will be mined via conventional open pit methods of blasting and excavation. Waste material from the open pit mining operation will be stockpiled in a waste dump to the east of the hematite mine pit. This is called the Hematite Waste Dump. Approximately 6.2Mbcm (~8.1Mlcm) of waste rock will be generated and stored in the waste dump. Hematite mining is expected to be mined for 5 years. The proposed design criteria for the hematite waste dump provided to Landloch by MGM include:

Height limit:	460 mAHD
Max. batter height:	40m
Length:	530m
Width:	480m
Bench height:	10-20m
Bench width on final shape:	10m
Batter angle (individually):	20° (36.4%)
Effective dump gradient[1]:	17° (30.8%)
Footprint:	25Ha
Storage capacity:	8,100,000m³
Storage requirements:	No PAF material has been identified
Revegetation:	Direct seeding during May or June with native species including native grasses, leguminous species, and local species.

1.2. Rehabilitation expectations

Post-mining waste dumps are recognised by both regulators and mining companies as posing a significant risk to the successful closure of a mine site.

The Department of Mines and Petroleum (DMP) is the lead agency for issues relating to mining and the environment. They state that waste landforms should be designed to "*ensure that the final structure is safe, stable, and not prone to significant erosion*" (DoIR 2001). The landform should also be able to support a sustainable ecosystem. The WA Environmental Protection Authority (EPA) has proposed similar standard objectives for rehabilitation of terrestrial ecosystems (EPA 2006).

Safety of landforms is largely concerned with the integrity of the landform to contain encapsulated materials and the geotechnical stability of the dump and the land on

[1] Gradient of a single batter without any benches constructed from the toe to the crest of the dump.

which the dump is sited. For the hematite waste dump, PAF materials are not anticipated to be exposed, hence their encapsulation is not likely to be required. The dump is being sited outside the limits set by regulatory guidelines for safety bund walls around abandoned open pit mines (MGM 2011). The waste rock has also been defined as, "*hard, geologically competent with little clay in the overall deposits*" (MGM 2011). Given these conditions and the geotechnically very low final batter angles[2], the dump is not expected to pose significant safety issues.

Stability of landforms is fundamentally concerned with erosion processes and their impact on batter design. This report addresses requirements to achieve erosional stability of the outer batter slopes. Development of a **sustainable ecosystem** requires a stable soil or growth medium layer. Without adequate depths of suitable material, there is little opportunity for vegetation to establish, vegetation assemblages to develop, and for fauna to return at closure. Importantly, waste dumps that do not meet these requirements are likely to be deemed unacceptable, and regulators may insist on re-shaping and re-working of landforms until they do meet expectations.

Disturbance of land by mining typically results in environmental performance bonds being placed on the mining company that estimate the relative cost of rehabilitation for different landforms, but not necessarily the actual cost of rehabilitation. In Western Australia, the total amount of mining security held is estimated to be 25% of the WA mining industry's total rehabilitation liability (DoIR 2006). In other words, the cost of rehabilitation can be expected to be significantly higher than the bond rate that is currently applied. Waste dump rehabilitation should be given serious consideration, with rehabilitation planning starting as early as possible to ensure that successful rehabilitation can be achieved as cost effectively as possible. In Landloch's experience, if not properly planned, rehabilitation can become very expensive or potentially unachievable. Costs can vary by a factor of 10 depending on the disparity between final landform requirements and the characteristics of the constructed landform. Much of this cost can be attributed to unnecessary double handling of waste materials. Landloch has also observed that where plans (that were made early) are carried out to design, the cost of rehabilitation can be less than the current bond rate. For a 25ha waste dump, this is equivalent to a potential savings of several hundreds of thousands of dollars.

1.3. Scope of works

Landloch was engaged by MGM to undertake the following tasks:

1) **Define rehabilitation goals and review available data –** Determine constraints to landform design based on stakeholder requirements, or physical and/or material limitations. Collate and review material characterisation data as provided to Landloch by MGM. Based on this assessment, identify materials needing additional characterisation, and other

[2] Mass failure of batter slopes is of little concern for rehabilitated landforms with batter gradients well below angle of repose, particularly for dumps located in the arid climates that apply across the mid-west region of Western Australia.

potentially useful resources. Select materials for detailed erodibility assessment.

2) **Erodibility and infiltration measurement –** Materials were subjected to simulated rainfall and overland flows and the data recorded used to derive erodibility and infiltration parameters for runoff/erosion models.

3) **Landform design –** Using the erodibility parameters to parameterise the runoff/erosion models, develop erosionally stable landform designs using site specific climate information.

4) **Rehabilitation guidelines and Key Performance Indicators (KPIs) –** Provide guidance on:
    i. Rehabilitation of the waste dump top.
    ii. Appropriate encapsulation of problematic materials if present.
    iii. Batter slope surface treatments (armouring, seeding, ripping).
    iv. Batter sheeting techniques (where mixing rock or tree debris is required).
    v. Monitoring requirements

   Using the final landform design defined and these guidelines, develop rehabilitation KPIs.

5) **Surface water management plan –** Define appropriate surface water management structures required for the operational phase of the landform.

2. ENVIRONMENTAL CONTEXT

2.1. Climate

Extension Hill is located in a semi-arid, hot, dry Mediterranean climate characterised by hot dry summers, and cooler wetter winters. Average annual precipitation values for Bureau of Meteorology (BOM) weather stations near Extension Hill are shown in Table 1. Data is available for only 1983-2011 for the Mount Gibson site, and these years are wetter than the long term average when compared with nearby stations of longer record lengths. If only the years 1983-2011 are considered for each site shown in Table 1, the difference in mean annual rainfall values between all the sites is reduced (Table 2). The rainfall statistics for the Mount Gibson station do however remain different to data for nearby stations in the region.

Based on data for Ninghan Station, the majority of rainfall (~55%) occurs during May to August, with a mean monthly rainfall of ~41mm during this period. June is the wettest month, averaging ~47mm. Mean precipitation decreases markedly during September to April, averaging ~17mm/month (Figure 1).

Table 1: *Average annual precipitation for various BOM weather stations near Extension Hill - all available data.*

BOM Station Name	Ninghan Station	Mount Gibson	Wanarra	Goodlands
BOM Station Code	07068	10075	08264	10026/10057
Distance from site (km)	21.4	21.5	38.5	54.3
Effective Record Length (y)	84.6	29.3	35.3	89.6
Record Period	1905-2011	1983-2011	1973-2011	1921-2011
Average Annual Precipitation (mm)	295	354	306	306

Table 2: *Average annual precipitation for various BOM weather stations near Extension Hill using 1983-2011 data only.*

BOM Station Name	Ninghan Station	Mount Gibson	Wanarra	Goodlands
Average Annual Precipitation (mm)	322	354	319	322

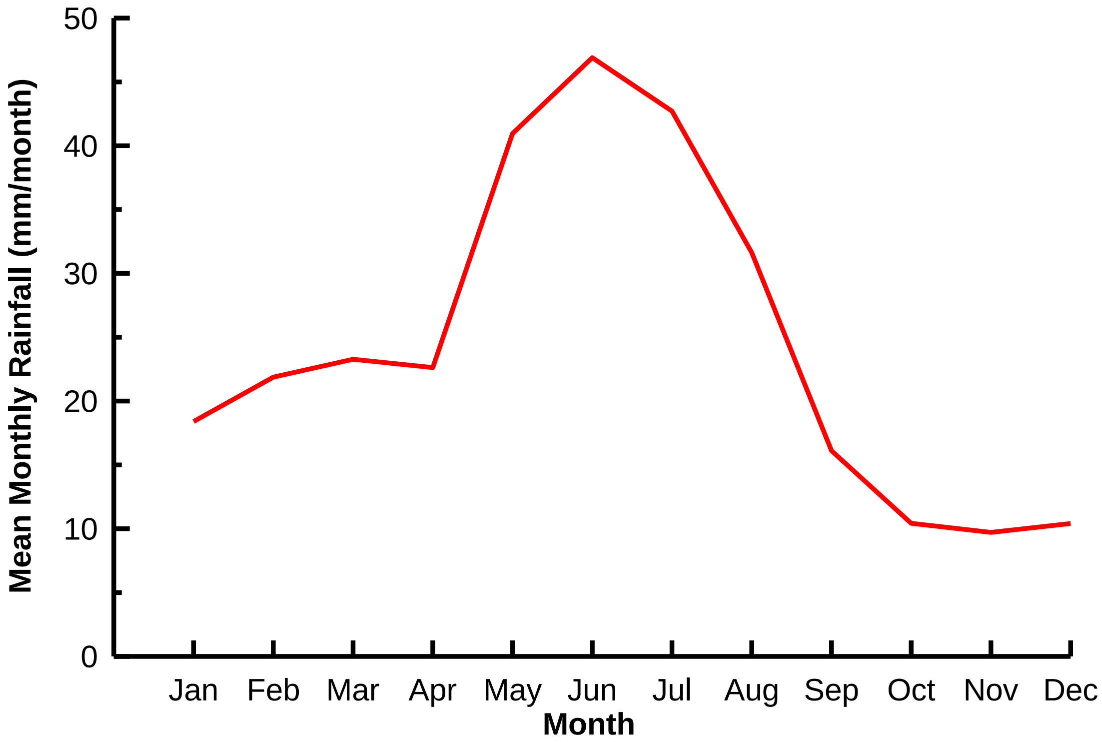


***Figure 1**: Mean monthly precipitation for Ninghan Station.*

2.2. Soils and landform

The topography typically consists of banded iron stone formations forming a series of hills and strike ridges interspersed with drainage areas of low gradient. Soils on the upper slopes of these hills are dominated by coarse fragments or rock outcrops. Soils increase in thickness downslope. The plains between the hills typically contain deep sandy loam soils (Payne *et al* 1998).

The hematite waste is planned to be constructed on the lower slopes of Extension Hill and will extend onto the plains. The sandy loam soils that will be disturbed and used for rehabilitation of the waste dump are likely to be highly transportable, and prone to detachment, particularly on steep slopes. This has a significant bearing on the stability of constructed landforms where these soils are typically utilised on slopes of much steeper gradient than the plains from which they come.

2.3. Wastes

Table 3 lists the wastes to be extracted from the pit (data supplied by site geologist on16 November 2011) and their respective proportions of the total waste volume.

Table 3: *Waste lithologies and their abundance.*

Lithology	Proportion of Total Waste (%)
Scree	4.1
Goethite	26.4
Felsic Volcanics	0.1
Band Iron Formation (BIF)	32.2
Hematite	36.2
Magnetite	0.4
Banded Iron Magnetite	0.3
Sediments	0.3

Wastes are dominated by Banded Iron Formation (BIF), hematite, and goethite wastes. These wastes comprise 94.8% of the total waste volume. These wastes have been generally classed as non-acid forming (Graeme Campbell and Associates 2005) although a tuff sample (volcanic) was classed as potentially acid forming due to the presence of pyrite. Volcanics (of which tuff is a component) comprises only 0.1% of the total volume of waste.

Blasting testwork carried out by Orica concluded that the rock is hard and geologically competent, and the clay proportions are low. The clay that exists shows no tendency to swell (MGM 2011). Given the lithologies in Table 3 and the indications provided by the blasting testwork, wastes are likely to be moderately rocky, but will contain an amount of fine-grained materials. The rocky component is likely to weather slowly and provide erosion resistance in the long term if used as armouring material.

3. MATERIAL CHARACTERISATION

3.1. Samples assessed and interpretation

Samples of lateritic (rocky) soil, sandy soils, BIF, and goethite were provided to Landloch in January 2012 for assessment of properties relating to plant growth, surface stability, and rock competence. A total of 12 samples were supplied. The fine component of each material (<2mm diameter) were assessed for:

- $pH_{1:5}$;
- $EC_{1:5}$;
- Particle size distribution (clay, silt, fine sand, coarse sand);
- Exchangeable Cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Al^{3+});
- Effective Cation Exchange Capacity (ECEC) measured as the sum of exchangeable cations;
- Exchangeable Sodium Percentage (ESP);
- Organic carbon;
- Total P;
- Total N;
- Available P and K (Colwell method);
- Available S; (KCl method); and
- Available trace elements (Cu, Fe, Zn and Mn) (DTPA method).

The coarse fraction (>16mm) were assessed for:

- Water adsorption;
- Rock particle density.

Results of material characterisation of these materials are shown in Tables 4-6. Cells shaded in red indicate values that are higher or lower than are typically considered suitable for plant growth, surface stability, or rock durability. These materials may require specific management.

All materials are non-saline. Soils tend to be acidic, with high Na and Al saturation percentages. These properties will tend to compete to cause dispersion (elevated Na concentration) and to cause clay flocculation (elevated Al concentration). High exchangeable Al is also linked to toxicity in plants, and vegetation tends to be sparse in affected areas. Importantly, if low pH values are “normal” for soils in the region, it can be expected that low vegetation cover levels would also be “normal”.

The clay content was insufficient to enable the creation of a bolus for all except three samples, and clay dispersion is therefore of little concern for these materials. For the three samples for which the Emerson Index test was performed, two did not disperse (class 5 and 6) and one did disperse once subjected to additional energy (Class 3). As such, the soils and wastes can be considered generally not prone to dispersion. The high coarse sand content also renders the soil not prone to tunnel erosion that can result from soil liquefaction.

Table 4: *Basic chemical and physical characterisation data for the fine component of Extension Hill materials.*

Test Parameter		Units	Sample ID											
			Sandy Soil 1	**Sandy Soil 2**	**Sandy Soil 3**	**Sandy Soil 4**	**Laterite Soil 1**	**Laterite Soil 2**	**Laterite Soil 3**	**Laterite Soil 4**	**BIF 1**	**BIF 2**	**Goethite 1**	**Goethite 2**
$EC_{1:5}$		*dS/m*	0.16	0.07	0.06	0.09	0.09	0.07	0.06	0.05	0.08	0.21	0.05	0.09
$pH_{1:5}$		*pH units*	5.19	5.20	4.80	4.74	4.85	4.61	4.53	4.37	5.06	7.93	7.94	8.38
Exchangeable Cations	ECEC	*meq/100g*	5.39	2.59	2.02	2.50	3.00	2.68	2.28	2.17	2.94	4.53	3.10	4.69
	K	%	6.76	8.26	5.77	5.78	5.7	5.21	5.32	4.70	4.94	6.34	5.4	6.2
	Ca	%	67	65.0	52.5	62.5	53.2	50.6	43.6	31.6	57.7	46.8	62.0	67.3
	Mg	%	17.5	14.2	13.0	12.9	16.0	13.8	17.9	13.70	23.8	18.3	25.8	19.6
	Na^	%	**8.48**	**6.9**	**10.2**	**10.0**	**14.60**	**11.1**	**10.4**	**9.10**	**13.0**	**28.4**	**6.90**	**6.80**
	Al	%	0.25	5.6	18.55	8.79	10.50	19.30	22.90	40.80	0.62	0.12	0.0	0.14
Emerson Index		Class	**3**	6	5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Clay Mineralogy[+]		-	K+I	K	K	K	K	K	K	K	K	K+I	K	K
Particle Size Distribution*	Clay	%	22.8	13.7	16.6	20.0	23.8	24.5	24.8	26.1	19.5	20.1	27.6	26.4
	Silt	%	0.00	0.00	0.00	0.0	1.02	0.71	0.31	0.00	0.52	0.21	0.40	0.72
	Fine Sand	%	26.9	20.4	36.5	36.3	44.9	42.3	38.1	37.7	22.8	27.0	42.9	41.6
	Coarse Sand	%	50.3	65.8	47.0	43.7	30.2	32.5	36.6	36.3	57.0	52.7	29.1	31.3

*Clay: <0.002mm; Silt 0.002-0.02mm; Fine Sand 0.02-0.2mm; Coarse Sand 0.2-2.0mm
^ Equivalent to Exchangeable Sodium Percentage (ESP)
[+] Clay mineralogy estimated based on the ratio of ECEC to clay. K: kaolinite, I: illite
ND: No data due to lack for fine fraction or inability to form bolus with soil (too sandy)

Table 5: *Fertility characterisation data for the fine component of Extension Hill materials.*

Test Parameter		Units	Sample ID											
			Sandy Soil 1	Sandy Soil 2	Sandy Soil 3	Sandy Soil 4	Laterite Soil 1	Laterite Soil 2	Laterite Soil 3	Laterite Soil 4	BIF 1	BIF 2	Goethite 1	Goethite 2
Total N		*mg/kg*	675	597	**392**	**491**	665	656	**390**	**355**	**380**	**154**	**482**	649
Total P		*mg/kg*	**78.3**	**47.5**	**83.4**	**93.5**	190	193	174	158	205	**48**	258	215
Available P (Colwell)		*mg/kg*	17.8	10.2	13.8	13.9	15.9	17.5	7.3	7.6	5.22	**2.02**	11.9	22.6
Available K (Colwell)		*mg/kg*	231	161	116	109	124	117	84.4	73.8	104	172	123	141
Organic Carbon		*%*	1.24	0.83	0.61	1.4	1.71	1.78	0.7	0.53	0.7	0.26	0.92	1.4
Available S (KCl)		*mg/kg*	14.5	**10.3**	16	14.1	18.7	15.4	19.5	24.6	25.9	24.7	16.4	16.6
Extractable Micronutrients	Cu	*mg/kg*	0.62	**0.06**	**0.01**	**0.01**	**0.07**	**0.07**	0.4	0.3	0.23	0.1	0.52	0.43
	Zn	*mg/kg*	0.44	**0.23**	**0.16**	**0.13**	0.62	0.23	**0.14**	**0.12**	1.34	1.51	0.47	2.97
	Mn	*mg/kg*	10.3	3.6	2.38	3.12	9.32	3.96	8.55	1.95	5.2	**0.14**	13.7	13.9
	Fe	*mg/kg*	33.3	41.3	22.6	40.4	40	39.8	11.6	10.1	27.4	8.97	20.2	30.9

Table 6: *Rock particle density and water adsorption values for the coarse component of samples from Extension Hill.*

Sample ID	No. Rocks Sampled	Mean Rock Particle Density (g/cm^3)	Mean Water Absorption (%)
Sandy Soil	ND	ND	ND
Laterite	3	2.7	3.0
BIF	12	3.3	1.5
Goethite	6	3.4	4.3

ND: No data due to lack of coarse fraction

The clay fraction is dominated by kaolinite clay types. They do not shrink and swell when dried and wetted (supported by previous blasting testwork), and tend to surface seal readily. They are erodible, and tend to hold low levels of nutrients.

Soil fertility is low, with total N values being generally low for all samples. Total P values can be low, though available P values tend to be adequate. Trace elements – Cu and Zn – are low for most samples.

Rocks sampled have high density and low water absorption values, indicating a material with low weathering potential. Particles with high density, assuming they are of sufficient size, are also highly suitable for use as rock armour for erodible surfaces such as batter slopes.

