Shire of West Arthur

Water Supply Security Strategy: Stage 1 - Review of Demand and Current Supplies

Shire of West Arthur

11 March 2022

WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

Document Status

Version	Doc type	Reviewed by	Approved by	Date issued
V01	Draft	Rohan Baird	Rohan Baird	03/12/2021
V02	Final	Scott Wills	Scott Wills	11/03/2022

Project Details

Project Name	Water Supply Security Strategy: Stage 1 - Review of Demand and Current Supplies
Client	Shire of West Arthur
Client Project Manager	Kerryn Chia
Water Technology Project Manager	Scott Wills
Water Technology Project Director	Rohan Baird
Authors	Scott Wills
Document Number	21040036_R01v02.docx

Ground Floor
430 Roberts Road
Subiaco WA 6904
Telephone (08) 6555 0105
ACN 093 377 283
ABN 60 093 377 283

Certified System Quality ISO 9001 SAI GLOBAL
Certified System Environment ISO 14001 SAI GLOBAL
Certified System OHS ISO 45001 SAI GLOBAL

EXECUTIVE SUMMARY

Background

The Shire of West Arthur, like the rest of the Wheatbelt, has been very dry for the last few years. Community consultation for the Shires strategic planning has shown that water security is the number one issue for many of the rate payers. To guide future decision making, the Shire has commissioned Water Technology to develop a water supply security strategy.

The Shire would like to secure water sources to ensure retention of population; ensure agriculture remains as the main economic activity of the district, mitigate risk of climate change and identify opportunities to minimise the financial impact to ratepayers.

The main objectives for the water strategy include:

- An estimate of water demand for a 10-year planning horizon (to 2030).
- An audit of current available water supplies including identification of known ground water and surface water supplies and the amount of water that could be drawn from these supplies.
- Identification of areas where water supplies need to be developed.
- Identification of alternate water supply options.
- A proposed plan for development of additional water supplies.

The South-west region has experienced a widely reported decline in annual rainfall since 1975 (CSIRO & BoM 2007; IPCC 2007b; CSIRO 2009a; Hope & Ganter 2010; IOCI 2012) and this is evident at the Darkan rainfall station, with a mean annual total of 480.2 mm for the period 1975 to 2020, an 11% decline on the long-term average. The most recent drought experienced in West Arthur was in 2015, which was the third driest year on record with a total rainfall of 307.5 mm, and came on the back of the 14th driest year in 2014 of 408.0 mm.

The reduced rainfall is a result of weakened and less frequent frontal systems, attributed to large-scale changes in southern hemisphere circulation patterns resulting from changes in global heat distribution (Frederiksen et al. 2012). The trend in rainfall decline is expected to continue, based on the climate projections from Global Circulation Models (GCM) results analysed as part of the *Surface Water Yields in South-west WA* (SWWASY) project (CSIRO 2009a).

Observed rainfall from 2000 to 2020 in the Shire of West Arthur has fallen by 69 mm (13%) compared with the 1961 to 1990 baseline climate average. The recent rainfall (post 2000) at Darkan townsite aligns with the average rainfall projected under a 'dry 2030' future climate. Provided the current rainfall trend continues along the dry 2030 projection, this is the best climate scenario to review water supplies for this Study. The 'wet 2030' and 'median 2030' climate scenarios have not been considered in this report.

Land use in the area is predominately broad acre cereal cropping and sheep grazing. The main town of Darkan has approximately 250 residents and offers a number of services including a Primary School, sports club and oval, a seasonal public pool and golf course. There is also a small industrial estate located immediately north-east of the townsite.

The primary water resource for this Shire is surface water. Farm dams, old railway dams and the Darkan Town Dam make up the majority of non-potable water supply for farmers and the town.

There are numerous operating groundwater bores around the Shire, but for the majority of bores the yield is relatively modest and the water is brackish to saline. Generally, groundwater bores are used by farmers to supplement their water supplies. The Darkan town does not currently use any groundwater for supply, but the

Shire does manage two community bores, Gorn Rd and Rees Rd, which can be used for road construction, stock water or firefighting water.

For farms, potable water is supplied by rainwater tanks and dams, but were the pipeline runs close to their property, farms can access the Great Southern Town Water Supply Scheme (GSTWSS) operated by the Water Corporation. Darkan is the first town along the scheme pipeline and all of the potable water supply in the town comes from the scheme. There are also 4 standpipes in Darkan which provide for firefighting water, water for shire works and public access. The Water Corporation strongly encourages the use of fit-for-purpose water provision by all parties where possible. That is, scheme water use for non-potable purposes should be a last resort where independent non-potable sources can't be established and utilised.

The Darkan town does not have a deep sewerage service, with wastewater disposed of by septic tanks and Aerobic Treatment Units (ATU's).

The Duranillin townsite, locate approximately 20km south of Darkan has a non-potable water supply scheme operated by the Shire and was originally set up to service 9 residence supplied by groundwater bore TOW9. Bore TOW 9 is located approximately 8 km west of Duranillin and water is pumped to the town via a trench with 50 mm poly pipe. In 2010 the groundwater supply started to show signs of becoming saline and more recently the bores salinity measured was 4,235 mg/L. The bore is also contaminated with iron reducing bacteria, which creates a brown sludge and hydrogen sulphide smell (rotten egg gas). The bore supply was discontinued in January 2020. The Shire is actively looking for a new water supply to replace bore TOW9.

There are two major river catchments within the Shire, the Collie River on the western side and the Arthur River on the eastern side. The Collie River flows west through the Darling Scarp and there are 21 sub catchments within the Shire, five with gauging stations operated by Department of Water rand Environmental Regulation (DWER). The headwater of the Arthur River is located about 30 km north of Wagin in the Arthur River Nature Reserve. Within the Shire of West Arthur, the Hillman River and the Beaufort Rivers flow into the Arthur River north of Duranillin. The Arthur River flows south into the Blackwood River at the junction of Balgarup River, adjacent to the Wild Horse Swamp Nature Reserve south of Moodiarrup.

Both the Collie River and Arthur River are too salty to provide a water supply with average salinities of approximately 10,000 and 6000 mg/L respectively.

The Shire of West Arthur is located within the Yilgarn Southwest Province and groundwater is contained in aquifer systems that are classified according to their constituent materials:

- Weathered rock (regolith) aquifers
- Fractured rock aquifers
- Surficial sedimentary aquifers
- Tertiary palaeochannels (Darkan and Beaufort palaeochannels)

In 2009, as part of joint funding from CSIRO, Southwest Catchments Council and the WA Department of Agriculture, CSIRO completed airborne geophysics assessment of the Darkan palaeochannel with the aim of more accurately defining the orientation of the palaeochannel and the quality (salinity) of the resource.

The Darkan palaeochannel was flown on 300 m line spacing with the data processing and inversion completed by CSIRO, with the investigation successful at determining the orientation of the palaeochannel and the quality (salinity) of the groundwater. The complete slide pack of results provided by CSIRO is included as Appendix A.

Water Demand Estimate

A water demand estimate was completed to establish the major water uses within the Shire and make an estimate of the likely demand to 2030. The results of the demand estimate are summarised in the Table below, with the most significant changes in demand attributable to firefighting and emergency stock water.

Summary of Water Demand Estimate for 2030

Water Use	Current Demand Estimate	2030 Demand Estimate	Change In Demand
Potable water	49,000	49,000	0
Darkan non-potable	35,550	37,010	1,460
Duranillin scheme	532	880	348
Firefighting water	5,220	15,600	10,380
Emergency stock water	180,000	300,000	120,000
Total	***270,302***	***402,490***	***132,188***

Water Resource Impact Assessment

To guide the prioritisation of water projects for the Stage 2 scope of work, a very coarse analysis of the 2030 'dry' climate impact on the Shires water sources was completed. The greatest impact was found to be on the Darkan Town Dam, which in an average year it will be necessary to pump approximately 18,000 kL/yr from Nangip Creek to top-up the dam, approximately half of the water demand from the dam (37,010 kL/yr).

The available groundwater data is too limited to make any assessment on the future reliability of the Shires groundwater bores, but with declining rainfall there is a risk of over abstraction of fresh groundwater resources leading to salt-water intrusion, as has occurred with the Duranillin groundwater supply (bore TOW 9).

Expansion of Water Sources

The Shire has completed a preliminary review of the opportunities to restore/refurbish the two railway dams but found the sites to be too constrained. The Hillman Railway dam is contaminated with asbestos.

Water Technology considers that the water supply for Duranillin is best resolved by blending as many sources as possible, as this will reduce the reliance on any one source. As part of the supply solution Water Technology recommends that the Duranillin Town dam be reassessed. It is understood that the dam was considered too small to offer a reliable supply to the town, but it may be adequate to provide a cost-effective supplementary supply when required.

The Shire has completed some analysis for consideration of a second Darkan town dam, which is intended to capture the stormwater runoff generated by the road drainage network. Water Technology considers the proposal is reasonable and understand that the major item to resolve for the Shire is the location of the dam. A location north of Coalfields Hwy would be appropriate, with the old CBH site a possibility.

There is a lack of meaningful drilling data to identify suitable areas to explore for additional groundwater supplies. To assist with future decision making we would encourage the Shire and farmers to complete bore logging and testing as per the DWER Rural Water Note 05 – *Simple Pumping Tests for Farm Bores* (Appendix B) for any new bores constructed, or any bores looking to be upgraded or integrated into the community supply. The prospective bore locations are heavily centred around the Darkan and Beaufort palaeochannels, but is possibly an indication of the rigour of the drilling programs undertaken for the palaeochannels, rather than a fair representation of the distribution of potential groundwater sources. But it is likely that the best groundwater prospects are in these palaeochannels as they represent the most significant groundwater targets.

Challenges and Constraints of Adaptation

Data

The most significant challenge to adaptation is currently a lack of data – flow data, water level data, groundwater test pumping data and water use data (meters). Without at least a basic level of data many assumptions need to be made and it is not possible to accurately assess the water demand, water use efficiency and supply reliability.

Water Use Efficiency

The first action to address a supply deficit is to improve water use efficiency, water conservation and water reuse. By reducing demand it is possible to free up water for other uses, or at least delay expenditure on new water supplies.

The most significant improvements in water efficiency will likely come from the irrigation systems in Darkan drawing from the Town Dam.

Flexible Supply

Surface water and groundwater supplies alone will not secure adequate water into the future. Water supply flexibility in an integrated network is the key to making use of the most cost-effective water while it is available, but with high cost produced water available when required.

This approach is particularly relevant for the Duranillin Town supply, where four water sources blended together (rainwater tanks, groundwater, dam water and produced water) should be able to provide a reliable supply.

On Farm Water Supply Management

Getting farmers organised on farm to improve the reliability of their supplies will offset the biggest risk to water supply within the Shire – stock water.

The priority is for farmers to check the available water yield of their supplies based on the 2030 climate, and either adjust their stocking rates to match or find more water. This activity needs to done as part of the normal business planning process. Appendix C includes Rural Water Note 02 (DWER, 2007) and Assessing Reliability of Farms Dams (DPIRD, 2003) to provide some guidance.

Recommendations - Priority Projects for Stage 2

Community Forum

- We recommend a community forum is held to present the results of this investigation and seek input into the water supply projects for development.

Beaufort Palaeochannel AEM

- We recommend the Shire liaise with GSDC to work up a proposal for the AEM mapping of the Beaufort Palaeochannel, ideally for the full length, but if this is not feasible, we suggest mapping from bore TOW7 (Figure 7-2) east to the Shire boundary (an approximate 25 km x 14 km grid).

- Following the AEM survey, a desktop assessment will be required to interpret the data and identify the most prospective groundwater supply locations for drilling and testing.

Refinement of Darkan Palaeochannel AEM

- While it may not change the results greatly, we recommend that the Shire take the opportunity to get CSIRO to re-run the 2009 AEM dataset using the new 2020 software to further refine the mapping. This will ensure the Shire and landholders are working with the best available mapping when targeting bore locations.
- Following completion of Darkan palaeochannel AEM refinement, we recommend that Water Technology liaise with Dr Richard George and complete a desktop assessment to interpret the data and identify eight prospective groundwater supply locations for drilling and testing, with the appropriate exploration sequence provided.

Emergency Stock Water

- We recommend that the Shire encourage as many farmers as possible to access farm water auditors through the Farm Water Supply Planning Scheme. Additional communication (newsletters, Facebook) and low cost (or free) training workshops around reliable water storage design tools are also encouraged.
- Noting the bore drilled at Hillman Rd in 2016 which is not yet equipped, Water Technology recommends test pumping of the Rees Rd, Gorn Rd and Hillman Rd bores to confirm the long-term pumping rate (or safe yield) and confirm the correct pump size for each bore.
- We recommend each of the bores is fitted with a meter which is read every 3 months as well as measuring the bore salinity every 6 months, with the data stored in one central file within the Shire.
- An additional 1,200 kL/day of supply capacity needs to be developed for emergency stock water to bring the overall supply up to 2,000 kL/day (assuming that the Kylie Dam project will be completed in the next few years and excluding the Growden Place standpipe due to water cost). With no significant dam projects available, all of the water will need to be provided by groundwater. It is expected that somewhere between 3 to 8 bores will be required to reach this supply and we propose the Darkan Palaeochannel as the most likely source of this supply.

Darkan Town Dam

- We recommend that the Shire fit a water meter to the Darkan Town Dam offtake and Nangip Creek pump station and read the meters at least once per month.
- We recommend the installation of a staff gauge into the town dam and Nangip creek semi-permanent pool (pump station) which is read once per week.
- We recommend survey of the Town Dam to confirm its capacity.
- Once the above data is available, we recommend a desktop analysis to calibrate the catchment runoff coefficients.
- We recommend a water efficiency review be completed for all the irrigation systems connected to the town dam. The audit will look into the correct sprinkler spacing and operating pressures, damaged sprinklers, wind drift and the irrigation schedules.
- To progress the second dam concept, we recommend a preliminary model of the stormwater pipe system is constructed to test the runoff volume generated using the dry 2030 climate to get an indication on the size and preferred location of the dam.

Duranillin Town Water

- We recommend a survey of residents water use (water consumption breakdown) and analysis on the size of rainwater tank required to meet each residents demand, assuming water carting over summer.
- We recommend an assessment of the Town dam, including current condition, survey of the dam capacity, catchment mapping, runoff analysis using 2030 climate data and options to expand the dam (if any).
- We recommend that the Shire liaise with GSDC to work up a proposal for the AEM mapping of the Beaufort Palaeochannel with a view to installing a new bore close to town.
- We recommend a preliminary CAPEX and OPEX assessment for a WaterGen unit (Watergen | Water from Air) with consideration given to the 30L/day (individual homes) and 200 to 6000 L/day (centralised) units.

CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

GLOSSARY OF TERMS

Abbreviation	Term
AEM	Airborne Electromagnetic
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ATU	Anaerobic Treatment Unit
CAPEX	Capital Expenditure
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Czv	Cainozoic Sediments
DBCA	Department of Biodiversity Conservation and Attractions
DoW	Department of Water WA
DPIRD	Department of Primary Industry and Regional Development WA
DSE	Dry Sheep Equivalent
DWER	Department of Water and Environmental Regulation WA
FAO56	Food and Agriculture Organisation of the United Nations: Paper 56 – Crop Evapotranspiration
GCM	Global Circulation Model
GL	Gigalitre (1 billion litres)
GSDC	Great Southern Development Commission
GSTWSS	Great Southern Town Water Supply Scheme
Ha	Hectares
kL	Kilolitre (1 thousand litres)
mBNS	Metres Below Natural Surface
mg/L	Milligrams per Litre
ML	Megalitre (1 million litres)
OPEX	Operational Expenditure
PET	Potential Evapotranspiration
Ts	Tertiary Sediments

1 INTRODUCTION

1.1 Project Aim

The Shire of West Arthur, like the rest of the Wheatbelt, has been very dry for the last few years. Community consultation for the Shires strategic planning has shown that water security is the number one issue for many of the rate payers. To guide future decision making, the Shire has commissioned Water Technology to develop a water supply security strategy.

The Shire Strategic Community Plan identify the following Visions and Outcomes related to water supply and security for its community.

Vision: Local Economy – Stable and sustainable agricultural industry and a dynamic and growing business sector

Outcome 2.1 Improved employment through diversification of the agricultural industry

Strategy: Investigate water security and development opportunities associated with water sources

Vision: Natural Environment: our natural assets are valued and meet the needs of the community

Outcome 3.2: Our water resources are well defined and used sustainably

Strategies: Develop a whole of Shire water strategy to better manage our water resources and target development of supplies

Invest in water security and manage existing water resources in a sustainable manner

Encourage development of private water supplies

1.2 Objectives

The Shire would like to secure water sources to ensure retention of population; ensure agriculture remains as the main economic activity of the district, mitigate risk of climate change and identify opportunities to minimise the financial impact to ratepayers.

The main objectives for the water supply strategy include:

- An estimate of water demand for a 10-year planning horizon (to 2030).
- An audit of current available water supplies including identification of known ground water and surface water supplies and an estimate of the volume of water that could be drawn from these supplies.
- Identification of areas where water supplies need to be developed.
- Identification of alternate water supply options.
- A proposed plan for development of additional water supplies.

