HYDROGEOLOGY STUDIES, FRANCES CREEK

Prepared for

Territory Iron Limited

17 February 2006

AGT Report No: 2006/2

CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Background

Territory Iron Limited (Territory Iron) is seeking to develop a number of open cut iron ore pits at the Frances Creek project area. Territory Iron is planning to conduct primary processing (crushing and screening) on site. Overall mine life will be a minimum of three years, and could be extended depending on exploration success (M. Dufty, pers. comm.).

A Notice of Intent document was submitted to regulatory authorities to determine the level of assessment for the project. The Northern Territory Minister for Natural Resources, Environment and Heritage determined on 20th December 2005 that the project would be assessed at the level of Public Environmental Report (PER).

Study Area

The hydrogeological *study* area is bounded by Eastings 795000 and 824500 (132^0), and Northings 8490000 and 8505900 ($-13^0$30’) Zones 52 and 53, MGA 94 (Pine Creek SD52-08, 1:50,000).

Mine-site Hydrogeology

A hydrogeological conceptual model has been developed that hypothesizes a dynamic, local groundwater system with localized, relatively short flow-paths. On this basis, all township/mine site runoff / groundwater throughflow ultimately finds its way into the headwaters of the Frances Creek and eventually into the Mary River to the east.

The geological formations of interest constitute unconfined (‘water-table’), fractured rock aquifers. Within the mineral processing/stockpile/tailings area, approximately 200 to 500 m west of the ore body trend formerly exploited in the open pits at Helene 4, 5, and 6/7, a concentration of (abandoned) high yielding water bores occurs. This is an area perceived to have additional structural complexity that may have locally enhanced the aquifer’s permeability.

The native Groundwater is a bicarbonate type water with a low salinity, three to four times that of the average Pit Water. The low salinity of pit waters suggests that the pits act as collectors and groundwater recharge points (groundwater sources) during the wet season and evaporative discharges (groundwater sinks) during the dry with very little throughflow; presumably because the local impact of the pit lake levels on groundwater flow is greater than that of the topographically dependant hydraulic gradients.

Risk Impact Assessment

A risk-based matrix is presented in the body of the report.

Drawdown of the water-table due to pumping is likely to be the only impact arising from local use of the water. Unless enormous amounts of groundwater are extracted; i.e. sufficient to cause dewatering of the fractured rock aquifer on a semi-regional scale, the impacts of pumping bores will be restricted to a local level (i.e. within, at most, a few kilometres of the mine-site). These impacts are completely reversible.

Relatively large flow rates may arise from dewatering of the deeper pits (e.g. in excess of 23 L/s was estimated as the seepage into Helene 6/7). The mining operation often results in a reduction in water quality. There may be impacts due to increased turbidity in discharging water as well as possible increase in nitrate content as a result of the use of ANFO type explosives. Provided that turbidity falls within acceptable limits and high levels of nitrate are not introduced by blasting, the majority of analysed pit waters could be disposed directly into surface drainage. High turbidity can be addressed by pumping to a temporary surface storage to permit settlement of fines before discharging to the environment.

Longer term impacts associated with the potential for the development of Acid Mine Drainage (AMD) may occur where sulphide minerals are exposed in the pit walls. In this regard, although it is not planned to mine at Thelma Pit 2, the possibility of the pit lake becoming a long-term source of AMD should be investigated.

The impact of disposal of good quality dewatering discharges into the surface drainage system would be locally increased stream flows with possible increased infiltration to groundwater during the dry season.

The beneficiation of the raw iron ore consists essentially of physical processes without the addition of environmentally undesirable reagents. Vertical seepage from tailings areas may contain slightly elevated levels of iron due to the solubility induced by abrasion. The "Heavy Metals" may be similarly slightly enriched but the current natural revegetation over the Tailings Settlement area suggests that there is little or no development of chemicals in solution which are toxic to vegetation.

Waste Dumps tend to be developed alongside each pit and in the short term any seepage from the dumps to groundwater would report to the pit. In the longer term the materials in the waste dumps will be subject to oxidation and any sulphides present will tend to form sulphate. Drainage from the waste dumps should, wherever possible be arranged so that it returns to the nearest pit rather than directly to the environment.

Any contaminants residing in a pit lake are likely to remain there or to move only a short distance into the surrounding fractured rock aquifer when driven by a recharge event. Subsequent evaporative discharge from the lake will tend to reverse this movement back towards the pit.

Impact on Existing Users (Beneficial Use)

The groundwater within a range of a few kilometres of the project site is generally suitable for all normal purposes, including domestic, agricultural and industrial.

The sole town water supply in the region is Pine Creek, situated 25 km south of Frances Creek; well outside the area of influence or impact on the groundwater resource.

All known mine-sites in the study area are disused. However, there are plans to reopen the Union Reef gold mine; and open the Mount Porter Mine. It is unlikely that there would be any derogation to supply from either these operations on the project area or vice versa.

Agriculture consists of rangeland grazing of cattle on the Mary River West and Ban Ban Springs Pastoral leases and as such is low intensity with scattered watering points; dams, soaks and bores. Pastoral bore water yields will not be affected. Esmeralda Farm, located 11 km south of Frances Creek, has no recorded water bores on its property.

All of these locations are believed to be beyond the range of any physical impact due to extraction of groundwater for water supply or pit dewatering at any of the proposed Frances Creek mining sites.

Discharges from pit dewatering should only be released to the surface drainage system if the quality is acceptable for aquatic ecosystems; otherwise temporary retention in a wetland treatment system or, where volumes are small, temporary surface storage and subsequent return to the pit is recommended.

Increased flow of a stream due to disposal of pit dewatering water is not expected to result in any significant deterioration of aquatic environmental conditions and will essentially be a one-off event terminating at the same time as mining.

The springs located in a tributary of Nellie Creek, approximately 10 km to the East of the township are believed to be sufficiently far from the mine site to be unaffected by any drawdown around pits or water supply bores at Frances Creek.

Pit lakes, left behind after mining ceases may provide additional refuge for aquatic life including water birds and freshwater crocodiles.

The NT *Mining Management Act 2001* addresses operational legislation. Under this act, essentially, an *operating mine* must satisfy the requirement for on-site containment of waste including wastewater. If such wastewater migrates off-site then the operator requires a Waste Discharge Licence (WDL) under the NT *Environmental Assessment Act*. AGT understands that such a WDL is issued by DNRETA ('Controller of Water' under the *NT Water Act, 1992)* who will stipulate the conditions including allowable quantity and quality of the wastewater to be discharged.

1. INTRODUCTION AND TERMS OF REFERENCE

1.1 Background

Territory Iron Limited (Territory Iron) is seeking to develop a number of open cut iron ore pits at the Frances Creek project area. Iron ore was extracted from a number of open pits from 1966 until 1974 from the old Frances Creek mining centre within the Frances Creek project area, when flooding and consequent damage to infrastructure forced closure. Several large fresh water storage dams used to supply the abandoned Frances Creek Township (the 'township') and mine treatment plant while mining operations were in progress. Territory Iron is planning to conduct primary processing (crushing and screening) on site.

The project area is located about 200 km south of Darwin (inset to Figure 1) and 25 km north of Pine Creek. The study area as designated by Australian Groundwater Technologies Pty Ltd (AGT) is given as Figure 1. The reasoning for setting these boundaries to the study area is discussed in Section 1.4.

Territory Iron holds exploration tenements over the area or has entered into agreements with other tenement holders and has submitted a Mineral Lease application for a 1,212 ha area. Figure 2 shows a conceptual site layout within the mineral lease application area. Mining will be limited to a narrow line of strike that follows the iron-rich horizon. The initial focus of mining will be the Helene 5 and Helene 6/7, Jasmine East, Rosemary, Thelma Rosemary and Ochre Hill areas (the latter site is located some 4 km north of Thelma 1; outside Figure 2's boundary), later moving north to the Millers deposit area situated some 10 km NNW of Ochre Hill. Overall mine life will be a minimum of three years, and could be extended depending on exploration success (M. Dufty, pers. comm.).

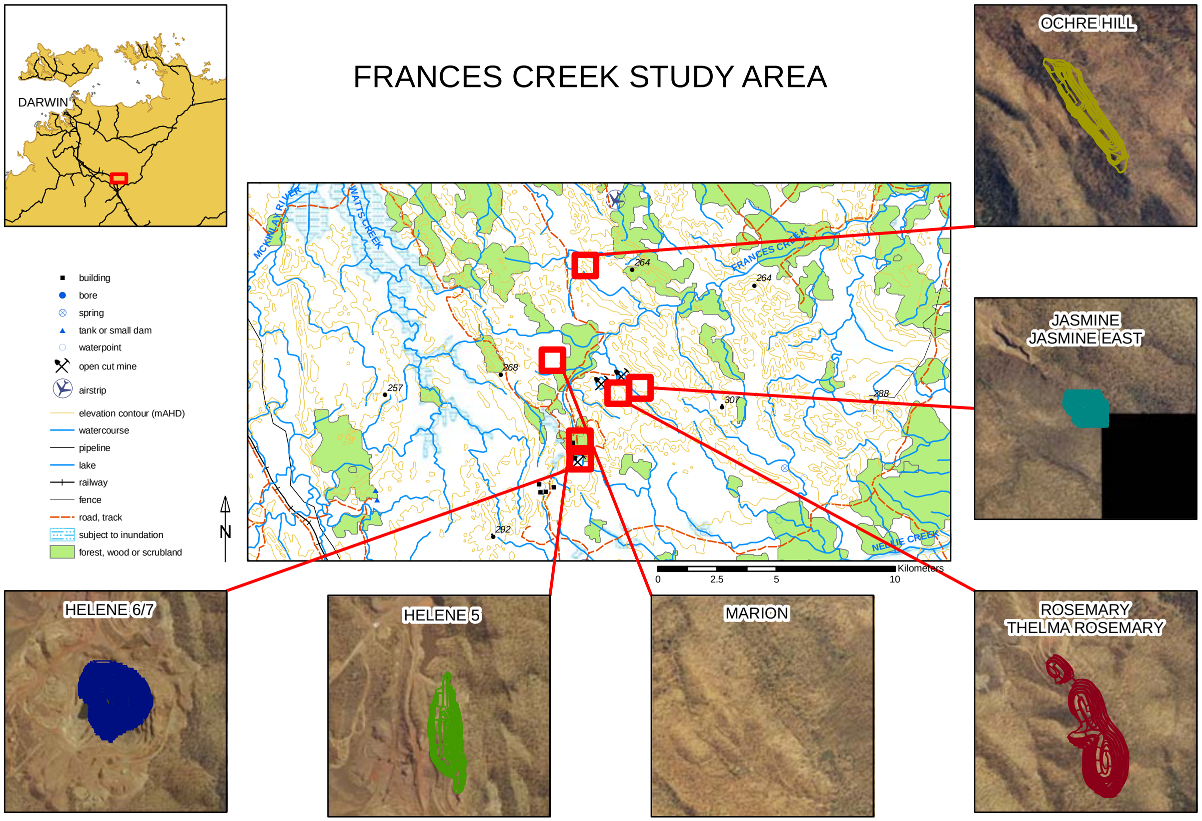


Figure 1 Frances Creek – Study Area Location Map (Note: Marion is a low priority exploration target)