3.2. Selection of materials for detailed study of erosion potential

The sandy soil is the dominant soil type available for rehabilitation, and only small proportions of the laterite soil are available. As a result, the sandy soil was selected for detailed investigation of erosion potential. The rockiness of the lateritic soil will also render this material more erosion resistant than the sandy soil, and as such any design developed for the more erodible soil can also be validly used for the more erosion resistant one.

BIF was also supplied as potential armouring material. A fresh BIF and a more weathered BIF material was supplied.

4. EROSION STUDY OVERVIEW

4.1. Materials studied

Studies were carried out on 3 different materials:

4) **Sandy soil**.
5) **Weathered BIF/soil mixture** – Weathered BIF waste was mixed with sandy soil in the ratio of 1 part soil to 2 parts weathered BIF.
6) **Fresh BIF/soil mixture** – Fresh BIF was mixed with the sandy soil in the ratio of 1 parts soil to 2 parts fresh BIF.

4.2. Bulk material properties assessed

A sample of the sandy soil supplied was sent to a commercial soil laboratory and analysed for:

- Soil $pH_{1:5}$;
- $EC_{1:5}$ as a measure of salinity;
- Exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Al^{3+});
- Effective Cation Exchange Capacity (ECEC), measured as the sum of exchangeable cations; and
- Particle size distribution.

This was conducted to confirm that the soils provided have similar properties to those sampled as part of the preliminary inspection, and to assist in parameterising the Water Erosion Prediction Project (WEPP) runoff and erosion model (outlined in more detail below).

4.3. Material erodibility

Although the concept of “erodibility” is broadly understood, its precise meaning can vary considerably within the framework of some erosion prediction models. The WEPP model (Flanagan and Livingston 1995), used in designing landform batters for waste landforms presented in this report describes material erodibility via a number of specific parameters:

- Interrill erodibility (K_i);
- Rill erodibility (K_R);
- Critical shear for rill initiation (τ_c); and
- Effective hydraulic conductivity (K_e).

Erodibility parameters for the WEPP model were derived from data collected during laboratory studies involving the:

- Application of simulated rain to a soil or waste surface to obtain estimates of K_i and K_e; and
- Application of surface water flows to obtain estimates of K_R and $\tau_{c.}$

Those parameters were then used in computer simulations of runoff and erosion in determining a range of landform design options that are presented in this report.

4.3.1. Rainfall simulation and overland flows

Loch *et al.* (2001) present a detailed description of the rainfall simulator used in this study (refer to Figure 2). Flat fan nozzles mounted on an oscillating manifold produce the simulated rain. Kinetic energy generated by the nozzles is ~29.5 J/m2/mm, consistent with the energy of natural rainfall at intensities >40 mm/h (Rosewell 1986; Kinnell 1987). The nozzles uniformly sweep back and forth across the plot, achieving good spatial distribution of the generated rainfall.

Interrill and rill erosion were determined by employing the following methodology:

1) Interrill erosion was measured by applying a simulated "storm" with known rainfall intensity to plots 0.75m wide and 0.75m long (Figure 2). Three plots of each material were run. Steady state runoff rates were measured and sediment and runoff samples taken. Any variations in the applied intensity were accounted for in the data analysis.
2) Rill erosion was measured by applying overland flows to flumes 0.4m wide and 2.0m long (Figure 3). Three plots of each material type were run. Samples of sediment in runoff were taken for each applied flow rate. No rainfall was used during the overland flow study.

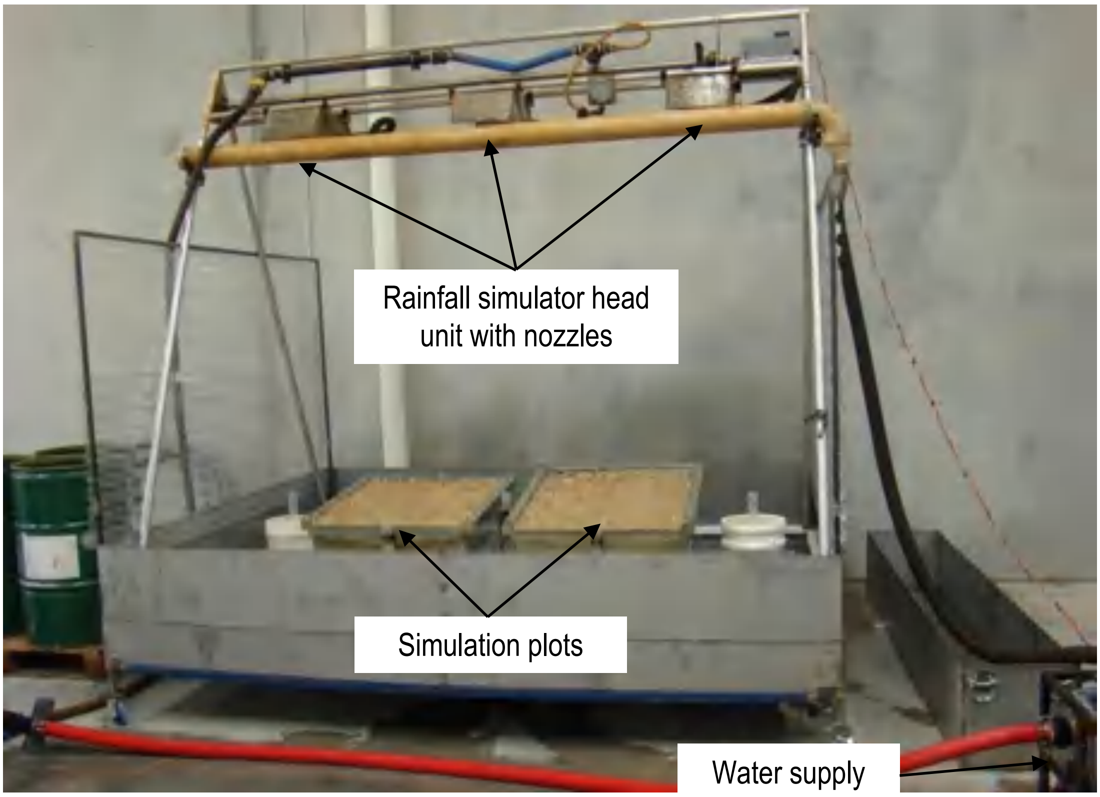


Figure 2: *Typical laboratory-based rainfall simulator installation.*

4.4. Computer simulation of runoff and erosion from landform batters

WEPP was used in this project for simulations of runoff and erosion because of its detailed treatment of slope profiles and erosion responses to varying climate and flow concentration conditions. It was developed by the United States Department of Agriculture (USDA) to predict runoff, erosion, and deposition for batter slopes (the term hillslope is customarily used in the United States of America) and watersheds.

WEPP is a simulation model with a daily input time step, although internal calculations can use shorter time steps. Plant and soil characteristics important to erosion processes are updated every day. When rainfall occurs, those plant and soil characteristics are considered in determining the likelihood of any runoff. If runoff is predicted to occur, the model computes sediment detachment, transport and deposition at points along the slope profile.

The erosion component of the WEPP model uses a steady-state sediment continuity equation as the basis for the erosion computations. Soil detachment in interrill areas is calculated as a function of the effective rainfall intensity and runoff rate. Soil detachment in rills is predicted to occur if the flow hydraulic shear stress is greater than the soil's critical shear stress, and when the sediment load of the flow is below transport capacity. Deposition in rills is computed when the sediment load is greater than the capacity of the flow to transport it. All WEPP simulations developed by Landloch used a 100-year stochastic climate sequence for the Extension Hill site.

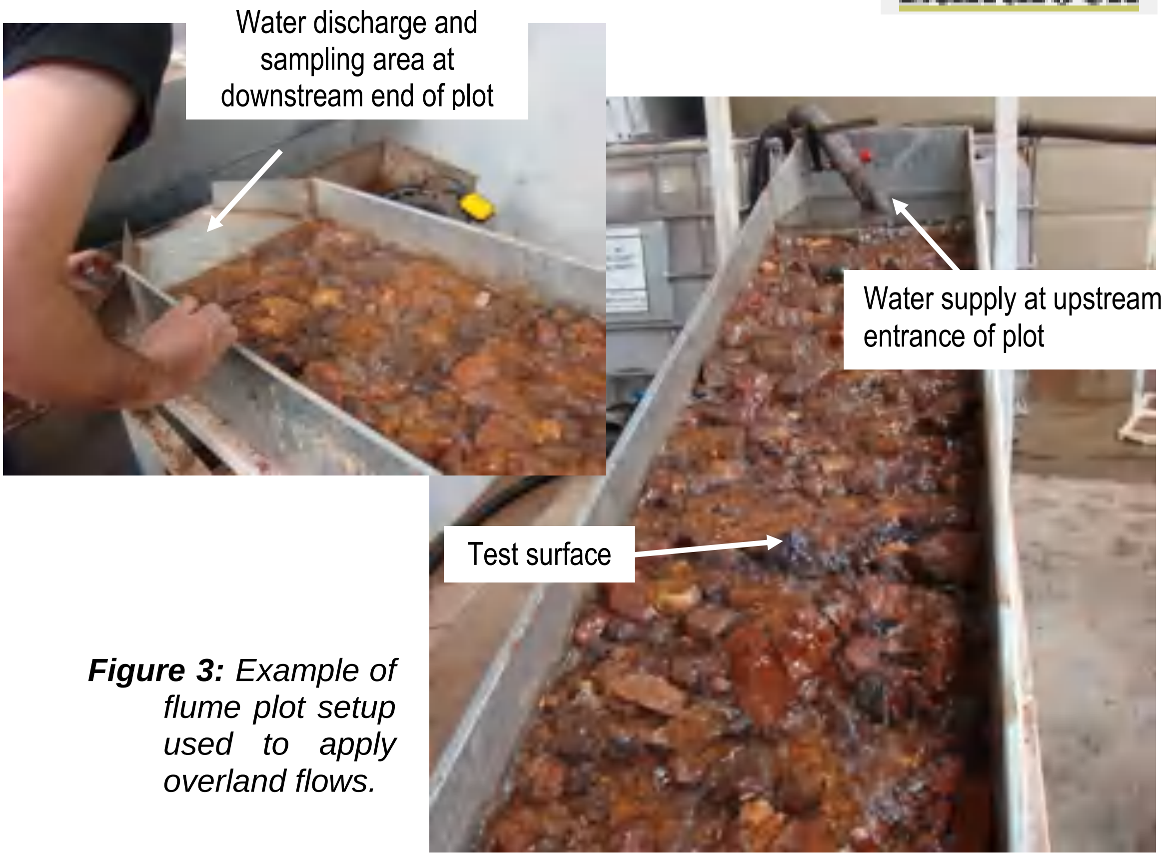


Figure 3: *Example of flume plot setup used to apply overland flows.*

4.4.1. Effective hydraulic conductivity (K_e) derived using simulated rain

Within WEPP, the rate at which water moves through a soil is measured by the effective hydraulic conductivity (K_e). K_e describes water movement through the soil profile in response to an applied potential difference in soil water (soil water deficit). K_e is derived by measuring a material's steady infiltration rate under simulated rain, and is strongly influenced by the characteristics of the surface crust. Effective hydraulic conductivity is essentially different to steady infiltration rate.

4.4.2. Interrill erodibility, Ki

Interrill erodibility (K_i) describes the detachment and movement of particles by the combined action of raindrops and shallow overland flows. Interrill erosion generally occurs relatively evenly over a batter slope.

The interrill erodibility parameter required by WEPP was calculated on the basis of sediment in runoff from the rainfall simulator plots, taking into account plot dimensions and gradient, and rainfall energy and intensity.

4.4.3. Rill erodibility (K_R) and critical shear (τ_c)

Rill erosion refers to the detachment and transport of sediment by turbulent flow within concentrated lines of overland flow.

Rill erodibility parameters required for the WEPP model are K_R (rill erodibility) and τ_c (critical shear for rill initiation). These parameters are used to predict changes in erosion processes and rates in response to changes in runoff rates, slope length, gradient, and land management.

K_R is the rate of detachment per unit area in a rill per unit of effective shear stress (see Equation 1 below) where τ_c is the flow shear stress at which particle detachment commences. This threshold is a function of both particle size and cohesion: the more cohesive the material, the higher the shear stress needed to commence sediment entrainment, whereas less shear stress is needed to entrain comparable-sized particles from less cohesive material.

Neglecting any effect of existing sediment loads, rill detachment capacity (D_c) in WEPP is calculated as:

$$D_c = K_R\,(\tau - \tau_c) \qquad (1)$$

where τ is the flow shear stress.

For soils with low rock contents, the critical shear tends to be lower and the rill detachment value tends to be higher than values measured on rockier materials. As such, soils tend to more rapidly develop rill networks and are more prone to rill erosion when compared with rockier materials.

5. LABORATORY RESULTS

Results of the chemical and physical characteristics of the sandy soil used in the detailed assessment of erosion potential are presented in Tables 7 and 8, and are comparable with data for soils assessed during the preliminary assessment (mean values for the sandy soils measured during the preliminary assessment are also given in these tables). The bulk sample is considered similar to that of other soils tested during the preliminary assessment.

Table 7: *Basic chemical properties for the loamy sand supplied and mean values for the sandy soil assessed in preliminary assessment.*

$pH_{1:5}$ (-)	$EC_{1:5}$ (dS/m)	Exchangeable Cations (meq/100g)					ESP (%)	ECEC (meq/100g)	Clay Mineralogy (-)
		Ca	Mg	Na	K	Al			
Bulk sample of sandy soil									
4.7	0.06	0.9	0.3	0.1	0.1	0.9	5.9	2.4	K
Sandy soil supplied during preliminary assessment (mean values)									
5.0	0.10	2.0	0.5	0.3	0.2	0.2	8.9	3.1	K

Note: Clay Mineralogy: K-Kaolinite

Table 8: *Particle size distributions of the materials supplied for assessment of erodibility and infiltration characteristics*[3]

Clay (%)	Silt (%)	Fine Sand (%)	Coarse Sand (%)
Bulk sample of sandy soil			
26	1	43	30
Sandy soil supplied during preliminary assessment (mean values)			
18	0	30	52

Use of this soil will likely not support significant levels of vegetation. Assuming that the soil is representative of the soil reserve available (Landloch has measured very low pH (4.6-6.2) for other soils in the vicinity of Mount Gibson's Extension Hill operation), establishment of a stable surface without any impacts from vegetation will be important.

Table 9 shows the WEPP erodibility parameters derived from laboratory-based measurements on various surfaces. Figure 4 shows examples of the test surfaces assessed.

Table 9: *WEPP erodibility parameters determined from laboratory-based measurements.*

Material	Interrill erodibility, K_i	Rill erodibility, K_R	Critical shear, τ_c	Effective hydraulic conductivity, K_e
	(kg.s/m^4)	(s/m)	(Pa)	(mm/h)
Sandy Soil	324,410	0.0037	24	18
1:2 mix of Sand and Weathered BIF	165,989	0.0041	40	50
1:2 mix of Sand and Fresh BIF	483,884	0.0014	30	35

[3] Gravel: >2,000 µm; Coarse sand: 2000-200 µm; Fine sand: 200-20 µm; Silt: 20-2 µm; Clay: <2 µm.

Figure 4: *Surfaces of sandy soil (top), fresh BIF mixed with sandy soil (middle) and weathered BIF mixed with sandy soil (bottom).*

5.1. Effective hydraulic conductivity (K_e) derived using simulated rain

The K_e values derived for the soil are lower than measured for either of the BIF/soil mixtures (Table 9).

The incorporation of rock into the soil has increased infiltration capacity in this case. Interactions between rock cover, rock size, the degree to which the rocks are embedded, and infiltration rate under rain are complex (Parsons *et al* 2009). Generally, studies of surface seal formation on agricultural soils (Loch 1989; Loch and Foley 1994) show higher infiltration rates when surfaces are protected (by rock or other covers) and not impacted by raindrops. In this case, the presence of rock likely acted to reduce surface sealing of the soil and maintain high infiltration rates as a result.

5.2. Interrill erodibility, Ki

K_i values for all surfaces do not vary considerably. For example, soils particularly prone to interrill erosion can have detachment parameters an order of magnitude higher than these values. The values assessed are similar to those measured for other gravelly and rocky soils.

5.3. Rill erodibility (K_R) and critical shear (τ_c)

Rilling was not observed for either the of BIF/soil mixtures. As such, the rill detachment parameters (K_R and τ_c) adopted for the BIF/soil mixtures represent detachment rates of soil from between the rock incorporated in the surface. The critical shear values adopted are equivalent to the mean values for which soil detachment was observed. Actual critical shear values would be higher than these values, and as such the modelling using this lower value can be considered conservative. Rilling was observed for the soil (Figure 5) and the rill detachment parameters adopted reflect the detachability of the soil surface.

Rill erodibility values were similar for all the materials, indicating that strong rill networks were not developed. The fresh BIF/soil mix did contain greater proportions of rock (Figure 5) than the weathered BIF/soil mixture, and as such detachment rates from this surface were slightly lower.

τ_c values are higher for both of the BIF/soil mixtures than the τ_c measured for the soil alone. The lower critical shear value for the soil (Table 9) indicates that it is more susceptible to detachment initiation than the BIF/soil mixtures. Erosion rates for the soil could therefore be expected to be higher than the BIF/soil mixtures.

Figure 5: *Surfaces after application of concentrated overland flows: Sandy soil (left), Fresh BIF/sand mix (middle), Weathered BIF/sand mixture (right).*

6. WEPP RUNOFF AND EROSION SIMULATIONS

6.1. Simulation assumptions for developing stable profile

Simulations of runoff and erosion using WEPP were conducted using the following general assumptions and model settings:

(a) Simulations were run for a 100-year climate sequence for the site. Appendix A contains greater detail on the derivation of that file.
(b) Rill spacing was set at 1m for the BIF/soil mixtures whereas a spacing of 5m was used for the soil to reflect the greater degree of flow concentration that will occur on hydraulically smooth slopes where rock is absent.
(c) Surface roughness was set at 3cm for all materials. This is consistent with a relatively smooth surface.
(d) No allowance was made for the effects of vegetation on erosion.
(e) Light cross-slope ripping will be applied to the final batter surface.
(f) ***No allowance*** was made for water from the top of the landform to discharge onto the batter slopes. Retention of water on top of the landform will considerably reduce potential erosion rates.

Rill spacing values adopted are based on Landloch's extensive experience with assessment of erosion on constructed landforms sheeted with similar materials. The rill spacing parameter in the WEPP model sets the slope width over which predicted runoff is automatically concentrated. Increased rill spacing increases the amount of flow in individual rills, increases the potential for critical shear to be exceeded and thereby increases the likelihood of rilling becoming more active in a given event.