The key issues identified by the Shire to be resolved are as follows:

- Interest in the development of a standpipe at Hillman on the Dardadine (Darkan) paleochannel.
- Water availability for firefighting and emergency stock supplies around the Arthur River area. The potential for the use of the Kylie Dam for water supply around the Arthur River region.

- Water supply to the Duranillin townsite. The supply to Duranillin has been a constant source of concern for residents and the Shire.
- Concerns raised about the time taken to refill the tank on the community standpipe in Darkan and the possibility of putting in another community standpipe. With more people carting water for drinking supply or for stock supply there has been an increased demand at the standpipe. Possibility of subsidising the commercial standpipe and the use of a card system at the standpipe (current cost $2.50 per kL).
- Darkan town dam supply and its reliability in a dry season.
- Water supply for agricultural purposes and the impact of climate change on farm supplies.

2 PROJECT OVERVIEW

To ultimately deliver a proposed plan for the development of additional water supplies it is necessary to first establish baseline information on the expected future water demand, a picture of where the suitable water is located and the vulnerability of the water sources into the future. In working through these steps, the appropriate scale and cost of water supplies can be considered to reduce the risk of misdirected investment or over investment of Shire funds.

The scope of this report is to address Stage 1 of the process as outlined below.

2.1 Stage 1

2.1.1 Estimate of Water Demand

- Inception meeting at the Shires office to introduce the project manager, discuss and agree on key dates and milestones, discuss and agree on invoicing arrangements, collect any background study information and discuss any queries the Shire may have with the proposed methodology.
- Engage with Water Corporation to obtain data on current scheme water demand in Darkan (including businesses) and data on average consumption values.
- From Shire records, assess the number of farm residence in the Shire and the potential demand for water carting to supplement farm water supplies in a drying climate.
- Review the Shires irrigation demand for sporting fields, parks and gardens, and the potential increase in water demand through planned townscape projects.
- Consider any gap in water supplies created by tourism and significant Shire events.
- Consider water demand from any significant unregulated supplies (i.e. groundwater or surface water).
- Consider emergency water demand for bushfires.
- Review the Shires projected population change over the next 5 to 10 years.

2.1.2 Audit of Current Water Supplies

- Engage with Water Corporation to confirm the scheme water supply for Darkan and any potential for expansion of the supply over the next 10 years.
- Liaise with DWER and DPIRD to understand the capacity of the town dams and the potential sustainable yield if the dams were expanded.
- Complete a desktop review of available hydrogeological information on the Darkan and Beaufort paleochannels. Liaise with The Shire, DWER and DPIRD to obtain any data not publicly available, including the Rees Road Bore and Gorn Road bore. Review sustainable bore yields, groundwater salinity and iron reducing bacteria issues.
- Confirm with DWER any regulatory requirements to reactivate or expand current supplies.
- Prepare and present results with recommendations for Stage 2.

2.2 Stage 2

2.2.1 Community Forum

Community forum to report on Stage 1 results and seek input into water supply options to consider as part of alternative water supply options.

2.2.2 Identify Areas for Development

Identify priority areas for water supply development based on demand, supply, vicinity to existing infrastructure and future townscape, tourism or industry expansion.

2.2.3 Alternative Water Supply Options

First Pass Feasibility Assessment

The assessment will focus on the practicality of collecting, treating and delivering water of appropriate quality from numerous potential sources including:

- Surface water – water courses and the heritage dams
- Groundwater - the Beaufort and Darkan paleochannel's and desalinisation sources,
- Rainwater storage - tanks
- Recycled water
- Town water runoff – where road drainage is collected in a pit and pipe drainage system and potentially treated using constructed wetlands, with the option to store the water using a Managed Aquifer Recharge (MAR) scheme.

The purpose of a first pass feasibility assessment is to exclude any options with fatal flaws from further consideration. The first pass assessment will include:

- Identify all potential sources within the priority areas for development.
- Assess the adequacy/reliability of source(s) – is there sufficient supply to warrant further investigation.
- Financial viability – is the cost of the option likely to be significantly greater than the current (typical) water supply cost to customers.

Additional Research and Understanding: Options Short-Listing

Options that pass the first pass feasibility assessment will be further refined based on additional research.

- Identify the likely quality of the water source based on available information and the suitability of the supply, making allowance for the potential to mix or 'shandy' the water.
- Identify any significant nearby receptors possibly impacted by demand and supply: groundwater dependent ecosystems, neighbouring groundwater users and residents.
- Provide a summary of the key infrastructure required.
- High level (order of magnitude) CAPEX and OPEX costing of short-listed options (up to five).
- Identify possible stakeholders for decision-making.
- Prepare and present results with a focus on low OPEX schemes.

Detailed Conceptualisation of Shortlisted Options

- Multi Criteria Decision Assessment (MCDA) to prioritise shortlisted options. The MCDA will include a stakeholder engagement process to assist ranking of the options based on a series of key values.
- Detailed conceptualisation of the 2 highest ranked shortlisted options.

2.3 Stage 3

- Prepare a detailed plan for implementation of the highest ranked option. The plan will include but not be limited to: detailed layout of the scheme, design of key infrastructure, operational staff resourcing/training, testing and monitoring requirements, detailed CAPEX and OPEX costings, and whole of life cycle costings.

3 BACKGROUND

3.1 Biogeographical Characteristics

3.1.1 Climate

The Shire of West Arthur experiences a Mediterranean climate characterised by cool wet winters and dry hot summers.

The average monthly minimum and maximum temperatures for Darkan range from 15 to 30°C in summer and 6 to 15°C in winter. There is a likelihood of frosts occurring from May through to October.

The mean total annual rainfall recorded at Darkan (BoM Station No. 010542) from 1913 to 2020 is 540.1 mm (Figure 3-1), which is also reflected by the Duranillin station (BoM station No.010547) with a mean total rainfall of 525.9 mm (recorded 1911 to 2015) and the Boscabel station (BoM Station No. 010520) of 514.4 mm (recorded 1916 to 2020).

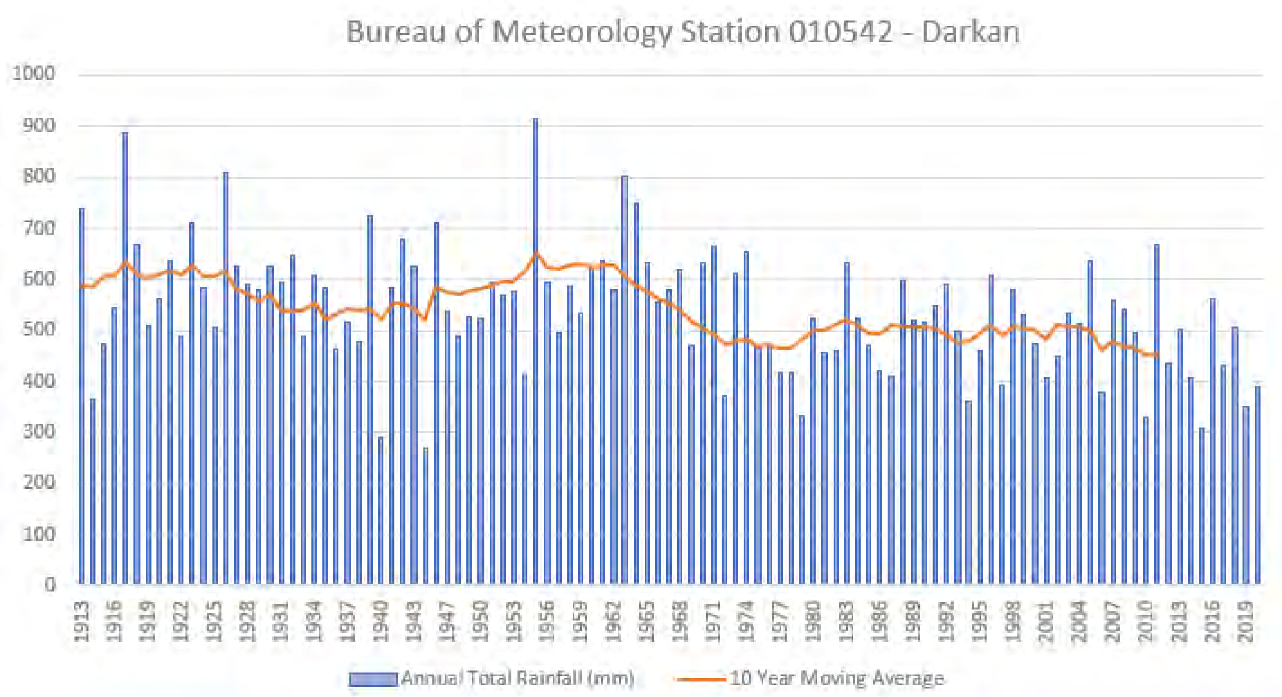


Figure 3-1 Darkan Annual Rainfall Totals 1913 to 2020

The South-west region has experienced a widely reported decline in annual rainfall since 1975 (CSIRO & BoM 2007; IPCC 2007b; CSIRO 2009a; Hope & Ganter 2010; IOCI 2012) and this is evident at the Darkan rainfall station, with a mean annual total of 480.2 mm for the period 1975 to 2020, an 11% decline on the long-term average. The most recent drought experienced in West Arthur was in 2015, which was the third driest year on record with a total rainfall of 307.5 mm, and came on the back of the 14th driest year in 2014 of 408.0 mm.

The reduced rainfall is a result of weakened and less frequent frontal systems, attributed to large-scale changes in southern hemisphere circulation patterns resulting from changes in global heat distribution (Frederiksen et al. 2012). The trend in rainfall decline is expected to continue, based on the climate projections from Global Circulation Models (GCM) results analysed as part of the *Surface Water Yields in South-west WA* (SWWASY) project (CSIRO 2009a).

Estimated Class A Pan evaporation is approximately 1600 mm a year (based on records from 1975 to 2005), with an estimate areal actual evapotranspiration (limited by water supply) of 600 mm year (based on climatology 1961 to 1990). Mean monthly rainfall in winter months from June to August generally exceeds evaporation.

3.1.2 Geology

The Shire of West Arthur lies within the rejuvenated drainage zone of the Blackwood River catchment and drains the Archaean (and minor) Proterozoic basement rocks of the Yilgarn Craton. Basement rocks of the Yilgarn Craton comprise mainly of heterogeneous Archaean gneiss complexes and younger, less intensely formed Archaean granitoid rocks. A number of suites of Proterozoic dykes and veins of predominately north-west orientation have intruded the basement rocks. The Darkan Fault, dissecting the craton, displays similar trends (WRC, 2000).

The material covering basement rocks (material between ground surface and fresh rock) is referred to as regolith. Regolith consists of sediments, colluvium and the lateritic weathering profile (saprolite). Sediments are found low in the landscape (valley floors), colluvium is situated on hill slopes and the preserved lateritic weathering profile is found high in the landscape.

Lateritic duricrust is common on hill-tops forming breakaways, and is frequently found west of the Hillman Zone, but is also present in the Narrogin Zone. Regolith in the Narrogin Zone also consists of extensive sheets of alluvium, lake sediments and associated dunes of sand of aeolian (wind derived) origin.

3.1.3 Soils

Landscapes are dominated by undulating rises and low hills with drainage lines leading onto broad, level valley floors of the Arthur River and Hillman Rivers. The Study Area covers three soil-landscape zones from west to east:

- Eastern Darling Range Zone (Eulin Uplands and Darkan soil-landscape systems).
- Southern Zone of Rejuvenated Drainage (Beaufort).

Ironstone gravelly soils dominate the ridges and crests along the western and north-western boundary of the Study Area (Eulin Uplands soil-landscape system). These soils extend down slopes into the Darkan soil-landscape system. Broad valley floors with saline wet soils and grey deep and shallow sandy duplex soils occur in the Beaufort and soil-landscape system.

<u>Soil landscapes of the undulating rises and low hills</u>:

Darkan: Dissected lateritic terrain with rock outcrops and narrow drainage lines in the west of the Study Area. Duplex sandy gravels, deep sandy gravels, shallow gravels and grey deep sandy duplex soils.

Eulin Uplands: Lateritic plateau remnants on ridge lines along the western margins of the Study Area. Duplex sandy gravels and loamy gravels with minor wet soils, semi-wet soils and grey deep sandy duplex soils.

<u>Soil landscapes of the broad alluvial plains</u>:

Beaufort: Broad valley floor of the Hillman River with minor dunes and lakes and swamps. Grey sandy duplex soils, with minor saline wet soils, alkaline grey shallow sandy duplexes and alluvial brown deep sands.

3.1.4 Land Use

Land use in the area is predominately broad acre cereal cropping and sheep grazing.

The main town of Darkan has approximately 250 residents and offers a number of services including a Primary School, sports club and oval, a seasonal public pool and golf course. There is also a small industrial estate located immediately north-east of the townsite.

3.1.5 Water Resources

The primary water resource for this Shire is surface water. Farm dams, old railway dams and the Darkan town dam make up the majority of non-potable water supply for farmers and the town. The Darkan Town dam is located south-west of the town on Nangip Creek and supplies water for irrigation of the sports oval, the primary school oval, the bowling greens and the caravan park.

The railway dams were built in the early 1900's to supply water to steam trains and generally consist of a dam, pipeline and cast iron storage tank. Where they remain in reasonable condition these assets are heritage listed. The Shire received funding from the WA State government in 2017 to undertake a refurbishment of the Kylie Siding Dam and install a new storage near to the heritage tank (Figure 3-3). This project on ongoing, subject to resolving the cultural values of the site.

Figure 3-2 Kylie Dam and Proposed New Tank Location

The Shire also has a standpipe on Boyup Brook - Arthur Rd in Moodiarrup, which draws salty river water from a creek feeding into Arthur River.

For the majority of farms, potable water is supplied by rainwater tanks and dams, but were the pipeline runs close to their property, farms can access the Great Southern Town Water Supply Scheme (GSTWSS) operated by the Water Corporation. In the Upper Great Southern, the GSTWSS supplies towns from Brookton in the north to Tambellup in the south and from Newdegate in the east to Boddington in the west. The scheme sources water from Harris Dam (72 GL), near Collie, and is supplemented from Stirling Dam (57 GL), near Harvey, as required. If required in the future, the scheme has design capability to be supplemented with water from the Southern Seawater Desalination Plant, near Binningup.

Darkan is the first town along the scheme pipeline and all of the potable water supply in the town comes from the scheme. There are also 4 standpipes in Darkan which are used for firefighting water, water for Shire works and public access.

Standpipe usage is limited to less than 49 kL/day under the standard service agreement that applies to the majority of Local Government Standpipes, including all of Shire of West Arthur's scheme water standpipes. Water use above 49 kL/day must be arranged with Water Corporation by exception.

The Water Corporation strongly encourages the use of fit-for-purpose water provision by all parties where possible. That is, scheme water use for non-potable purposes should be a last resort where independent non-potable sources can't be established and utilised.

The Darkan town does not have a deep sewerage service, with wastewater managed by septic tanks and Aerobic Treatment Units (ATU's).

There are numerous operating groundwater bores around the Shire, but for the majority of bores the yield is relatively modest and the water is brackish to saline. Generally, groundwater bores are used by farmers to supplement their water supplies. The Darkan town does not currently use any groundwater for supply, but the Shire does manage two community bores, Gorn Rd and Rees Rd, which can be used for road construction, stock water or firefighting water. In 2016 the Shire drilled a bore at Hillman Rd, but it has not yet been equipped with a pump.

The Duranillin townsite, located approximately 20 km south of Darkan has a non-potable water supply scheme operated by the Shire and was originally set up to service 9 residence supplied by groundwater bore TOW 9. Bore TOW 9 is located approximately 8 km west of Duranillin and water is pumped to the town via a trench with 50 mm poly pipe. In 2010 the groundwater supply started to show signs of becoming saline and more recently the groundwater salinity was measured at 4,235 mg/L. The bore is also contaminated with iron reducing bacteria, which creates a brown sludge and hydrogen sulphide smell (rotten egg gas). The bore supply was discontinued in January 2020. The Shire is actively looking for a new water supply to replace bore TOW 9.

The Shire is currently permitted to take 100 kL per week from the Darkan Town scheme free of charge, to ensure there is sufficient flow through the system. This water is either diverted to the town dam for irrigation or trucked to Duranillin regularly. Water is available to the three Duranillin residents currently using the scheme between 8 am and 3:30 pm on a Thursday only.