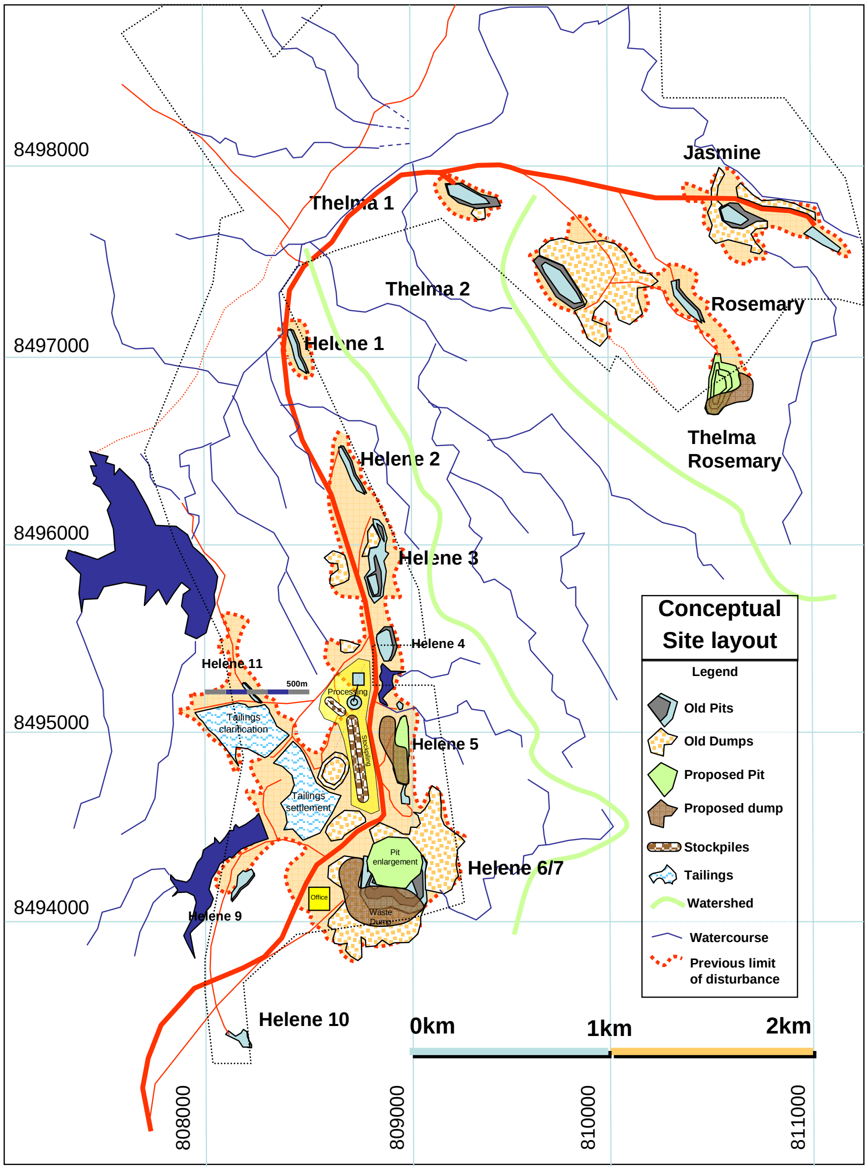


Figure 2 Frances Creek Proposed Mine – Conceptual Site Layout

A Notice of Intent document was submitted to regulatory authorities to determine the level of assessment for the project. The Northern Territory Minister for Natural Resources, Environment and Heritage determined on 20th December 2005 that the project would be assessed at the level of Public Environmental Report (PER). It is our understanding that the hydrogeological report, or abstracts thereof, shall form part of this PER.

1.2 Scope of Work

AGT has been engaged by MBS Environmental (MBS) to input hydrogeological expertise to assist MBS to prepare the PER on behalf of Territory Iron.

The scope of work is reproduced from the MBS document re. W:\Territory Iron\Frances Ck\Baseline Studies\TI Hydrogeology scope.doc.

MBS requires the following tasks to be undertaken:

- Describe the site and regional groundwater systems including confined and unconfined aquifers, ground soaks and expressions.

- Discuss for both site and regional groundwater systems:

  (a) Their significance

  (b) Their current uses

  (c) Beneficial uses

  (d) Flows and discharge rates

  (e) Water levels and quality

  (f) Characterisation of the water

- Describe how the project may have the potential to impact on site and regional groundwater systems. Impacts as a result of pit dewatering and potential discharge of excess water to the natural environment should be considered. This should include discussion of potential impacts on water levels, water quality, current uses and beneficial uses.

- Liaise with regulatory authorities to obtain information relating to local and regional groundwater systems.

- Liaise with Territory Iron to obtain information relating to groundwater intercepted during exploration programs, i.e. locations where groundwater encountered, depth where groundwater encountered, approximate flow rates and water quality.

- Prepare a report detailing the findings of the work. The report shall include:

  (a) Details of methods used to conduct the work

  (b) Results of any field surveys, groundwater monitoring or database searches

(c) Maps showing locations where existing groundwater abstraction or monitoring bores are located within and nearby to the project area

Recommendations for additional work and management measures that may be implemented as part of the mining plan to prevent or minimise adverse impacts on groundwater should be provided separate to the report for consideration by Territory Iron.

1.3 Data Acquisition and Collation

The following data sets were acquired for the study:

- Cadastral / topographic;

  (a) Contours of ground surface (5 m over Ochre Hill; 2 m intervals elsewhere);

  (b) Aerial photos [NT Gov DLPE-maps, 1:50,000 NTc1410 series, Mary River Catchment; Run 9, 166-192; Run 10, 133-165; Run 11, 100-132; Run 12, 067-099, and 1999 air photo full project area coverage ('registered mosaic') in ECW format (from MBS)];

  (c) 'Google Earth' satellite photos including oblique views (AGT);

- Water quality;

  (a) Laboratory surface water (pit) analyses November 2005 sampling round (results pending from Thelma 2 pit) (December 2005 surface water quality previously undertaken but results not yet available);

  (b) Summary of field readings during dewatering of Helene 6/7;

  (c) Laboratory results for a few samples during dewatering of Helene 6/7;

  (d) and see below 'Field Visit'.

- Bore Information;

  (a) Mineral drilling (RC and 1 DD drilled holes – no groundwater information; from Territory Iron);

  (b) NT Government Department of Natural Resources, Environment and the Arts (DNRETA) Hydrological Station Database (Registered Numbers [RN], locations, groundwater information for bores);

  (c) DNRETA Regulation 8s'for selected bores (drillers logs')

- Pit Information;

  (a) pit designs (Dwg and .shp file from MBS):

    (i) des_h51 is Helene 5;

    (ii) des_oh1 is Ochre Hill;

    (iii) des_tr1 is Thelma Rosemary;

    (iv) run2 pit 9 je (shell design for Jasmine East); and,

    (v) run2 pit 11 h67 (shell design for Helene 6/7);

  (b) Helene 6/7 pit contour plan, and pit volume versus pit depth curve (.pdf format from Bob Reed);

  (c) comments re. Helene 6/7 pit dewatering program (9th June - 12th July 2005) (from Bob Reed);

- Site visit (10th January 2006);

  (a) Photographs and Observations of;

    (i) Bores;

    (ii) Pits;

    (iii) Rock fractures patterns in pit faces

  (b) Water sample from Bore RN 6322 ('B001') delivered to NTEL for full physio-chemical analysis and results received February 2006

1.4 Definition of Study Area, Physical Description and Regional Land Use

The study area is bounded by Eastings 795000 and 824500 (132^{0}), and Northings 8490000 and 8505900 (-13^{0}30') Zones 52 and 53, MGA 94 (Pine Creek SD52-08, 1:50,000). The boundary areas were set on the basis of the regional geology that controls the hydrogeology (the 'regional groundwater system'). Basically the eastern and southern boundaries form 'no flow' groundwater hydraulic boundaries, whilst the western boundary is a potential small groundwater province, and the northern boundary is a groundwater 'sink' beyond which it is considered that there would be negligible impact from mining activities due to the substantial distance and 'dilution' by major river systems; viz. the Mary River and the McKinlay River.

The land surface of the eastern three-quarters of the study area is quite rugged (especially over the metasediments of the Mundogie Sandstone and the areas marginal to the Allamber Springs Granite) and consists of a dissected plateau (described as 'rocky ridges' in BMR, 1987) with a NW - SE structural grain (Figure 3) with ground elevations sloping gently from maximum heights of about 300 m AHD (over sediments within the hornfels contact aureole of the granite) in the south to 230 m AHD in the north. Superimposed on this surface is the NE flowing Frances Creek that descends from 200 m AHD at the township to 80 m at the NE corner of the study area. The various dams lay at a topographic elevation of about 170 m AHD

Numerous ephemeral gullies drain the project area which is in the upper catchments of Nellie Creek to the south, and Frances Creek to the north. Both drain eastwards to the Mary River; the former over a reach of some 30 km; the latter over about 25 km. The main drainage divide between these two catchments is roughly along a line between the abandoned township in the west and Mount Saunders in the east. The catchment of Frances Creek exhibits strong trellis type drainage indicative of a joint-controlled geomorphological environment.

The western one-quarter of the study area is more subdued and is occupied by the relatively broad valley of Watts Creek that heads NNW (described as 'floodplain' and immediately to the west, 'granite pavement and tors').

The closest edge of the extensive and prolific fractured and karstic rock aquifer (Cambrian to Ordovician - mainly limestones and dolomitic sandy limestones) of the Daly Basin is situated over 30 km from the study area to the SW.