Surface roughness of 3cm is consistent with a relatively smooth surface, effectively simulating the surface that will develop after some years of exposure to rainfall. For a rocky surface this is a conservative setting at the rock provides additional roughness that will limit detachment.

Although vegetation is to be established on the batter slopes, no vegetative cover was considered in the modelling. This reflects a general observation that levels of ***surface contact*** cover developed by vegetation in this arid environment are likely to be too low to have appreciable impacts on erosion potential. The high Al levels may also limit vegetation growth. Therefore, the aim of the simulation was to identify a slope that would initially be stable **without** vegetation. Any vegetation establishment will increase erosion resistance.

6.2. Definition of "acceptable" soil loss

The concept of "tolerable" or "acceptable" soil loss is widely mentioned when considering erosion from agricultural land. Tolerable soil loss is defined as a rate of erosion such that land productivity is sustained (Wischmeier and Smith 1978), and is therefore of greatest relevance to agricultural situations rather than to mine site rehabilitation. It also ignores the pronounced temporal variations in erosion rates evident in arid regions. Currently, there is no widely adopted methodology for assessing what is an acceptable erosion rate for rehabilitated lands.

Also, a simple measure of average erosion rate in tonnes per hectare per year gives no information on the way in which that erosion may develop and impact on a landform over the long term. Erosion models such as the Revised Universal Soil Loss Equation (RUSLE) or WEPP simply consider the same land surface year after year. In practice, rilling in one year may well develop into gullies in subsequent years if the erosion continues to incise the soil surface. Alternatively, a rill may become armoured, and erosion rates may reduce through time.

Therefore, Landloch's approach to landform design aims to create slopes where rilling and consequently, gullying potential, will be minimised. (Interrill erosion is generally relatively insignificant relative to potential rates of erosion by rilling on steep slopes. Surfaces eroded by interrill erosion typically become armoured in any case.) If conditions that encourage gullying are avoided, the slope should be resilient. Gully erosion potential is increased by:

- Use of inappropriate surface materials;
- Use of inappropriate batter shapes (including heights, and gradients); and
- Increasing flow shear stress through concentration of surface water flows by either excessively large rip lines or berms.

Based, on Landloch's considerable experience in modelling erosion, and assessing erosion processes and erosion rates in the field, landforms designed with a predicted average erosion rate (averaged over the entire slope length) of <5 t/ha/y, together with a predicted maximum erosion rate at any point on the slope of <10 t/ha/y, exhibit a low tendency to rill. These values were adopted as the threshold above which a landform batter was deemed to erode at an unacceptable rate.

6.3. Definition of the maximum allowable batter gradient

The maximum allowable batter gradient (or batter gradient section in the case of a concave slope) is a function of the:

- Ability of vegetation to establish and grow on those batters, and
- Safety of operators traversing the slope while constructing the batters.

Figure 6 illustrates the typical relationship between batter gradient and vegetation (DME 1996). Batters with gradients <36% (20º) tend to support revegetation with success classed as fair to very good. From a safety perspective, batter slopes >~45% (~25º) are typically unsafe to operate on, with dozers tending to slip on such slopes. Therefore, batter gradients <36% (20º) were investigated as part of the development of stable batter slopes.

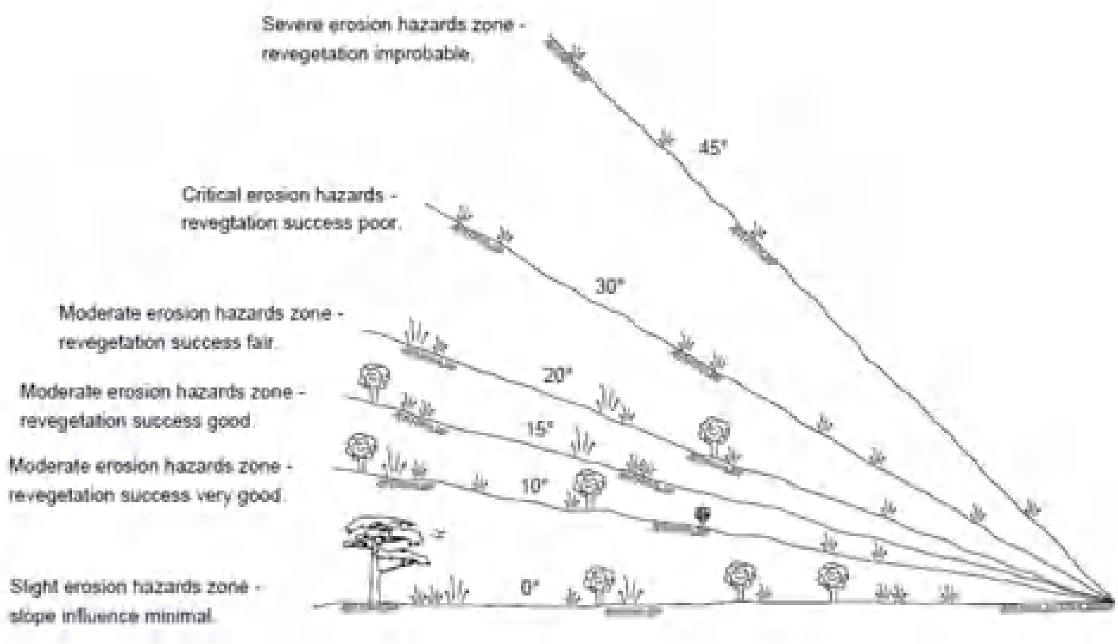


Figure 6: *Influence of batter gradient on revegetation and erosion (DME, 1996).*

6.4. Berms and landform stability

The waste landform designs that are currently planned for Extension Hill include the use of 10-20m high linear batters at gradients of ~20º (~36%) separated by ~10m wide berms. This is consistent with now defunct regulatory guidelines (DME 1996).

Since 1995 (approximately), the use of berms has been strongly questioned within the WA mining industry. By 2005, the role of berms in concentrating flows and in creating gullies was becoming widely accepted, and by 2009, all reference to berms was removed from the DMP web site. DMP staff have stated publicly in industry forums that – given the current best management practices being applied by the mining industry – use of the obsolete batter design guidelines (DME 1996) is no longer appropriate. DMP now recommend that landforms be designed using the characteristics of the prevailing environment (climate and landscape), and the properties of the materials being stored (hence the approach taken in this report). A prescriptive approach to design – as fostered by previous guidelines – is no longer acceptable.

Consequences of this prescriptive approach are documented by Howard *et al.* (2010) and Vacher *et al*. (2004). Created berms fill with sediment and wear down by erosion and weathering. They lose their capacity to hold sediment, and over time surface water breaks through and discharges downslope in concentrated flow lines. That flow will add to the surface water already collected in the next downslope berm and cause it to more rapidly overtop and discharge downslope. Thus, once one berm "fails", there will be a general failure down the slope and a rill or gully is created. Observations of hundreds of waste dumps by Landloch in many varied locations has led to the clear conclusion that landform configurations that include berms on erodible materials create a "flow-concentrating" landscape, and that flow concentration is the main reason that gullying is such a common feature of waste dump landforms. The Leading Practice Sustainable Development Handbook for Mine Rehabilitation (DITR 2006) – considered representative of current best practice for the Australian mining industry – states that gullies often develop as, *"a direct consequence of concentration of run-off by the berms and discharge of concentrated flows onto batter slopes once the berms fail"*.

Therefore, berms are not recommended for use on erodible materials such as the Extension Hill soil, and stabilisation of landform batters is best achieved through construction of batter slope profiles that minimise the:

- Potential for runoff to generate and for particles to detach; and
- Risk of surface water flow being allowed to concentrate.

Berms are less likely to create batter instability on erosion resistant materials such as rock armoured surfaces. Rock armoured surfaces have an intrinsic hydraulic surface roughness that acts in a similar way to the roughness created by berms. However, the roughness of the rock armoured surface is effectively permanent, will not rapidly erode or weather (if competent rock is chosen), and cannot be removed via fire or grazing. Hydraulic roughness from rock provides the same perceived functions as berms in terms of water trapping and improved plant establishment and growth[4]. Where hydraulic roughness of the surface is sufficiently high and erosion resistant surfaces can be created, the transient surface roughness created by berms becomes redundant, and represent an unnecessary rehabilitation cost and risk of failure.

Therefore, use of berms with rocky materials is largely a waste of time. Continuous batter slopes (e.g. single linear or concave slopes) will likely provide better stability. Berms were not considered within the runoff/erosion modelling.

6.5. Temporal variation in predicted runoff and erosion

The 100 years of annual rainfall contained within the WEPP climate sequence displays some temporal variation, though the variation is not as great as observed in climates such as the Kimberley or the Pilbara regions of Western Australia (Figure 7). One consequence of rainfall variability is that predicted annual runoff rates will also vary. Therefore, it is possible that no or very little erosion occurs in some years.

Figure 8 shows the annual runoff for the three materials as predicted by WEPP, when rainfall is applied to a 40m high batter with gradient of 18 degrees. This shows that for the materials with higher hydraulic conductivity values (soil/rock mixtures), a greater proportion of years without runoff are predicted to occur. For example, for the weathered BIF/soil mixture, more than 80% of years are predicted to not runoff. Without runoff, erosion cannot occur. For the soil on this particular batter height and gradient, ~25% of years are predicted to have no runoff.

[4] Long-term maintenance of surface roughness is highly desirable, particularly in an arid environment where very little surface contact cover is provided by vegetation.

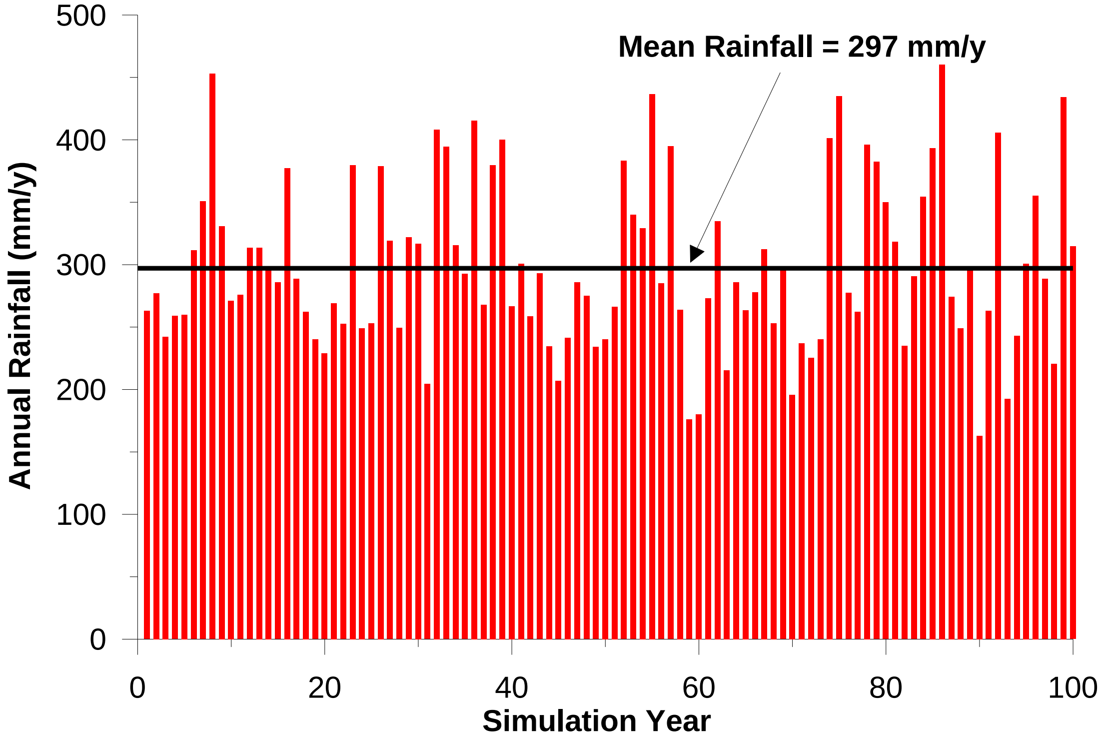


Figure 7: *Variation in annual rainfall in the 100 year climate sequence for Extension Hill used for simulations in WEPP.*

The predicted erosion rate varies even more than rainfall and runoff, as erosion is a function not only of total runoff but also the detachment characteristics of the material. Hence materials that are hard to detach tend to have lower erosion rates than more detachable materials.

Figure 9 shows the variation in predicted erosion for the three materials for 100 years of simulation of a 40m high batter with gradient of 18 degrees. Note the variation in scale of the vertical axes of the three plots.

Very few years are predicted to erode when rock is incorporated in the soil surface. This is due to their high critical shear values and low detachment rates. Further, the low erosion rates of the rock/soil mix covered slopes when compared to the soil-covered slope reduced the likelihood of rilling forming.

The two highest runoff and erosion years shown in Figure 8 and 9 (years 27 and 99) are associated with rainfall events of 156mm/day and 138mm/day respectively. The 156mm event had a duration of ~10 hours, and the 138mm event had a duration of ~6 hours. Both events have average storm intensities greater than the design intensity of a 1 in 100 year event of the same durations. Therefore, the rocky slopes are predicted to have low erosion potential even in extreme events. A soil covered slope is likely to rill heavily in an extreme event for this given batter configuration (40m high, 18 degrees gradient).

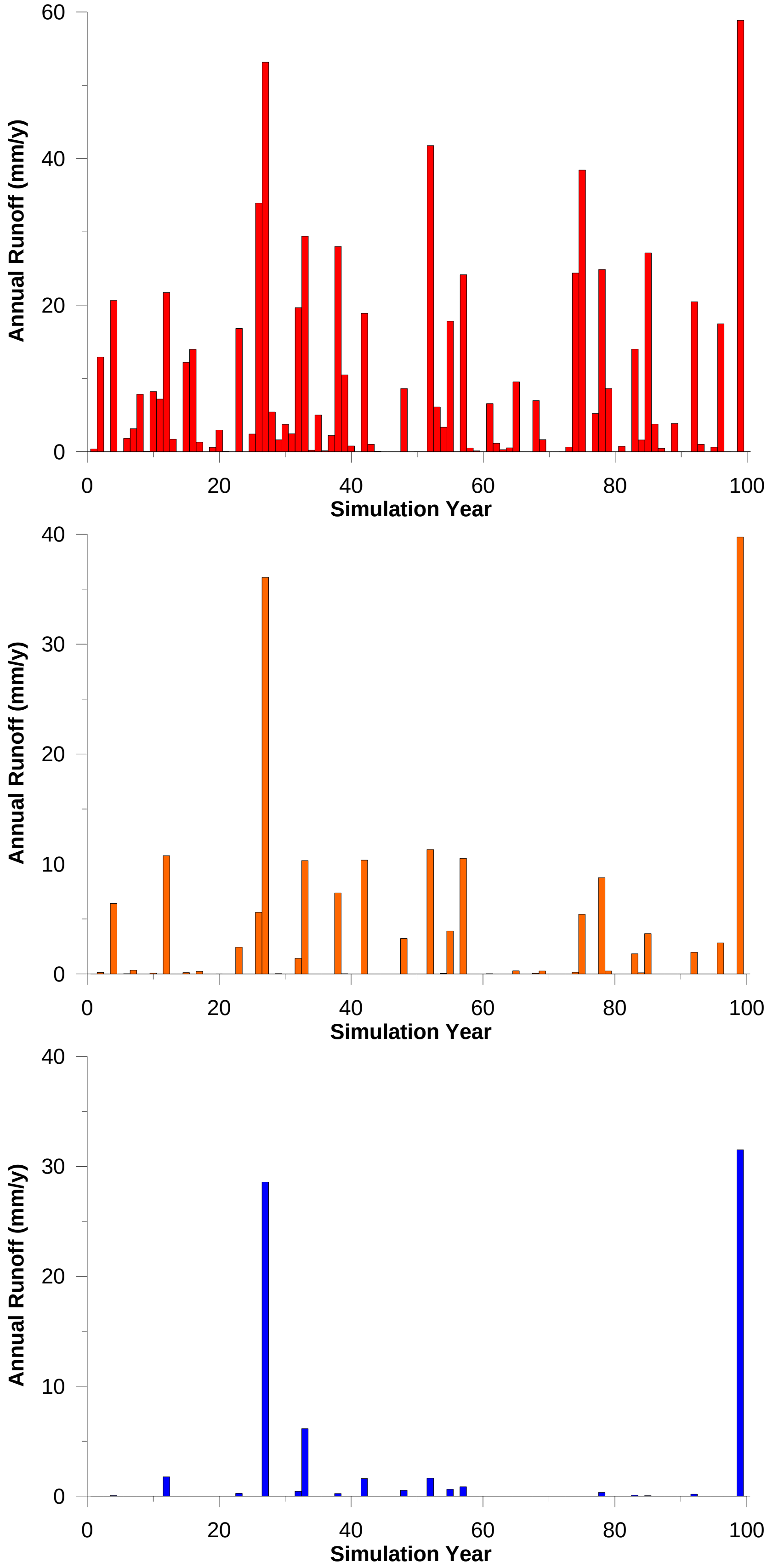


Figure 8: *Predicted runoff potential for three materials placed on a 40m high linear batter with gradient of 18 degrees: Soil (top), Fresh BIF/soil mix (middle), and weathered BIF/soil mix (Bottom)*