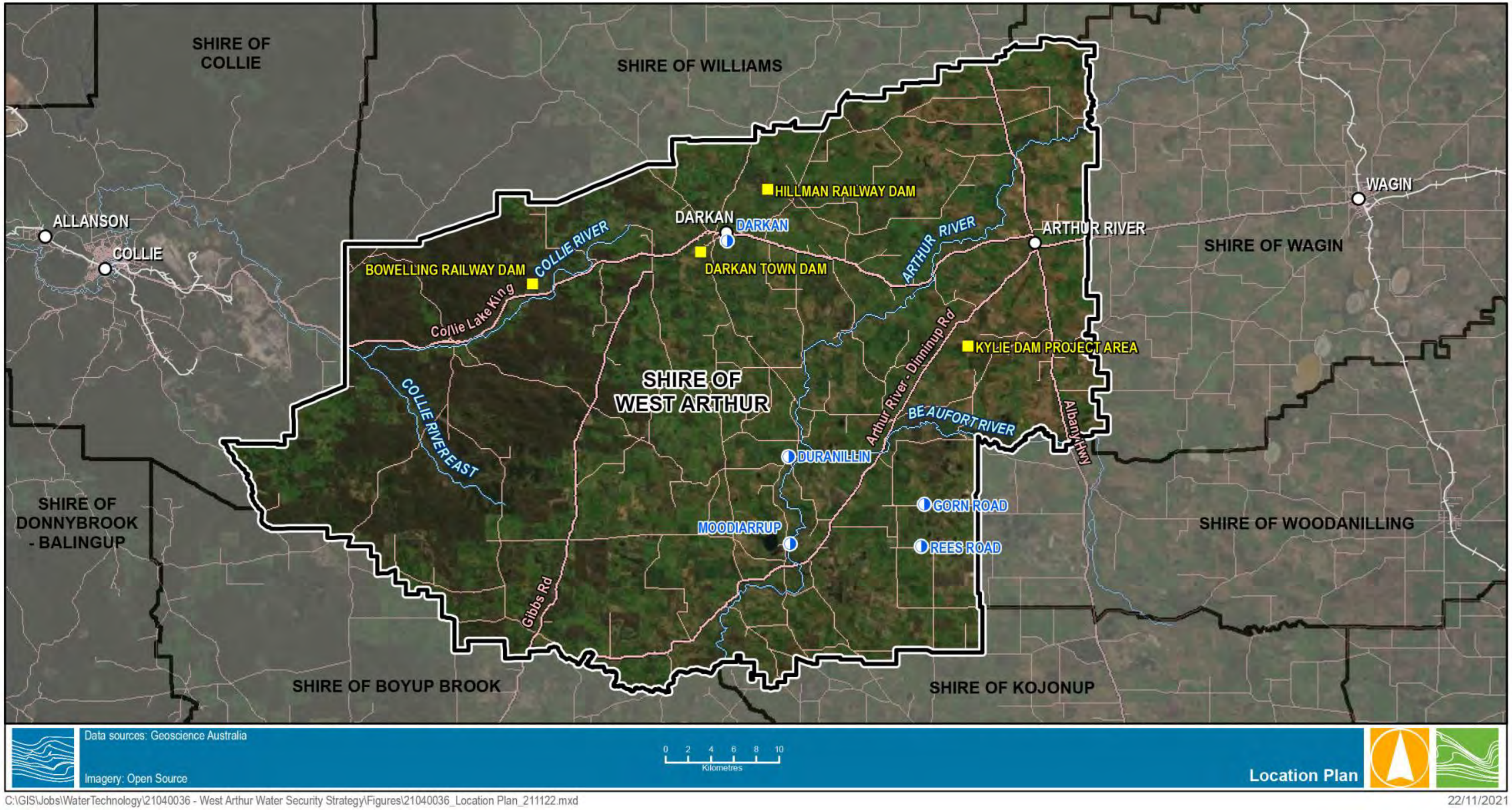


Figure 3-3 Location of Water Resources

3.2 Surface Water Rivers and Tributaries

3.2.1 River Catchments

There are two major river catchments within the Shire, the Collie River on the western side and the Arthur River on the eastern side (Figure 3-7).

3.2.1.1 Collie River

The Collie River flows west through the Darling Scarp and there are 21 sub catchments within the Shire, five with gauging stations operated by Department of Water rand Environmental Regulation (DWER) (see Figure 3-7). Discharge plots are available for sites 612230, 612044 and 612016 and are shown in Figure 3-4. As part of the *Wellington Reservoir Modelling* completed by DWER (2018) site 612230 – Collie River East Tributary, James Crossing was analysed for streamflow and runoff. The results of DWER analysis are summarised in Table 3-1 below.

Table 3-1 Runoff Analysis of James Crossing Sub Catchment

Gauging Station ID	612230
Catchment Area (km^2)	171
Native Vegetation %	46
Period of Observed Record (1991 to 2015)	
Average Rainfall (mm/yr)	585
Average Streamflow (GL/yr)	7
Average Runoff (mm/yr)	38
Average Runoff (%)	6

Variability in streamflow within a catchment is mainly influenced by the decreasing rainfall gradient running west to east and the extent of native vegetation (DWER, 2018). The results for the James Crossing sub catchment show that the runoff coefficients from rural catchments in the South-west are generally quite low (< 10%), even with more than half of the catchment cleared of native vegetation as is the case within the James Crossing sub catchment.

3.2.1.2 Arthur River

The headwater of the Arthur River is located about 30 km north of Wagin in the Arthur River Nature Reserve. The longest tributary of Arthur River is the Beaufort River, but other tributaries include Hillman River, Kojonup Brook, Narrogin Brook and Yilliminning River.

Within the Shire of West Arthur, the Hillman River and the Beaufort Rivers flow into the Arthur River north of Duranillin. The Arthur River flows south into the Blackwood River at the junction of Balgarup River, adjacent to the Wild Horse Swamp Nature Reserve south of Moodiarrup.

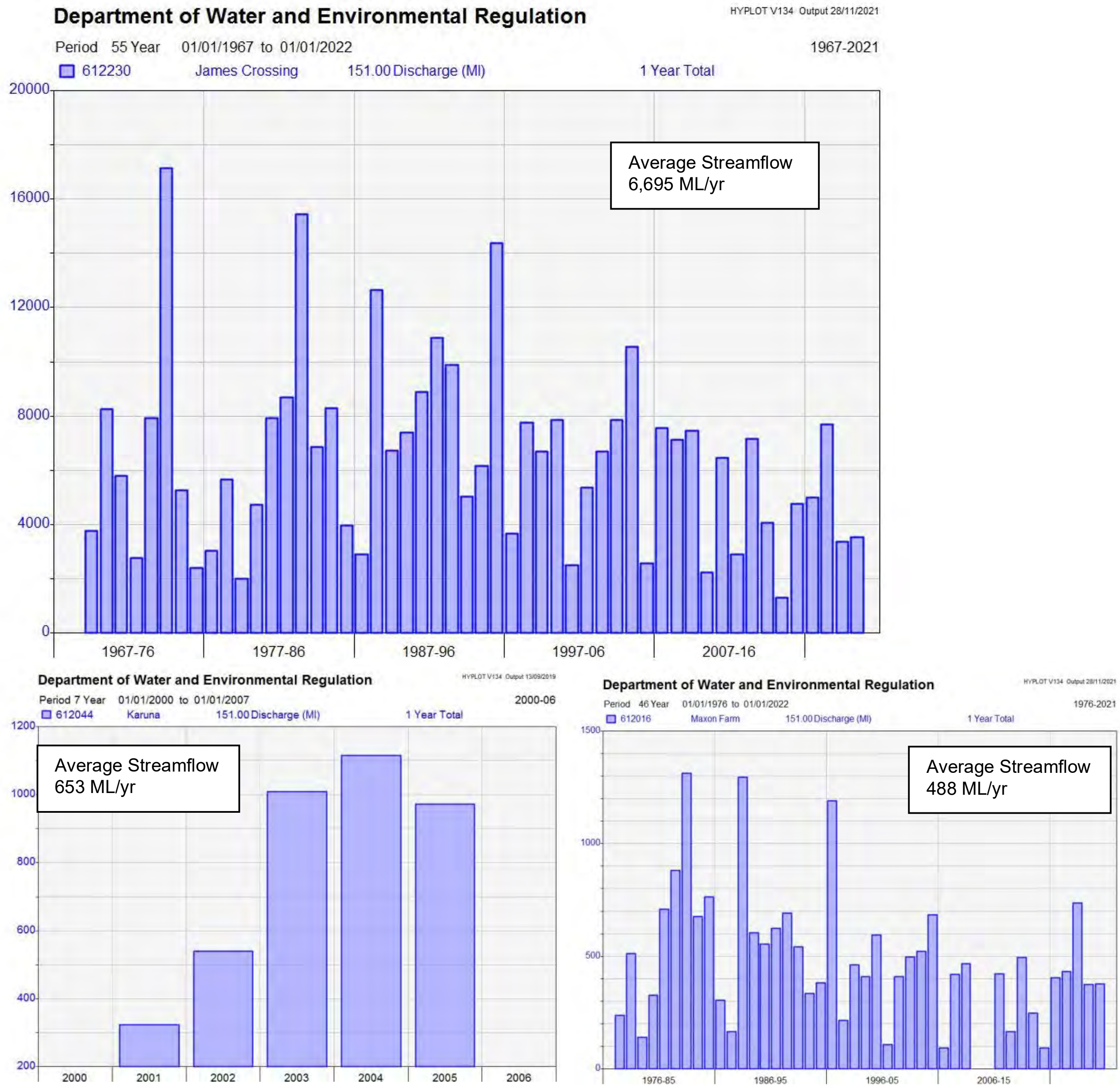


Figure 3-4 Collie River Catchment Stream Discharge Plots (Source: DWER, 2021)

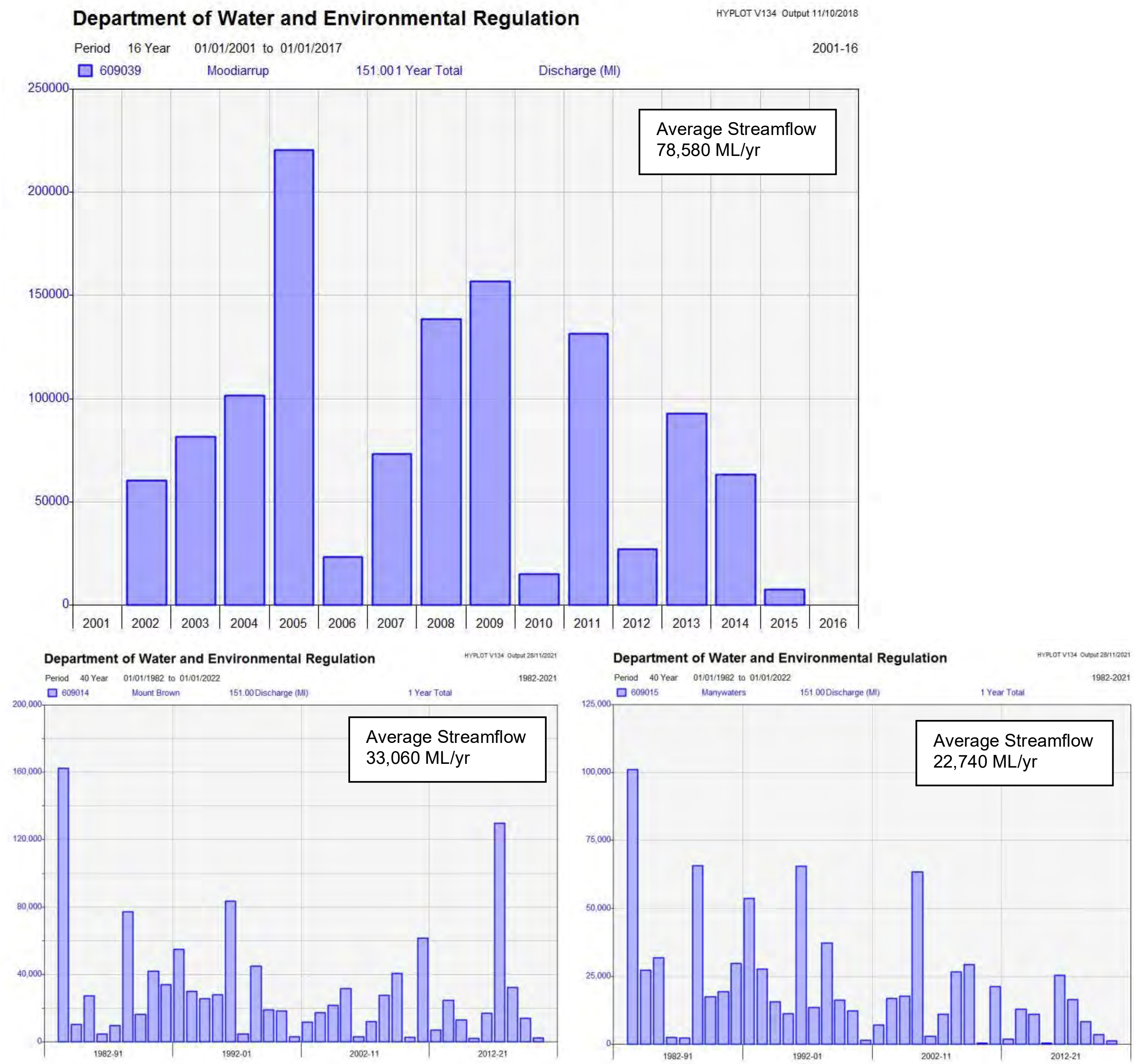


Figure 3-5 Arthur River Catchment Stream Discharge Plots (Source: DWER, 2021)

There are 23 sub catchments of the Arthur River within the Shire, with three gauging stations operated by DWER (Figure 3-7). Discharge plots are available for the three sites 609039, 609014 and 609015, and are shown on Figure 3-5.

3.2.2 River Salinity

Native vegetation coverage can significantly influence the salinity level within a river (DWER, 2018). With much of the Shire and upstream catchment of Arthur River cleared for agriculture, the salt mobilised by the rising water tables tends to concentrate in the valley floors. This is reflected by the consistently high salinity measurements for all the rivers at the gauging locations, with an increasing trend over time from the 1970's up until 2012, which is the period of the available record (Table 3-2, Figure 3-6).

Table 3-2 Average River Salinity at DWER Gauging Locations

Site ID	Average Salinity (mg/L)	No. of Readings
Collie River		
612026	13,378	525
612025	4,225	201
612016	13,254	1758
612044	7,482	24
612230	10,053	2785
Arthur River		
609014	6,987	907
609015	5,555	893
609039	6,862	133

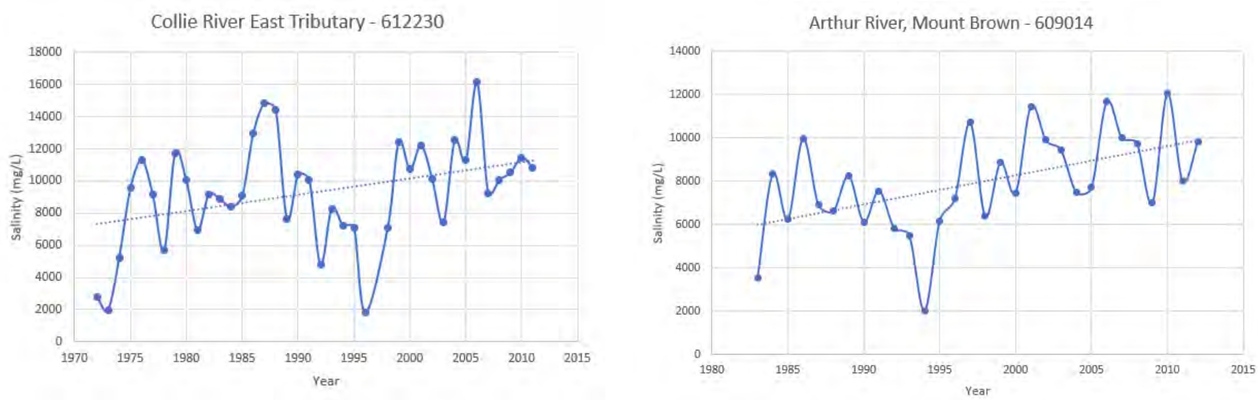


Figure 3-6 River Salinity Trends Using Average Annual Salinity

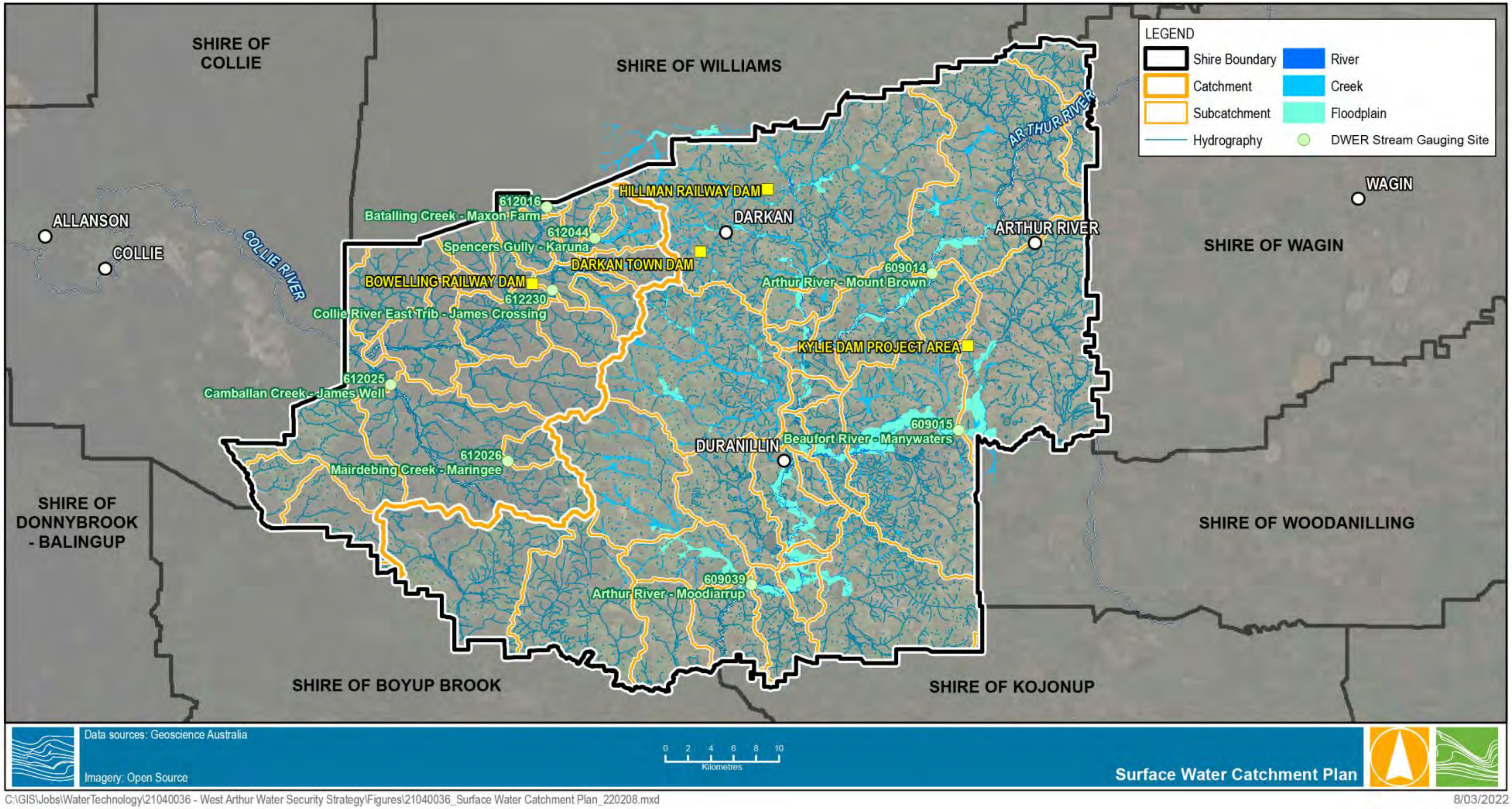


Figure 3-7 Surface Water Catchment Plan

3.3 Groundwater and Aquifer Systems

The Shire of West Arthur is located within the Yilgarn Southwest Province and groundwater is contained in aquifer systems that are classified according to their constituent materials:

- Weathered rock (regolith) aquifers
- Fractured rock aquifers
- Surficial sedimentary aquifers
- Tertiary palaeochannels

Aquifers exist in the weathered profile, fractures and joints of crystalline rocks (prevalent in the Yilgarn South West Province) and unconsolidated and lithified sediments. Faults, fractures and joints are commonly localised and therefore groundwater potential in this aquifer is limited. Similarly, the weathered profile of crystalline rocks contains only localised groundwater as these materials exhibit variable, but predominantly low, porosity and hydraulic conductivity (George, 1992; George *et al*., 1994; Clarke *et al*., 2000). As a result, the most substantial supplies of groundwater within the Shire will likely be restricted to the tertiary palaeochannel sediments or Surficial aquifers as these sediments are generally more permeable.

A comprehensive description of the aquifers is presented in Water & Rivers Commission (WRC) (2000) *Hydrogeology of the Blackwood River Basin*, and the details relevant to the Shire of West Arthur have been summarised below.

3.3.1 Weathered Rock Aquifers and Aquicludes

The gneissic and granitoid rocks of the Yilgarn Craton cover over 85% of the Blackwood River Catchment. Where these rocks outcrop they represent areas of high surface runoff with little recharge and therefore reduced long-term groundwater supply potential. However, with the incidence of outcrop in the craton approximately 20%, the remaining area is deeply weathered and may contain groundwater in pore spaces within the weathered profile and in fractures/joints below the weathering front.

3.3.1.1 Aquifer Materials and Location

The weathering profile, where fully developed, is typified by a complex vertical zonation. The fragmental disintegration of granitic bedrock at the weathering front produces a friable zone with high intergranular porosities, often referred to as 'grus' (Nahon and Tardy, 1992). In rocks containing low quartz, saprock develops which is generally compact and has lower hydraulic conductivities. Grus is described by many authors (e.g. Johnston *et al*., 1983; Johnston, 1987a,b; George, 1992; George *et al*., 1997; Clarke *et al*., 2000) as saprolite 'grit' or saprolite and is ascribed saturated hydraulic conductivities approximating 0.5 m per day. Saprolite develops as primary minerals weather to the secondary clays, which occur above the grus in granitic rocks and commonly above the saprock in gneissic rocks (Nahon and Tardy, 1992; Dobereiner and Porto. 1993; Cody, 1994).

Saprolite contains variable quantities of groundwater. This is due to the mineralogical variation of granitoid and gneissic basement rocks giving rise to weathered material with a range of porosity, but generally low permeability and hydraulic conductivity (Anand and Gilkes, 1984, 1987; Anand *et al*., 1985; McCrea *et al*., 1990). Low hydraulic conductivities recorded at less than 0.05 m per day correlate with clay- rich sections within the saprolite, which frequently develop at the top of the profile forming an aquitard (George *et al*., 1997). Saprolite commonly grades upwards into mottled and ferruginised zones that tend to correlate with clay dominant sections (Bettenay *et al*., 1980). However, in granitoid rocks containing major quartz, an arenose horizon (sandy, quartz-rich zone) may develop at the top of the profile (Nahon and Tardy, 1992). Weathered rock aquifers in granitoid and gneissic rocks are therefore different.

3.3.1.2 Bore Yields and Groundwater Quality

Higher bores yields are obtained from the grus, which develops specifically through the weathering of granitoid rocks. Saprolite, developed from the weathering of gneissic rocks, has low transmissivity and forms an aquitard where clay-rich zones develop.

Groundwater conditions within the weathered rock aquifer are unconfined, but semi-confined conditions develop where a clay-rich saprolite forms within the weathered profile, or where overlying surficial sediments contain major clays such as in palaeochannels. Perched aquifers may form in surficial sediments where the weathered rock aquifer is semi-confined and low hydraulic gradients delay groundwater from discharging into drainage lines.

The groundwater in weathered rock aquifers of granitoid and gneissic rocks is typically brackish to highly saline. In the Blackwood Catchment, groundwater salinity typically increases from west to east, with fresh to brackish groundwater generally restricted to the western margin of the Yilgarn Craton, in the Lower-middle Catchment. Here, higher rainfall and undulating topography increase recharge and effectively flush salts from the catchments. Within catchments and sub catchments there is a general topographic control on salinity; lower landscape areas contain groundwater with higher salinities than groundwater higher in the landscape.

Mafic dykes and sills have been mapped throughout the Yilgarn Craton. As these Proterozoic crystalline rocks contain only minor quartz, and produce high volumes of clay minerals during weathering, they form aquicludes. Recent work by Clarke *et al*. (2000) suggests that the hydraulic conductivity of material in the weathered profile of mafic dykes is similar to, or greater than, that of granitic rocks. However, these results contradict Johnston *et al*. (1983), McCrea *et al*. (1990) and Engel *et al*. (1987), who found that these dykes possess low hydraulic conductivities and were likely to form barriers to groundwater travelling down gradient through weathered granitoid and gneissic basement. Hence the hydrogeology dykes can tend to be site specific.

The salinity of the groundwater in aquifers located behind dykes is dependent on the quality of the water received up gradient via throughflow. These groundwater resources are localised and yields vary according to the position of the dyke in relation to the local groundwater flow regime.

3.3.2 Fractured Rock Aquifers

3.3.2.1 Aquifer Materials and Location

Major and minor faulting, which has produced fracturing of the crystalline basement rocks of the Yilgarn Craton, exerts control on the movement of groundwater. Faults align with preferential weaknesses in the basement rocks, a number of which coincide with the margins of previously injected intrusives such as Proterozoic mafic, and quartz dykes and sills. These fractures may contain groundwater depending on groundwater processes, basement topography, and the ability of the faults, dykes or sills and low hydraulic conductivity zones within the weathered profile to form effective barriers to groundwater flow (George *et. al*., 1997). Highly fractured fault zones form a potential groundwater resource as their hydraulic conductivities are commonly high when fault gouge or smear (clay) is not present (Clarke, 1998).

3.3.2.2 Bore Yields and Groundwater Quality

Drilling records show that groundwater yields up to and greater than 500 m^3/day have been obtained where zones fractured from faulting are intercepted. However, areas with high yields are limited in their extent and bore yields from the granitoid and gneissic basement rocks are typically small (<10-50 m^3/d). The highest yields are obtained from the fractured-zone aquifers where they occur at the base of the weathering profile, commonly at depths of 5-20 m below the weathering front. Bore yields from weathered rock aquifers may be enhanced where the basement rocks are fractured, if the bores are extended up to 10 m into the fractured basement.

High-yielding fractured-rock aquifers are more likely to be detected in the more brittle rocks in the craton, such as Archaean quartzites and Proterozoic quartz dykes and veins. These rocks consist almost entirely of quartz and may hold substantial groundwater in joint and fracture systems. The quality of the groundwater is likely to be fresh to brackish, depending on the quality of the recharge. However, due to their limited dimensions and sporadic occurrence, these rocks represent only a minor groundwater resource, and bore yields are dependent on the amount of recharge and the size and hydraulic conductivity of the aquifer. Shear zones and ductile faults are more likely to be impermeable.

Locating fractures that are prospective for groundwater is complex and may be assisted through techniques such as interpretation of aerial photographs and geophysics. In the Shire of West Arthur, the groundwater potential of fractured-rock aquifers has not been investigated in detail.

3.3.3 Surficial Sedimentary and Tertiary Palaeochannel Aquifers

3.3.3.1 Aquifer Materials and Location

Surficial aquifers in the Yilgarn South West Province are generally unconfined and comprise mainly heterogeneous alluvial sediments of late Tertiary to Quaternary age. Quaternary alluvial sediments are deposited along modern drainage lines of the Blackwood River and consist of clay with sand lenses. Cainozoic alluvial and colluvial deposits comprising sand, silt, clay, gravel and minor laterite are widespread in the upper-middle and upper catchments, occupying broad river valleys and relict alluvial systems of the Hillman, Arthur and Beaufort Rivers. These sediments either overlie weathered granitoid basement rocks or early Tertiary sediments, the latter occupying palaeochannels.

In the upper-middle and upper catchments, Tertiary sediments (Ts) occupy major palaeochannels in broad valleys, commonly beneath variable thicknesses of Cainozoic sediments (Czv) (Hawkes, 1993; George et al., 1994; Perry, 1994; Prangley, 1994a,b, 1995a,b; Waterhouse et al., 1995; Commander et al., 1996). These sediments form minor to major unconfined to semi-confined aquifers and comprise Eocene to Miocene/Pliocene alluvial sands and clays, commonly overlain by lacustrine clays and silts. The thickness and lateral extent of the Tertiary sediments preserved in the palaeochannels are reliant on the depth of incision within the palaeovalleys. The average width of these channels is approximately one kilometre, and mapped lengths range from about 8 to over 50 kilometres.

The sediments are estimated by George et al. (1994) to attain a maximum thickness in the Beaufort Palaeochannel of over 70 m. Sediments within the channels are not always in continual hydraulic connection, thereby restricting major groundwater resources to areas where such connection occurs.

3.3.3.2 Bore Yields and Groundwater Quality

Bore yields and groundwater quality within the surficial and palaeochannel aquifers are dependent on a number of variables influenced by landscape position. These are, the thickness and lateral extent of high hydraulic conductivity zones (commonly sands and gravels with high intergranular porosities), the degree of hydraulic connection between these zones and the source (quality), and quantity of groundwater throughflow and recharge.

Tertiary sedimentary aquifers within palaeochannels, generally contain groundwater with high salinities associated with poorly drained lower landscape areas. These areas typically contain only localised aquifers and receive poor quality recharge from either or both the overlying surficial aquifers (due to evapo-concentration of ponded runoff, and/or the weathered profile of adjacent granitoid basement rocks. Fresh to brackish groundwater is more commonly located in the central to upper sections of the palaeochannels. This occurs where the major source of groundwater recharge is fresh, derived from the process of throughflow from up-gradient sections of the palaeochannels containing fresh groundwater, or from the direct infiltration of rainfall. Groundwater at the edges of the palaeochannel is commonly saline as the recharge is obtained mainly from the neighbouring weathered granitic rocks. The intermixing of fresh groundwater in the central channel and saline groundwater at the channel margins produces an intermediate zone of brackish groundwater.

High bore yields are therefore restricted to zones containing minimal clay, whereas clay-dominated sediments are characterised by lower yields and generally higher salinities. The groundwater potential of the palaeochannel aquifers has been investigated in several localities within the Upper and Upper-middle Catchments of the Blackwood River.

3.3.3.3 Beaufort Palaeochannel

In the Beaufort Palaeochannel (Figure 3-9), the main palaeodrainage of the Blackwood Catchment, a network of over 60 km of Tertiary sediments has been identified (Hawkes, 1993; Prangley, 1994a,b, 1995a,b). The aquifer previously described as the Cordering Palaeochannel has been confirmed as part of the Beaufort Palaeochannel, and is referred to as the Dingo Swamp area, in the western end of the Towerinning section.

At Boscabel, the Tertiary sediment sequence comprises lacustrine sands, clays and silts and ranges in thickness from 13 to 55 m, generally increasing from upper landscape areas to valley floors. The sand units in these sequences vary from very poorly defined to well defined multiple units, and comprise very fine to coarse or pebble-size clasts, generally coarsening downwards. The total thickness of sands range from 5 to 26 m, with individual units varying from 5 to 17 m (Figure 3-8).

A clay layer, up to 20 m thick overlies these sands. A surface water divide produces an 'upstream' and 'downstream' flow system resulting in groundwater discharging east of the divide in the Beaufort Flats and to the west into the Beaufort River. Groundwater systems in these sediments are unconfined to confined, with the water level or potentiometric surface being between 1 and 8 m below ground level. Airlift yields from these sand units are in the range of 40 to 280 m^3/d. However, there is no apparent correlation between the thickness of sand units and the groundwater yields. Groundwater salinity ranges from 1,000 to 7,500 mg/L and generally increases with depth, as observed in bore BOS 4 (Prangley, 1994b).

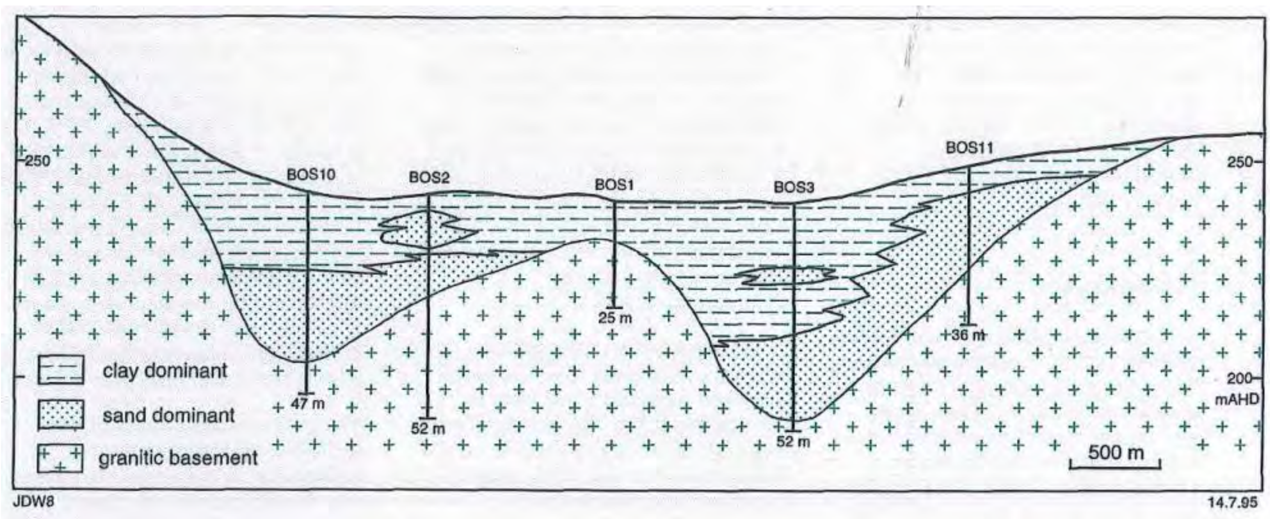


Figure 3-8 Geological Cross Section of Beaufort Palaeochannel, Boscabel (Waterhouse et.al., 1995)

In the Towerrinning area Tertiary sediments consist predominantly of sands and clays and range in thickness from 8 to 39 m. Unlike Boscabel, the thickness of sediments shows no obvious correlation with topography. Sand units are 4 to 28 m thick, typically coarsening downward. Bore yields from sands range from 12 to 187 m^3/d. (Prangley, 1995a). A surface-water divide between TOW 9 and 31 produces an 'upstream' and 'downstream' groundwater flow system resulting in discharge east of the divide at Darlingup Springs (McCombe, 1999) and about 15 km to the west at Dingo Swamp and Haddleton Springs. Groundwater systems vary from unconfined to confined conditions, with all high-yielding bores (>100 m^3/d) sourced from confined systems.