The SW boundary of the Kakadu National Park is formed by the east bank of the Mary River. Its closest boundary comes within 2.5 km of the NE corner of the study area and 23 km NE of the township. There are no known settlements within the study area including Aboriginal communities. There are no known agricultural developments within the study area. Mary River West and Ban Ban Springs are the nearest cattle stations, situated to the SW and NW of the study area, respectively. Esmeralda Farm is situated 8 km south of the southern boundary of the study area

Perennial or semi-permanent pools are common along the Mary River, NE of the study area, and along the McKinlay River, just north of the study area. This is due to shallow groundwater levels in topographically low areas and the locally permeable nature of the bedrock.

The 1,250 mm rainfall isohyet crosses Pine Creek Township. There is pronounced summer rainfall especially during the months of January - March when the area comes under the influence of the subtropical NW monsoonal trough (peak average monthly rainfall is 350 mm in February). Five months, May - September, usually have very little rainfall. Pan evaporation is high with a mean of 3,500 mm/a. Vegetation is mostly medium-high to tall semi-deciduous eucalypt woodland in the lowlands to open mid-height woodland and sparser grasses on slopes and ridge tops.

The McKinlay River with a mean flow of 2.77 m3/s has a runoff coefficient of 0.19 (19 %) that presumably indicates substantial surface runoff loss to the sub-surface (refer Section 3.2.3 for a discussion concerning recharge).

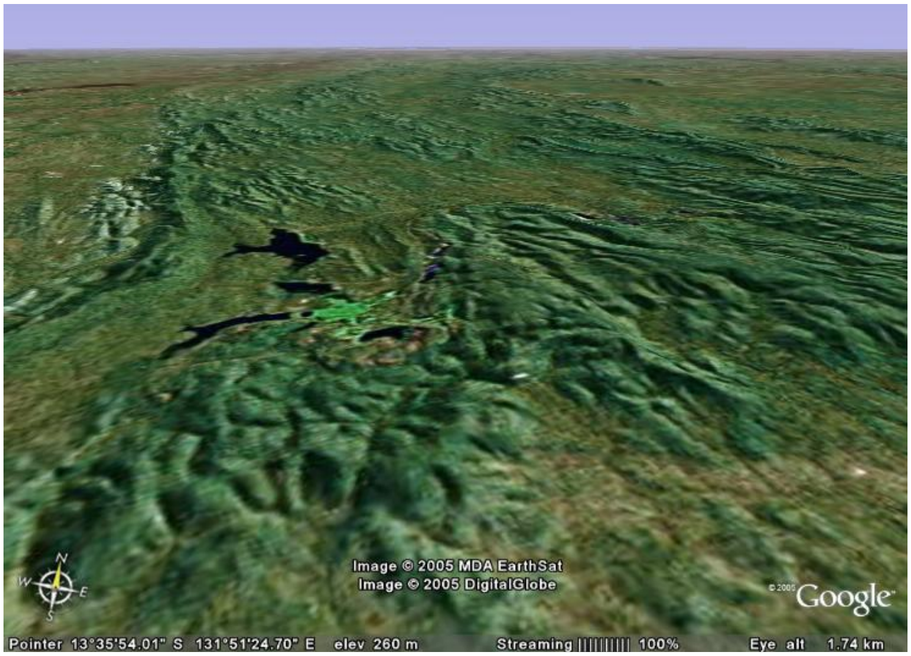


Figure 3 Frances Creek Study Area - Oblique Satellite Views (orientations annotated)

The project area includes the following topographic and cultural features:

- Watts Creek (including its headwaters) flowing south to north through the western area with a widening floodplain to north;
- Mount Porter (292 m AHD) headwaters of Watts Creek;
- Union Extended Mines, 7.5 km west of the township;
- Abandoned Frances Creek township, 3 km NE of Mt Porter;
- Nellie Creek just intercepts SW boundary flowing ENE then north (outside study area);
- Allamber Springs and associated pools – on northern catchment area of Nellie Creek 10 km east of the township;
- An unnamed peak (291 m AHD) 2 km due E of the township and 1 km SSE of Helene 6/7;
- Mount Saunders (307 m AHD) forms pinnacle of watershed between Nellie Creek to south and Frances Creek to north;
- Frances Creek roughly diagonally bisects the study area flowing north (from Mount Porter) then NE where it enters the Mary River 4 km beyond the NE corner of the study area (near Mary River Homestead);
- The old Frances Creek mine and associated pits occupy the headwaters of Frances Creek. The western and SW part (Helene series of pits) abut an arcuate, roughly N-S trending ridge, that constitutes the watershed between Frances and Watts Creeks'. On the eastern side of these mines are situated on the upper (Helen 6/7) and lower slopes of a much broader, plateau-like, ridge that has bee cut through where Frances Creek turns to flow north-eastwards. Here, the Thelma, Jasmine series; and Rosemary are situated on the lower slope of a significant tributary valley that flows north-westwards to join Frances Ck 1 km NW of Jasmine;
- A number of Aboriginal archaeological sites are situated immediately to the north of the mine-site.

2. REGIONAL HYDROGEOLOGY

2.1 Regional Geology

The geology of the study area (Figure 4) is structurally and stratigraphically complex. It occupies the western limb of a regional anticline (Thelma Anticline). Several different fold axial plane orientations from north-south to east-west are present with plunges ranging from horizontal to very steeply west. Faulting on a regional to local scale is also common.

The study area consists of early Proterozoic sedimentary and low-grade metamorphic rocks of the Pine Creek Geosyncline. The sedimentary rocks are mainly shale, siltstone, sandstone, conglomerate, and iron formations; pelitic rocks are commonly carbonaceous (BMR, 1987). Volcanic sedimentary rocks are also present including tuffs. The geosynclinal sequence is intruded by igneous rocks including pre-tectonic dolerite sills and syn- to post-tectonic granite plutons (comprising the 'Cullen Batholith') with metamorphic contact aureoles in the adjacent meta-sediments and meta-dolerites and dolerite dykes; the latter rarely cropping out (BMR, 1987).

The sediments, volcanic and dolerite sills are moderately to tightly folded about axial planes which strike to the SSE in the Frances Creek area and dip vertically or steeply either side of vertical. The fold axes plunge northerly or southerly in different parts of the inlier generally at shallow angles. This accounts for the attenuated outcrop pattern. Slaty to phyllitic cleavage is present in pelitic rocks and a less-prominent spaced fracture cleavage in sandstone. Both cleavages are the axial plane surfaces to the isoclinal folds and are either near vertical or dip steeply to the SW (BMR, 1987).

The regional folding is locally modified by the NW-trending 'Pine Creek Shear Zone' that, regionally, follows the embayment of Early Proterozoic metasediments (Burrell Creek Formation) between two lobes of the Cullen Batholith. This zone is about 3 km across (west of the McKinlay Granite) in the study area. Regional lower greenschist grade metamorphism accompanied the folding event during a major episode of deformation between 1870 - 1810 Ma. Metasediments within the zone are schistose and chloritic, and bedding and cleavage are parallel and vertical (BMR, 1987). Watts Creek follows the Pine Creek Shear Zone.

The south-western boundary of the study area is cut by a NW-trending fault that the Wildman Formation abuts against at depth. Along the eastern and southern extremities of the study area extensive granites of the Cullen Batholith truncate the metasediments including, in the Frances Creek area, the Allamber Springs Granite.

A simplified stratigraphic table pertaining to the study area is given as Table 1.

The Koolpin Formation varies in thickness but its precise thickness in any area is difficult to determine because of the inclusion of variably thick sills of Zamu Dolerite in the sequence.

The Mount Bonnie Formation is a transitional sequence which contains interbedded units of both Koolpin facies and Burrell Creek facies rocks. The base of the Mount Bonnie Formation is defined as the base of the lower of two major greywacke mudstone units each generally 20-50 m thick. The two thick greywacke mudstone units are separated by 30-60 m of laminated siltstone, shale, chert and tuff (Arafura Res, 2004 quoting Goulevitch, 1980).

The Gerowie Tuff is a marker bed situated between Mt Bonnie and Koolpin Formations; it is less extensive than the latter two formations. Bands of tuff, tuffaceous chert and tuffaceous siltstone continue through the Mount Bonnie Formation and, in places, into the lower Burrell Creek Formation.

An angular to conformable contact separates the Wildman Siltstone and Koolpin Formation (Arafura Res, 2004 quoting Stuart Smith et al., 1993). The boundaries between the Koolpin Formation, Gerowie Tuff, Mount Bonnie Formation and Burrell Creek Formation are conformable.

Basement geology for the Frances Creek area is published on the NTGS Pine Creek 1:250,000 Metallogenic Map. The Masson Formation occurs in a generally north dipping 0.5- 1.5 km wide band against the Allamber Springs Granite. This is overlain by a wide zone of folded and faulted Mundogie Sandstone and Wildman Siltstone. Overlying the Mundogie Sandstone is the Wildman Siltstone. Along the western edge of the study area lays a band of Koolpin Formation and Gerowie Tuff.