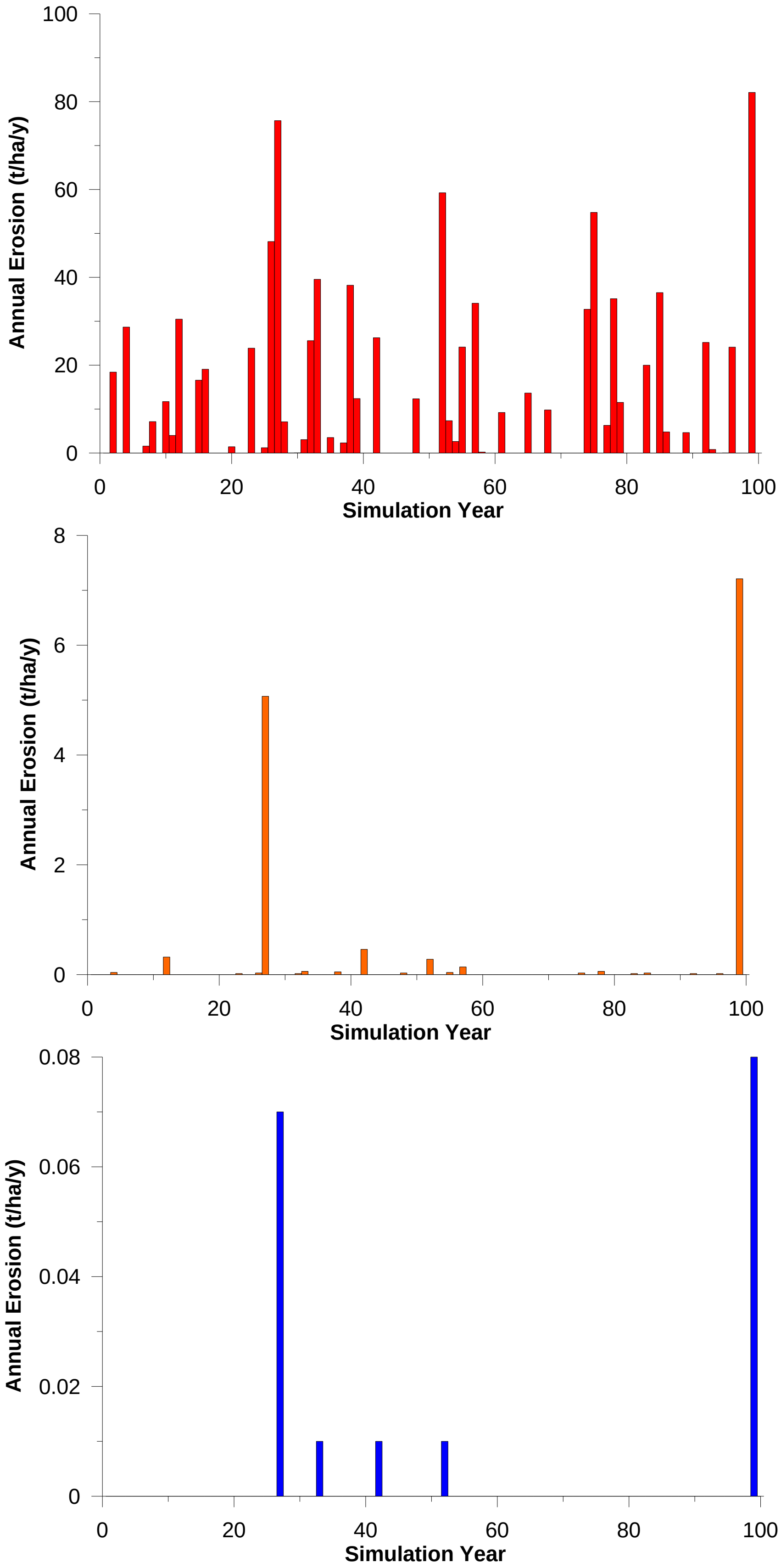


Figure 9: *Predicted average annual erosion for three materials placed on a 40m high linear batter with gradient of 18 degrees: Soil (top), Fresh BIF/soil mix (middle), and weathered BIF/soil mix (Bottom).*

6.6. Variation in erosion caused by flow concentration

Elimination of flow concentration is critical to stabilising waste landforms. This will involve eliminating features such as berms, and large rip lines that will fill over time. Table 10 shows predicted erosion rates for a 40m high batter with gradient of 18 degrees. Cells shaded red contain values that exceed the erosion threshold values set for this project.

Table 10: *Variation in predicted erosion for changing rill spacing*

Material	Rill Spacing (m)	Predicted Average Annual erosion (t/ha/y)	Largest Annual Soil Loss (t/ha/y)
Soil	5	**9.6**	82
	10	**9.8**	79
	20	**9.6**	74
Fresh BIF/soil mix	1	0.1	7.2
	2	0.6	23
	5	1.2	33
	10	1.4	33
	20	1.5	33
Weathered BIF/soil mix	1	0.0	0.1
	2	0.3	10
	5	0.7	36
	10	0.8	40
	20	0.8	40

Importantly, significant increases in rill spacing are not predicted to increase erosion rates for the rocky mixtures. A very large rill spacing of 20m is not predicted to create erosion rates that exceed the average annual erosion threshold values set. Therefore, use of a rocky surface is predicted to be relatively resistant to erosion, even if greater than expected flow concentration occurs. Given that larger rill spacings tend to be created by poorly constructed landforms, the stability of the rocky surfaces even at large rill spacings provides greater certainty that slight variations in the quality of works (e.g. rip lines slightly off contour in places) will not lead to significant slope failure. It will not guarantee low erosion rates if the quality of rehabilitation works is grossly inadequate.

6.7. Variation in slope erosion caused by the materials

Erosion rates not only vary through time, they also vary at each point along the slope. Assuming no runon from upslope, erosion rates are low at the crest of a slope, and tend to increase as slope length increases. The way in which they increase differs from material to material. In order to demonstrate how erosion rates for the different materials differ along the slope, WEPP was run for an 80m high linear batter[5] with gradient of 18 degrees (Figure 10).

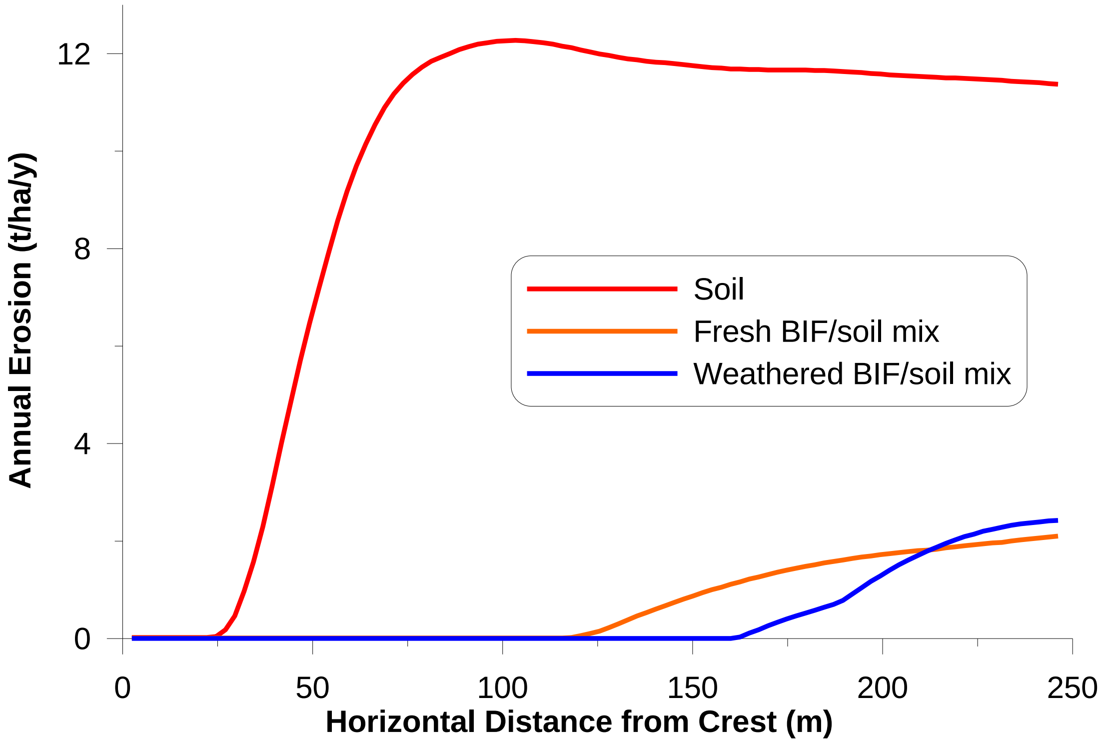


Figure 10: *Predicted average annual erosion rates along an 80 m high slope sheeted with soil, Fresh BIF/soil mix, and Weathered BIF/soil mix at 18 degrees.*

Erosion rates of the BIF/soil mixtures are limited by the rate of material detachment. These material mixtures are predicted to maintain very low erosion rates for a significant proportion of this slope, with flow accumulation increasing the shear stress and initiating rilling on the lower half of the 80m high slope. For lower slopes, rilling may not be initiated, rendering a very stable batter slope. The trend in erosion of the soil is different to that of the BIF/soil mixtures. Erosion of the soil rapidly increases to high levels near the top of the slope and maintains relatively consistent (and high) erosion rates for the great majority of the slope length.

Clearly, MGM is not going to build an 80m high waste dump. Use of a 40m high dump batter (half the horizontal distance shown in Figure 10) with a gradient of 18 degrees (half the slope length of that shown in Figure 10) would essentially ensure the development of a slope on which rilling is not predicted to readily initiate.

[5] A very high batter was used simply to ensure that observable erosion was predicted for the rocky mixtures.

7. DEVELOPMENT OF STABLE SLOPE PROFILES

Given that the preliminary assessment of material stability (section 6) has shown that use of a BIF/soil mix to sheet the waste dump batters is predicted to result in stable soil surfaces, and that use of soil alone is likely to result in construction of batter slopes infrequently subjected to highly erosive runoff, WEPP simulations were performed for a linear batter and a maximum dump height of 40m sheeted with the fresh BIF/soil mix. Use of the weathered BIF/soil mix on the same slope would also have sufficient erosional stability

Modelling of the BIF/soil mixture considered a linear batter only as:

1. A linear batter is likely to be sufficiently stable without having to modify batter shape; and
2. Construction of linear batters is simpler than constructing concave batter shapes.

Modelling constrained the horizontal length of the batter to the same length or shorter than that assumed in the current conceptual designs, ensuring that they will fit in the currently allocated footprint.

A concave batter profile was also developed for use if only soil was applied to the surface. A maximum dump height of 40m was used, and the footprint was necessarily increased to accommodate the concave profile.

7.1. Linear batter design for rocky surfaces

A 40m high linear batter profile sheeted with the BIF/soil mix is predicted to be stable when a batter gradient of 18º (32.5%) is adopted. The design batter is outlined in Table 11.

This slope profile is predicted to have an average annual erosion rate of 0.2t/ha/y, with a peak erosion rate of 1.1t/ha/y occurring at the toe of the batter.

Because it does not contain a berm, this profile has a slightly smaller footprint than the configuration that included a berm.

Table 11: *Detailed information on the recommended linear slope profile used when BIF is incorporated into the soil on the final landform with gradient of 18 degrees.*

Horizontal Distance From the Crest (m)	Batter Gradient (%)	Batter Gradient (º)
0-123	32.5	18

If the footprint is kept constant and the berm is not used, a batter is gradient of 16 degrees can be adopted and would have sufficiently low erosion potential. This alternate design batter is outlined in Table 12. Reducing gradient to 16 degrees reduces predicted average annual erosion rates to 0.1t/ha/y and predicted peak erosion rates to 0.8 t/ha/y.

Table 12: *Detailed information on the recommended linear slope profile used when BIF is incorporated into the soil on the final landform with gradient of 16 degrees.*

Horizontal Distance From the Crest (m)	Batter Gradient (%)	Batter Gradient (°)
0-123	28.7	16

Obviously, if more storage is not required, adoption of the lower gradient is preferred, but either batter gradients (16 or 18 degrees) are predicted to offer sufficient erosion stability, with predicted rates being well below the threshold values set for this project.

The 40m high batter design should still be constructed in lifts of 10 or 20m vertical height, with the lifts set back at a distance such that when the lifts are battered down during rehabilitation, the berm created during construction is removed. Table 13 lists the required setback distances, assuming an angle of repose of 37 degrees (~75%). These setback values would necessarily need to be changed by MGM if the angle of repose is not ~37 degrees.

Table 13: *Required setback distances.*

Final Slope Gradient (degrees)	Constructed Lift Height (m)	Horizontal Setback Distance Assuming 37° Angle of Repose (m)
18	10	17.5
	20	35.0
16	10	21.6
	20	43.2

Construction of dumps in lifts greater than 20m tends to increase the cost of rehabilitation as dozing is increasingly difficult. In some cases, dozing is made impossible, and trucks and excavators are required to reshape the dump (at considerably higher cost).

7.2. Concave batter design for soil covered surface

The recommended concave batter profile for a soil covered slope is given in Figure 11. Table 14 provided details of the recommended shape.

Figure 11: *Concave batter profile recommended for use when only soil is applied to the final landform surface.*

The concave option is predicted to have an average annual erosion rate of 1.0t/ha/y, and a peak erosion rate of 1.8t/ha/y. This landform should also be built in 10-20m lifts, with the setback distances modified such that the berms constructed during operations are removed. The berm width necessarily reduces as final slope gradient increases.

Table 14: *Detailed information on the recommended concave slope profile used when only soil is used on the final landform batter.*

Horizontal Distance From the Crest (m)	Batter Gradient (%)	Batter Gradient (º)
0-31	32.5	18
31-87.5	17.6	10
87.5-250	12.3	7

7.3. Landform recommendation

Addition of rock into the sandy soil provides the following benefits:

- Significantly reduces the predicted number of runoff and erosion events.
- Reduces detachment potential so that runoff events erode less material.
- Significantly increases the possible maximum batter height such that a 40m high batter could be constructed using a linear profile.
- Eliminates the need for berms which are difficult and costly to construct properly (so that they remain functional in the long term).

Therefore, use of a rocky/soil batter is recommended. The configuration listed in Table 12 (40m high, 18 degrees, no berm) is preferred. However, in footprint is limited, the configuration listed in Table 11 is also satisfactory.

Segregation and stockpiling of sufficient quantities of BIF waste will be required in order to mix into the sand during rehabilitation works. The mixing ratio of 2 parts rock to 1 part soil is required. Either fresh or weathered BIF can be used.

If insufficient rock exists to create the rocky surface, the concave design outlined in Table 14 should be adopted.

8. OPERATIONAL SURFACE WATER MANAGEMENT

The waste dump is being constructed by advancing the active tip face from the existing Extension Hill land surface towards the final waste landform footprint. During operations, surface water should be directed over the tip face (at a location away from the active tipping area) and captured by a bund wall constructed at the final footprint of the rehabilitated landform. This bund will act to hold all runoff and sediment generated from storm events with a recurrence interval of less than 100 years. Water will discharge during larger events via a rock armoured drain outlet to the south of the bund wall. The surface water plan is given in Appendix B. More detail is given below.

8.1. Bund wall and drain

The bund wall should be constructed from rocky waste material, and at rehabilitation of the dump, the bund should be incorporated into the final landform batter. The bund should be 2m tall, and can be created by paddock dumping the material into place.

Directly to the east of the bund wall, a drain 10m wide, and 0.5m deep should be constructed to convey water from the drain in events greater than 1:100 year recurrence interval. Events with shorter recurrences intervals will be retained within the drain and the water will be allowed to infiltrate and/or evaporate. The drain is designed to accommodate runoff and sediment from a 50ha area.

With this approach, there may be issues with runoff water ponding against the inner face of the bund wall and seeping under it, and possibly causing some slumping of the bund. To mitigate this, the bund wall should be compacted during construction and monitored regularly during operations for slumping.

The drain should be cleaned once its capacity reaches 30% full. The sediment removed from the drain during cleaning should be placed at the toe of the waste dump tip face, and not on the bund wall or on the outside of the bund wall (i.e. out of the dump footprint).

The drain should also be cleared of localised blockages caused by concentrated blowouts (gullies or mass wastage) that may block the flow of water from the drain to the outlet during larger events.

8.2. Drain outlet

During large runoff events, water will be allowed to discharge from the drain. Given the sandy and non-dispersive nature of the waste materials, it is anticipated that much of the sediment load will deposit within the drain and that the discharged water will have low sediment concentrations.

At the discharge point, a rocky zone should be created to further dissipate energy at the outlet. This zone should extend 5m downstream of the outlet, and be constructed flush with the surrounding land surface. Competent, slow-weathering rock with a diameter of 150-200mm should be used. The material should have <10% fines (material less than 25mm diameter).

8.3. Monitoring

The drain and the outlet must be inspected on a monthly basis or after a rainfall event. Non-compliance with agreed performance criteria will be identified by visual inspections identifying:

- accumulation of sediment off the site;
- excessive sediment accumulation on the site;
- excessive erosion on the site; and/or
- poorly maintained, damaged, or failed erosion and sediment control infrastructure.

Visual inspections should include assessment of:

- the capacity of the drain to store future sediment loads (use of sediment depth markers is recommended);
- Integrity of the inner face of the bund wall, to ensure that it was not been excessively scoured;
- Occurrences of excessive sediment deposition (whether on-site or off-site);

- Occurrences of material other than sediment being stored within the drain, e.g. waste;
- Occurrences of a blowout on the tip face causing localised blockage of the drain' and/or
- Changes to footprint size that may trigger re-evaluation of surface water management needs.

9. GENERAL LANDFORM RECOMMENDATIONS

The following recommendations refer to all landforms to be rehabilitated, irrespective of material type (unless otherwise stated).

9.1. Fertiliser application

Soil nutrient status of all materials is low (Table 5), though not expected to be high given the seasonally-controlled low rainfall regime and the local (native) vegetation that is considered to be adapted to low-fertility conditions. However, when topsoils are stripped, handled, and stockpiled, the existing nutrient in standing biomass is commonly lost. Therefore, successful and rapid re-establishment of native vegetation will require fertiliser application.

Likely fertiliser requirements are not high – N and P requirements could be supplied through application of 100-150 kg/ha of DAP (diammonium phosphate). Trace elements should also be applied.

Application of a typically immobile element such as P to the surface of soils high in iron oxides is unlikely to be successful, as it will be almost completely unavailable to plants. Therefore, incorporation of fertiliser to a depth of at least 0.1 m is strongly recommended. This could be done while incorporating rock into the soil to create the required rock armour.

Trialling fertiliser rates is encouraged, particularly because there may be considerable fixation of P in the soils, and application rates may need to be increased to obtain a response to P if fixation rates are high. It is also advisable to trial application and incorporation of single superphosphate as a source of P, as it is likely to be less susceptible to rapid immobilisation of P than, for example DAP.

9.2. Landform tops

For the recommended batter profile to be stable and sustainable, it will be critical to retain runoff on the top of the rehabilitated landform. Discharge of concentrated flows from the top of waste landforms onto the outer batter slopes is a very common cause of gullying and landform failure. This will be particularly true for Extension Hill, where the majority of runoff occurs from few rainfall events.

The risk of uncontrolled discharge of surface water from the dump top can be managed by:

a) installing appropriate crest bunding;
b) installing appropriate cross-bunding; and
c) increasing the infiltration capacity and water use of vegetation on the dump.

9.2.1. Waste dump batter crest bunding

Uncontrolled discharge of runoff from the tops of dumps is a major cause of gullying on the outer batter slopes, and dump top perimeter and cross-bunding are ***essential***. The average annual rainfall for Extension Hill is low, and extreme events also produce relatively small rainfall events. For example, a storm with a duration of 72 hours and an average recurrence interval of 100 years will deliver ~168 mm of rain at an average intensity of ~2.36mm/hr (BOM 2012). The perimeter bunds should be:

- At least 0.75 metre high;
- Thoroughly compacted and constructed of stable material;
- Have their outer face continuous with the outer batter profile and have the same surface treatments applied to it;
- Have a width across the top of the bund of at least 2 m; and
- Have their inner face sloping gradually inwards at a gradient of 1V:10H.

