# Developing Water Supplies from Saprolite Regolith

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**Abstract**

Extensive areas of saprolite regolith are present on plateau land development over cratonic regions of the earth. These saprolite zones often contain significant water saturated sections and represent large storages of groundwater.

Groundwater storages in saprolite, although widely used for village and small rural supplies particularly in subtropical regions where groundwater is at a shallow depth and of low salinity, are rarely developed as a major water source. The principal reason for lack of usage of saprolite groundwater as a major resource results from inherent low to very low hydraulic conductive properties.

Much knowledge of saprolite hydrogeology has been gained through development of open pit mines containing these rocks. Long term observations show that a considerable portion of dewatering results from drainage from saprolite rather than from limited storage in fracture zones containing dewatering bores sited in underlying crystalline rock.

This paper includes examples taken from widely separate climate regions of the earth where saprolite has been dewatered through use of underdrainage from linear structures in the crystalline bedrock. Underdrainage makes use of both inherent palimpsest structures in saprolite as well as the 'delayed yield' factor familiar in development of phreatic aquifers. This underdrainage has resulted in large sustained groundwater yield.

Knowledge gained from open pit mine dewatering has provided sound examples for potential extractable storage values from saprolite. This knowledge has proven valuable where applied to planning water supplies from underdeveloped saprolite regions particularly those in arid plateau lands that lack alternative water sources.

## INTRODUCTION

Extensive saprolite regolith is present on plateau lands of cratonic regions and, where water saturated, potentially contain large storage of groundwater. These groundwater sources are extensively used for small town and rural supplies in temperate to tropical regions where annual rainfall provides reliable recharge and saturation to a shallow depth below ground level. Saprolite has inherent low hydraulic conductivity and it is this factor that has largely precluded its use for large sustainable groundwater abstraction particularly in arid-semiarid regions.

This paper describes examples where significant sustainable groundwater supplies have been identified and utilised from saprolitic regolith. Three main factors govern use of these sources: water quality requirement; impact on the local aquifer; and ultimate balance of abstraction with the regional recharge regime.

Plateau-land saprolite regolith has developed over a long period and in many parts of the world, mostly since post Cretaceous uplift. This ancient regolith shows complex chemical reorganisation and often exhibits a distinct chemically layered profile through leaching during temperate wet climate cycles to chemical deposition during drier climates (Morgan, 1993). These profiles also present complex and repeated limited cycles of erosion and deposition with little major change in elevation. This follows the Fairbridge and Finkl (1980) cycle for plateau development.

The extent and remaining thickness of any saprolite layer mostly depends on magnitude of the last major uplift and subsequent erosion phase. In some regimes reintroduction of a more tropical climate has produced a secondary saprolite/lateritic development superimposed on an older eroded saprolite profile. These features are exhibited in tropical/subtropical regions of northwest Africa, Indochina and northeastern Australia particularly in less stable areas close to craton boundaries.

## METHODS

Identification of an exploration target firstly requires definition of a required abstraction rate, total abstraction volume and water quality. This latter factor determines possible requirement for use of water blending or, in the need for potable water, the use of desalination.

Except in rare cases where there is a high rate of sustainable recharge such as from a large river source or high tropical rainfall, the endemic storage factor becomes the guiding principal for exploration. Endemic storage is the principal criteria for water development in arid-semiarid regions where extensive saprolite regolith developed on crystalline rock provides a target for inferring the existence of a stored groundwater source (Morgan, 2003). Abstraction from this source depends on available storage relative to the required abstraction rate and regional aquifer recharge rate.

Examples of water supply development from saprolite regolith in relation to requirement and regional impact is presented in the following examples.