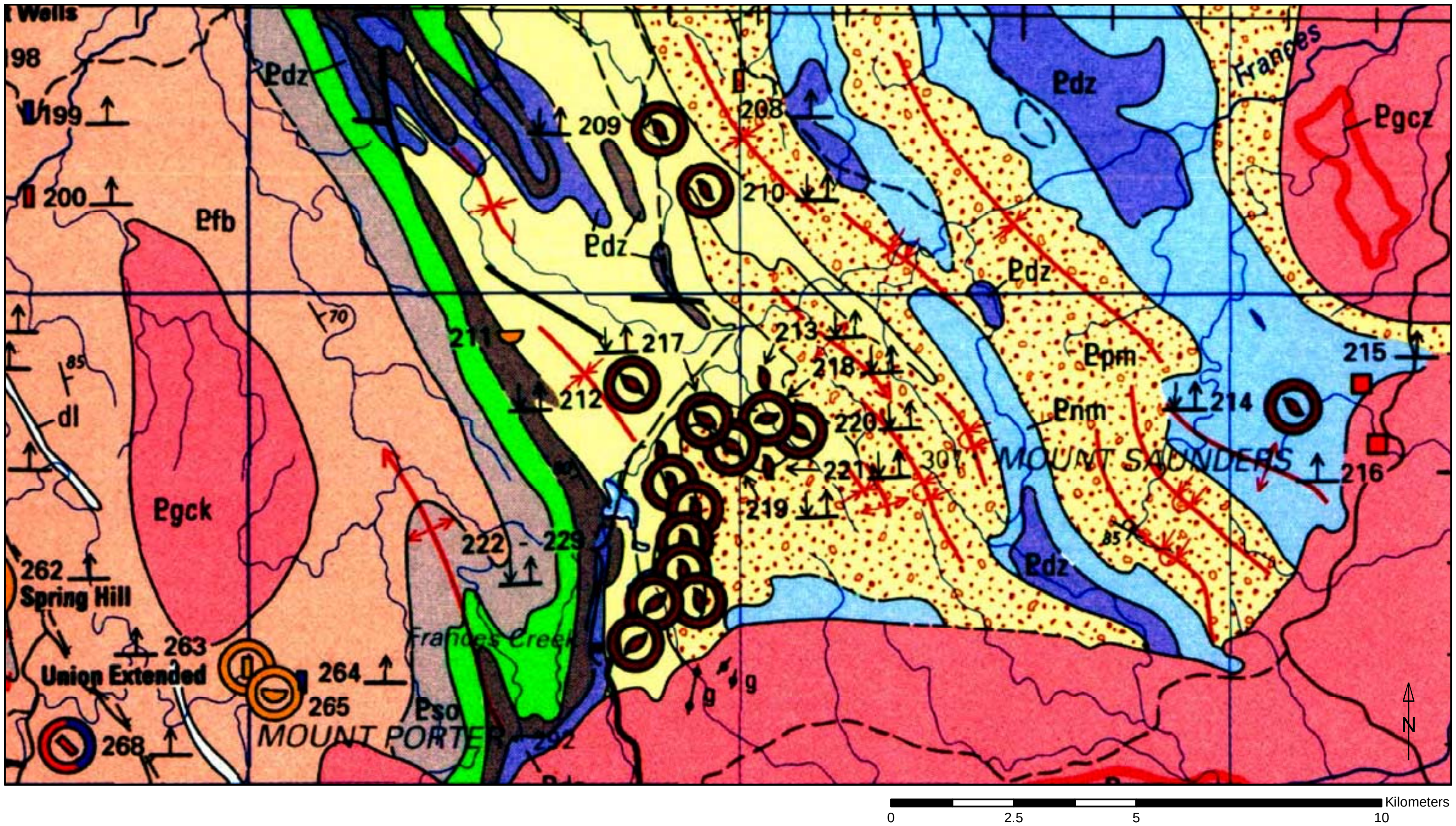
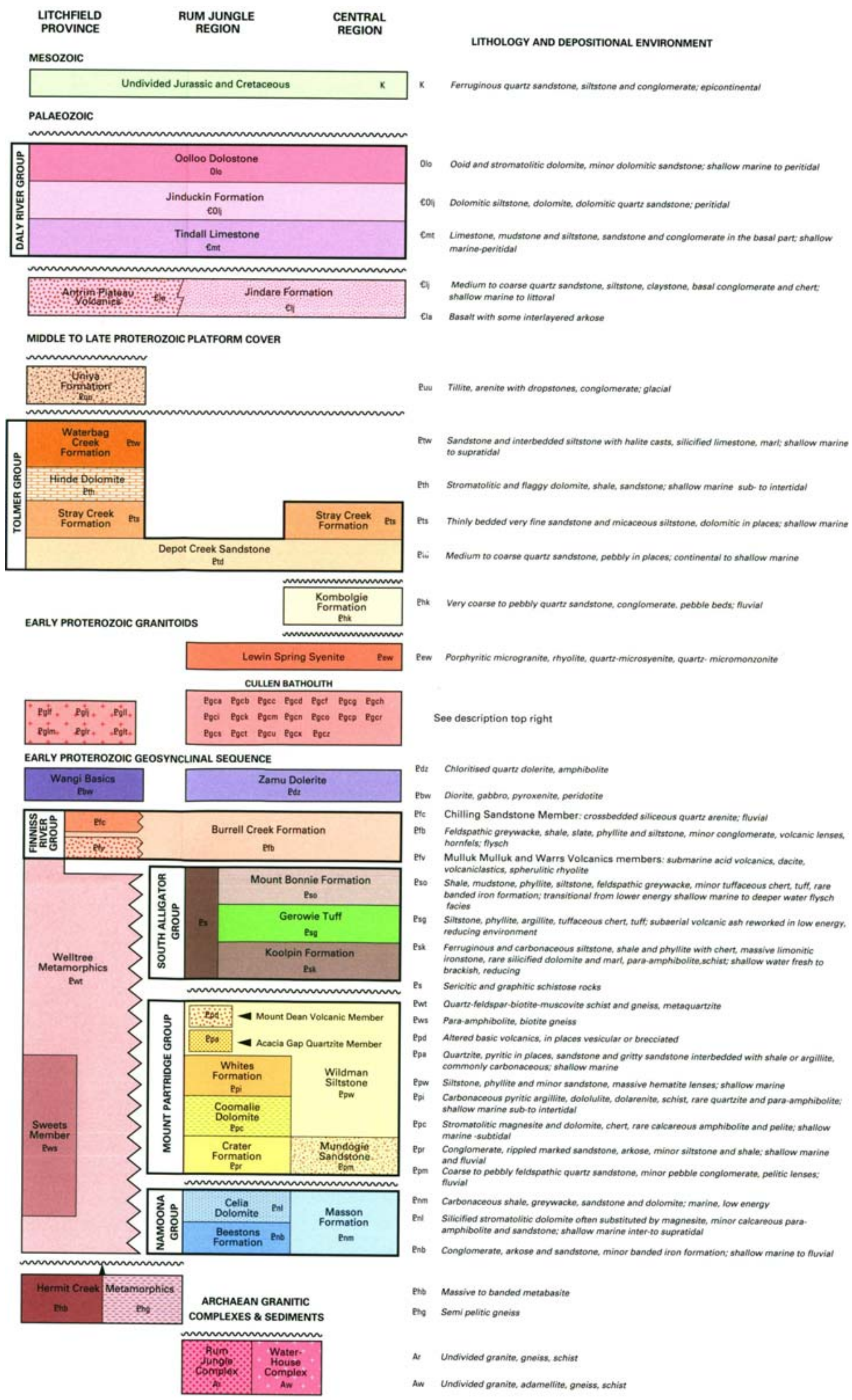


Figure 4 Geological Map of Study Area (extracted from Geoscience Australia digital data 1:250,000 sheet Pine Creek SD52-08) (key over page)



(brown circles with central 'inflections' represent mineral deposits)

2.2 Project Area Geology

The iron deposits occur as semi-continuous lenses at Frances Creek. They are fault breccia, haematitic ironstones folded in sympathy with the isoclinal folds in the lower member of the Wildman Siltstone. They crop out as prominent, discontinuous ironstone ridges up to 50 m high, over a strike length of 15 km. The largest bodies are (from south to north); Helene, Thelma 2, Ochre Hill and Saddle (BMR, 1987). The ironstones thicken within fold hinges at the Helene pits. They are contained within carbonaceous phyllite and siltstone.

The eastern sector of the project area is dominated by a NW-SE trending syncline and overturned syncline whose axis consists of Mundogie Sandstone with outer limbs of Masson Formation with some Zamu Dolerite in the north and the south.

The township and mine-site is a structurally complex area consisting of series of N (veering NW to the north) trending tight or isoclinal anticlines and synclines (from W to E) that gently plunge to the NNW (forming a zigzag pattern of outcrop).

Three small outliers of Mesozoic Cretaceous sedimentary rock, elongated NW - SE, cap the ridge to the east of the mine-site. They border the Helene series of pits, the Rosemary series and the Jasmine pits, respectively.

Alluvium occupies the valley of Frances Creek through much of the mine-site.

Table 1 Frances Creek Study Area – Simplified Stratigraphy

Western Area		Mine-site Area		Eastern Area		Far E. and S. Area	
Formation	**Lithology**	**Formation**	**Lithology**	**Formation**	**Lithology**	**Formation**	**Lithology**
Qa	Alluvium	Qa	Alluvium	Qa	Alluvium		
Qf	Black & brown humic soils	Qf	Black & brown humic soils	Qf	Black & brown humic soils	Qf	Black & brown humic soils
				Cz	Lithosols (red & yellow Earth)	Czg, Czs, Czl (in south only)	Gravel, Fe stone concretions, sand
		K	Pebbly to v. coarse Sandstone; Minor basal pebble conglomerate incl. massive haematite pebbles				
McKinlay Granite	Granite					Various Granites (of Mt Cullen Batholith)	Granites incl Monzonite
Burrell Ck. Formation =< 1,500 m thick	Greywacke, siltstone, mudstone & shale. Some slate, phyllite. Minor volcanic conglomerate & hornfels						
		Zamu Dolerite Few m – 100s' m thick	Dolerite & amphibolite	Zamu Dolerite	Dolerite & amphibolite		
Mt Bonnie Formation	Shale, mudstone, phyllite, siltstone, tuff						

200 – 700 m thick							
Gerowie Tuff =< 400 m thick	Tuff, tuffaceous chert & tuffaceous siltstone. Some interbedded laminated chert & carbonaceous siltstone.						
Koolpin Formation < 100 - > 500 m thick	Sulphidic carbonaceous & dolomitic siltstones & shales, with Fe chert; Fe-stone, siliceous dolomite, Phyllitic mudstone						
		Wildman Siltstone 800-1,000 m thick	Medium-thinly bedded; laminated. Pyritic carbonaceous/dolomitic siltstone, ironstone lenses, shale breccia at depth, hornfels & minor sandstone				
		Mundogie Formation =< 500 m thick	Arkose, coarse quartzitic sandstone, minor chert & conglomerate intervals. Interbedded siltstone & shale (sometimes carbonaceous)	Mundogie Formation	Arkose, quartzitic sandstone, minor chert & conglomerate. Interbedded siltstone & shale (sometimes carbonaceous)		
				Masson Formation	Carbonaceous phyllite, slate, siltstone, minor laminated m-c quartzite & massive ironstone		

2.3 Hydrogeology (Regional Groundwater Systems)

The complex stratigraphic and structural geology results in a rather complex hydrogeological environment. Aquifer characteristics show extreme variation according to lithology, tectonic hiatus, and geomorphological history. Peneplanation, deep chemical weathering (including the production of the ironstones), weathering (to produce laterite profiles in the Cretaceous mesas), sheet-wash (in the Tertiary) and cyclic erosional and aggradational episodes (in the Quaternary) are the geomorphological agents of the area's more recent geological history that may have had an influence on the regional hydrogeology.