The gentle inward gradient ensures that any water that ponds will be ponded well away from the outer batter slope, thereby minimising the potential for any sink-hole that forms to reach the outer batter slope.

9.2.2. Waste dump cross bunding

It is critical to ensure that any runoff generated on the top of a constructed landform does not travel significant distances and concentrate to create prolonged ponding. Cross-bunding should be used to prevent flow concentrations on the flat areas of the waste dump top (Figure 12). It should be constructed such that:

- compacted bunds are 0.5 m high – 1 m wide across the top – to create cells of 1-3 ha in area on the top of the landform;
- the land surface within each cell is as close to level as possible; and
- surface ripping will hold rainfall excess close to its point of origin. Deep ripping can be tolerated on the dump top, as there is little concern of rip lines failing and causing gully erosion.

9.2.3. Infiltration capacity and vegetation water use

To maximise infiltration into the dump top, reduce the time of ponding, and increase the availability of water to vegetation, it is recommended that prior to spreading topsoil, the dump top should be ripped with dozer tines on a <1 m spacing to the greatest depth possible. The aim of the initial deep ripping is to break up any compaction of the surface due to vehicle traffic and to increase the depth of drainage. Soil should then be spread to a depth of 100-200 mm and vegetation seeded, with the seeding mix focussing on deep-rooted and perennial species. Use of deep rooted vegetation will maximise the rooting depth available to use infiltrating water (and in turn reduce the potential for deep drainage to depths below the active root zone).

9.3. Batter slopes

To achieve long-term stability of batter slopes on this landform, it is critical that flow concentration be minimised. Concentration of overland flow can be prevented by:

(a) Minimising the size of cross-slope rip lines;
(b) Ensuring good quality rehabilitation works; and
(c) Maximising surface coverage by rock.

The created rip lines should be no larger than 300mm. Creation of small rip lines is desirable to provide some initial surface roughness and to ensure thorough incorporation of the rock into the soil surface.

Note that – given the low annual rainfall and high Aluminium levels for some soils – vegetation is highly unlikely to establish at levels sufficient to cause any significant reduction in erosion potential. Vegetation is aesthetically desirable, but is unlikely to modify runoff or erosion on the batter slopes.

Given the extreme importance of minimising flow concentration on the batter slopes, it will be essential that construction does not create flow-concentrating features. Of particular concern are:

- Rip lines off contour;
- Irregular dump footprint shapes (see section 8.6); and
- Sharp corners which render ripping on the contour extremely difficult.

If possible, equipment used for rehabilitation works should have precision guidance systems installed. Operators should be highly skilled and experienced. It is noted that rehabilitation earthworks are significantly different to earthworks typically conducted by mining staff, and requires great precision and adherence to the specified designs if successful rehabilitation is to be achieved.

9.4. Dump construction

When constructing the waste landform, it is recommended that waste be placed in lifts with the spacing between the lifts set to minimise the amount and distance of material movement required during final reshaping to exactly balance the cut and fill. Minimising the volume of material to be moved during reshaping can significantly reduce rehabilitation costs (savings of >50% have been observed).

As much as possible, each lift should be completed prior to construction of the next lift. Failure to complete lifts prior to commencing the next lift tends to increase the costs and complexity of subsequent rehabilitation works.

9.5. Sheeting batter slopes with rock armour

Waste dump batters being sheeted with a rock/soil mixture must use rock with a D_{50} of ~70-100mm and a rock particle density >2.7g/cm³. This rock/soil mixture will form the growth media layer. Note that a rock material with a D_{50} of 70-100mm will contain a range particle sizes ranging from some fine-grained material to rocks much larger than 100mm diameter (Figure 12). The sourced rock should have no more than 10% of the rock greater than 300mm, and no more than 10% of the rock less than 25mm in diameter. Photographic techniques are available to derive particle size distributions of waste rock stockpiles, and could be used in this case as evidence that these criteria are satisfied. Key requirements for the sheeting layer include:

- Sufficient rock should be added such that >30% cover is achieved (Figure 12 shows surface with projected cover of ~30%).
- A sufficiently thick layer of rock/topsoil mixture (at least 0.5m) should be applied to reduce the risk of exposure of any underlying finer grained waste.

Figure 12: *Example of a rocky surface with a D50 of ~80 mm. The tray in which the surface is housed is 0.75 m square.*

Both these requirements can be achieved by laying a 200mm deep layer of rock sheeting over the slope initially, and then mixing a 200mm deep layer of rock armour material into 100mm of soil. Establishment of this 300 mm thick sheeting layer can be practically achieved by:

- Spreading the rock to be used as armour over the underlying waste at a thickness of 400 mm;
- Spreading topsoil over the rock to be used as armour at a thickness of 100mm (at this point fertiliser should also be spread);
- Ripping the two layers together to a depth of ~300mm with triple tines spaced < 1 m apart. Ripping with a single ripper is not recommended.

9.6. Landform shape

Where batters are not linear or convex in plan view, there is potential for water-concentrating areas (indents) to be created (Figure 13). Indents may be large or quite small, but are of concern irrespective of magnitude. Such features should be avoided if at all possible.

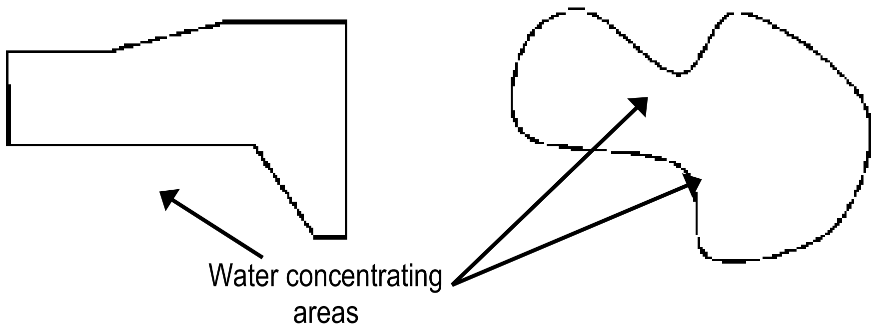


Figure 13: *Conceptual plan view of a waste landform showing flow-concentrating features.*

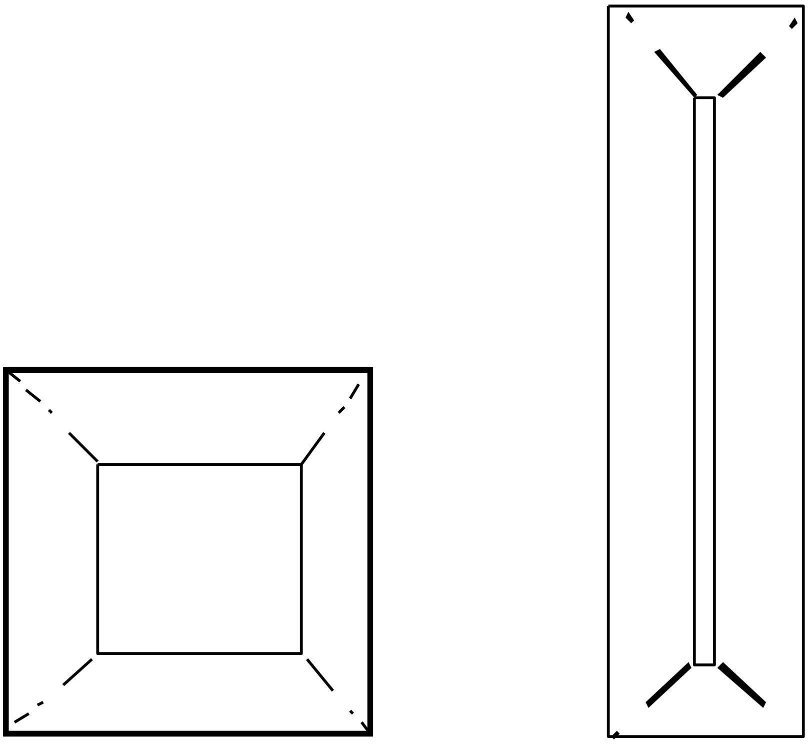
From Landloch's experience with many waste dumps across Australia, one consistent observation is that erosion (rills, gullies) occurs most frequently on corners of waste dumps. Dozers are less successful at cross-ripping on-contour when the dozer works around corners, irrespective of the skill of the operator. Not surprisingly, the problem is accentuated when the corner is sharp. Ideally, all corners should have a radius of curvature of at least 100 m.

Landform shape also influences the potential cost of rehabilitation. Rehabilitation of batter surfaces is considerably more expensive than rehabilitating flat waste landform tops (it is estimated that batters are 4 times more expensive that dump tops to rehabilitate). Therefore, wherever possible and within the design specifications outlined in this report, the surface area of the waste dump top should be maximised and the perimeter of the batters minimised. This can be done by changing the landform shape. Landforms that are more circular or square in plan view tend to have smaller perimeters and larger dump tops than do longer, more rectangular waste landforms (for dumps that store the same volume of waste). Modifying shape can also alter the storage volume available.

As an example (sourced from Chandler, Willgoose, and Hancock 2002), Figure 14 shows two waste landforms of similar footprint, heights, and slope gradients. However, Dump A differs from Dump B in that:

- It stores 35% more waste;
- Its perimeter is 20% less; and
- Its waste dump top is 3.5 times larger.

Therefore the costs of rehabilitation would be less per unit volume of waste rock stored for Dump A than Dump B. Assuming a cost of $10,000/ha and $40,000/ha for rehabilitating the dump top and batters respectively, Dump A would cost 17% less to rehabilitate than Dump B.



Dump A **Dump B**

Figure 14: *Two waste landforms with similar footprint, but different storage volumes and batter perimeter (source Chandler, Willgoose, and Hancock 2002).*

9.7. Monitoring strategies

Waste dump monitoring programmes must be consistent with site requirements. Otherwise, the data collected are likely to be of little value.

Often erosion monitoring is interpreted to mean erosion measurement, and there are certainly situations where the rate of erosion is of primary concern. There are also situations where trends in erosion rates are just as important as actual erosion rates. For example, knowing whether a gully is stabilising or becoming more active is often more important than information on the actual rate of erosion from the gully.

Erosion monitoring may include:

- Measurements of average erosion rates
- Measurements of gully/rill activity,
- Sediment concentration in runoff,
- Presence/absence of gullies.

Measurement of erosion trends (not withstanding any site requirements to the contrary), is likely to be more beneficial than measurement of actual erosion rates. Demonstration that erosion rates are not increasing or are trending downwards and that the frequency of rills and gullies is not increasing is likely to effectively demonstrate that the constructed landform is stable. These data can then be compared with predictions made by the WEPP model as a means of validating the model results and gaining further confidence that the predicted results are being achieved on site. Where erosion trends differ, remediation works can be put into action rapidly if needed, and can more readily target the cause of the instability. Often, remediation works focus on the areas where materials are eroding and depositing, rather than considering more broadly the landscape features that are the cause of flow concentration and/or the elevated detachment potential of the constructed surfaces.

Monitoring of vegetation and fauna should also be performed. However, establishment of landscape stability is a prerequisite to any functional ecosystem and monitoring of vegetation and fauna prior to establishment of a stable soil profile is likely to be of little value.

10. KEY PERFORMANCE INDICATORS

The overarching objective of most rehabilitation related closure actions is to establish a sustainable ecosystem that is as similar to the pre-existing ecosystem as can be achieved within the limits of recognized good practice rehabilitation techniques and the post-mining environment (adapted from ICMM, 2005). The assessment and completion criteria outlined in the following section aim to achieve this objective, acknowledging that to achieve this, actions must be taken throughout the “landform’s life”. As such, the “life” of the waste landform is divided into the following stages:

6. Planning;
7. Landform Construction;
8. Initial Rehabilitation Performance;
9. Monitored Rehabilitation Performance; and
10. Sustainability.

10.1. Rehabilitation stages

The **Planning** stage includes goals that are necessarily fulfilled prior to landform construction commencing. These goals will influence the style of landform design employed, the final landform shape (gradients, and height) and footprint. Additionally, rehabilitation requirements set at the planning stage will have ramifications for dumping procedures and rehabilitation resource provisioning (topsoil and rock sourcing and stockpiling). Many criteria associated with this stage are performed routinely and hence completion will be straightforward. Failure to properly plan can lead to rehabilitation failure.

In terms of timing, it can be expected that Planning should be relatively closely followed by consideration of **Landform Construction** actions (certainly before construction proceeds too far). The assessment and completion criteria at this stage broadly relate to quality control issues during construction. These are essential to rehabilitation success. These criteria should be used to ensure (and document) that construction has complied with the designs developed during the planning process. In this report, the Landform Construction stage also includes traditional rehabilitation activities, reshaping, rock augmentation, ripping, seeding etc. This is in recognition that the mining department is likely to be responsible for these actions, and therefore their successful completion **to specification** should remain their responsibility.
It must be noted that land rehabilitation activities are vastly different to waste dump construction activities, even though they may use similar machinery. Rehabilitation actions require considerable skill and finesse to successfully complete. Rehabilitation should be undertaken by skilled operators with experience in successful land rehabilitation.

Once rehabilitation activities are completed successfully, it is suggested that the rehabilitated dump should then be assessed on the basis of its **Initial Rehabilitation Performance** over the period 12-24 months. This is dependent on weather conditions and whether there has been potential for consolidation of soil surfaces and suitable vegetation establishment. If problems are identified at this stage, then early remedial actions can be initiated.

If initial performance is satisfactory, the dump would then move into a phase of **Monitored Rehabilitation Performance**. During this phase the vegetation community develops and a range of soil processes continue to establish. Landform stability should continue to improve in response to surface armouring and consolidation, and development of some litter and root mass in the surface layers. This is effectively the transitional stage from “newly rehabilitated land” to “established rehabilitated land”.

Once monitored performance shows that the landform has achieved **Sustainability** (on the basis of monitoring information), it can be classified as having been successfully rehabilitated.

10.2. Landform stability related completion criteria

Table 15 below outlines the landform surface stability related rehabilitation goals, associated criteria, and quantitative measures and/or techniques used to address these criteria for the 5 rehabilitation stages outlined above. Some of these criteria may have already have been met through existing work, while others will require closure plans to be made to meet these criteria.

These criteria relate to landform stability, and as such criteria relating to vegetation have not been provided. Some material characterisation criteria have been included in the tables (i.e. ARD) but have not been expressly considered in this report. Financial provisioning has also not been considered, however, it is assumed the sufficient financial provisioning is made to ensure appropriate rehabilitation and closure tasks can be performed. The need for these should be established and incorporated along with the land stability criteria into the site's closure plans.

Table: 15: *Suggested landform stability related closure rehabilitation assessment and completion criteria.*

Stage 1 - Planning		
Goal	**Assessment and Completion Criteria**	**Suggested Quantifiable Indicator Measure(s) or Technique(s)**
Define goals for rehabilitated landform	Rehabilitated land use determined.	• Assessment of existing land use capabilities.
	Acceptable levels of off-site impacts defined.	• Average values of suspended sediment in runoff not exceeding background levels by an agreed amount (suggest 20%). • Dust levels in air not exceeding background levels by agreed amount.
	Acceptable visual appearance defined by stakeholders.	• Dump height no higher than existing hills in region. • Absence of gullies.
	Stakeholder consultation completed & agreement achieved.	• Proposals presented to stakeholders and receiving majority support among stakeholders.
Characterisation of soils and wastes	ARD potential identified and managed where appropriate.	• Determine presence of potentially acid-forming materials using standard test methods. Where present, develop an acid drainage management plan.
	Other contaminants in waste rock (e.g. heavy metals) identified and managed where appropriate.	• If presence of heavy metals is indicated by mineralogy, assess using standard heavy metal screening methods. Where present in high concentrations, assess potential mobility using water/solute modelling. If present and mobile, develop management plan consistent with best practice.

	Waste rock competence and weathering potential assessed.	• For rocks to be used as armour on the surface of the waste landform, assess lithology, rock density, mean rock particle size, water absorption. If material does not meet the following criteria, it should not be used:
		  ◦ Density >2.7 g/cm^3;
		  ◦ Mean rock size 70-100mm,
		  ◦ <10% rock >300mm
		  ◦ <10% rock <25mm
		  ◦ Water absorption to be less than 5%;

	Sufficient volume of growth media to cover waste rock landform available.	• Soil survey of disturbance areas, including assessment of depths of suitable growth material able to be retrieved from disturbance areas.
	Sufficient volume of other rehabilitation resources (e.g. rock) available.	• Resource inventory report listing available volumes of suitable rock types.

Table: 15 cont'd: *Suggest landform stability related closure rehabilitation assessment and completion criteria.*

Stage 1 cont'd - Planning		
Goal	**Assessment and Completion Criteria**	**Suggested Quantifiable Indicator Measure(s) or Technique(s)**
Characterisation of soils and wastes (cont'd)	Suitable physical and chemical properties of growth media (pH, salinity, dispersion, fertility).	• pH and Electrical Conductivity (EC), exchangeable cations, Cation Exchange Capacity, Exchangeable Sodium Percentage (ESP), Emerson Dispersion Index, Total N, Total P, available P, Available K, available K, Organic Carbon, Trace elements (Cu, Fe, Mn, Zn).
	Erodibility of growing media assessed.	• Field or laboratory measurements of runoff and erosion used to develop WEPP erosion model parameters.
Preparation of conceptual stable landform design	Stability (erosion) of landform demonstrated.	• WEPP simulations using site parameters, with predicted average erosion <5 t/ha/y and peak erosion at all points <10 t/ha/y.
	Stability in extreme events demonstrated	• WEPP simulations show low erosion rates in extreme events
	Potentially acid-forming materials and fibrous materials suitably encapsulated.	• Acid forming and fibrous materials management plan consistent with best practice.
	Contingency plans for erosion/stability risks developed.	• Monitoring plan developed and necessary actions identified for dealing with potential instability.
	Appropriate runoff management.	• Runoff management plan, including provisions for control of water on dump top, from the top to the toe of the dump, and appropriate disposal from the toe to the receiving environment. • Runoff management plan for use during dump construction.
	Engineering designs of structures completed.	• Certified engineering designs e.g. toe drains, sediment basins.
	Landform design is consistent with agreed rehabilitated land use.	• Landform batter slope gradients and roughness such that agreed land use is not impeded.
Rehabilitation resources provisioning	Sufficient space for soil stockpiling allowed in site layout.	• Stockpile locations of sufficient size present on mine layout. • Stockpiling of topsoil no deeper than 2 m.
	Sufficient space for armour rock stockpiling allowed in site layout.	• Armour rock stockpile location of sufficient size present on mine layout.