Groundwater salinity in the Towerrinning section drillholes ranges from 340 to 8,700 mg/L, with fresh groundwater observed in two localities. Bore TOW 31, drilled in a confined groundwater system in the recharge area of a small subcatchment, has groundwater salinity of 340 mg/L (Figure 3-9). However, two bores in this transect, in close proximity to TOW 31, recorded groundwater salinity in the range of 1400 to 2400 mg/L, indicating fresh groundwater is likely to occur within localised pockets or lenses. Bores in this transect show that groundwater salinity increases with depth. Bore TOW 9, located in another subcatchment, also records fresh groundwater resources with salinities of about 560 mg/L (Prangley, 1994a). However, the extent of this fresh groundwater resource also appears to be limited as other bores, drilled within the same flow path, record much higher groundwater salinities ranging between 4,800 and 8,700 mg/L. The groundwater flow path within the TOW 9 transect indicates a decrease in salinity from up-gradient to down-gradient areas that could be attributed to a variety of factors such as dilution effect, increased recharge, or increasing thicknesses of the sand unit or units.

3.3.3.4 Darkan Palaeochannel (Hillman River Section)

Up to 23 m of Tertiary sediments, primarily sands and clays, overlain by up to 5 m of Quaternary sediments were identified whilst drilling a transect of four bores across a valley in the Hillman River (Figure 3-10), 9 kms north of Darkan. Two bores, TOW 43 and TOW 44, intersect Tertiary sands and produce yields ranging from 230 to 302 m^3/day. Yields decrease from the centre to the edges of the valley, where the Tertiary sequence thins (Prangley, 1995b). The aquifer is unconfined to semi-confined. Semi-confined conditions are produced by a discontinuous 2 m thick weathered clay layer; depth to the water level at the centre of the valley is 0.5 m below the land surface. The salinity of the groundwater ranges from 5,600 mg/L in the centre of the valley to 26,000 mg/L near the margins of the palaeochannel.

3.3.3.5 Darkan Palaeochannel (Dardadine Tannery Section)

Exploratory bores drilled 12 km northeast of Darkan, in an area known to produce high yielding fresh water bores and permanent fresh water soaks, identified atleast 30 m of Tertiary sands containing fresh water (Rockwater Pty Ltd, 1990). Drilling delineated a tract of sediments, approximately 20 km in length (Figure 3-10), from Albany Highway to the east of the Dardadine sub-basin (a small Tertiary basin delineated by gravity surveying and limited drilling by Western Collieries Limited). The salinity in this section of palaeochannel is low, around 450 mg/L, influenced by fresh recharge from overlying sandy soils. Up to 30 million cubic metres of freshwater are estimated to be stored in this 20 km-long section of palaeochannel, if the channel sands are approximately 500 m wide and the depth ofthe channel is at least 45 m (Rockwater Pty Ltd, 1990). Lower bore yields and increased groundwater salinity are expected at the palaeochannel margins where the thickness of the sands decreases, grading to interbedded sands and clays, and saline groundwater from adjacent weathered granitoid rocks recharges the Tertiary sediments.

Yields from test pumping one of the high-yielding bores at the Tannery Pumping Site indicate that the bore can be continuously and safely pumped at 320 m^3/d with the drawdown effect extending 950 m down-gradientand 500 m up-gradient (Rockwater Pty Ltd, 1992). This test confirmed that the palaeochannel aquifer is only partially confined by the overlying Cainozoic and Quaternary sediments, as water levels in these materials were affected by the extraction of groundwater from the palaeochannel.

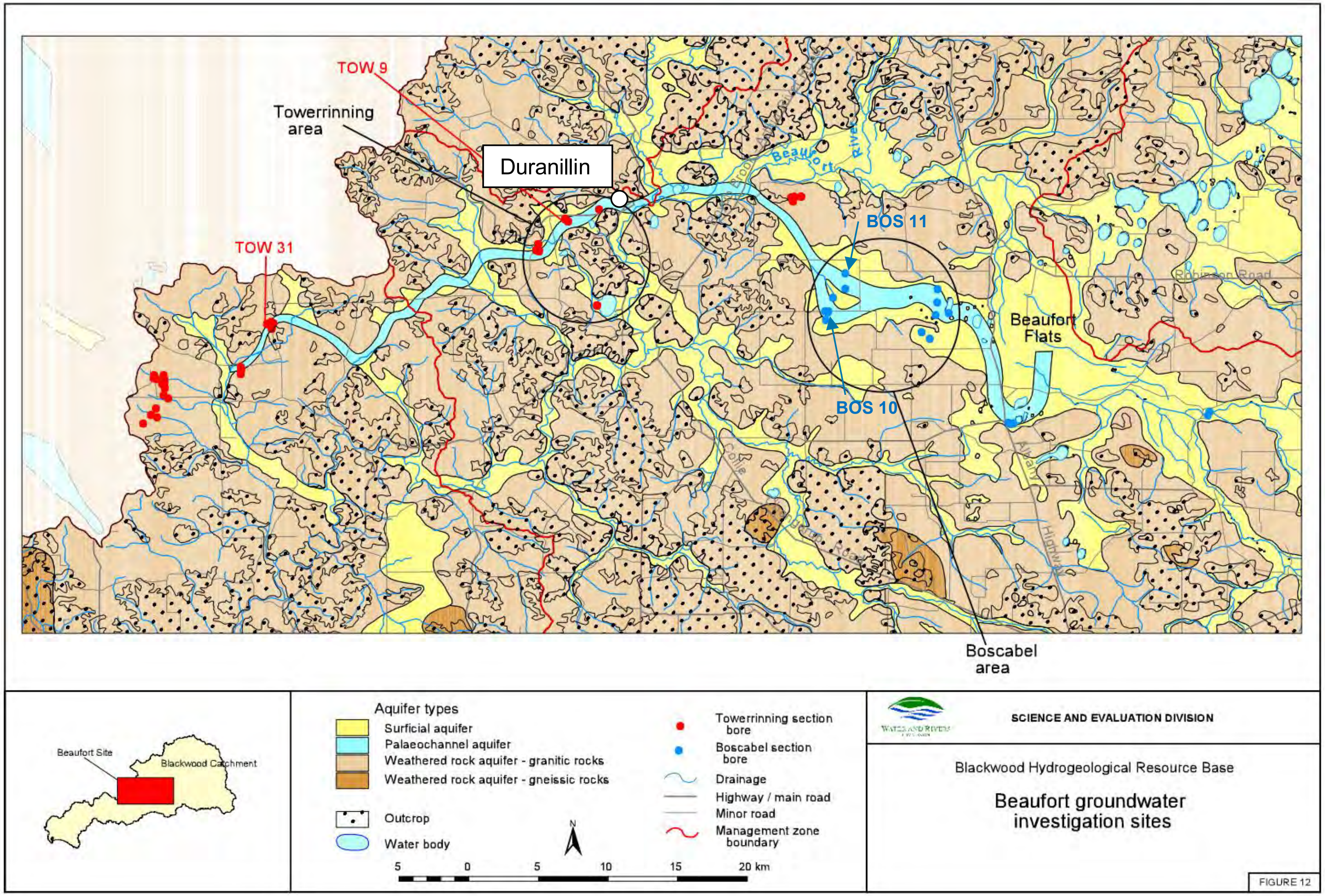


Figure 3-9 Beaufort Palaeochannel (taken from WRC, 2000)

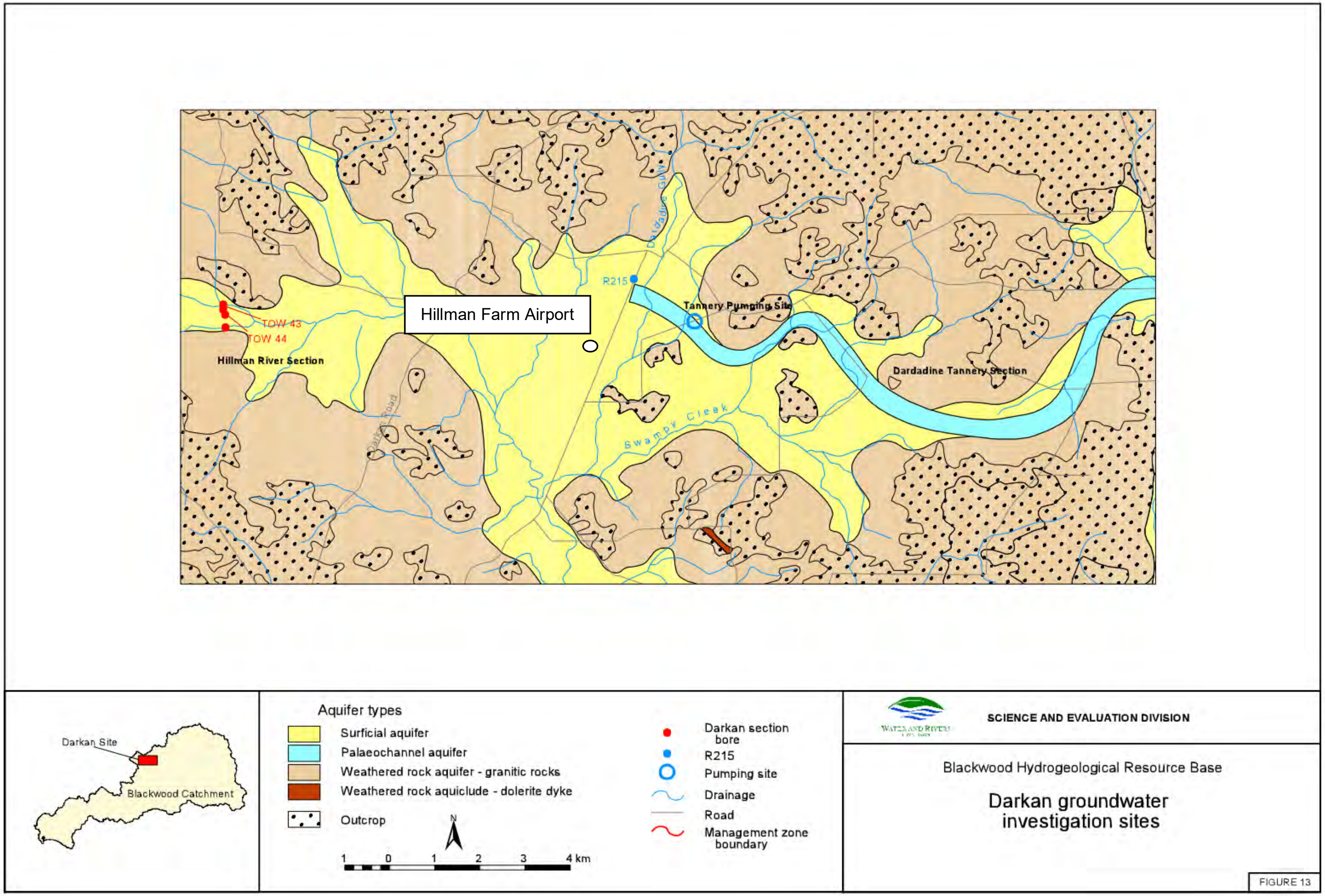


Figure 3-10 Darkan Palaeochannel (taken from WRC, 2000)

3.3.3.6 CSIRO AEM Mapping of Darkan Palaeochannel

In 2009, as part of joint funding from CSIRO, Southwest Catchments Council and the WA Department of Agriculture, CSIRO completed airborne geophysics assessment of the Darkan palaeochannel with the aim of more accurately defining the orientation of the palaeochannel and the quality (salinity) of the resource.

The airborne electromagnetic (AEM) works on the principle of transmitting a current through the loop or coil of a transmitter. This in turn generates a magnetic field which induces a series of eddy currents in the earth below the coil. These eddy currents in turn generate a secondary magnetic field which is detected and measured by the receiver coil mounted at the rear of the transmitter loop. Variations in ground conductivity, caused by salt in the groundwater, or the presence of clays or other materials, will vary the magnitude of the induced or secondary magnetic field. By combining measurements of ground conductivity along each of the flights lines, a map of conductivity is generated, as it varies with depth across the landscape.

The Darkan palaeochannel was flown on 300 m line spacing with the data processing and inversion completed by CSIRO. The investigation was successful at determining the orientation of the palaeochannel and the quality (salinity) of the groundwater (Figure 3-11). The complete slide pack of results provided by CSIRO is included as Appendix A.

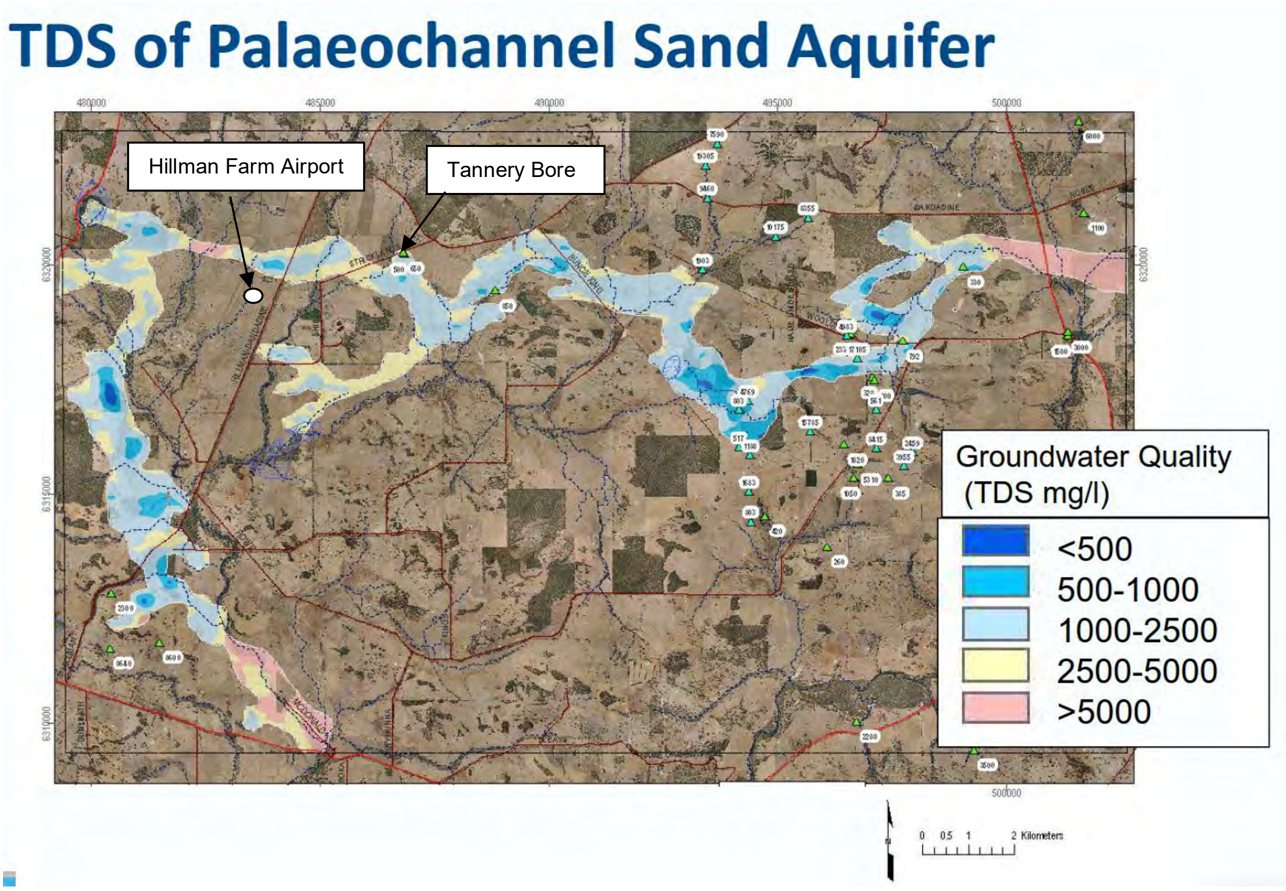


Figure 3-11 AEM mapping of Darkan Palaeochannel

3.4 Future Climate Change Projections for South-west WA

In 2013, the Department of Water (DoW) developed standard climate scenarios for five broad climatic regions within the state, which were later published in *Selection of future climate projections for Western Australia* (DoW, 2015). The aim of the report was to enable consistent application of climate projections; capture the associated range of uncertainty; and provide climate scenarios in a readily accessible and applicable form suitable for water planning assessments.

In DoW (2015), The Department developed climate scenarios for five regions, covering the entire state. The climate scenarios are reported using anomalies – the average change in a climatic variable for a future period compared to the baseline period. Standard monthly climate anomalies were developed for the following regions, variables, scenarios and time horizons:

- Regions: South-west, Central-west, Pilbara, Kimberley, Central
- Variables: Rainfall, temperature, relative humidity, radiation, FAO56 reference potential evapotranspiration (derived), Penman evaporation (derived)
- Scenarios: Wet, median, dry
- Time horizons: 2030, 2050, 2070, 2100

A 30-year baseline period is an appropriate length of record for use in modelling (for example, integrated surface water and groundwater models). The baseline period of 1961–90 was selected for WA with consideration of the following:

- stationarity in rainfall (i.e. the statistical properties of the time series do not change over time)
- consistency with baseline periods used in other studies
- sufficient variability within the period
- the availability of measured climate variables for that period.