Dames and Moore, 1989 produced a hydrogeological map. It covers parts of the 1:250,000 topographic sheets Pine Creek SD52-08, Mt Evelyn SD53-05, Katherine SD53-09, and Fergusson River SD52-12. Mining company water supply and dewatering investigations provided much of the information on the groundwater resource exploration and development to produce this map. Figure 5 reproduces that part of the map covering the study area, whilst Figure 6 presents a W-E section across this map and accompanying legend for the Pine Creek region.

Table 2 summarises the hydrogeology based upon the stratigraphy as given in Table 1. It has been partially adapted from Dames &Moore, 1989.

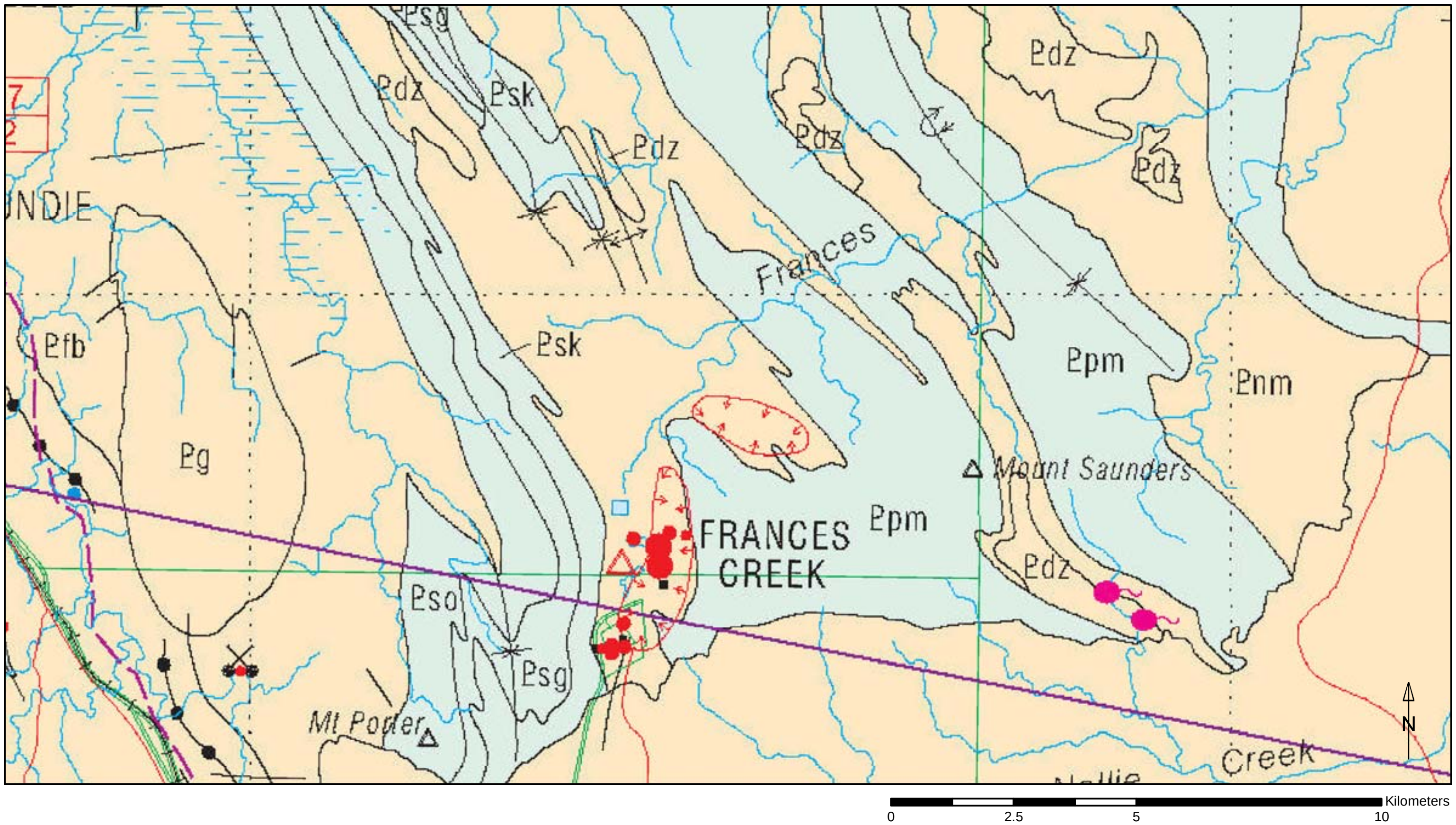


Figure 5 Hydrogeological Map of Study Area (Extract taken from Dames & Moore, 1989; updated 2002) (key on p. 24)

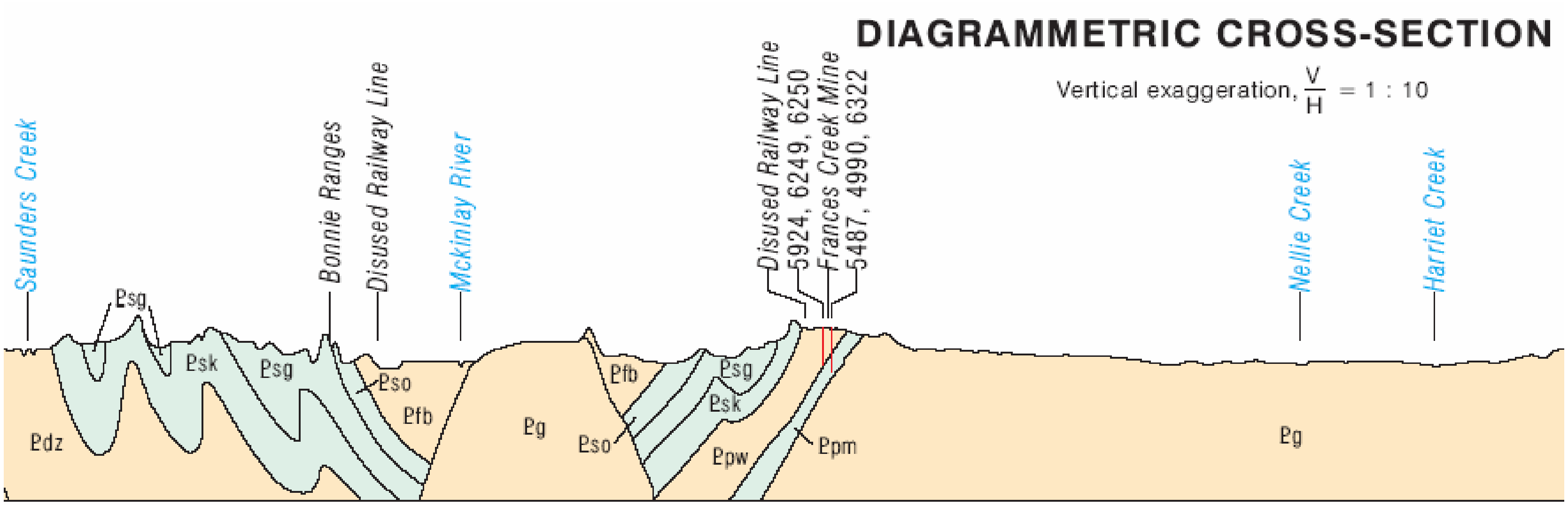
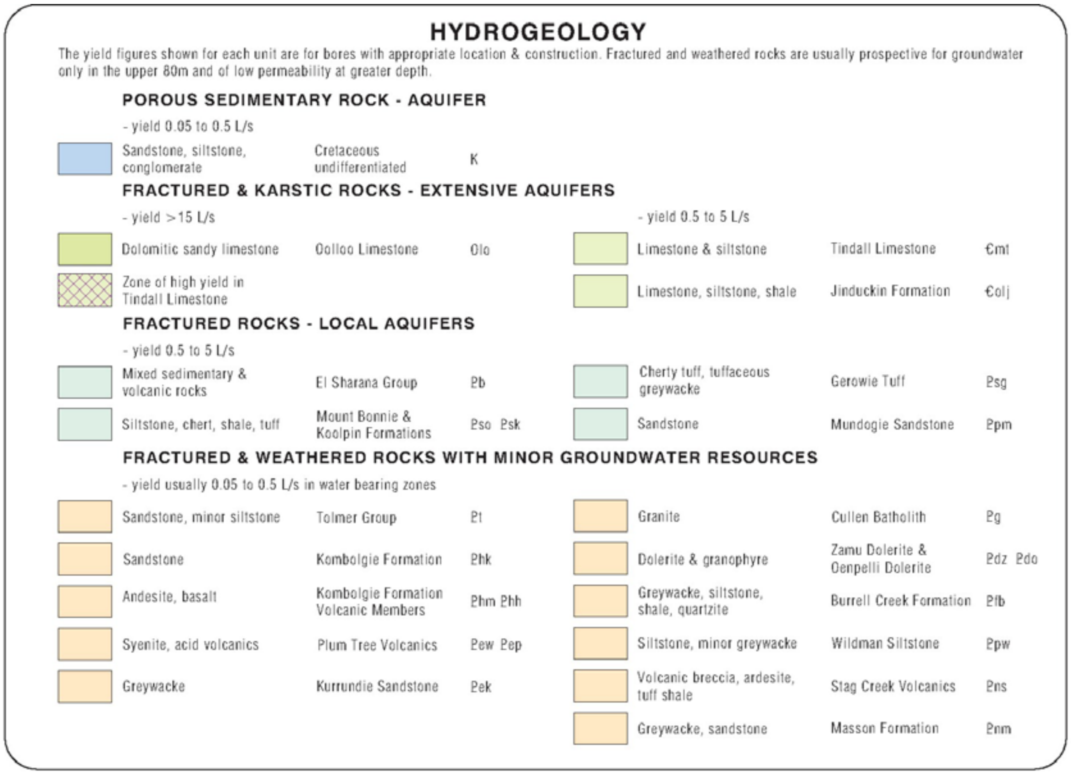


Figure 6 Hydrogeological Section of Study Area (Extract taken from Dames & Moore, 1989; updated 2002) (line of section purple on Figure 5)