Table: 15 cont'd: *Suggest landform stability related closure rehabilitation assessment and completion criteria.*

Stage 2 – Landform Construction		
Goal	**Assessment and Completion Criteria**	**Quantifiable Indicator Measure(s) or Technique(s)**
Ground disturbance	Sufficient growth media resources retrieved and stockpiled appropriately during soil stripping.	• Periodic checks during operation, and post operation check & sign-off.
	Sufficient rock retrieved and stockpiled appropriately during ground clearance and mining.	• Periodic checks during operation, and post operation check & sign-off.
Construction	Waste materials dumped consistent with final landform design parameters.	• Periodic checks during operation, and post operation check & sign-off.
	Underlying spoils consistent with design.	• Periodic checks during operation, and post operation check & sign-off.
	Contaminants managed appropriately during construction.	• Periodic checks during operation, and post operation check & sign-off.
Reshaping to final landform shape	Outer batter slopes constructed to design profile (±2°).	• Post operation check and sign-off.
	Topsoil spread to specified depth (±5 cm).	• Post operation check and sign-off.
	Rock armour applied as specified.	• Post operation check and sign-off.
	Bunding on waste dump top constructed to specification.	• Post operation check and sign-off.
	Surface water control structures constructed to specification.	• Post operation check and sign-off.
Batter slope ripping	Completed to design depth (±10 cm).	• Post operation check and sign-off.
	Ripping completed on surveyed contour with no deviations >0.2 m vertical.	• Post operation check and sign-off.
	Specified degree of soil/rock mixing achieved (±10% cover).	• Post operation check and sign-off.
Fertilisers and amendments	Fertiliser applied at specified rates.	• Certification by contractor.
	Fertiliser incorporated where specified.	• Certification by contractor.

Table: 15 cont'd: *Suggest landform stability related closure rehabilitation assessment and completion criteria.*

Stage 3 – Initial Rehabilitation Performance		
Goal	**Assessment and Completion Criteria**	**Quantifiable Indicator Measure(s) or Technique(s)**
Erosion stability	Absence of gullies or existing gullies stabilising.	• Geomorphic Gully Assessment System (GGAS).
	Minimal rilling and/or evidence of rills stabilising.	• Ecosystem Function Analysis (EFA) rill assessment system and geomorphic indicators.
	Bunding suitable (no slumping, breakouts, tunnelling).	• Report on bund assessment.
	Rill erosion rates and location consistent with model predictions.	• Comparison of observed rill erosion with modelled rill erosion using erodibility parameters developed during landform design process.
	Surface of landform is armouring.	• Rock cover estimates at specified level.
	Soil surface stability increasing.	• Landscape Function Analysis (LFA) soil stability methodology.
	Remediation actions developed (if stability is unsatisfactory).	• Remediation action plan.

Stage 4 – Monitored Rehabilitation Performance		
Goal	**Assessment and Completion Criteria**	**Quantifiable Indicator Measure(s) or Technique(s)**
Erosion stability	Absence of gullies and existing gullies stabilising.	• Geomorphic Gully Assessment System (GGAS).
	Minimal rilling and evidence of rills stabilising.	• Ecosystem Function Analysis (EFA) rill assessment system and geomorphic indicators.
	Bunding remains suitable (no slumping, breakouts, tunnelling).	• Report on bund assessment.
	Surface armouring fully developed.	• Rock cover estimates reaching constant value at specified level.
	Soil surface stability approaching self-sustaining levels.	• Landscape Function Analysis (LFA) soil stability methodology.

Table: 15 cont'd: *Suggest landform stability related closure rehabilitation assessment and completion criteria.*

Stage 5 – Sustainability		
Goal	**Assessment and Completion Criteria**	**Quantifiable Indicator Measure(s) or Technique(s)**
Erosion stability	Absence of gullies or existing gullies stabilised.	• Geomorphic Gully Assessment System (GGAS).
	Minimal rilling and evidence of rills stabilised.	• Ecosystem Function Analysis (EFA) rill assessment system and geomorphic indicators.
	Surface armouring fully developed.	• Rock cover estimates reached constant value at specified level.
	Soil surface stability approaching self-sustaining levels.	• Landscape Function Analysis (LFA) soil stability methodology.
Geomorphic risk assessment	Low potential for flow concentration.	• Evaluation of stability of batters and waste dump tops.
	No visible sources of concentrated flows.	• Evaluate presence of uncontrolled surface flow discharges and concentration.
	Bunding remains suitable (no slumping, breakouts, tunnelling).	• Report on bund assessment.

11. CONCLUSION

A rehabilitation and landform design has been developed for the Extension Hill hematite waste dump.

It is based on:

- Consideration of the prevailing climate and its erosivity;
- Known factors critical for stability of natural and disturbed surfaces;
- Characterisation of the erodibility of the typical surface materials present;
- Computer simulations of runoff and erosion on the range of typical slopes and surface materials, with consideration of levels of cover needed to achieve stability; and
- Landform development simulations to consider the interactions between dump shape, material properties, and flow concentration.

Consequently, the closure recommendations provided are based on site data and its interpretation using well-validated procedures.

12. REFERENCES

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13. DISCLAIMER

1. The calculations leading to results listed in the attached document are based on experimental information on soil/waste properties. They are also based on climate information which was supplied to the person making the calculations. It remains impossible to check the accuracy and relevance of that climate information, and, therefore, relevance of the results shown in the attached document are only probabilities (chances).
2. Erosion calculations used the WEPP model. Landloch can take no responsibility for any errors that may be the result of inadequacies in the coding or content of that model.
3. The information relating to weather patterns and other information, on which the calculations for the attached document are based, was supplied to Landloch and used to develop a WEPP climate file. While all endeavours have been used to check the information, Landloch cannot guarantee that there are no inaccuracies in the data, which in turn may generate errors in calculations or modelling outputs.
4. It is impossible and has been impossible to verify the accuracy or relevance of any of that information.
5. The calculations in the attached document are based on that unverified climate information.
6. It is not possible to guarantee that any prediction or result contained in the attached document will or might occur.
7. No guarantee is given that any prediction or result contained in the attached document will or might occur.
8. All models used in the preparation of information included in this document can have errors or inadequacies that may generate miscalculation and provide data that could be misleading. Whilst making every endeavour to ensure these limitations of the models do not impact on the final recommendations, management options and landform design, Landloch cannot guarantee the complete accuracy of interpretation and therefore limits liability for the results of actions resulting from implementation of this report to the fees charged.

14. GLOSSARY OF TERMS

Consolidation refers to increases in soil bulk density and cohesive strength that occur as a consequence of repeated wetting and drying under natural conditions.

Armouring refers to the accumulation of coarse (rocky) particles at the soil surface due to preferential removal of finer size fractions.

Interrill erosion describes the detachment and movement of particles by the combined action of raindrops and shallow overland flows. When a drop impacts the flow, the resulting turbulence ejects particles up into the flow, and the particles remain in the flow for a period of time, during which the particle travels some distance in the direction of flow. In the absence of raindrop impact, such shallow flows have little or no erosive capacity.

Rill erosion refers to the detachment and transport of sediment by concentrated lines of overland flow. Rill development is associated with development of characteristic turbulence patterns that cause the incision of rill channels. In agriculture, rills are defined as flow channels small enough to be removed by tillage.

Gullies are defined in agriculture as overland flow channels too large to be removed by tillage.

Erodibility refers to the rate of detachment and/or movement of soil in response to some erosive force. The exact definition of erodibility varies from model to model, depending on the types of erosive forces considered. Equally, the units of erodibility may seem somewhat counter-intuitive, but are a function of the units used in calculating erosive forces. Some models, such as WEPP, use different erodibility factors for different erosion process.

Rill erodibility (WEPP) is the rate of detachment in a rill per unit of effective shear stress.

Critical flow shear stress for rill initiation is the flow shear stress at which rill detachment commences.

Flow shear stress is a function of flow depth and gradient, with effective shear stress being calculated as total shear less critical shear.

APPENDIX A: GENERATION OF A WEPP CLIMATE SEQUENCE FOR EXTENSION HILL MINE

INTRODUCTION

Climate input files for Extension Hill are needed to simulate runoff and soil loss with the Water Erosion Prediction Project (WEPP) model. For each day of simulation, WEPP requires ten daily weather variables:

- Precipitation (mm),
- Precipitation duration (hrs),
- Peak storm intensity,
- Time to storm peak,
- Average minimum temperature,
- Average maximum temperature,
- Dew point temperature,
- Solar radiation,
- Wind speed, and
- Wind direction.

Of these, the four precipitation-related variables (underlined in list above) are of particular importance because previous studies have shown that predicted runoff and soil loss are most sensitive to these precipitation variables (Nearing *et al*., 1990; Chaves and Nearing, 1991).

For most sites around the world, complete historical weather data on these variables are not available. To use WEPP for runoff and erosion prediction, synthetic weather sequences that statistically preserve the mean and variations in the historical observations are required. CLIGEN is a stochastic weather generator that can be used to provide WEPP climate input files. CLIGEN has been extensively assessed for a wide range of climates in Australia, and it was found that CLIGEN was most suitable to provide the required climate input for WEPP to predict runoff and soil loss in Australia (Yu, 2003).

This report briefly summarises how climate parameter values were prepared for CLIGEN to generate 100 years of daily data for the Extension Hill site.

DATA AND METHOD

Daily patched pointed climate data were sourced from the Bureau of Meteorology's weather station at Ninghan Station (station 7068). Data exists at this station from 1905 to present, for an effective rainfall record length of 94.3 years Patched point data is observed data with missing or low quality values patched with interpolated data.

The Patched Point data were used to derive daily rainfall, temperature and solar radiation climate parameters for the site.

Pluviograph (rainfall intensity) data are available from the BOM's Wongan Hills Research Station (8138), 145 km from site. It contains data from 1952 to 2010 with an effective record length of 47.7 years. These data were used to generate rainfall intensity parameters for the site.

Using the data sets outlined above, the following parameter values were computed and used for the site:

- Mean daily precipitation on wet days for each month,
- Standard deviation and skewness coefficient of daily precipitation for each month,
- Probability of a wet day following a dry day for each month,
- Probability of a wet day following a wet day for each month,
- Mean daily max. temperature for each month,
- Standard deviation of daily max. temperature for each month,
- Mean daily min. temperature for each month,
- Standard deviation of daily min. temperature for each month,
- Mean maximum 30-min rainfall intensity for each month, and
- Probability distribution of the dimensionless time to peak storm intensity.

These parameter values were assembled to create a CLIGEN parameter file for the site. Use of generated wind data has been switched off because no long-term wind data were available for the site, and Priestley-Taylor's method for estimating the potential evaporation will automatically be used by WEPP.

A 100-year climate sequence was generated using CLIGEN version 5.1 (Yu, 2002). The generated file is called NinghanStation.cli, and was generated for the arbitrary dates from 1 Jan 2100 to 31 December 2199.

DATA ASSESSMENT

The quality of the simulated climate sequence was compared with the patched point data.

The long-term mean annual rainfall for the Ninghan Station data set is 283 mm and 302mm for the CliGEN climate sequence. The WEPP climate file contains higher average rainfall values than the observed data from Ninghan Station, resulting in a conservative assessment of runoff potential. Figure A-1 shows that mean monthly rainfall values are well preserved.

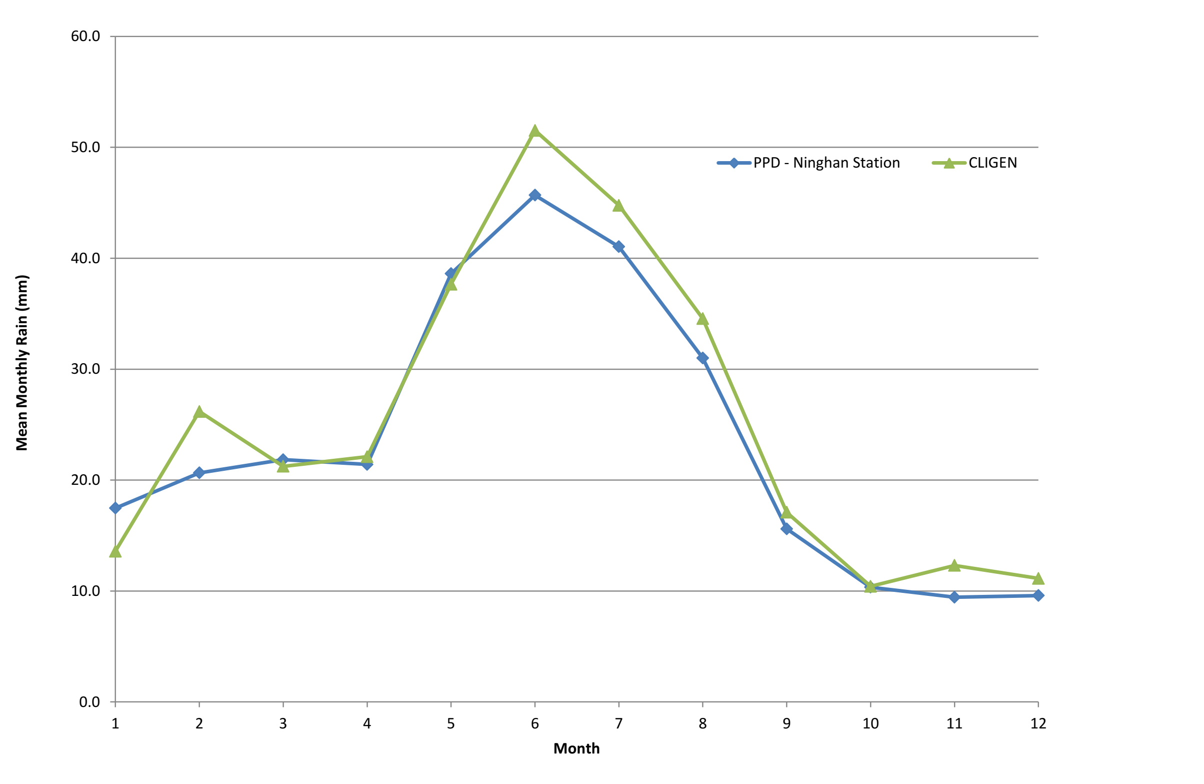

Figure A-1: *Observed and CLIGEN simulated mean monthly rainfall for the Extension Hill site.*

The extreme daily rainfall events were also compared. Figure A-2 shows the annual daily rainfall compared with their average recurrence interval (ARI) for both the observed data and CliGEN data sets. It can be seen that for this particular sequence, the observed and simulated maximum daily rainfall totals match quite well, especially given the fact that rainfall at the site is highly variable. It shows that the extreme events in the CliGEN dataset occur at the same frequency as observed and measured from climate data.

CONCLUSION

A 100-yr CLIGEN-generated climate file for the Extension Hill site was developed based on observed data (daily data and rainfall intensity data) from the Ninghan Station and Wongan Hills Research Station weather stations operated by BOM.

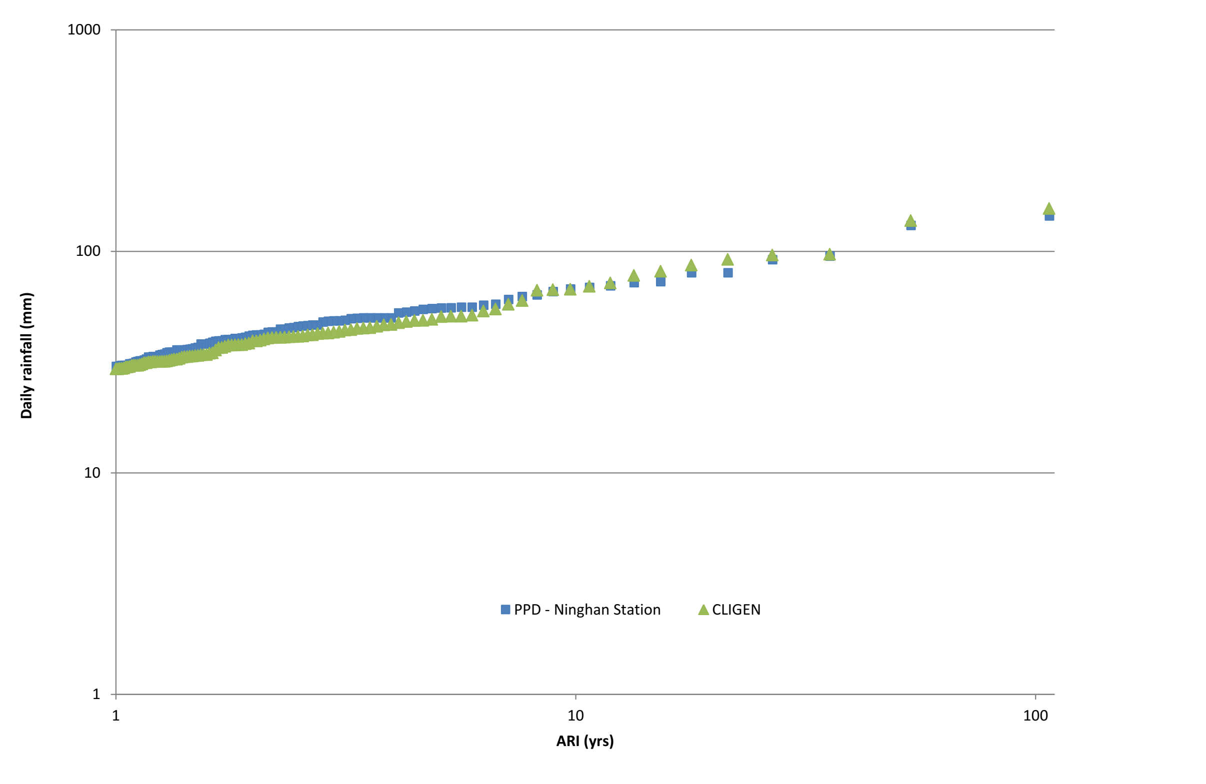

Figure A-2: *Maximum daily rainfall amount versus average recurrence interval.*

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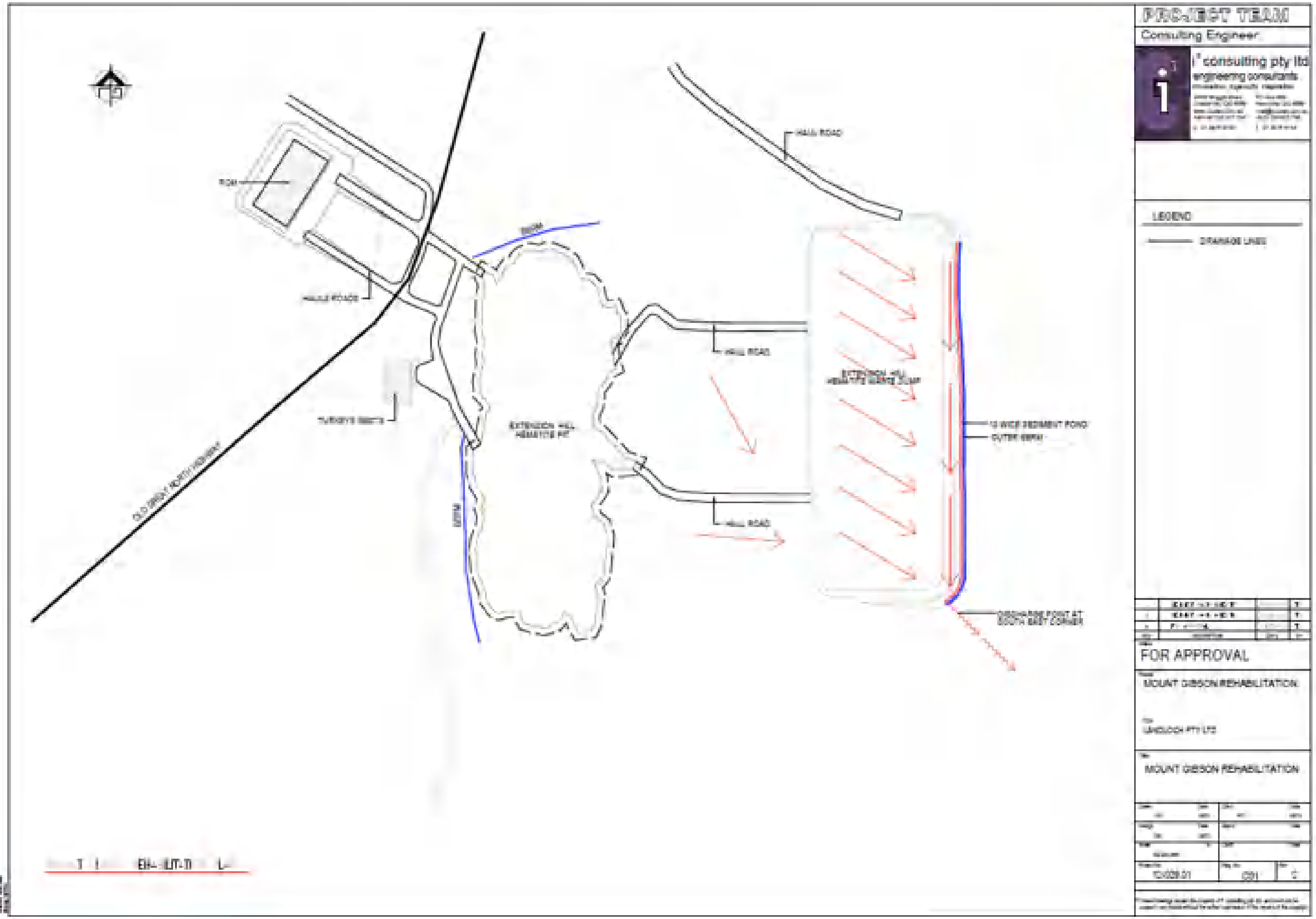
APPENDIX B: OPERATIONAL SURFACE WATER MANAGEMENT PLAN