## DUKETON MINING AREA

The Duketon mining area is located in the northeastern part of the Archaean Yilgarn Craton (Figure 1). The principal example provided from this region is through development of Garden Well Gold Mine. At this mine, gold mineralisation is hosted in a north-northwest 60 degree east dipping layered sequence of shale, volcanogenic flows and clastics interlayered with mafic and ultramafic intrusives. Saprolite development and oxidation extends up to a depth of 120 metres below ground level. Gold milling commenced August 2012 with initial water usage of $4MkLy^{-1}$. With additional gold resources identification throughout the area, water requirement for milling has been increased to a planned $12MkLy^{-1}$ for a current planned life to at least 2025 (Morgan, 2015).

Test pumping on fourteen dewatering bores located in selected highly conductive fractured rock zones in Stage 1 Pit provided the following average hydraulic parameters:

transmissivity $47.45m^2d^{-1}$

storativity $1.5 \times 10^{-2}$

Pumping from the pit after 295 days at 19,568m3d-1 resulted in development of an elongate groundwater depression in the surficial and saprolite layer (Figure 1). This depression is 80 metres deep with an average radius of 700 metres. Analysis of pit drawdown data provided for an update on hydraulic factors as following:

| **Direction** | **Transmissivity ($m^2d^{-1}$)** | **Storativity (dimensionless)** |
|---|---|---|
| North | 26.37 | $4.25 \times 10^{-3}$ |
| South | 35.34 | $9.58 \times 10^{-3}$ |
| East | 20.78 | $2.49 \times 10^{-2}$ |
| West | 17.14 | $3.44 \times 10^{-2}$ |
| Average | 24.91 | $1.78 \times 10^{-2}$ |

Both test pumping data and continued drawdown data shows that the fracture zones in which the bores are located exhibit rapid depletion of storage.

Analysis of catchment recharge shows that only 7.2 percent of the abstraction of 4MkLy-1 is derived from rainfall infiltration, therefore, it is concluded that the major part of supply is derived through delayed yield drainage from saprolite (Morgan 2012).

Observed agreement between hydraulic parameters derived from pumping tests and those derived from rate of development of the drawdown depression provides confidence in predicting aquifer performance for the remaining life of the mine. The modelled drawdown for mine life to 2025 is shown on Figure 2. This analysis also provided confidence for modelling drawdown performance in the recently identified mines in the Duketon area, namely Dogbolter, Petra, Coopers and Baneygo in which exploratory water drilling has demonstrated that they are likely to have similar hydraulic properties to that of Garden Well Gold Mine.