HYDROGEOLOGY
The yield figures shown for each unit are for bores with appropriate location & construction. Fractured and weathered rocks are usually prospective for groundwater only in the upper 80m and of low permeability at greater depth.
POROUS SEDIMENTARY ROCK - AQUIFER
- yield 0.05 to 0.5 L/s
Sandstone, siltstone, conglomerate
Cretaceous undifferentiated
K
FRACTURED & KARSTIC ROCKS - EXTENSIVE AQUIFERS
- yield >15 L/s
Dolomitic sandy limestone
Oolloo Limestone
Olo
Zone of high yield in Tindall Limestone
- yield 0.5 to 5 L/s
Limestone & siltstone
Tindall Limestone
€mt
Limestone, siltstone, shale
Jinduckin Formation
€olj
FRACTURED ROCKS - LOCAL AQUIFERS
- yield 0.5 to 5 L/s
Mixed sedimentary & volcanic rocks
El Sharana Group
Ꝑb
Siltstone, chert, shale, tuff
Mount Bonnie & Koolpin Formations
Ꝑso Ꝑsk
Cherty tuff, tuffaceous greywacke
Gerowie Tuff
Ꝑsg
Sandstone
Mundogie Sandstone
Ꝑpm
FRACTURED & WEATHERED ROCKS WITH MINOR GROUNDWATER RESOURCES
- yield usually 0.05 to 0.5 L/s in water bearing zones
Sandstone, minor siltstone
Tolmer Group
Ꝑt
Sandstone
Kombolgie Formation
Ꝑhk
Andesite, basalt
Kombolgie Formation Volcanic Members
Ꝑhm Ꝑhh
Syenite, acid volcanics
Plum Tree Volcanics
Ꝑew Ꝑep
Greywacke
Kurrundie Sandstone
Ꝑek
Granite
Cullen Batholith
Ꝑg
Dolerite & granophyre
Zamu Dolerite & Oenpelli Dolerite
Ꝑdz Ꝑdo
Greywacke, siltstone, shale, quartzite
Burrell Creek Formation
Ꝑfb
Siltstone, minor greywacke
Wildman Siltstone
Ꝑpw
Volcanic breccia, ardesite, tuff shale
Stag Creek Volcanics
Ꝑns
Greywacke, sandstone
Masson Formation
Ꝑnm

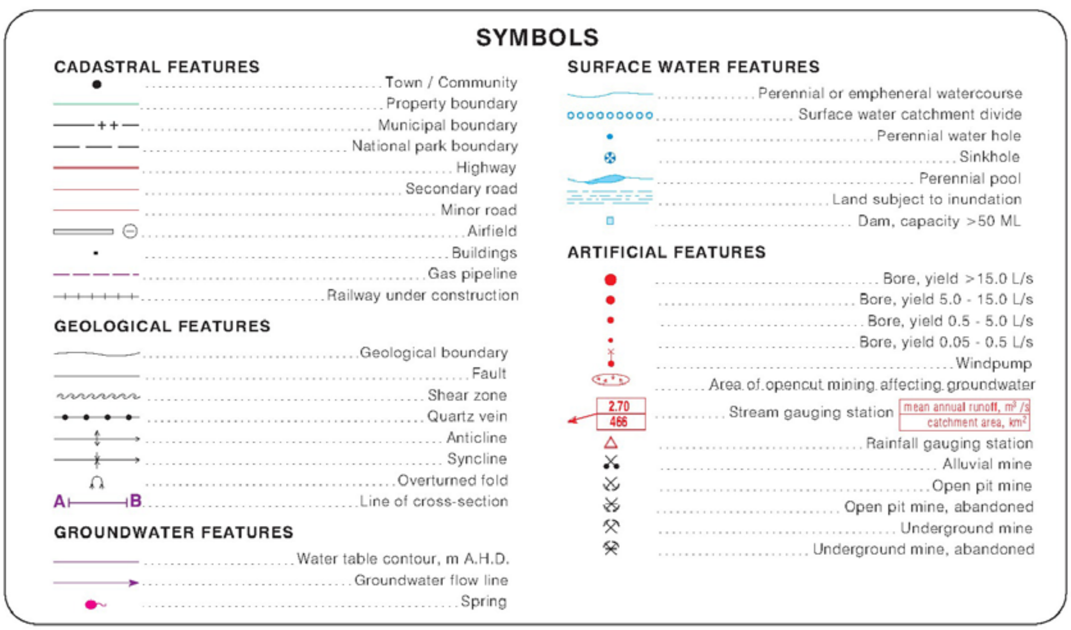

SYMBOLS
CADASTRAL FEATURES
Town / Community
Property boundary
Municipal boundary
National park boundary
Highway
Secondary road
Minor road
Airfield
Buildings
Gas pipeline
Railway under construction
GEOLOGICAL FEATURES
Geological boundary
Fault
Shear zone
Quartz vein
Anticline
Syncline
Overturned fold
A B
Line of cross-section
GROUNDWATER FEATURES
Water table contour, m A.H.D.
Groundwater flow line
Spring
SURFACE WATER FEATURES
Perennial or empheneral watercourse
Surface water catchment divide
Perennial water hole
Sinkhole
Perennial pool
Land subject to inundation
Dam, capacity >50 ML
ARTIFICIAL FEATURES
Bore, yield >15.0 L/s
Bore, yield 5.0 - 15.0 L/s
Bore, yield 0.5 - 5.0 L/s
Bore, yield 0.05 - 0.5 L/s
Windpump
Area of opencut mining affecting groundwater
2.70
466
Stream gauging station
mean annual runoff, m³/s
catchment area, km²
Rainfall gauging station
Alluvial mine
Open pit mine
Open pit mine, abandoned
Underground mine
Underground mine, abandoned

Table 2 Hydrostratigraphy (adapted from Dames & Moore, 1989)

Formation	**Dominant Lithology** (in terms of influence on water-bearing capacity	**Aquifer Type** (all are phreatic; i.e. essentially unconfined)	**Groundwater bearing Capacity**	**Comments**
Qa	Silt, sand, clay	-	Minor localised, discontinuous ephemeral, phreatic aquifer	Too thin in most places to bear & retain groundwater Reported < 5 m thick
Qf	Humic soil & clay	-	V. minor & highly localised	Cause temporary water-logging?
Czl, Czs, Czg, Cz	Fe-stone, sand, gravels, lithosols	-	Permeable; 'drainage conduits'	Above regional water-table. May form highly localized, temporary water-tables on lower slopes ('fans') with seepage faces
Cretaceous	Fe sandstone & conglomerate	Effectively non-aquifer	Permeable; 'drainage conduits' by direct rainfall	Lay above regional water-table, too small in study area to form significant 'perched' aquifers
Cullen Batholith	Granite	Effectively non-aquifer	v. little	
Zamu Dolerite	Dolerite	Effectively non-aquifer	v. little	
Burrell Creek Formation	Greywacke, shale, slate	Fractured & weathered rock aquifer	Minor, localised permeable zones	Low yield (0.05 – 0.5 L/s)
Mount Bonnie Formation	Shale siltstone, tuff, 'greywacke'	Fractured & weathered rock aquifer	Minor, localised permeable zones	? < 0.5 L/s
Gerowie Tuff	Siltstone, tuff, tuffaceous chert	Fractured rock aquifer	Minor localised aquifer	(0.5 - 5 L/s possibly)
Koolpin Formation	Mudstone, chert, siliceous dolomite	Fractured rock aquifer	Minor localised aquifer	(0.5 - 5 L/s possibly)
Wildman Siltstone 'Upper'	Siltstone, sandstone (minor 'greywacke')	Fractured & weathered rock aquifer	Minor, localised permeable zones	Low yield (0.05 – 0.5 L/s)

Formation	**Dominant Lithology** (in terms of influence on water-bearing capacity	**Aquifer Type** (all are phreatic; i.e. essentially unconfined)	**Groundwater bearing Capacity**	**Comments**
Wildman Siltstone 'Lower'	Phyllite, siltstone (minor 'greywacke')	Fractured & weathered rock aquifer	Minor, localised permeable zones	Low yield (0.05 – 0.5 L/s)
Mundogie Sandstone	Arkosic sandstone, coarse quartzitic sandstone	Fractured rock aquifer	Localised aquifer	Higher yields than other formations listed (0.5 - 5 L/s)
Masson Formation	Quartzite, siltstone, phyllite ('greywacke'); ironstone	Fractured & weathered rock aquifer	Minor, localised permeable zones	Low yield (0.05 – 0.5 L/s)

Dames &Moore, (1989) state that “Reliable groundwater sources are difficult to locate in the fractured Proterozoic rocks of the Pine Creek Geosyncline”. The fractured and karstic rock (limestone) extensive and prolific aquifers of the Daly Basin are too far from Frances Creek either to be impacted upon or be considered as an economic source for water supply.

A group of springs is shown on the hydrogeological map located on a tributary of Nellie Creek, approximately 10 km to the east. Most of the terrain between Frances Creek and these springs is occupied according to the hydrogeological map, by Mundogie Sandstone which is classified as a “local” aquifer. The rocks in the immediate vicinity of the springs are mapped as Zamu Dolerite (listed as “Fractured and weathered rocks with minor groundwater resources”)[1]. Drawdown due to mining generated impacts is not expected to spread widely in these relatively low (bulk) permeability materials.

Much of the discussion in Sections 2.3.1 and 2.3.2 is taken from Dames & Moore, 1989.

The various lithological units described in Table 2 each have their own hydraulic properties but these properties are heavily overwritten by structurally controlled features (fractures, joints shear zones faults) which tend to dominate over lithology in determining patterns of groundwater flow.

A conceptual model for the fractured rocks of the study area is discussed in Section 3.3 and Appendix C.

In terms of groundwater flow systems, the study area is believed to contain many “local scale” flow systems driven by topography and recharge/discharge processes.

2.3.1 Fractured Rocks – Local Aquifers

Fractured rock aquifers are typically extremely varied in their hydraulic parameters making an assessment of yield problematic.

Three hydrogeological units were classified in the study area; Mount Bonnie and Koolpin Formations; Gerowie Tuff, and Mundogie Sandstone.

Mt Bonnie and Koolpin Formation

Isoclinal folding and intense faulting, varied lithology and brittle fracture has produced a locally, intensely fractured aquifer with zones of dolomite secondary permeability giving high yielding bores (e.g. at Coronation Hill and Cosmo Howley). Yields of 0.5 - 2 L/s are anticipated outside major structural features and up to 10 L/s along prominent faults.

[1] assigned as a non-aquifer in this report’s interpretation.

Gerowie Tuff

Prospective yields are up to, and sometimes in excess of, 5 L/s with highly (deeply eroded) permeable zones confined to fault and shear zones. Mine water supplies, in the past, have been developed in this formation at Cosmo Howley and Mount Bonnie.