PROJECT TEAM
Consulting Engineer
i3 consulting pty ltd
engineering consultants
LEGEND
DRAINAGE LINES
HAUL ROAD
HAUL ROAD
HAUL ROAD
EXTENSION HILL HEMATITE PIT
FOR APPROVAL
MOUNT GIBSON REHABILITATION
MOUNT GIBSON REHABILITATION

Appendix D Stakeholder Liaison Management

Hazard	Outcome	Initial Controls
Incorrect information provided to stakeholders	May impact on MGM's reputation	• Only senior management and nominated HSEC team members to liaise with stakeholder.

Step #	Work Procedure
	Responsibility The HSEC Department are responsible for managing and coordinating the implementation of this work instruction.
1	**Identified Stakeholders** The following stakeholders have been identified as key stakeholders for the Project: • Department of Environment Regulation • Department of Parks and Wildlife • Office of the Environmental Protection Authority • Department of Mines and Petroleum • Department of Water • Department of the Environment (Commonwealth) • Department of Health • Department of Agriculture and Food • Shire of Yalgoo • Shire of Perenjori • Shire of Dalwallinu • North Central Malleefowl Conservation Group • Australian Wildlife Conservancy • Bush Heritage Australia • Pindiddy Aboriginal Corporation • Extension Hill Pty Ltd • The Badimia People
2	**Regular Stakeholder Communication** Regular communication, involvement and participation with stakeholders to discuss a variety of topic areas is to be undertaken by the site General Manager, HSEC Manager and/or a nominated member of the HSEC Department as follows: • Communicate at least quarterly with each of the surrounding stations to ensure the Proponent is a

	'good neighbour' and to discuss concerns/complaints. • Communication at least quarterly with the Shires of Yalgoo and Perenjori to update the Shire's Elected Members and/or staff with the Project's progress and to provide a forum for potential issues to be raised and addressed. • Meet annually with Pindiddy, ABHF, AWC, DPaW and Shires of Yalgoo, Dalwallinu, Perenjori and North Central Mallefowl Conservation Group to discuss environmental issues such as weed management, bush fire management, protection of Mallefowl and introduced fauna species management. • Liaising with relevant stakeholders including DER, DMP, the Shires of Yalgoo and Perenjori, Australian Wildlife Conservancy, Australian Bush Heritage Fund, Pindiddy Aboriginal Corporation, Ninghan Regional Conservation Association, the Widi Mob, the Badimia People and Extension Hill Pty Ltd (as a minimum) on a regular basis, but at least every two years as part of planning for the closure of the mine. • Regular attendance and active participation at Regional Conservation Association meetings. All key stakeholders are to have contact details for a relevant person from the HSEC Department or senior management within MGM so that issues can be raised directly as they arise.
3	**General Community** Additionally, appropriate strategies are to be employed to inform members of the general community. These may include: • Printed material • Information on the internet • Central contact point for public liaison • Public displays • Open days/tours • Comments/complaints register will be established
4	**Records** Meetings with key stakeholders are to be recorded through formal minutes of the meeting. Telephone communications with key stakeholders are to be recorded on **08.19 FM01 Record of Telephone Communication**. These forms are to be stored in the folder G:\1.0 HSEC Management System\08.00 Environment\08.19 Community\Telephone Communications.
5	**COMMUNICATION/TRAINING** All personnel affected by the content of this document will receive further instruction or explanation on the relevant parts of the document, if required.

Reference Documents	• *08.19 FM01 Record of Telephone Communication*

Rev	Date	Revision description	By	Check	Approved
0	29.4.2008	Developed	J. Sackmann	T. Darley J. Ranford	15.10.2008
1	29.08.2010	Issued	J. Sackmann	J. Ranford	29.08.2010 J. Ranford
2	05.05.2014	Reformatted and Revised	J. Sackmann	S. Churchill G. Hewitt	16.05.2014 S. Churchill

DECLARATION AND VERIFICATION OF SWI

Any changes to the working/task/process conditions, a JHA is to be completed

A Safe system of work shall be discussed and understood prior to undertaking this task

EMPLOYER: ___________________ **DEPARTMENT:** ____________________

EMPLOYEE NAME: _________________________________

EMPLOYEE SIGN: _________________________________

SUPERVISOR NAME: _________________________________

SUPERVISOR SIGN: _________________________________

DATE: _________________________________

Appendix E Letter from Perenjori Shire re: Rail Siding Closure

SHIRE OF PERENJORI

Fowler Street, Perenjori, 6620
PO BOX 22, PERENJORI, 6620 Western Australia
Telephone: 08 9973 1002 Facsimile 08 9973 1029
E-mail: admin@perenjori.wa.gov.au

WESTERN AUSTRALIA'S
WILDFLOWER COUNTRY

Your Ref :-
Our Ref :-
Enquiries :-

12 September 2008

Mr Peter Panek
Extension Hill Haematite
Project Manager
Mount Gibson Mining
PO Box 55
West Perth WA 6872

Dear Peter

Rail Siding Taking Over by Perenjori Shire

You will recall during your discussions with the Shire that Council expressed an interest in taking over the Perenjori Rail Siding when Mount Gibson Iron's Extension Hill project is complete.

As you know the Shire of Perenjori is seeking to diversify the local economy and has embraced the opportunities offered by the development of the iron ore industry in this region. We are not however relying on mining alone to secure that economic diversity.

We are in the process of reviewing the Shire or Perenjori Town Planning Scheme and have identified an area east of the proposed Mount Gibson Mining Rail siding as a potential location for an industrial area. Being able to retain the rail siding and related infrastructure would widen the scope of potential developments that we would be able to attract following the cessation of the Extension Hill project.

In conclusion we view the rail siding as a potential strategic asset for the development of the Shire, and would like to take over the site when you cease operations. If it is possible to include this option in your mine closure plan it would be greatly appreciated.

Please contact me if you require and further information or clarification.

Yours faithfully

Stan Scott
Chief Executive Officer

Appendix F Standard Work Instructions Relevant to Management of Key Risks

Hazard	Outcome	Initial Controls	
Weeds Erosion Failure of native vegetation re-growth Bush fires	May impact on native vegetation regrowth. Compromises long term stability of the waste dump. Failure to achieve completion criteria. Damage to rehabilitated areas.	• Restricted access area procedures to miminise potential for weed introduction. • Rehabilitation techniques as described below to miminise erosion.	• Seeding as required to promote native vegetation regrowth. • ERT, water carts available as required.

Step #	Work Procedure
	RESPONSIBILITY The HSEC Department are responsible for managing and coordinating the implementation of this work instruction.
1.1	**COMPLETION CRITERIA** The closure objectives for the Extension Hill Hematite Operation are detailed in the *Mine Closure Plan* and reviewed and updated every 3 years. To measure whether these objectives have been met completion criteria have been assigned to the objectives.
1.2	**CLOSURE** A conceptual mine closure plan (*Conceptual Closure Plan*) has been developed and approved by the relevant government departments. A complete *Mine Closure Plan* is required to be submitted to the Department of Mines and Petroleum by October 2014. This plan will be implemented and reviewed periodically throughout the operations life. Appropriate monies shall be accrued throughout the operation's life to ensure sufficient resources are available to achieve final closure and relinquishment.
1.3	**REHABILITATION MATERIALS** Vegetation, topsoil, subsoil, and hollow logs and trees will be stockpiled in accordance with the *MGX-EH-SWI-HSEC-380 Site Clearance Protocol*. Where possible, stockpiling is to be avoided in favour of direct return to rehabilitation areas and clearing will be scheduled to occur as close as possible to the mining of the cleared area. The Survey Department will maintain a database of topsoil and subsoil resources, including storage locations, quantities and the source vegetation community types. As stockpiled topsoil is subject to chemical changes over time, prior to rehabilitation of material from long term stockpiles (>12 months), soil chemical analysis of major nutrients (nitrogen, phosphorous, potassium) and pH will be conducted to allow soil improvement techniques to mitigate deficiencies. Soil chemical analysis will be compared with representative soils in the applicable vegetation community to be restored. Fertiliser application rates will be developed upon evaluation of soil nutrient content. Throughout the life of the project, sustainable seed harvesting is to be undertaken as appropriate to ensure sufficient local provenance seed is available for rehabilitation activities. Seed is to be treated and stored in a de-humidified, air-conditioned area.

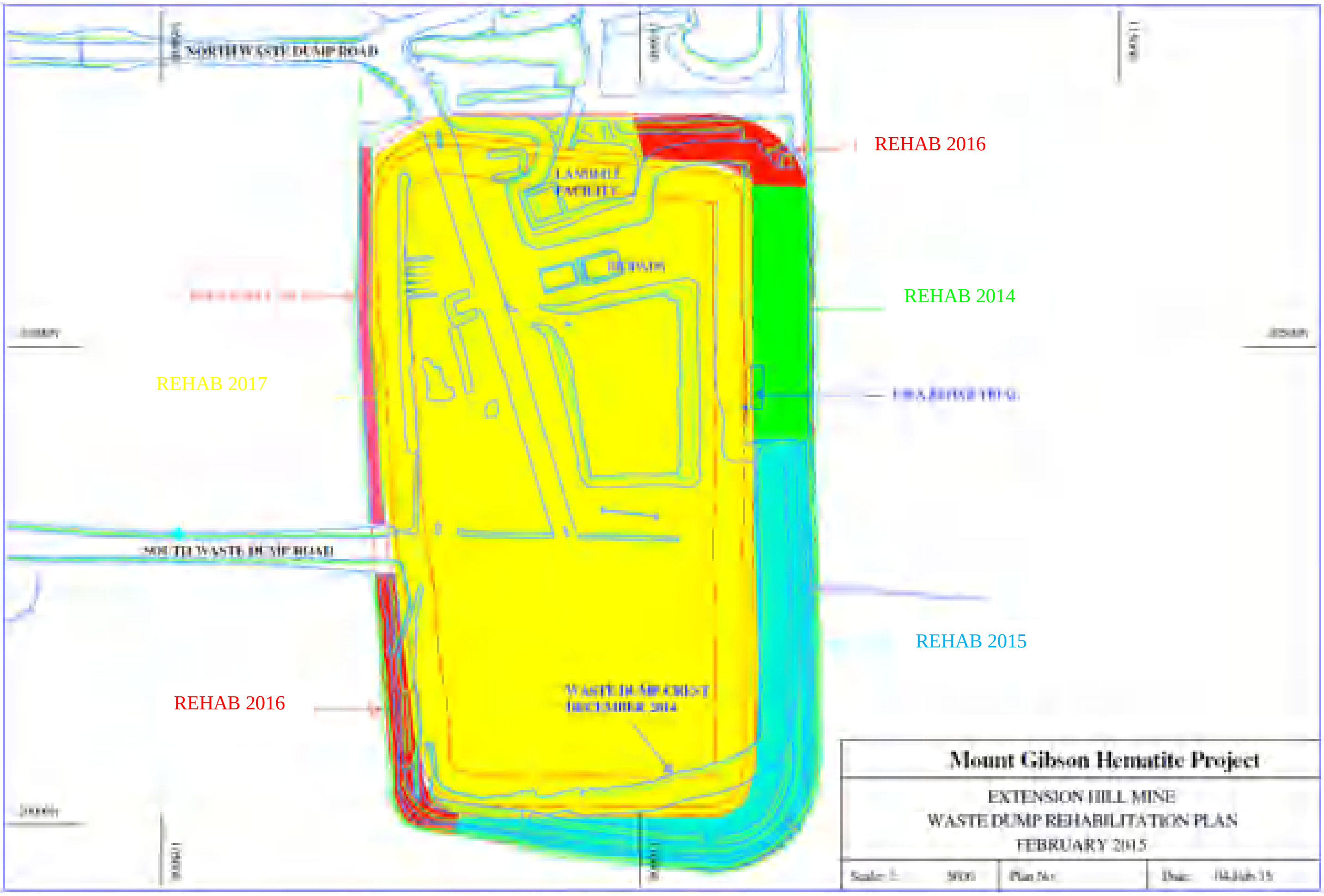
1.4	**GENERAL REHABILITATION** Rehabilitation is to be undertaken progressively throughout the life of the mine. Appendix A shows the staged rehabilitation plan. The rehabilitation techniques will be reviewed in light of the research, on-site trials and the performance of previous rehabilitation. Rehabilitation in general (non waste dump) areas, such as borrow pits and infrastructure areas is to be conducted as follows: • Ripping to at least 0.5m of the existing surface is to be completed. • Subsoil must then be re-spread to a depth of 0.2 – 0.3m. • Topsoil is to be re-spread over the subsoil to a depth of approximately 0.1m. • Where available tritter is to be spread over the topsoil. • The entire surface must then be ripped to a depth of less than 0.3m. • Hollow logs and trees are to be arranged across the surface where available to re-establish fauna habitats. • Where monitoring indicates insufficient regrowth has occurred or is likely to occur, infill planting or direct seeding with local provenance seeds will also be undertaken. Post rehabilitation topography is to replicate pre-disturbance topography wherever possible. Areas undergoing rehabilitation are to be designated as restricted access areas (*Site Access Protocol*).
1.5	**WASTE DUMP REHABILITATION** Design The waste dump design should set out to achieve a radius of curvature of at least 100m to avoid flow concentration and erosion on corners. The surface area of the waste dump top should be maximised to minimise the perimeter of the batters and the higher costs associated with rehabilitating batters. Surface To prevent runoff from the top of the waste dump from impacting the batter stability, crest bunding must be at least 0.75m high and made of stable, compacted material. The bunding should be at least 2m wide across the top, with the outer face forming a continuous slope with and having the same surface treatments as the outer batter profile. The inner face should slope inwards at a gradient of 1V:10H to reduce the potential for sink-hole formation. Cross bunding is required to prevent prolonged ponding. Cross bunding should consist of compacted bunds 0.5m high and 1m wide across the top. The bunding should be at sufficient density to create cells 1-3ha in size. The surface of each cell should be level and ripped to the greatest depth possible using <1m spacing between tynes. Subsoil should be re-spread to a depth of 200mm followed by topsoil to a depth of 100mm. Seeding (primarily deep rooted and perennial species) will be undertaken as required. Batter Slopes Rocky waste material will be placed on the slopes of the waste dump during construction and finer waste material will be contained within the dump. The slopes will be battered to an 18º gradient. Topsoil will be re-spread to a depth of 100mm. To mix the topsoil with the underlying rocky material and reduce erosion potential, the slopes will be ripped on contour using a triple tyne ripper with 1m spacing and rip lines no larger than 300mm.

1.6	**REHABILITATION MONITORING** Monitoring of rehabilitated sites is to be conducted, as per *MGX-EH-SWI-HSEC-393 Environmental Monitoring*. Records of monitoring will be used to gauge the success of the rehabilitation work and guide improvement in the rehabilitation process.
1.7	**COMMUNICATION/TRAINING** All personnel affected by the content of this document will receive further instruction or explanation on the relevant parts of the document, if required.