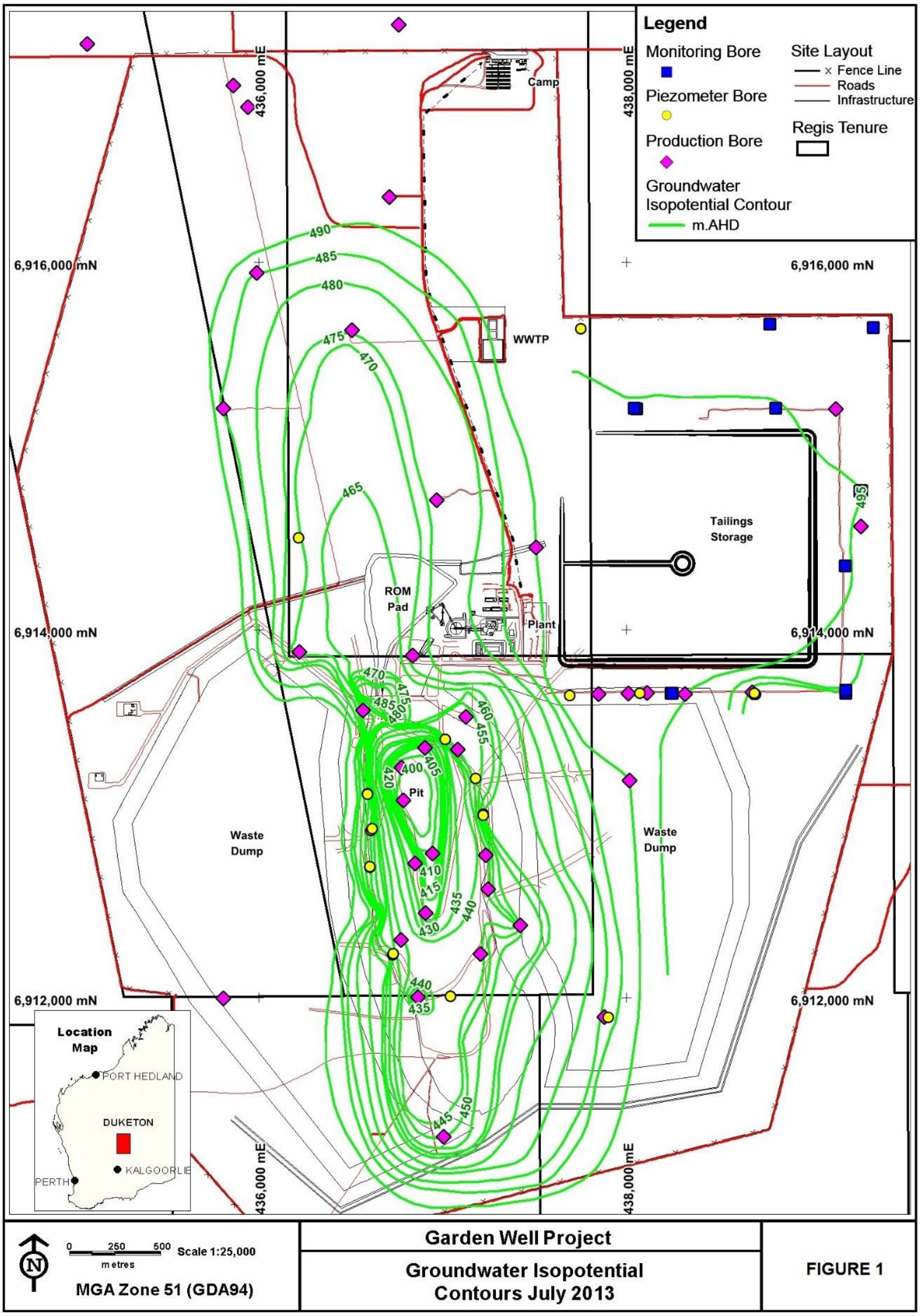


**Figure One | Groundwater Isopotential Contours, July 2013**

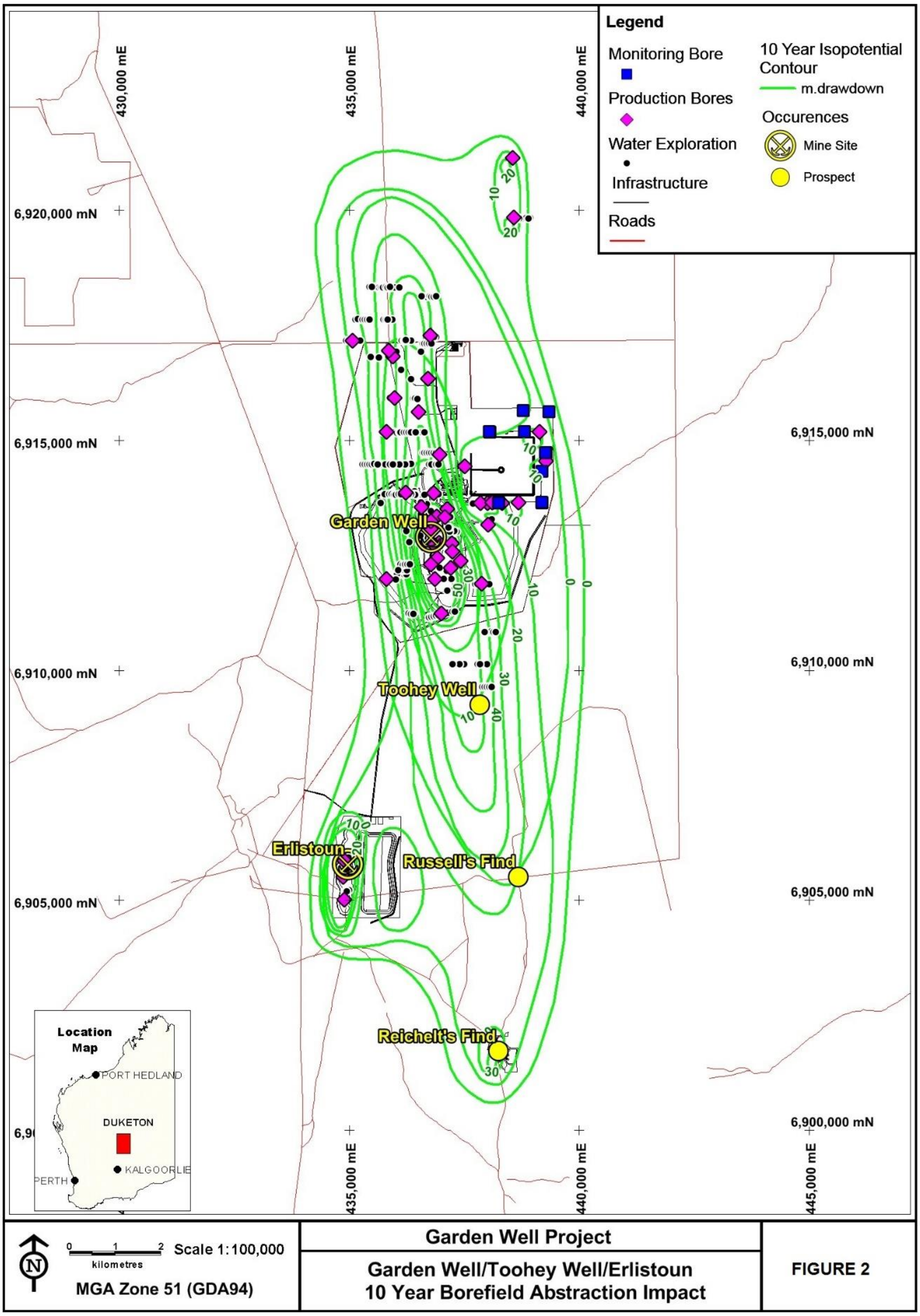


**Figure Two | Garden Well / Toohey Well / Erlistoun 10 year Borefield Abstraction Impact**

## NIMARY - JUNDEE MINING AREA

Nimary-Jundee mining area lies in the northern section of the Great Plateau of Western Australia (Figure 3). This part of the Plateau is little eroded and retains most of the ancient profile of Cretaceous and early Tertiary sediment lying over an existing weathered profile (Morgan, 1965 and Ollier et al, 1988).

The Archean bedrock is a west dipping layered sequence of basalt, dolerite and gabbro interlayered with carbonaceous sediment. The whole sequence is intersected by a complex of aplite, porphyry and lamprophyre dykes and a set of east-northeast trending Proterozoic dolerite dykes emplaced along shears. The regolith consists of a surficial layer of up to 15 metres of lateritised transported sediment which overlies up to 30 metres of completely oxidised and chemically reorganised saprolite. Saprolite passes downward into saprock (50% more of residual rock) and, at depths of 90 to 120 metres, into non-oxidised Archean crystallised rock. Groundwater is encountered between 18 to 20 metres below ground level with a salinity range of 600mg.L-1TDS to over 40,000mg.L-1 TDS.