Mundogie Sandstone

The Mundogie Sandstone Occurs extensively in the Frances Creek area where it is intensely folded and faulted. From results outside the 'Pine Creek Mining Region' (at Goodparla where yields of 1 - 1.5 L/s are attained), it was designated as "a locally prospective aquifer".

2.3.2 Fractured and Weathered Rocks with Minor Groundwater Resources

The stratigraphic units are not presented in Dames & Moore (1989) due to the relatively uniform nature of the groundwater prospects and lack of significant water supplies. Instead they were grouped under "Fractured and Weathered Rocks with Minor Groundwater Resources". However, they include the Masson Formation, the Wildman Siltstone, the Mount Bonnie Formation and the Burrell Creek Formation.

The rocks within this category are usually of very low permeability except along fault lines, tensional fold features and where they have been intensely weathered. Even within these zones of enhanced permeability their restricted volume results in the sustainable yield being less than 0.5 L/s. The Burrell Creek Formation is atypical in that sustainable yields of 0.5 to 2 L/s are locally obtainable from bores located in some shear and fault zones.

The granites of the Cullen Batholith are effectively impermeable.

2.3.3 Groundwater Quality

Regionally, the groundwater is typically of low salinity with high levels of bicarbonate and a pH that is slightly acid to slightly alkaline.

The fractured aquifers of the study area are characterized by groundwater that rarely exceeds a salinity of 700 mg/L, is high in bicarbonate and contains the cations, calcium, magnesium and sodium in proportions tending to be highest in magnesium.

A Durov plot is reproduced from Dames & Moore, 1989 as Figure 7 that shows the water type as a bicarbonate-rich water. In its representation, analytical data from the study area are included (viz. from Table 4). The analysis of the sample taken from RN 6322 ('B001') at the township (see Figure 9) in January 2006 is plotted on it for comparative purposes. Its hydrochemical signature is one of a recharge water with little ion exchange taking place as a result of 'mixing in the aquifer'.

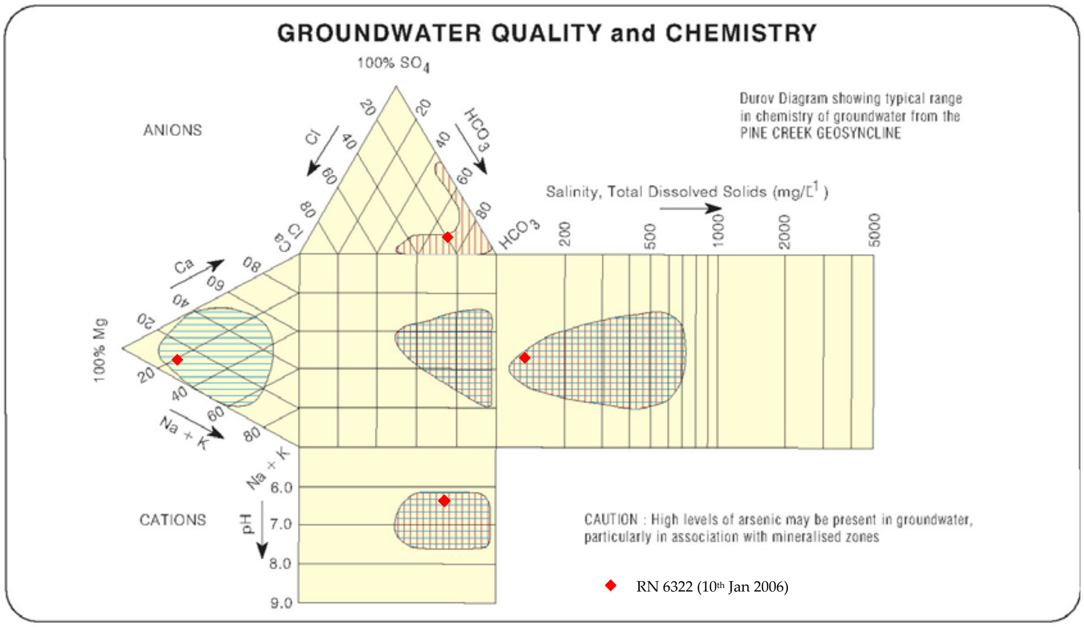


Figure 7 Durov Diagram of Groundwater Chemistry (reproduced from Dames & Moore, 1989 showing Bicarbonate-type Groundwater)

The major ion water quality is good; however there is a presence of heavy metals that is typical of mineralised zones.

2.3.4 Project Area Water Bore Information

Typically airlift yields are rarely sustainable in this geological environment as with prolonged pumping the enlarging cone of drawdown intersects less permeable zones and as the more permeable zones dewater, the rate of flow at the bore is not sustained. Bore yield reduction is reported toward the end of the dry season. Seasonal water-table ('standing water level' or 'SWL' in bores) fluctuations often exceed 5 m so, in the absence of rainfall recharge the saturated aquifer thickness is said to considerably reduced (Dames & Moore, 1989).

A statistical summary of bore depths indicated that the Burrell Creek Formation had a mean bore depth of 52 m, a mean airlift yield of 0.8 L/s (sample size of 17) (Dames & Moore, 1989).

Indications from the hydrogeological map are that there are few water bores in the region and where more than one bore exists; they tend to be close together presumably as water supply bore-fields. A map of known bores for the project area (from DNRETA's database) is plotted as Figure 8 with an exploded view on an aerial photograph base map on Figure 9. Evidence of this geographical clustering may be seen on these maps. Note that most of these water bores are now disused. Table 3 summarises water bore information for the project area.

2.3.5 Project Area Mineral Drilling

AGT was supplied with a spreadsheet of exploratory mineral drilling coordinates for mainly reverse circulation (RC)-drilled holes drilled on tenements EL9999, AN389 and EL10137. However it did not contain any groundwater information. After enquiry AGT was advised that no useful groundwater information was recorded due to the need to inject substantial amounts of water for the RC operation and, in any case, compressors held the groundwater back (Arnhem Geological Exploration, Karl, pers. comm.). Furthermore, Arnhem Geological Exploration examined diamond drill holes and reported that most of the holes failed to reach the water-table. The deeper holes in Helene 6/7 pit were collared below the level of the water-table and "made an enormous amount of water". Arnhem Geological Exploration gave an opinion that the mineralized zones were aquifers and on some occasions (in the pit) these groundwater-bearing zones were drilled through into dry rock below the (mineral) targets.

Sorting the exploratory drilling spreadsheet by pit and EOH (total drilled depth; all holes drilled perpendicular to ground surface) indicates a range of total hole depths of:

- Helene 5: 42 – 96 m bgl;
- Helene 6/7: 25 -76 m bgl;
- Ochre Hill: 19 -68.5 m bgl;
- Rosemary: 24 - 78.1 m bgl; and,
- Thelma-Rosemary 34 – 49 m bgl.

Taking the maximum hole depth at each pit site and interpolated 'average' water-table elevations, Helene 5, Ochre Hill and Thelma-Rosemary drill-holes would not have struck groundwater.