Constant monthly scaling was adopted by DoW to downscale the outputs of GCMs from a global resolution to those suitable for local analysis. The method involves applying a different scaling factor to each month of the year, for each climate variable. This was the most appropriate method considering the size of the study area (being the state of WA) and the advantages of the small time and computational costs, simplicity and practicality for large regions.

For the South-west region the 2030 rainfall decline projected by DoW is 14% for the dry scenario and 5% for the median. The wet scenario projects a 2% decline by 2030. These changes are relative to the 1961 to 1990 baseline.

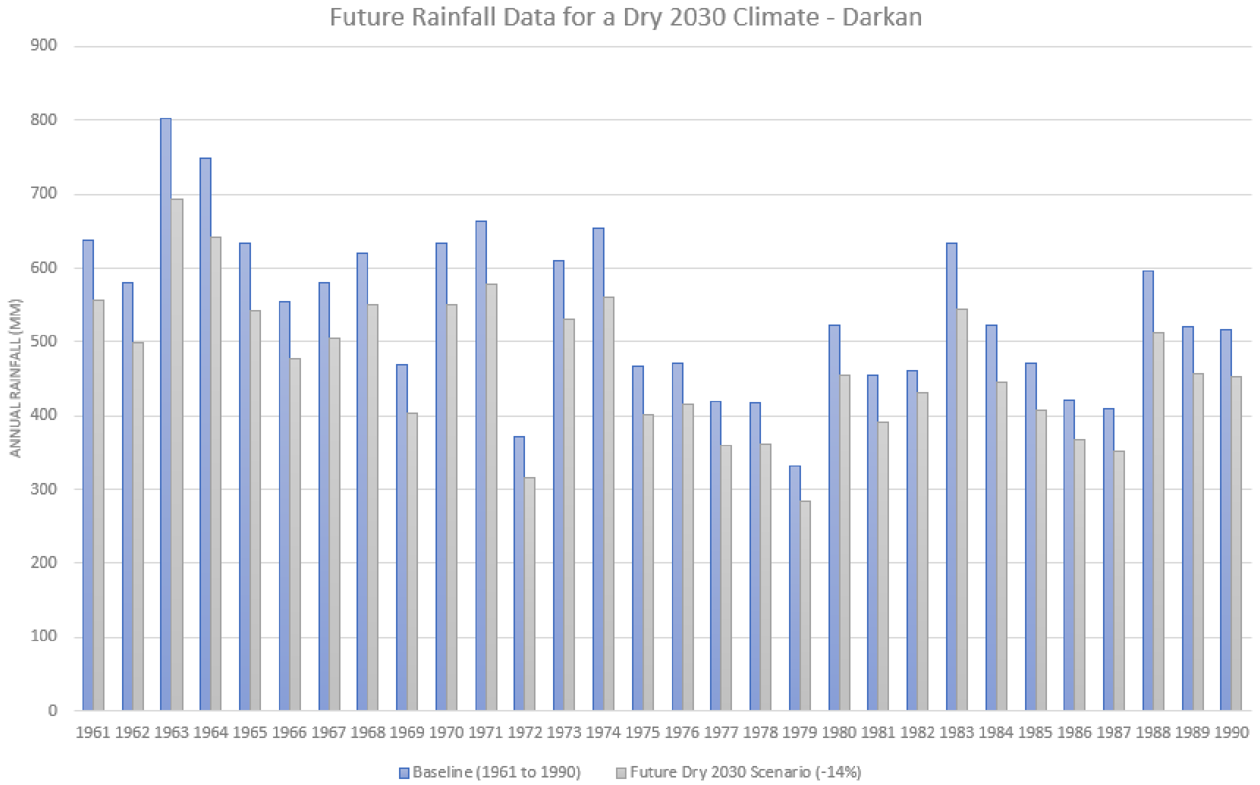


Figure 3-12 Future Rainfall for a Dry 2030 Climate - Darkan

3.4.1 Planning for a 'Dry 2030' Climate

Observed rainfall from 2000 to 2020 in the Shire of West Arthur has fallen by 69 mm (13%) compared with the 1961 to 1990 baseline climate average. The recent rainfall (post 2000) at Darkan townsite aligns with the average rainfall projected under a 'dry 2030' future climate. Provided the current rainfall trend continues along the dry 2030 projection, this is the best climate scenario to review water supplies for this Study. The 'wet 2030' and 'median 2030' climate scenarios have not been considered in this report.

A synthetic 'Dry 2030' rainfall dataset developed using the methodology in DoW (2015) is shown in Figure 3-12 and will be used for the water supply estimates presented in Section 7.

4 THE WATER PLANNING FRAMEWORK

4.1 The State Water Plan

The State Water Plan (Dept. of Premier and Cabinet, 2007) sets out the WA State Governments commitment to strategically and effectively manage the State's water resources.

The six key pillars to the plan are:

- Build on strong foundations – to build on the five years of collaboration that lead up to the release of the State Water Strategy in 2003.
- Adapt to climate change – support ongoing research into the nature of climate change.
- Integrated management for the environment – statutory water planning, providing legal security to water entitlements for the environment, more metering and monitoring are practical measures to improve water management for the environment.
- Managing supply and demand – increasingly demand will be met through water conservation, efficiency and recycling. The State is committed to further significant advances in these areas, enabled by research, rebates and industry partnerships.
- Community involvement – regional and local water planning will facilitate community engagement on the water cycle and local actions to implement State Water Plan 2007.
- Vision and objectives – the plan has established a vision for water resource management in WA, supported by the seven objectives outlined in the plan.

The Water Policy and Planning section of the plan outlines the water planning framework, the water plans that are the primary responsibility of the Department of Water (Figure 4-1). The Rural Water Plan released by DoW in 2004 is an example of a Strategic Water Issue Plan.

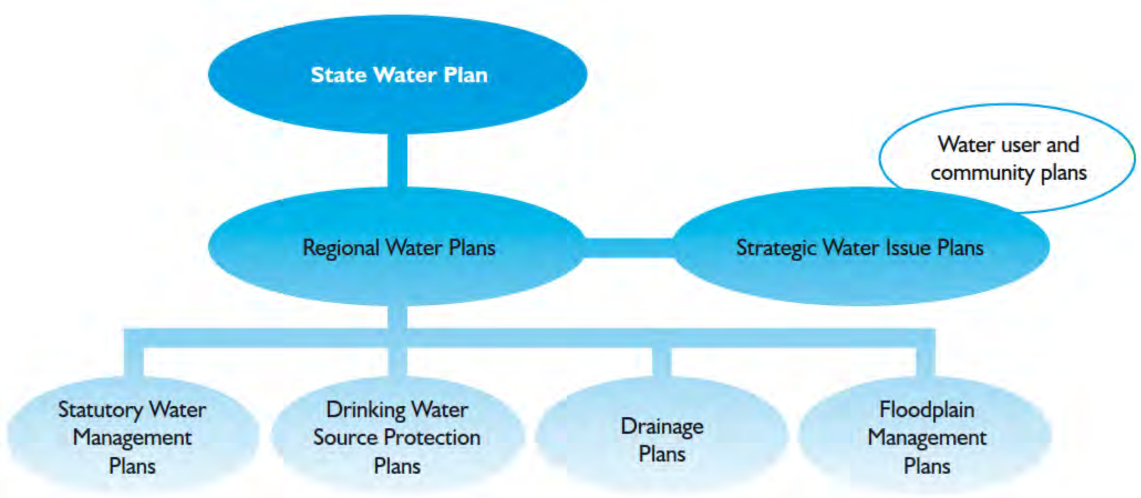


Figure 4-1 The Water Planning Framework

4.2 The Rural Water Plan

In 1992, the State Government established a Farm Water Strategy Group to develop long-term solutions to the ongoing water supply problems in the dryland agricultural region.

The group included farmer and government representatives and concluded that:

- The most acceptable, practical and economic solution to water supply problems was one that encouraged optimum development and use of on-farm water supplies;
- Emergency farm water supply arrangements should be provided by government;
- Low cost and good quality off-farm water encouraged farmers to cart water;
- Farmers were reluctant to invest in more reliable on-farm supplies; and
- Farmers developing their own on-farm supplies faced far greater risks than those connected to piped supplies.

A Farm Water Plan was completed by late 1994 and has been largely adopted since then.

During 2000, an extensive review of the Farm Water Plan was undertaken under the guidance of the Office of Water Regulation and the Rural Water Supply Coordinating Committee (later the Rural Water Advisory Committee). The review led to a commitment by the State Government to maintain the operation of the original Farm Water Plan, re-badged as the State Rural Water Plan.

A 2004 review also reinforced the key role played by the plan in improving rural water supplies, better managing existing water resources and securing dryland communities against serious water deficiency. The Rural Water Plan was reviewed again in 2010 and continued to operate largely unchanged until 2020.

DWER is currently reviewing the Rural Water Plan and in the next version it will be converted to a Guideline (in preparation).

The Guideline is based on the principles of sustainability and water self-sufficiency. Therefore, the primary focus of the Guideline will be on improving on-farm water supplies to improve preparedness for periods of low rainfall and drought and less reliance on off-farm and public water supplies.

5 WATER DEMAND ESTIMATE

The purpose of this water demand estimate is to establish the major water uses within the Shire and make an estimate of the likely demand to 2030.

5.1 Darkan Townsite

5.1.1 Potable Scheme Water

The Darkan townsite is the major connection point for the Shire of West Arthur to the GSTWSS, with a number of farm services also accessing the scheme along the pipeline.

As an overview Water Corporation have provided a summary of meter readings from the Darkan GSTWSS offtake and also the Darkan Town meter, with the difference attributed to a number of farms serviced between the two meters.

Table 5-1 GSTWSS Meter Readings 2015 to 2020 (kL)

Meter	2015	2016	2017	2018	2019	2020	Total
Darkan GTWS Offtake	112,120	87,237	66,646	65,338	133,796	101,362	566,499
Darkan Town	56,687	40,578	48,212	52,047	49,136	46,281	292,941

Note: Data provided is raw scheme data, this may vary from billed data due to unaccounted water such as firefighting, leaks, scouring, as well as normal discrepancies in calibration of various meters.

Within the Darkan town supply the Shire operates 4 standpipes, namely:

- Quindanning Road (50 mm connection)– firefighting purposes only.
- Shire Depot (50 mm connection) – Local government purposes only.
- Horwood St (25 mm connection) – Public use, connected to a storage tank.
- Growden Place (50mm connection) – Commercial use, fast fill. Installed December 2020.

Table 5-2 Available standpipe meter readings 2017 to 2020 (kL)

Meter	2017	2018	2019	2020	Total
Quindanning Rd	646	309	235	14	1,204
Horwood St	5524	5349	5282	8693	24,848

Note: Growden Place Standpipe meter reading up to 9 November 2021 is 755 kL.

With all of the services provided by the Shire, they are the biggest scheme water user from the Darkan Town meter, averaging 12,000 to 15,000 kL/yr. The four highest water uses for the Shire are the Horwood St and Growden Place standpipes, irrigation of Robert L Perry Park (Lot 195 Coalfields Rd) and the Tennis Courts.

The public swimming pool is a sub-meter to the Darkan Primary School meter (Department of Education). The pool is open from October to April each year. Based on approximately 10 weeks of meter readings taken between November 2020 and February 2021 the total water consumption by the pool for 7 months is approximately 700 kL/yr.

The highest commercial consumer on the Darkan Town supply averages 667 kL/yr (2017 to 2020) and the highest residential consumer averages 456 kL/yr over the same period. The typical residential consumption is approximately 250 kL/yr.

The population of the Shire has been steadily declining, from 1293 in 1976 to 988 in 1996 and 824 in 2016. The population of Darkan remained steady at 266 in 1976 and 265 in 1996. While an updated figure for 2016 is not available, a significant change is not expected over the next 8 years to 2030.

5.1.2 Non-Potable Water – Darkan Town Dam

All non-potable water supplied to the town comes from the Town Dam and is used primarily for irrigation. Based on an assessment of the dam using an aerial image, it is estimated to hold a maximum volume of approximately 55,000 kL. We do recommend that the dam is surveyed to confirm capacity.

The main irrigation demand from the town dam is summarised below.

Table 5-3 Darkan Town Irrigation Areas

Facility	Area (ha)	Irrigation Rate (kL/ha/yr)	Annual Irrigation Demand (kL/yr)
Sports Oval	2.00	7800	15,600
Bowling Green	0.15	8000	1,200
Primary School Oval & Gardens	1.50	7500	11,250
Caravan Park camping sites	1.00	7500	7,500
Total	***3.65***		***35,550***

Anecdotally, in recent years the dam has only been half full (23,000 kL) at the end of winter, including with additional pumping from Nangip Creek (unmetered). In response to low storage levels the irrigation rate is reduced, which is a substantial issue for the maintenance of high use sports fields.

Potential evapotranspiration (PET) is expected to increase 2.5% to 2030. The baseline PET is approximately 1600 mm/yr, so 2.5% change is 40 mm/yr. Over the total irrigation area of 3.65 ha this equates to an additional irrigation demand of 1,460 kL/yr.

We recommend a water demand estimate of 37,010 kL/yr is used for water supply planning.

5.2 Duranillin Townsite Non-Potable Water

There are currently 3 registered water users in the Duranillin Town site water supply operated by the Shire. Up until 2014, the Duranillin water supply was used by 9 residences with a total consumption of 2,000 kL per year, averaging approximately 220 kL/yr for each residence.

Presumably due to ongoing issues with water quality, the water consumption reported by the Shire for the 3 users is highly variable, as follows:

Table 5-4 Duranillin Water Use 2019/20

User 2019/20 Financial Year	Use from Jul 19 to Apr 20 (kL)
User 1	405
User 2	120
User 3	7
Total	**532**

One of the users has a rainwater tank, but it is not large enough to support the household, and the other two do not have rainwater tanks. One residence does not have roof gutters to collect rainwater.

The Shire has recently received a request for a new meter by a resident, which would take the scheme up to four residents. It is anticipated that if a reliable and good quality water supply is found for the Duranillin supply that consumption by the residence would return to approximately 220 kL/yr on average. For water supply planning we recommend a demand estimate of 880 kL/yr on average.

5.3 Firefighting Water

Firefighting water is predominately supplied by farmers from their own sources. Where additional water is required there are sources available to the community, namely the Darkan standpipes (refer section 5.1.1), the Moodiarrup standpipe and unmetered groundwater bores located at Gorn Rd and Rees Rd. There is currently no firefighting water supply in the western part of the Shire, but this is not an issue as there is significant State Forest on the western side of the Shire and the fire response is managed by Department of Biodiversity Conservation and Attractions. (DBCA).

The Shire is also progressing the refurbishment of the old Kylie Railway Dam, with the addition of a new tank and standpipe. The Kylie Dam has an estimated maximum storage volume of 22 ML (22,000 kL).

In an attempt to try and quantify the annual demand for firefighting water a 'back of the envelope' calculation was completed based on a discussion with ex Shire President Ray Harrington, as follows:

> Average number fire units attending a fire:
> 25 units of 10,000 L and 25 units of 5,000L = 375 kL
>
> Firebomber = 60 kL (assumes 2850 L/trip x 21 trips)
>
> Anecdotal No. of fires per year = 12
>
> Total fire water demand = 5,220 kL/yr

It should be noted that this estimate includes water used by fire bombers, which currently draw water from a 20,000 L tank at Hillman airport and is refilled from the Quindanning Rd standpipe.

In Western Australia, the number of days with a severe fire danger is anticipated to double by 2090 (Climate Council, 2015). Not only will the frequency of fires increase, but they are also likely to burn for longer and affect more area. In this context, we recommend a fire water demand of 3 times the current estimated use or 15,600 kL/yr is used for water supply planning.

5.4 Emergency Stock Water

The most recent estimate of stock numbers was in 2015/16 and shows that sheep numbers in the Upper Great Southern have declined from 7,312,500 in 1993 to 3,242,890 in 2016. For the Shire of West Arthur the change over this period was 976,900 to 469,992 sheep. Cattle and pigs make up a much smaller number, approximately 6,000 and 2,000 head respectively.

Stock water demand estimates are generally calculated on a Dry Sheep Equivalent (DSE) basis with a DSE defined as a 45kg dry (i.e. not lactating) ewe. Pigs and cattle consume water at rates of 2 and 10 DSE respectively (Farmer and Coles, 2003). The maximum daily DSE drinking rate in January/February in the West Arthur area (data taken from Wagin) is 6.3 L/day assuming a water salinity of 3,300 mg/L (Farmer and Coles, 2003).

The summer watering rates for stock used in this assessment are as follows:

- Sheep 7.7 L/day (assuming an average sheep weight of 55 kg)
- Cattle 63 L/day
- Pigs 12.6 L/day

Assuming 5 months (151 days) of watering (Dec to Apr), multiplying out the stock numbers by the watering rates, produces a theoretical total stock water demand of approximately 600,000 kL, or a daily demand of 4,000 kL.