Open pit mining in the area commenced August 1995 with pit dewatering through steel cased bores and sump pumps. Interaction of drawdown between several adjacent open pits resulted in the groundwater depression shown on Figure 3. This drawdown ranged from 2549 to 2440 metres reduced level through the saprolite-saprock section. Minimal groundwater inflow was observed from little to non-oxidised pit floors in late stages of dewatering development. Hydraulic parameters derived from multiple tests on dewatering bores provide the following parameters:

| | |
|---|---|
| average abstraction rate | 3,274.5$m^3d^{-1}$ |
| average drawdown radius | 1600 metres |
| pumping time | 1764 days |
| average dewatering depth | 60 metres |
| average aquifer thickness | 73 metres |
| average transmissivity | 9$m^2d^{-1}$ |
| average storativity | $4.12 \times 10^{-3}$ |

This drawdown configuration shows close agreement where listed hydraulic parameters are applied to the Hanna et al (1994) analytical solution for open pit dewatering. The close agreement achieved in this dewatering solution provides confidence for application of these hydraulic parameters to other similar saprolite profiles in the region.

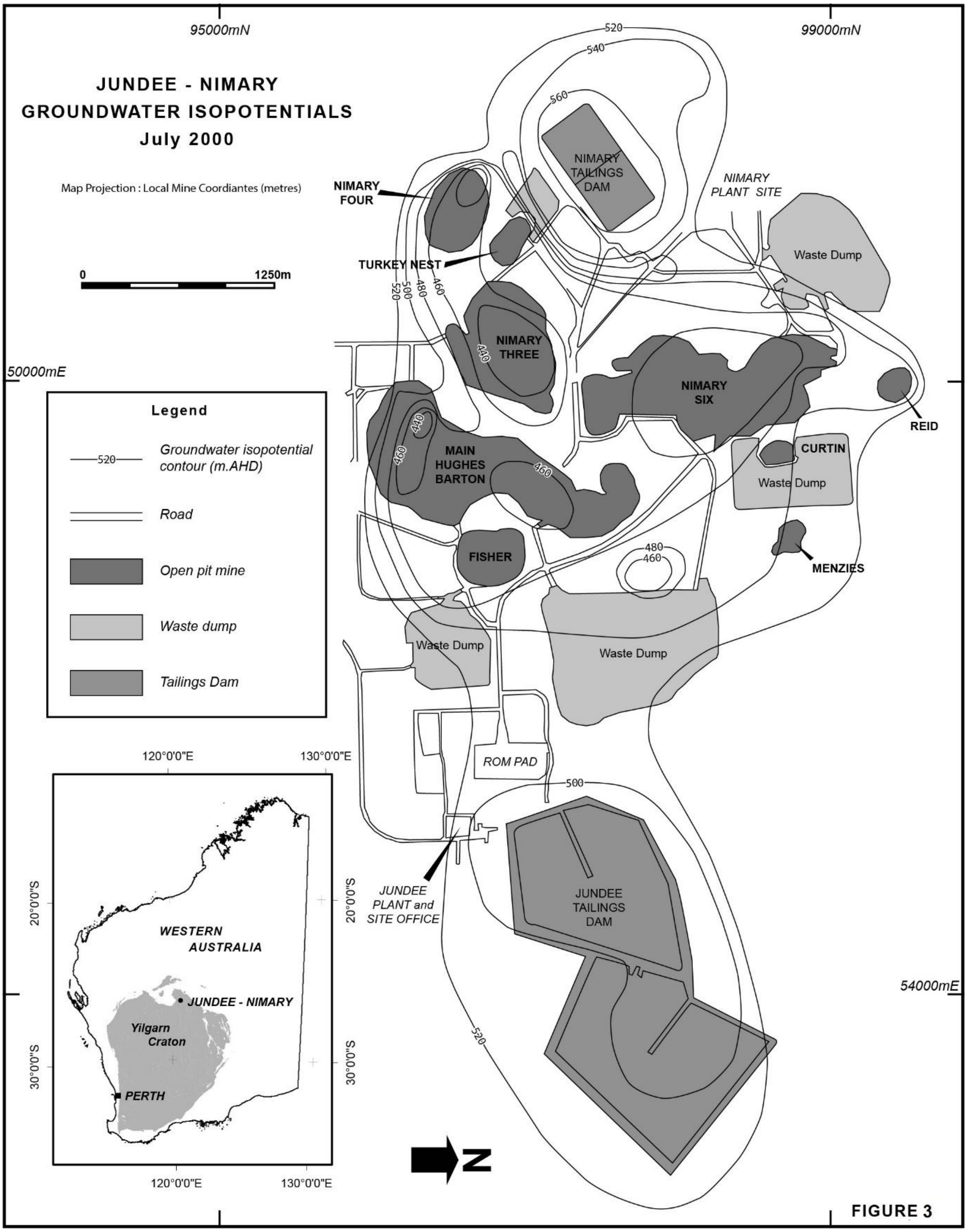


**Figure Three | Jundee - Nimary Groundwater Isopotentials, July 2000**

## EASTERN BOREFIELD, WILUNA

The Eastern Borefield is located in the northern end of the Archean Yilgarn Craton 11 kilometres east of Wiluna (Figure 4). The initial borefield was developed in 1984 with abstraction from a calcrete capped palaeochannel. On depletion of this source the thick granite derived saprolite/saprock source was developed by deepening existing bores.

Since 1984 and to approximately 2004, between 0.8MkLy-1 to 1.2 MkLy-1 of groundwater has been abstracted for gold processing at Wiluna. Water salinity ranges from 1000mgL-1 to 10,000mgL-1 total dissolved solids. During this period a drawdown depression developed in the alluvial saprolite/saprock layer. This drawdown depression ultimately stabilised under a steady abstraction rate of around 1.1MkLy-1 to the form shown on Figure 4 to achieve a balance with annual average recharge. Recharge rate has been estimated to be 0.70% of average annual rainfall on the borefield catchment (Morgan 1999, p1210). Evaluation of storage depletion rate versus recharge provides a storativity value of 4.4 x 10-2.