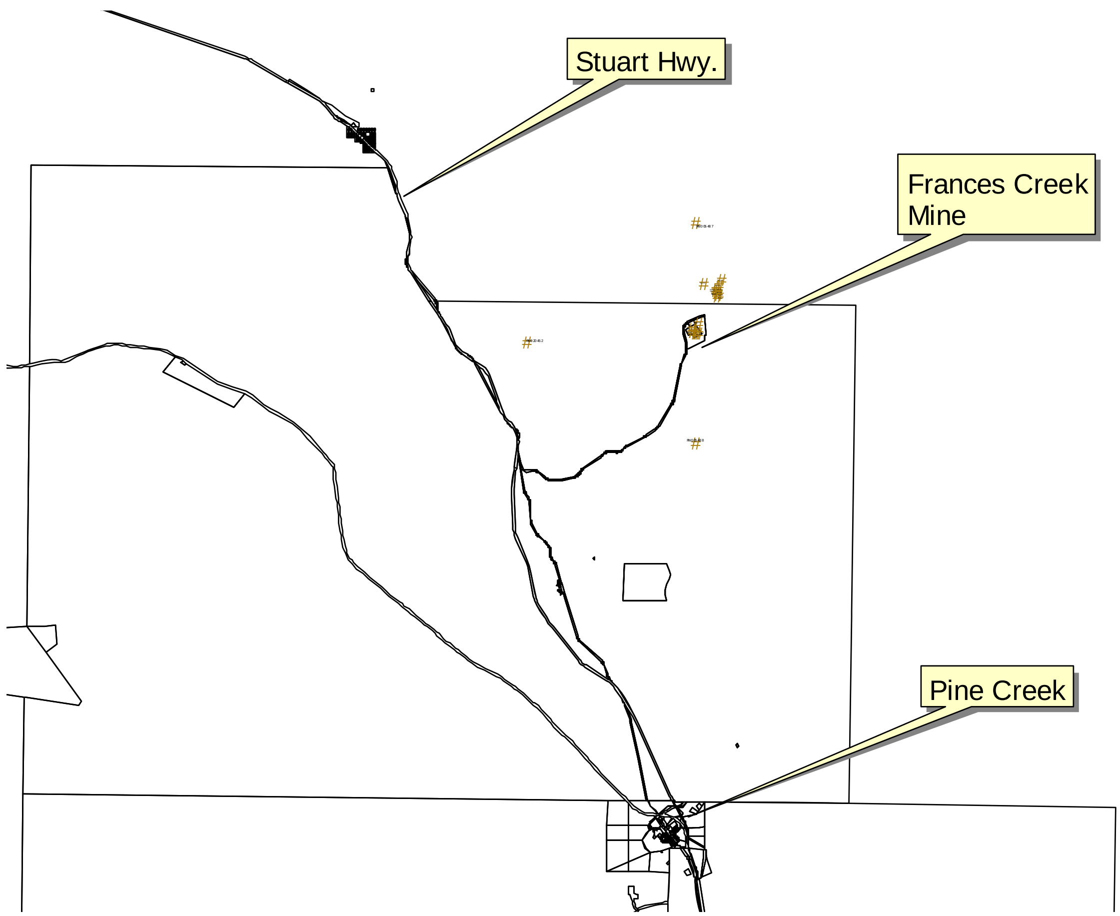


Figure 8 Water Bore 'Density' Map – Frances Creek Project Area

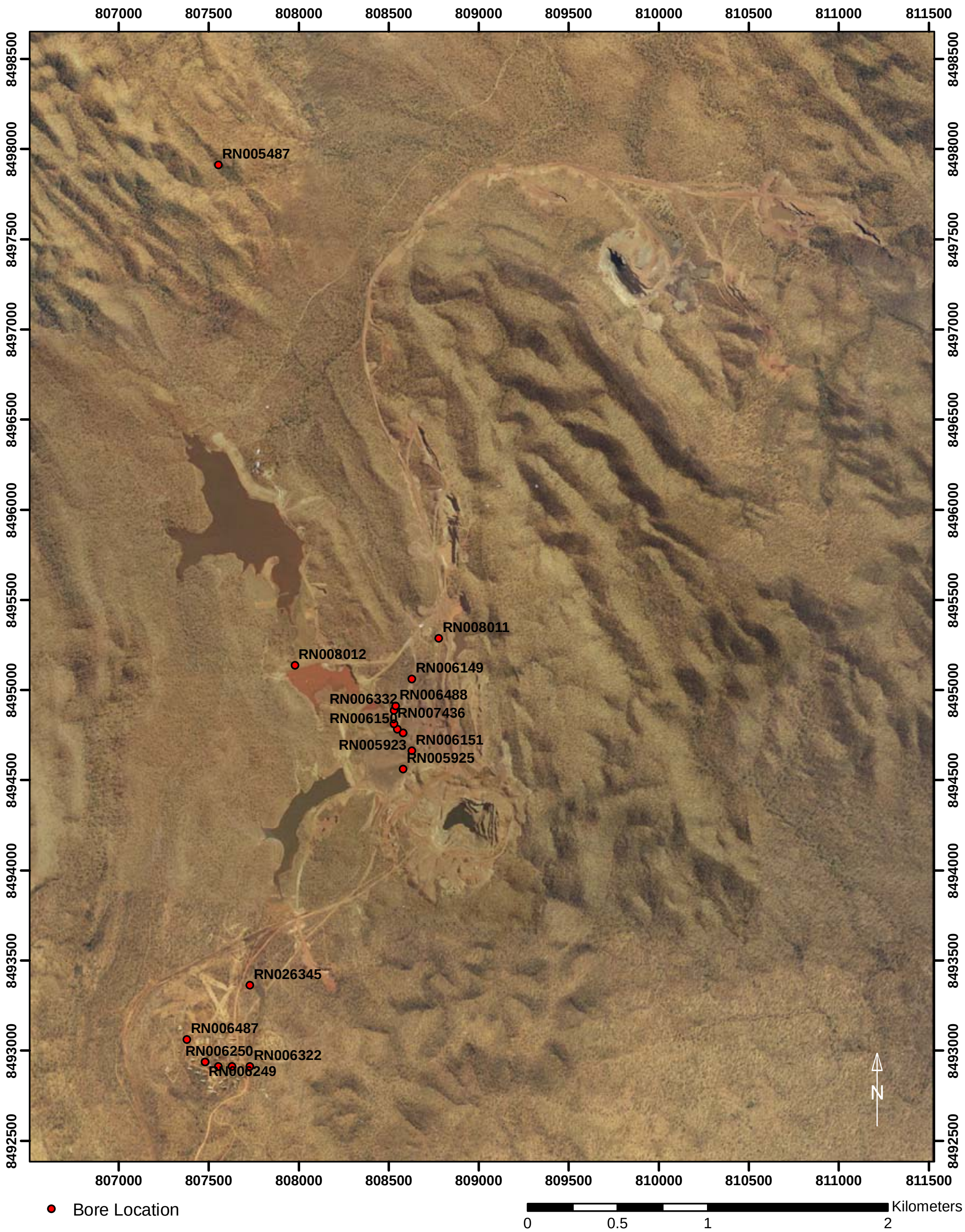


Figure 9 Water Bore Location Map – Frances Creek Project Area (excluding Ochre Hill)

Table 3 Summary of Water Bores - Frances Creek Project Area

Bore RN	Bore Name	Owner	Easting	Northing	Elevation (m AHD)	Drill Depth (m bgl)	Date Drilled	SWL (m bgl)	Yield (L/s)
4990	TOWN SITE NO.1 FRANCES CREEK	FRANCIS CREEK	807555	8492911	213	37	Jul-65	27.4	0.6
5487	TOWN SITE NO.2 FRANCES CREEK	FRANCES CREEK TOWNSHIP	807555	8497911	192	44	Jul-66	28.9	0.9
5488	FRANCES CREEK IRON MINING GRP	NO.1 FRANCES CREEK	807555	8487911	?	40	Jul-66	19.8	1.1
5922	NO.1 FRANCES CREEK	FRANCES CREEK IRON MINING GRP	808580	8494761	194	61	Aug-67	18.3	5.0
5923	NO.2 FRANCES CREEK	FRANCES CREEK IRONING MINE	808580	8494761	194	55	Aug-67	18.3	7.6
5924	NO.3 FRANCES CREEK	FRANCES CREEK MINING Co.	807630	8492911	211	78	Sep-67	24.4	2.0
5925	NO. 4 FRANCES CREEK	FRANCES CREEK IRON MINING Co.	808580	8494561	200	61	Sep-67	42.6	62.5
6149	NO. 7 FRANCES CREEK	FRANCES CREEK IRON MINING Co.	808630	8495061	200	76	May-68	24.4	9.0
6150	NO. 8 FRANCES CREEK	FRANCES CREEK MINING Co.	808550	8494781	194	98	Jun-68	-	-
6151	NO. 9 FRANCES CREEK	FRANCES CREEK MINING Co.	808630	8494661	201	84	Jun-68	36.6	2.3
6249	TOWNSITE NO.7A FRANCES CREEK	FRANCES CREEK MINING Co.	807480	8492936	215	98	?	-	-
6250	TOWNSITE NO. 7 FRANCES CREEK	FRANCES CREEK MINING Co.	807480	8492936	215	107	Jun-68	-	-
6322	NO. 15 FRANCES CREEK	FRANCES CREEK MINING Co.	807730	8492911	213	123	Oct-68	39.6	1.5
6332	NO. 13 FRANCES CREEK	FRANCES CREEK MINING Co.	808530	8494886	194	88	Nov-68	18.3	25.0
6487	NO. 11 FRANCES CREEK	FRANCES CREEK MINING Co.	807380	8493061	219	52	?	19.7	0.9
6488	NO. 12 FRANCES CREEK	FRANCES CREEK MINING Co.	808540	8494911	195	67	?	-	-
7436	CAMP SITE BORE NO.3 FRANCES CREEK	FRANCES CREEK MINING Co.	808530	8494811	194	95	Dec-70	44.2	7.6
8011	RAILWAY BORE FRANCES CREEK	FRANCES CREEK MINING CAMP	808780	8495286	206	121	Oct-72	27.4	3.3
8012	CAUSEWAY BORE FRANCES CREEK	MARY RIVER STATION	807980	8495136	189	?	?	-	-
20452	UNION EXTENDED MINE MT. WELLS AREA	FRANCES CREEK IRON MINING Co.	799930	8492461	133	17	Aug-78	-	1.0
25630	JACOBSEN C SPRING HILL	-	795080	8493361	137	39	Apr-88	14	5.0
26319	K. JANSEN MT WELLS GARDEN LEASE	-	795830	8504311	87	35	?	12	-
26345	FIMCO P/L FRANCES CREEK	FIMCO	807730	8493361	205	?	?	12.2	-
29457	McKEDDES GOLD MINE NO.1	-	810425	8505261	110	48	Sep-94	-	-
29458	McKEDDES GOLD MINE NO.2	-	810330	8505351	113	30	Sep-94	15	12.0
29459	McKEDDES GOLD MINE NO.3	-	810430	8505271	110	36	Sep-94	15	12.0
29580	McKEDDES GOLD MINE NO.4	-	810430	8505261	110	42	Sep-94	22	6.0

Key to Table 3:

RN = NT Gov. registered No.; Grid Datum MGA94, Zone 52; Elevation from NASA Shuttle Radar

2.3.6 Regional Groundwater Flow

It has not been possible to determine regional groundwater flow directions owing to the paucity of SWL information as bores are clustered in terrain whose elevation is highly variable. Hence, groundwater velocities cannot be determined with any credibility and thus the travel-time / attenuation of any contaminant plume which may reach the groundwater body cannot be directly assessed.

2.3.7 Mine Dewatering

Regionally, Dames and Moore's (1989) account of historical mining operations indicates open pits of up to 50 m depth. They reported that due to the low intrinsic permeability of most of the rock formations, dewatering requirements were generally low and, in some cases, could be maintained by pit sump pumping (Dames & Moore, 1989). In their opinion, there was no geotechnical requirement for dewatering due to the competent nature of the pit walls. Further it was stated that where permeable zones were intersected these were liable to dewater quickly due to limited groundwater storage.

3. HYDROGEOLOGY OF THE MINE-SITE AND TOWNSHIP

Table 2 and Figure 5 should be cross-referenced when reading Section 3 of the report.

The proposed mining areas, a series of ironstone lenses, follow a major fold structure which has resulted in a complex "Z" shaped pattern of outcrop with the Helene deposits located on the western limb of the structure where the township is also situated.

The various Thelma/Rosemary deposits are situated on the 'diagonal' or 'middle' limb of the "Z" and Jasmine lies on the eastern limb. Ochre Hill is situated some 5 km to the north of Jasmine on the extended eastern limb of the structure.

Geological logs of Frances Creek water bores identified the fractured rock aquifers at the time of drilling (1965/72) as the Masson Formation but more recently published hydrogeological mapping (Dames & Moore, 1989) indicates the outcropping geological unit to be the Wildman Siltstone.

The yields listed in Dames and Moore (1989) of "usually 0.05 to 0.5 L/s in water bearing zones" may well apply to the Wildman Siltstone/Masson Formation in structurally undisturbed areas but, within the highly folded environment around the Frances Creek mine-site, the more brittle rocks are highly fractured. Deep weathering combines with fracturing to produce bore yields which can be one to two orders of magnitude greater than suggested, especially in favourable situations near minor fold axes where tensile stresses can lead to open fractures.

3.1 Bore Yields

Of the 14 bores within the project area reported to have recorded yields the distribution of yields is as follows:

>[2] 2 L/s	5 bores
2 to 5 L/s	4 bores
5.1 to 10 L/s	3 bores
> 10 L/s	2 bores

[2] > represents 'greater than'