The community water supplies available for emergency stock water are summarised in Table 5-5, noting the Kylie dam project is still awaiting completion. The Moodiarrup standpipe is excluded as the water is too salty for stock to drink.

Table 5-5 Capacity Details of Community Stock Water Supplies

Source	Total Water Storage (kL)	Daily Supply Rate (kL)
Kylie Dam	22,000	115 (for 191 days)
Gorn Rd Bore	Unknown	400
Rees Rd Bore	Unknown	Unknown (estimate 200)
Horwood St Standpipe	Scheme supply	100
Growden Pl Standpipe[1]	Scheme supply	500
Total		**1,115**

1. *Cost of water is approximately $10 per kilolitre.*

The last drought experienced in the Shire was 2014 to 2016. Anecdotally, in December 2015, water supply was at an all-time low and many famers were in search of any water access point to be able to maintain livestock. Demand on scheme water was very high, with significant wait times being experienced at the Darkan town (Horwood St) standpipe. The Gorn Rd bore was upgraded with a pump and cleared area for vehicles to fill in January 2016, but was only used for a few weeks before a heavy rainfall event of 150 mm occurred from 19 to 21 January 2016. The rain fell on most parts of the Shire filling up the farm dams.

Of the 147 agriculture businesses registered in the Shire, 37 (25%) accessed the Horwood St standpipe in 2015. While not all of the users were accessing the standpipe for stock water, it is expected that significant number were. Excluding Kylie dam and Gorn Rd (not operating), the delivery capacity of the community water supplies in December 2015 was approximately 800 kL/day, or 80% of the theoretical demand for 25% of farms (1,000 kL/day). It should be noted that livestock will not be distributed evenly amongst farms and the ~25% of farmers who accessed the standpipe may have a larger or lesser proportion of the Shires livestock, but this theoretical estimate suggests and undersupply of 20% in summer 2015/16.

While achieving the total water supply required is important, excess supply will most likely be needed to ensure the delivery rate is adequate in times of water stress. We recommend that the Shire uses a water demand estimate of 300,000 kL at 2,000 kL/day (50% of the total theoretical demand) for emergency stock water supply planning.

5.5 Industrial Use

Due to the high cost of water from the Growden Place bore, the Shire has indicated that it would like access to a non-potable water supply to allow expansion of the Darkan Industrial Area. More industry is needed in the town to provide economic benefits to local businesses and the community (including the Darkan Primary School).

Water demand and usable water quality varies greatly between industrial activities. The water required to expand the industrial area can only be assessed once a proposal is submitted. The water demand could potentially be supplied from a new Town Dam (see section 8.2) or a new bore in the Darkan palaeochannel (refer section 8.3.2).

5.6 Water Demand Summary

The water supply planning demand estimate is summarised in Table 5-6 below.

Table 5-6 Summary of Water Demand Estimate for 2030

Water Use	Current Demand Estimate (kL)	2030 Demand Estimate (kL)	Change In Demand (kL)
Potable water	49,000	49,000	0
Darkan non-potable	35,550	37,010	1,460
Duranillin scheme	532	880	348
Firefighting water	5,220	15,600	10,380
Emergency stock water	180,000	300,000	120,000
Total	***270,302***	***402,490***	***132,188***

6 WATER RESOURCE IMPACT ASSESSMENT

The analysis competed in this section for the surface water dams is very coarse, working on monthly data to generate annual totals, with uncalibrated runoff coefficients. The results are intended to guide prioritisation of water projects for Stage 2. A refined water balance is generally completed on a daily timestep and includes all potential losses, which can be considered as part of the Stage 2 scope of work for the assets identified for further analysis.

6.1 Darkan Town Scheme Supply

The following advice was provided by Water Corporation in relation to demand management for the GSTWSS (*pers. comm*. Mick Irving, Water Corporation).

> *"Water restrictions: Darkan is currently subject to the permanent 2-day-per-week sprinkler roster that applies to most of the southern part of the State. The applicability of water restrictions is determined by the Government of the day, so it is difficult to advise on the likelihood of any changes, however Water Corporation is not aware of any supply-driven drivers specific to Darkan that would result in further restrictions for the town at this stage.*
>
> *Standpipe restrictions: There are no plans to restrict standpipe use or flow rates in Darkan. However, it should be noted that:*
>
> *During significant dry periods, Water Corporation may temporarily restrict standpipe use or standpipe flow rates at strategic locations throughout the GSTWSS (or other schemes), to ensure town water use can be maintained as a priority. If this is required, it would ordinarily be undertaken in consultation with key stakeholders including the relevant water and agriculture Regulators, and Local Government. Under the current scenario as outlined above, and considering the current number of publicly accessible standpipes in Darkan (1x50 mm and 1x25 mm), Darkan would be considered fairly low risk in terms of the likelihood of restrictions, but this would be assessed as required in the case of a dry period event.*
>
> *Standpipe usage is limited to less than 49 kL/day under the standard service agreement that applies to the majority of Local Government Standpipes, including all of Shire of West Arthur's scheme water standpipes. Water use above 49 kL/day must be arranged with Water Corporation by exception, and will be governed under our Major Consumers Framework, which will include the establishment of a Major Consumers Agreement.*
>
> *Scheme water supply is not guaranteed during a bushfire. Supply is often lost due to power interruptions and damaged infrastructure. While fire standpipes and hydrants are important, it is also important that customers and communities do not rely on scheme water in their emergency response plan. DFES should be consulted with regard to suitable fire and emergency response planning."*

6.2 Darkan Town Dam Supply

The Town Dam catchment area is shown in Figure 6-4 along with the Nangip Creek pump station catchment. The dam storage details are not available, but based on an assessment of the aerial image the following approximate dimensions have been assumed:

Base area = 6,300 m^2
Maximum Depth = 6m
Batter slope (v:h) = 1:3
Maximum storage vol. = 55,000 kL
Surface area at max vol. = 12,500 m^2

The ‘dry 2030’ synthetic rainfall dataset (see Section 3.1.4) has been used to assess the impact to the Town dam storage with the results shown below in Figure 6-1. With the dam half full, an additional evaporation loss of potentially 13,000 kL/yr should be subtracted from the storage results.

The results of the assessment are relatively sensitive to the runoff coefficient used. There are no gauged small catchments in the area and no water level readings available for the dam with which to calibrate the catchment runoff coefficients. Half of the Town Dam catchment has been shaped by a grader and the remainder is farm paddock, so based on experience a runoff coefficient of 30% was selected for the baseline data. A runoff coefficient of 10% was used for the dry climate because with declining rainfall the catchment dries out more often and so does not ‘wet up’ as often, which is when runoff occurs.

As the rainfall is a synthetic dataset it is not appropriate to look at the result from any one year, the results should be interpreted based on the whole dataset. The Town Dam results show that for the dry 2030 climate the dam will not fill, the maximum annual storage is approximately 48,000 kL, the minimum annual storage is approximately 13,000 kL and the average annual storage is 31,500 kL, which is below the estimated water demand of 37,010 kL/yr.

The Shire have advised that they pump from Nangip Creek opportunistically when the creek is flowing. Factoring in evaporation (subtract 13,000 kL), in an average year it will be necessary to pump approximately 18,000 kL/yr from Nangip Creek to top-up the dam.

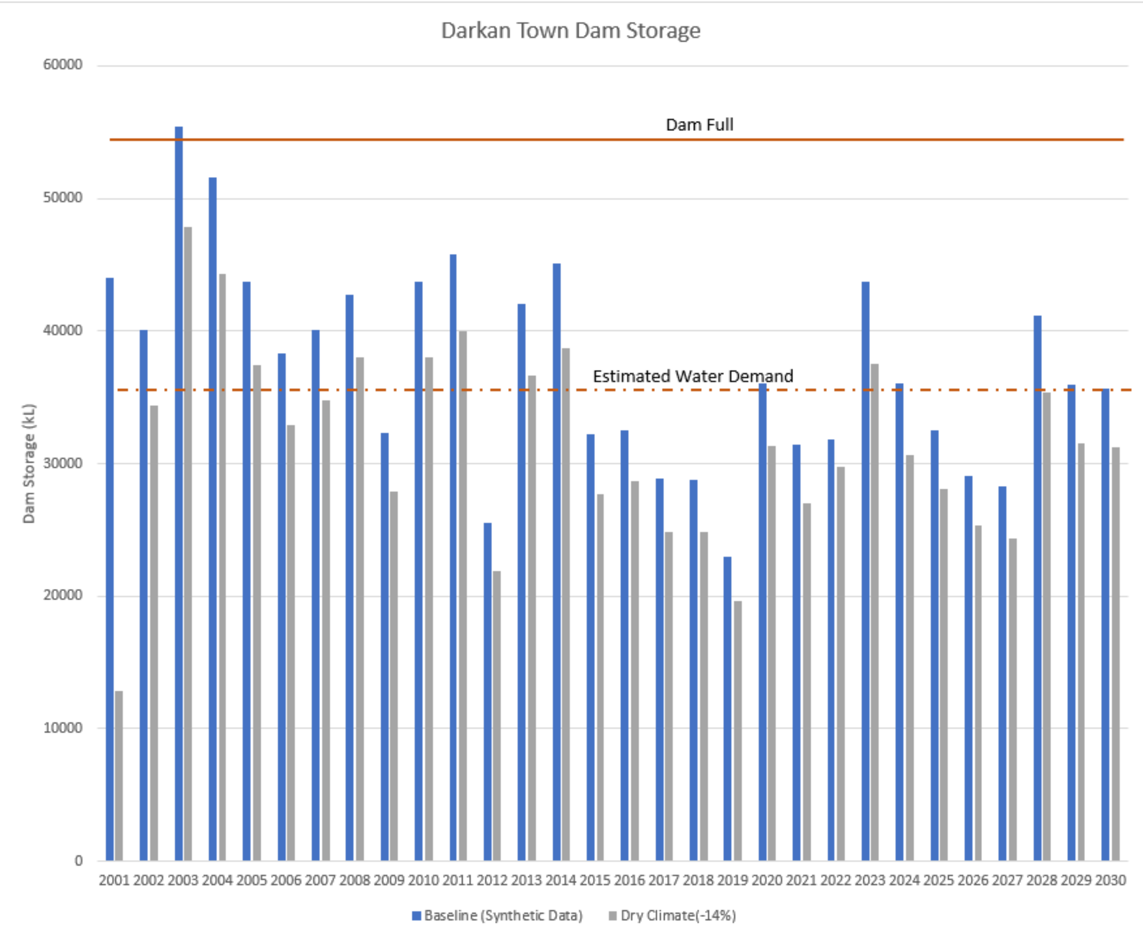


Figure 6-1 Projected Dry 2030 Town Dam Water Storage

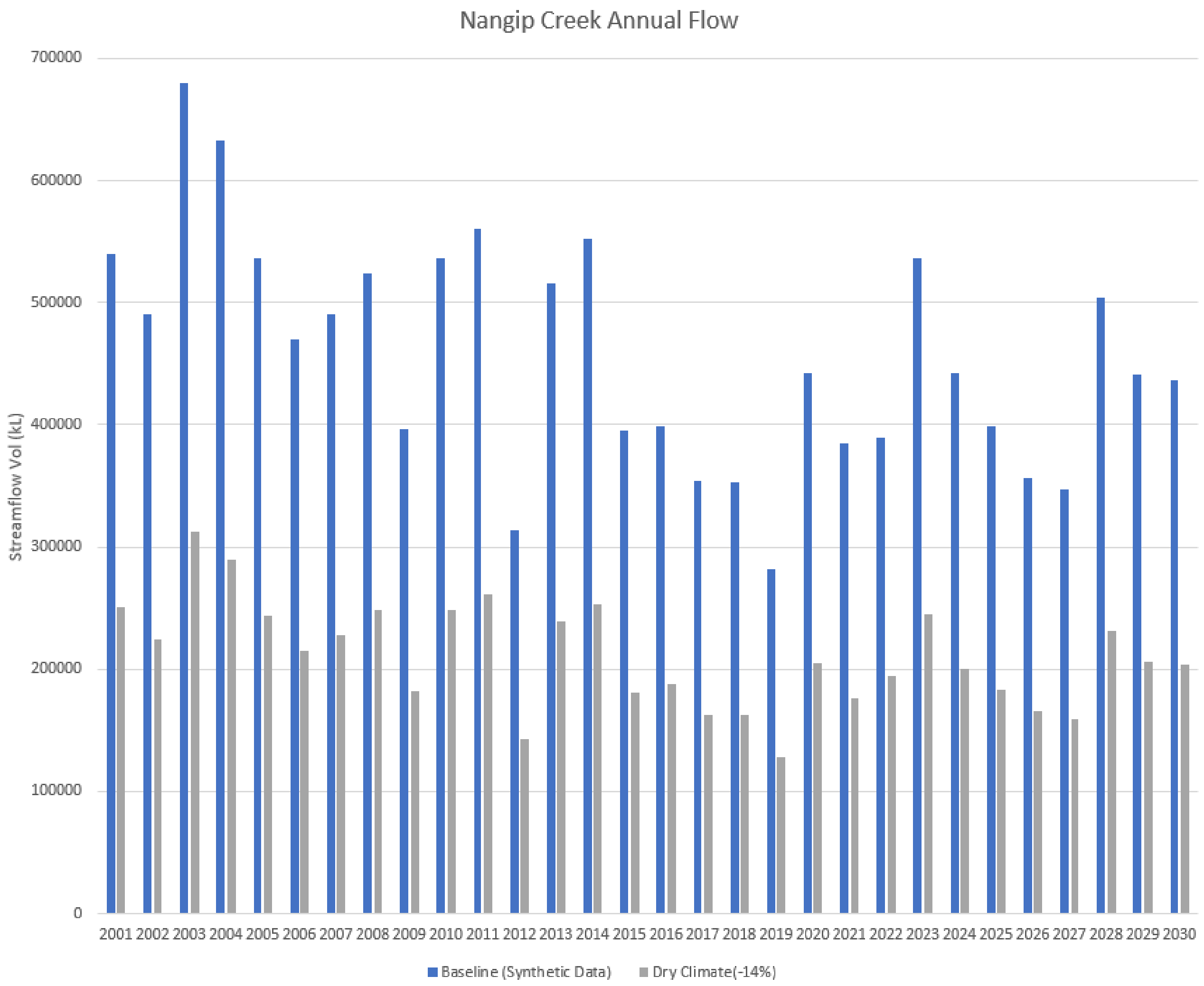


Figure 6-2 Projected Dry 2030 Annual Discharge Volume for Nangip Creek

The estimated runoff coefficients assumed for Nangip Creek were 15% for the baseline climate and 8% for the dry climate. The results show for the dry 2030 climate that the maximum annual discharge will be 310,000 kL, the minimum annual discharge will be 130,000 kL and the average annual discharge will be 210,000 kL. There are a number of small dams (approximately 12) located in the catchment of Nangip Creek, upstream of the pump station. The dams may significantly alter the results presented here and a desktop analysis to calibrate the runoff coefficients should be undertaken as part of the Stage 2 scope of works.

The results suggest that there will be sufficient water to top up the dam in an average year (18,000 kL), depending on how effective the Shire's system is at capturing the water. In the minimum discharge year approximately 50,010 kL will need to be pumped from Nangip Creek to meet the full estimated demand (37,010 kL) plus evaporation loss (13,000 kL).

6.3 Duranillin Supply

A new water supply is needed for Duranillin due to the salinity of the bore. The Shires records show that the bore was constructed in 1995 at which time the recorded salinity was 660 mg/L. By 2010 the salinity had risen to 2,940 mg/L and the most recent reading in 2017 shows a salinity of 4,325 mg/L.

The intrusion of saline water into the aquifer indicates that the annual abstraction is greater than the fresh water recharge. Whether this is a function of a small recharge area, low transmissivity of the recharge zone or a reduction in recharge due to reduced rainfall is unclear, but what is a clear is that groundwater can be limited and needs to be carefully managed.

6.4 Kylie's Dam

The Kylie Dam catchment is shown in Figure 6-5. There are two contour drains on the east and west side of the dam which increase the catchment area by approximately 1 km^2. Approximately two thirds of the Kylie Dam catchment is bush reserve and a runoff coefficient of 5% was selected for the baseline data and 3% for the dry climate data.

The dam storage capacity is reported in the Kylie Dam funding application as 22 ML (22,000 kL) and this value has not been checked by Water Technology. With the dam half full the evaporation loss will potentially subtract 3,000 kL/yr from the storage results.

The Kylie Dam results show that for the dry 2030 climate the dam will fill in most years. The maximum annual discharge from the catchment is 39,000 kL (dam overflowing), the minimum annual storage is approximately 16,000 kL and the average annual catchment discharge is 26,000 kL (dam overflowing).