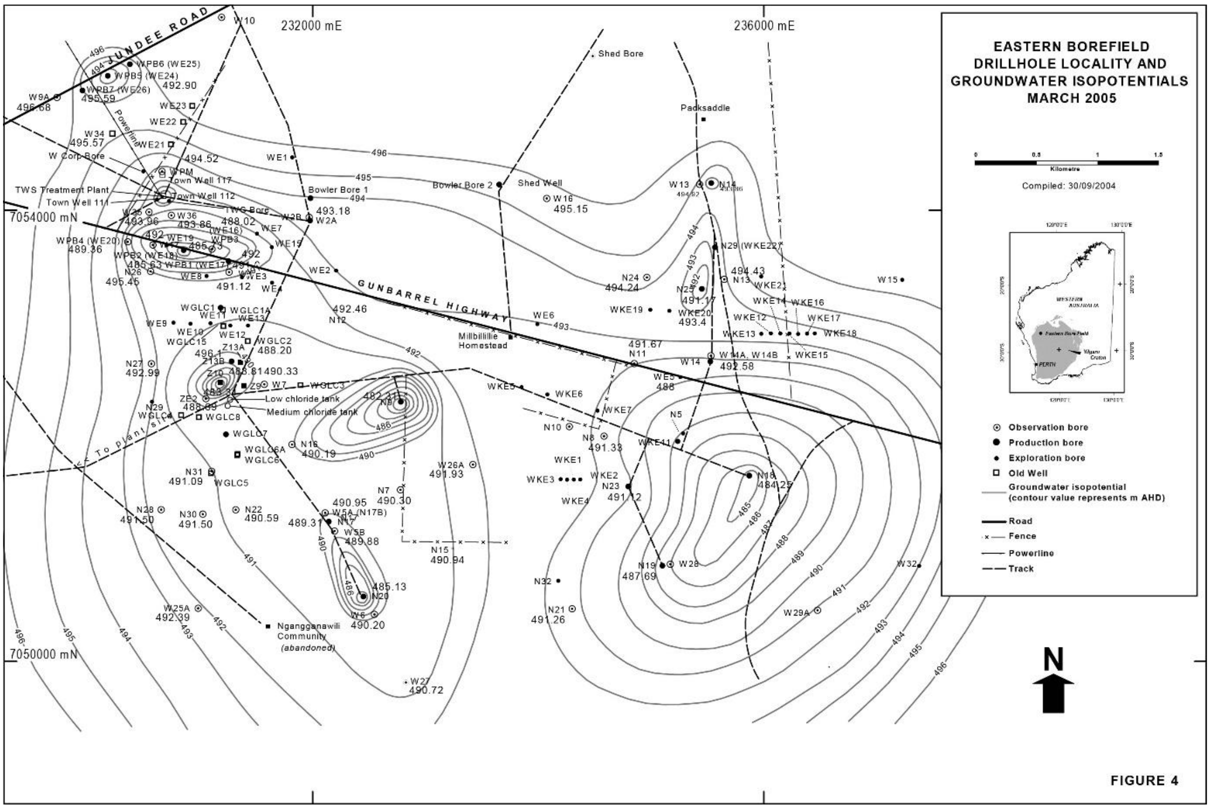


**Figure Four | Eastern Borefield Drillhole Locality and Groundwater Isopotentials, March 2005**

## BONIKRO CÔTE D' IVIOR

Bonikro mine is located in the Proterozoic Oumé–Fettékro Greenstone Belt of West Africa (Figure 5). Geology of the mine area is composed of granophyric–porphyry intruding Proterozoic Birimian Basalt, carbonaceous shale and tuff. The deeply oxidised and saprolitic regolith has been dissected by numerous rock structure controlled stream channels in a halted erosion cycle. These channels are being infilled with younger lateritic alluvium and colluvium. The present tropical climate has superimposed a younger laterite development onto the older eroded saprolitic and sediment layer.

Groundwater abstraction draws from fractured zones in quartz veins, pegmatite dykes and fracture zones occurring at the intersection of a prominent conjugate regional fracture joint set. Groundwater storage is derived from the overlying saprolite. These structurally positioned abstraction sites mostly coincide with surface drainages which provide ideal recharge conditions from storm runoff as well as from maintained effluent flow between rainfall events.