Reference Documents	• *Conceptual Closure Plan* • *Mine Closure Plan* • *MGX-EH-SWI-HSEC-380 Site Clearance Protocol* • *Site Access Protocol* • *MGX-EH-SWI-HSEC-393 Environmental Monitoring*

Rev	Date	Revision description	By	Check	Approved
1	29.04.2009	Issued	J. Sackmann	J. Ranford	20.10.2008 J. Ranford
2	06.04.2014	Reformatted and Revised	J. Sackmann	M. Holland S. Churchill R. Olney M. Walker A. Murphy	16.04.2014 S. Churchill
3	16.09.2015	Revised	J. Sackmann	P. Salmon	16.09.2015 P. Salmon

Appendix A – Staged Rehabilitation Plan



DECLARATION AND VERIFICATION OF SWI

1. Which Department maintains a database of topsoil and subsoil resources?

   ____

2. What is the purpose of re-spreading hollow logs and trees?

   ____

   ____

3. How high does the waste dump crest bunding need to be?

   ____

4. What is the maximum batter slope gradient for the waste dump?

   ____

Any changes to the working/task/process conditions, a JHA is to be completed

A Safe system of work shall be discussed and understood prior to undertaking this task

EMPLOYER: ____________________ **DEPARTMENT:** ____________________

EMPLOYEE NAME: ________________________________

EMPLOYEE SIGN: ________________________________

SUPERVISOR NAME: ________________________________

SUPERVISOR SIGN: ________________________________

DATE: ________________________________

SITE WORK INSTRUCTION (SWI)	MGX–HSEC–EH–SWI–382	Mount Gibson Iron
Risk Register Score	**Weed Management**	**Extension Hill**

Hazard	Outcome	Initial Controls	
Weed infestation	Reduction in biodiversity	• Weed hygiene practices	• Weed control activities

Step #	
1	**Purpose** To specify requirements for weed management and monitoring, including control measures, in order to ensure no detrimental effect on native vegetation and biodiversity of the area due to the introduction or spread of weed species as a result of mining activities.
2	**Scope** This Site Work Instruction (SWI) covers weed management on the mine tenements and is applicable to all personnel and visitors at Extension Hill Hematite Operation.
3	**Weed Identification and Recording** A description (including pictures) of weed species recorded within the tenements is included in Appendix A. Weed identification charts are to be put up around the site to assist personnel in recognising and identifying any weeds they may come across. Known weed populations on the tenement area are mapped (Figure 1 and 2) and recorded in the Weed Register. Personnel are to complete a 08.00-FM01 Significant Flora/Fauna Sighting Form if they identify weeds on site or notify the Environment Department directly of the sighting. The Environment Department is to investigate and verify any reported sightings, update the Weed Register and take appropriate control measures (Section 6).
4	**Weed Hygiene Practices** Weed hygiene practices, including a requirement for vehicles and equipment to be weed free when brought on site, washdown and inspection procedures are detailed in **02.15.01 – Site Access Protocol**. All fill being imported into the pastoral area is to be inspected by the Environment Department and treated, as required. Importing/sourcing fill material from weed infested areas is not permitted.
5	**Restricted Access Area Procedures** Areas containing weed species with high biodiversity risk rating (CALM 1999) are to be designated as restricted access areas until such time as the population is eradicated and monitoring indicates that the area is weed free. Restricted Access Areas are to be clearly demarcated by appropriate signage, fencing and/or flagging, as necessary (see **02.15.01 –Site Access Protocol**).

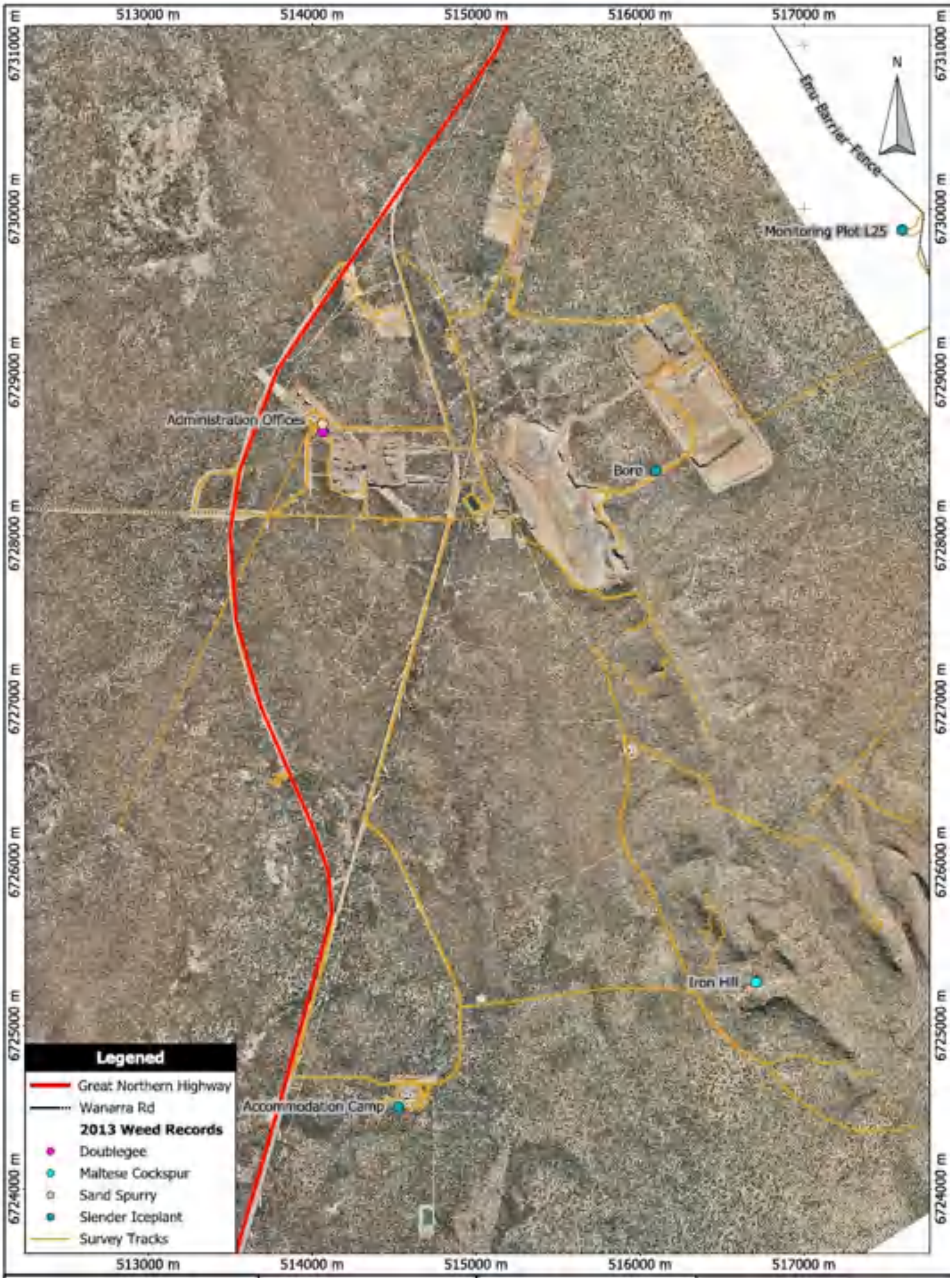


Figure 1 Weed locations on the mining tenements – 2013 survey

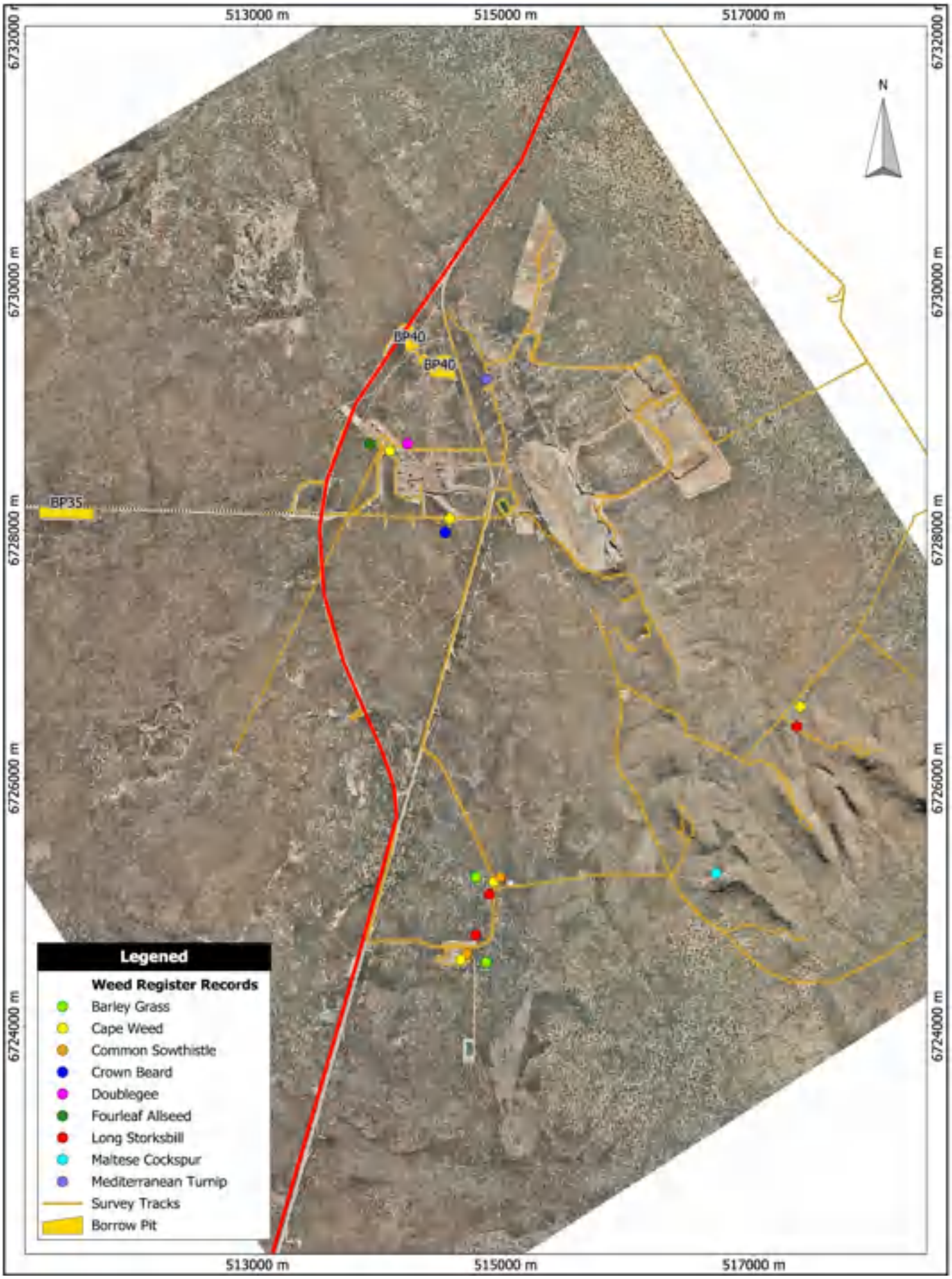


Figure 2 Weed locations on the mining tenements – historical weed register

6	**Weed Eradication** On site weed eradication will be undertaken in accordance with the Weed Removal Techniques in Appendix A, and under the direction of the Environment Department. Particular care should be taken when using chemical controls in order to avoid impact on other vegetation and surface, groundwater and soil contamination. Optimum spraying conditions are when weeds are young, air temperature is less than 30°C, winds are low, a good soil moisture profile is present and wetting agents are used. Consideration is to be given to the use of manual and/or hand control methods for weeds in close proximity (within 100m) of significant flora and advice is to be sought from Department of Parks and Wildlife prior to spraying within 100m of Declared Rare Flora.
7	**Weed Monitoring** Weed monitoring, including monitoring to assess the effectiveness of weed control measures undertaken, is to be undertaken regularly in accordance with **MGX-HSEC-EH-SWI-393 Environmental Monitoring**.
8	**Communication/Training** Mine workers will receive training against relevant requirements of this SWI as part of their site induction process.
9	**Records** Records related to this Site Work Instruction shall be maintained in accordance with **13.00 – Records Management.**

Reference Documents	• 02.15.01 – Site Access Protocol • MGX-HSEC-EH-SWI-393 Environmental Monitoring • Department of Conservation and Land Management (CALM) 1999, *Environmental Weed Strategy for Western Australia*, Environmental Protection Branch, Department of Conservation and Land Management. • ATA Environmental 2007, *Extension Hill and Extension Hill North Weed Management Plan*, Prepared for Mount Gibson Mining Limited and Extension Hill Pty Ltd.

Rev	Date	Revision description	By	Check	Approved
0	29.4.2008	Developed	J. Sackmann	J. Ranford	20.10.2008
1	23.08.2014	Reviewed and reformatted to SWI	J. Sackmann	S. Churchill	08.09.2014

DECLARATION AND VERIFICATION OF SWI

Any changes to the working/task/process conditions, a JHA is to be completed

A Safe system of work shall be discussed and understood prior to undertaking this task

EMPLOYER: ____________________ **DEPARTMENT:** _____________________

EMPLOYEE NAME: ___________________________________

EMPLOYEE SIGN: ___________________________________

SUPERVISOR NAME: ___________________________________

SUPERVISOR SIGN: ___________________________________

DATE: ___________________________________

Appendix A

Botanical Name	Comments	Weed Removal Techniques
Acetosa vesicaria Ruby Dock 	Mainly in disturbed areas.	Remove isolated plants by cutting their roots at least 20cm below ground level. Individual plants may be wiped with a mixture of 1L glyphosate (450g/L) in 2L water. On small infestations 0.5g chlorsulfuron (600g/kg) plus 100ml Tordon 75-D in 10L water in winter will control existing plants and seedlings for about a year. Some seeds remain viable for 20 years. 2L/ha glyphosate can be used selectively in some seasons when dock is green and annuals are not. Metsulfuron is also effective.
Anagallis arvesis Scarlet Pimpernel 	Competes with small herbs. Mainly a problem in moist, very disturbed areas when the plants become more vigorous.	Try Glyphosate/Roundup or Glean at 15g/ ha. Ally/Brushoff do control this weed.
Arctotheca calendula Capeweed 	Mainly in disturbed areas where extra water/nutrients encourage lush growth.	Glyphosate/Roundup knapsack, 100ml in 15L of water or stronger solution on large plants. Lontrel 1 in 100 has been used successfully by Main Road Department on over one year old direct seeded, woody seedlings and mature bush.
Bromus diandrus Great Brome Grass, Brome Grass, Ripgut 	Competes with natives	Fusilade or similar herbicide at 12L/ha when actively growing.
Bromus rubens Red Brome	Competes with natives	Fusilade or similar herbicide at 12L/ha when actively growing.

Botanical Name	Comments	Weed Removal Techniques
Carrichtera annua Ward's Weed	Most of the Brassicaceae weeds have dormant seeds that will continue to germinate over the season and for several years.	Manual removal is effective but must be done at lest every 8-10 weeks. In bushland situations, fairly selective control can be achieved with 100ml spray oil plus 0.1g Eclipse or 0.5g Logran in 10L water. 5ml Brodal is often added to this mix to provide residual control of seedlings. Spray the plants until just wet from the seedling stage up to podding.
Centaurea melitensis Maltese Cockspur 	Usually disturbed areas, e.g road verges. Annual or Biennial	Suggest trying Glyphosate or Tryquat. Several other herbicides, e.g. 2, 4-D, Bromoxyn, 1+MCPA, are known effective control.
Echium planatgineum Paterson's Curse 	In highly disturbed areas usually on heavy soils.	Hand weed small populations or use a wick applicator and Glyphosate. Use Glyphosate/Roundup 75-100ml in 15L water.
Ehrharta longiflora Annual Veldt Grass 	Easy to control.	Remove small populations by hand. Fusilade or similar spray at 2L ha, before flowering.
Erodium botrys Long Storksbill		No specific information on herbicide control. Suggest Glyphosate, Roundup or Sprayseed/Tryquat. Ally/Brushoff will control some species 5g/ha.

Botanical Name	Comments	Weed Removal Techniques
		
Hedypnois rhagadioides Cretin Weed 	Disturbed habitats	No specific information on herbicide control. Suggest Glyphosate/Roundup 100ml in 15L water, or use weeding wand at higher rate.
Hypochaeris glabra Smooth Catsear 	Competes with native herbs, especially in richer soils and disturbed areas. Annual or perennial.	Glyphosate/Roundup 100ml in 15L water, or use weeding wand at a higher rate. Apply when rosettes are fully developed, at the early flower stage.
Medicago truncatula Barrell Medic	It is relatively tolerant to glyphosate, grazing and mowing.	Exclude stock to reduce dispersal of burrs. Hand pull odd plants in winter before flowering. For small infestations and grass dominant areas an annual application of 10ml Torodon 75-D in 10L. Water in early winter gives excellent control of existing plants and has residual activity to control later seedlings. Bushland, 25ml of wetting agent plus 10ml of Lontrel or 1g of Logran in 10L water applied in early winter. Metsulfuron also provides good control.
Monoculus monstrosus Stinking Roger 	Found in a wide range of soils.	Pull out small populations prior to seeding. No specific information on herbicide control. Suggest Roundup/Glyphosate 75-100ml in 15L water, or Tryquat/Sprayseed.

Botanical Name	Comments	Weed Removal Techniques
Pentaschistis airoides False Hairgrass 	Widespread	Suggest Fusilade or similar herbicide at 2L/ha
Petrorhagia dubia Velvet Pink 	More vigorous on disturbed sites	No specific information on herbicide control. Suggest Glyphosate/Roundup 75-100ml in 15L water or Tryquat/Sprayseed.
Rostraria pumila Tiny Bristle Grass		Fusilade or similar herbicide at 12L/ha when actively growing.
Sisymbrium orientale Indian Hedge Mustard 	Widespread	Some species are controlled by Glyphosate/Roundup 10-20ml in 10L water plus 0.25% wetter. Apply to small plants. Higher rates may be necessary on large plants.

Botanical Name	Comments	Weed Removal Techniques
Sonchus oleraceus Common Sowthistle 	Common	Manually remove isolated plants or graze the area to prevent seed set for several years. Single plants may be sprayed with 50ml glyphosate (450g/L) in 10L water or wiped with a mixture of 1L glyphosate in 2L water at any time before budding. Spray small areas with a mixture of 100ml of Tordon 75-D plus 25ml wetting agent in 10L of water in June each year. In bushland situations 4L/ha 2,4-DB (400g/L) or 80ml 2,4-DB (400g/L) plus 25ml wetting agent in 10L of water for hand spraying will provide reasonably selective control when applied in June. A repeat application may be necessary in late spring in areas where spring germination occurs.
Spergularia rubra Sand Spurry	Found in disturbed areas.	No specific information on herbicide control. Suggest Glyphosate/Roundup 75-100ml in 15L water when actively growing.
Trifolium tomentosum Woolly Clover	Clovers are relatively tolerant to glyphosate, grazing and mowing.	Prevent seed set for 5 years. Hand pull odd plants in winter before flowering. For small infestations and grass-dominant areas an annual application of 10ml Torodon 75-D in 10L water in early winter gives excellent control of existing plants and has residual activity to control seedlings. In bushland, 500ml/ha Lontrel or 50g/ha Logran applied in early winter provides reasonably selective control. Use 25ml wetting agent plus 10ml Lontrel or 1g Logran or 0.1g metsulfuron (600g/L) or 0.1g chlorsulfuron (750g/kg) in 10L water for hand spraying when they are actively growing. Repeat annually for several years.
Ursinia anthemoides Ursinia 	Usually in disturbed areas.	Pull out small populations before they spread. No specific information for herbicide control. Suggest Glyphosate/Roundup at 75-100ml in 15L water knapsack, preferable before flowering.

Appendix G Extension Hill Hematite Mine Decommissioning Plan and Schedule