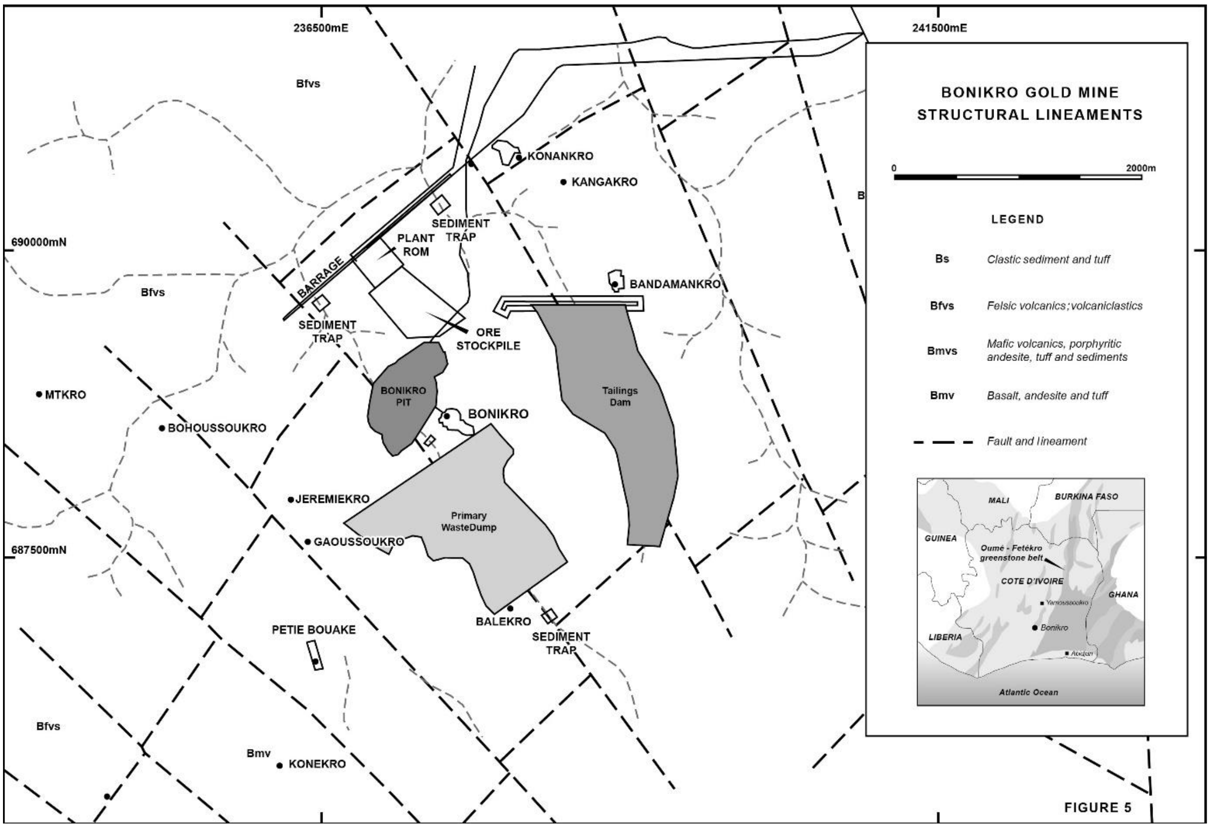


**Figure Five | Bonikro Gold Mine Structural Lineaments**

## ARAGUAIA FOLD BELT, BRAZIL

Araguaia Fold Belt region of Brazil hosts an extensive highly oxidised and water saturated regolith developed on Paleoproterozoic rocks of the Inland Plateau of Brazil. This region has a subtropical climate enhancing groundwater recharge along numerous incised river channels maintaining effluent groundwater discharge conditions through much of non-rain periods.

The regolith has developed continuously since emergence from a Cretaceous sea. Saprolite and oxidation is extensively developed to depths of more than 120 metres. Groundwater occurs at depths mostly less than 10 metres below the surface and.is mostly less than 1000mgL-1 TDS.

This region clearly contains a major undeveloped storage of good quality groundwater. The complexly structured basement containing layers of brittle crystalline rock has potential for development of underdrainage systems to the extensive saprolite storage.

## CONCLUSIONS

Long term borefield abstraction and open pit dewatering of saprolite rock sections derived from a range of rock formation, climate and topographic styles show that large storages of groundwater can be effectively abstracted from saprolite profiles. Three principal conditions for abstraction are:

1. a sustained drawdown to provide conditions to induce delayed yield;
2. an underdrainage system such as may be provided by brittle rock fractures, lava flow tops, silicic ultramafic caprock, concealed palaeochannels and other similar water conductive rock conditions;
3. analysis of regional recharge conditions to provide for an estimation of long term dewatering impact on the aquifer.

It is to be noted that in most mine development situations in saprolite areas, test pumping has been conducted while the aquifer is under semiconfined to confined conditions. Confined aquifer test pumping mostly provides very low storativity values. Storativity values are shown to increase under delayed yield conditions as an open pit exposes the aquifer to semiconfined-unconfined conditions (Morgan 2012).

Storativity values ranging from 1.53 x $10^{-2}$ to 4.2 x $10^{-3}$ have been obtained from prolonged pumping in a wide range in saprolite terrains. These examples provide confidence in inferring a groundwater resource (Morgan, 2003) or providing prefeasibility estimates of available water resources from a saprolite region. With increasing knowledge of hydraulic parameters and dimensions of the saturated regolith under investigation, a higher confidence in status of the water resource can be achieved.

The ultimate extent of development of a drawdown depression under a given abstraction regime can be balanced with regional recharge. Climate, topography and geological conditions determine the rate of recharge. This balance is clearly expressed in the examples provided for Duketon and Wiluna, Eastern Borefield, on the Yilgarn Craton of Western Australia, to a probable extent at Bonikro and to an inferred status for Araguaia.

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