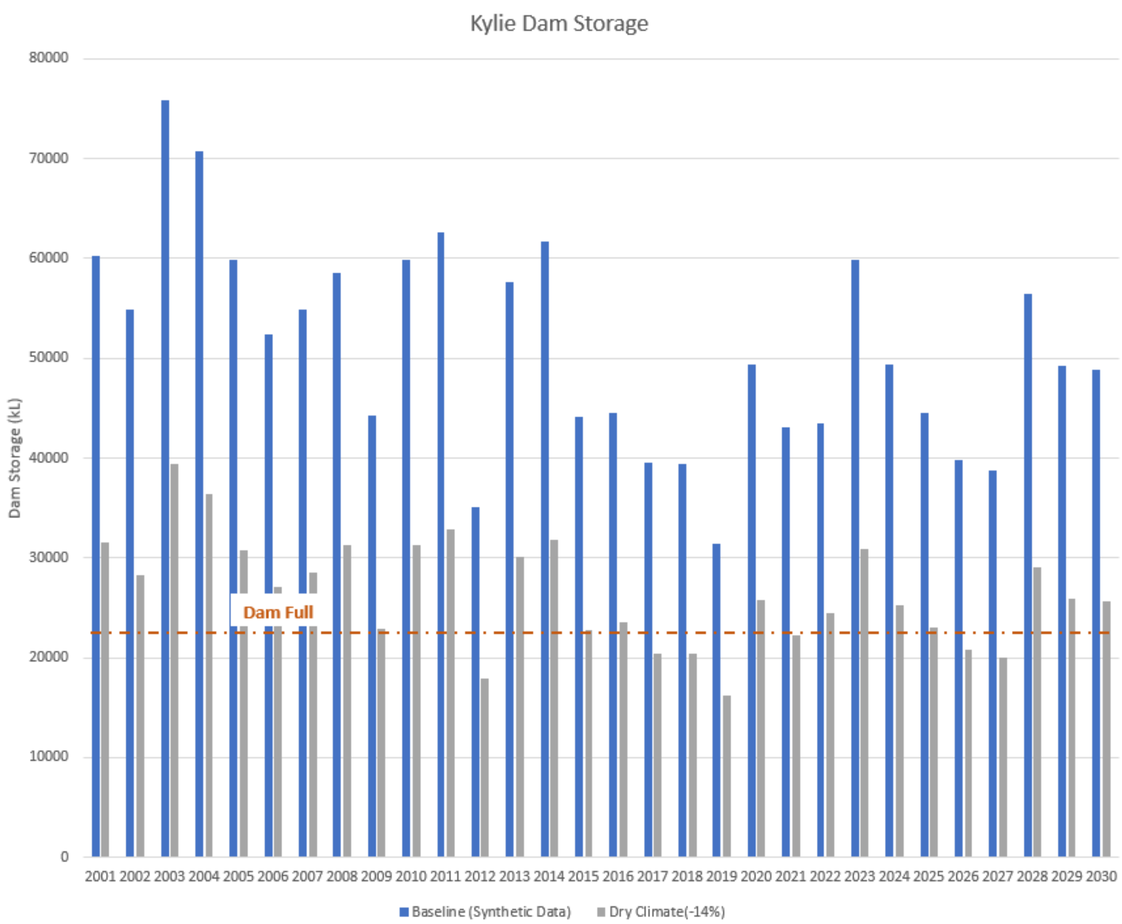


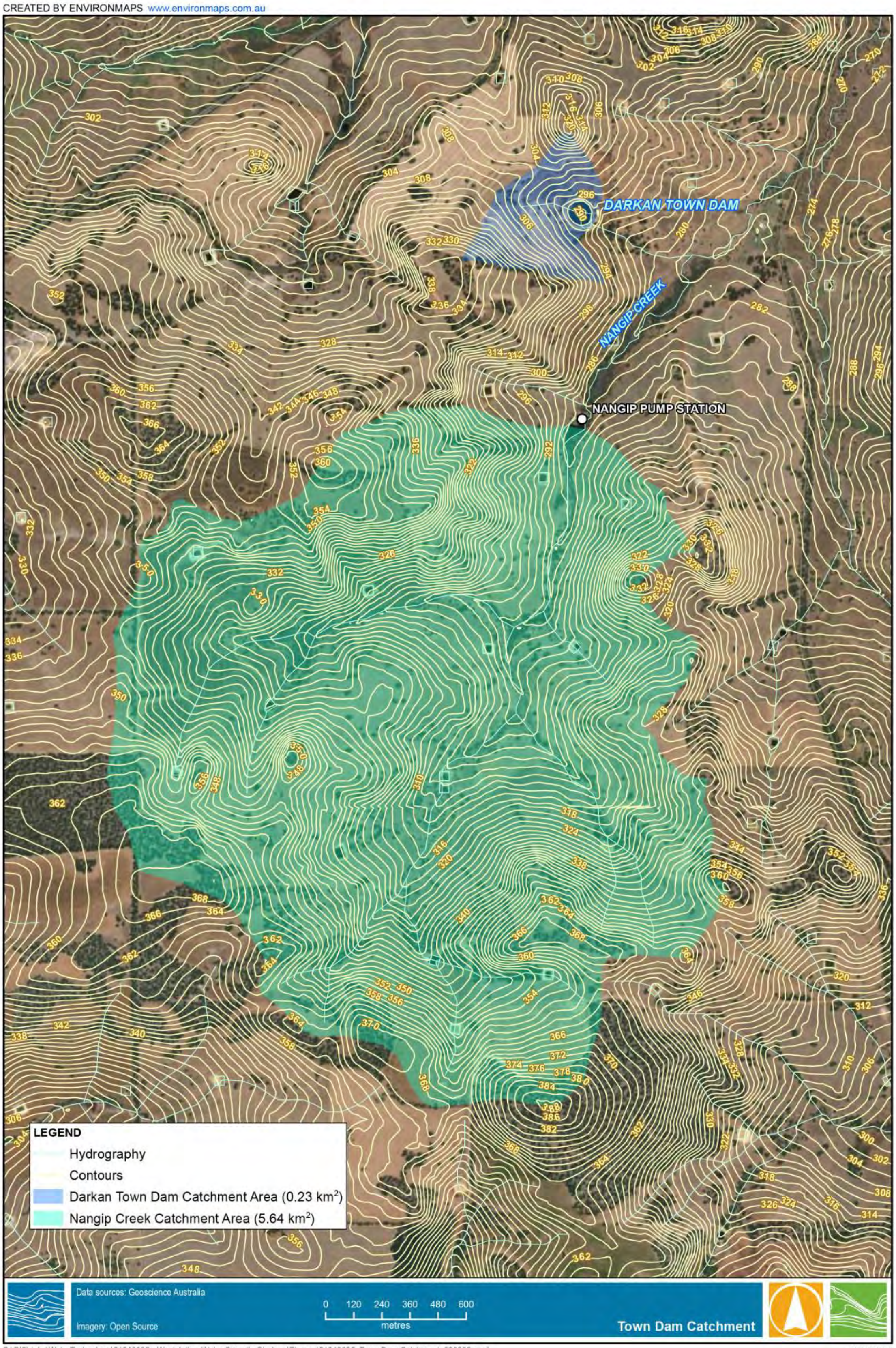
Figure 6-3 Predicted Dry 2030 Kylie Dam Water Storage

6.5 Gorn Road and Rees Rd Bores

No test pumping data or salinity measurements have been provided for either of the two bores, but we do know that the Gorn Rd bore is pumped at 5L/s (300 L/min) intermittently. The Gorn Rd bore is located within the Beaufort Palaeochannel which explains the relatively high yield from the bore (Figure 7-5).

More investigation of the Beaufort Palaeochannel is needed as discussed in Section 8.3.3 to confirm the available resource. There are some significant water users already accessing the palaeochannel within the Shire of Woodanilling and with declining rainfall there is a risk of over abstraction leading to salt-water intrusion. As a firefighting water supply the salinity of the water is not a concern, but if the bore is to be used as an emergency stock water supply or for road construction then the salinity in the Gorn Rd bore should be monitored.

CREATED BY ENVIRONMAPS www.environmaps.com.au



C:\GIS\Jobs\WaterTechnology\21040036 - West Arthur Water Security Strategy\Figures\21040036_Town Dam Catchment_220302.mxd 2/03/2022

Figure 6-4 Darkan Town Dam and Nangip Creek Catchment Plan

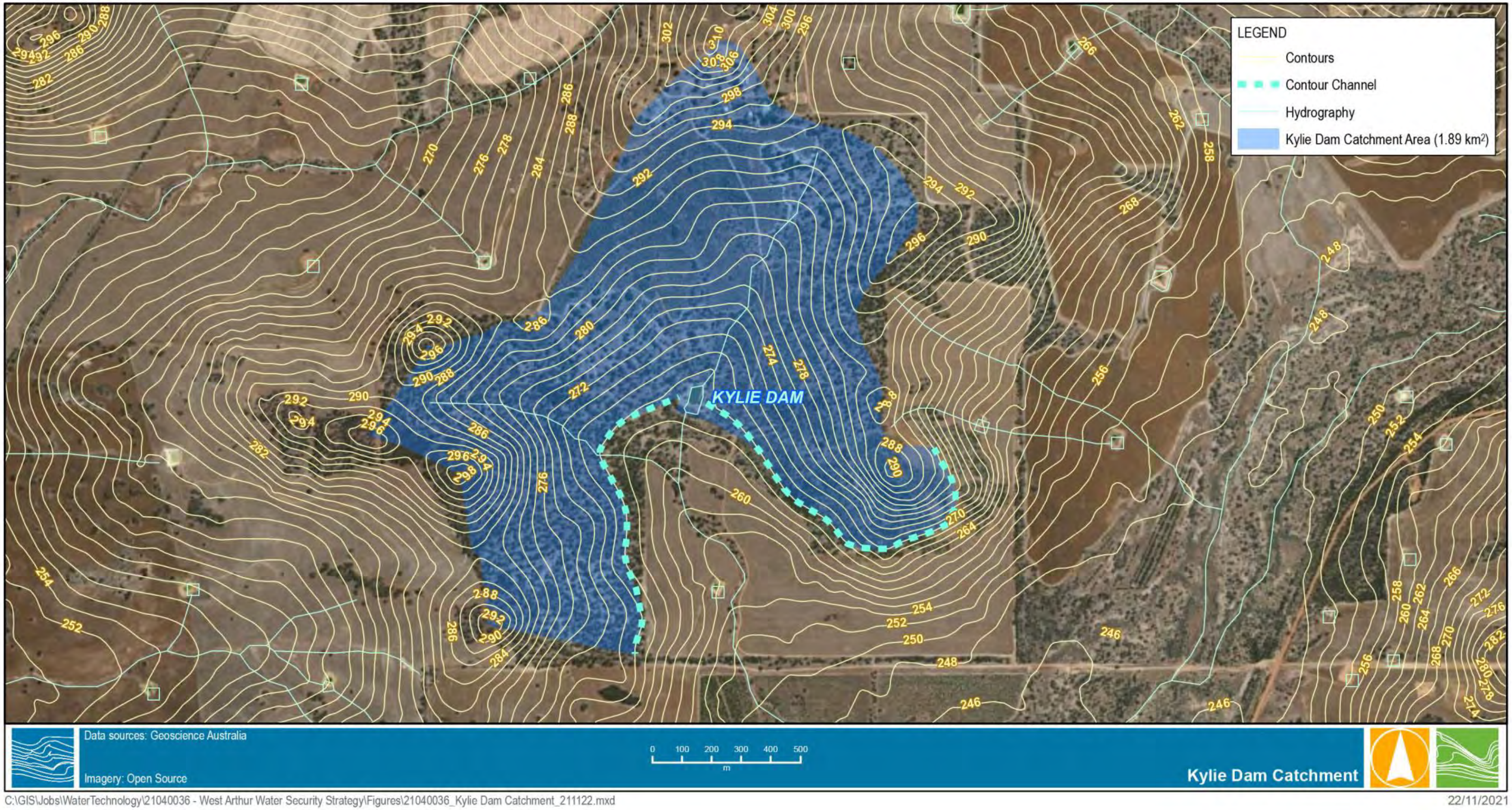


Figure 6-5 Kylie Dam Catchment Plan

7 POTENTIAL ADAPTATION OPTIONS

7.1 Expansion of Water Corporation Scheme Supply

There is not anticipated to be any significant increase in potable water demand to 2030, with all of the additional demand for non-potable uses (Table 5-6).

Water Corporation strongly encourages the use of fit-for-purpose water provision by all parties where possible. That is, scheme water use for non-potable purposes should be a last resort where independent non-potable sources cannot be established and utilised (*pers. comm*. Mick Irving, Water Corporation).

Water Corporation has recently completed a pipe connection between Harris Dam and Stirling Dam, to supplement water supply as required. The Stirling Dam is part of the Perth Integrated Water Supply Scheme (IWSS) and if required in the future, the scheme has design capability to be supplemented with water from the Southern Seawater Desalination Plant, near Binningup. This is a significant expansion of the scheme and source capacity is expected to be sufficient for the foreseeable future.

7.2 Expansion of Surface Water Sources

7.2.1 Hillman and Bowelling Railway Dams

The Shire has completed a preliminary review of the opportunities to restore/refurbish the two railway dams but found the sites to be too constrained. The Hillman Railway dam is contaminated with asbestos.

7.2.2 Duranillin Town Dam

In the copy of the council agenda item regarding "Duranillin non potable water supply" provided to Water Technology by the Shire, the history of the project notes:

> *In July 1993, at a Community meeting it was resolved not to further pursue a potable water supply; the Council intended to follow a WA Water Authority recommendation to reconstruct an existing town dam and reticulate it with a pressurised supply*.
>
> *In November 1994 residents wrote to Council with concern that the reliance on rainfall for the dam proposal and Council investigate a non-potable underground supply as there was quite a deal of information already available*.

Water Technology considers that the water supply for Duranillin is best resolved by blending as many sources as possible, as this will reduce the reliance on any one source. As part of the supply solution Water Technology recommends that the Duranillin Town dam be reassessed. It is understood that the dam was considered too small to offer a reliable supply to the town, but it may be adequate to provide a cost-effective supplementary supply when required.

7.2.3 A Second Darkan Town Dam

The Shire has completed some analysis for consideration of a second town dam, which is intended to capture the stormwater runoff generated by the road drainage network as shown in Figure 7-1. Water Technology considers the proposal is reasonable and understand that the major item to resolve for the Shire is the location of the dam. A location north of Coalfields Hwy would be appropriate, with the old CBH site a possibility.

Initially, Water Technology recommends that meters are fitted to the water offtake at the existing dam, along with the Nangip Creek pump station pipe to measure and refine the water demand estimate and to better establish the reliability of the existing town dam supply. The preliminary analysis (Section 6.2) suggests that there is a risk of insufficient supply by 2030 and the proposal for a second dam should be progressed.

Existing underground drains

Existing Open drain

Figure 7-1 Darkan Stormwater Pipe Network

7.2.4 Rainwater Tank on Darkan Sports Complex

The Shire have previously considered fitting a large rainwater tank to Darkan Sprots Clubhouse. The two potential water uses for water are irrigation of the bowling greens or non-potable use within the clubrooms.

Meter readings provided by Water Corporation show that the Sports Clubroom used 238 kL in 2019 and 199 kL in 2020. The bowling greens use approximately 1200 kL/yr.

The roof area of the clubrooms is approximately 1050 m^2 and with an average rainfall to 2030 of 468 mm/yr the roof will yield an average of approximately 491 kL/yr. The nearest tank size that will fit on the site is a 483 kL tank. For the dry climate scenario the minimum runoff from the roof area will be 298 kL (from 285 mm of rainfall).

Given the complexity of replumbing the building for a non-potable water supply, it is recommended to use the water to irrigate the bowling greens. In an average year the storage tank would account for approximately 40% of the lawn bowls irrigation, but the water efficiency of synthetic fields is improving all the time, so when the field is replaced a more water efficient surface should be selected to try a match up with the tank storage.

While the project does not have a significant impact on the overall no-potable water demand within the town, if it can be demonstrated to be a relatively low-cost water supply (and it may delay construction of the second town dam) then we recommend the Shire progress the project.

7.3 Expansion of Groundwater Resources

7.3.1 Investigation Sites

A review of the DWER and Department of Primary Industry and Regional Development (DPIRD) groundwater monitoring databases reveals many thousands of registered data points within the Shire of West Arthur dating back to the 1970's, but on interrogation most of the data points have no drilling log and no reliable water level or salinity reading. Figure 7-2 shows a summary of the groundwater data points where either a drilling log, reliable water level or reliable salinity measurement(s) is available. There is a total of 273 sites shown on Figure 7-2.

Focusing in on the deeper bores (> 10m depth) with the potential to provide information on suitable pumping locations, Figure 7-3 shows the range of salinity readings and includes 90 bores in total. From this pool of 90 bores a total of 12 bores have an estimated yield of at least 50 m^3/day (or 35 L/minute) and are shown in Figure 7-4. A flow rate of 50 m^3/day was selected as the cut-off, based on practical filling times for large water tanks (5,000 to 10,000L) from a standpipe, and which in most cases would still require a buffer tank.

It should be noted that many of the yield estimates recorded are based on airlifted volumes by the driller and do not represent a long-term pumping rate (or safe yield).

The final analysis overlays the estimated yield with salinity and identifies the locations that we have described as 'groundwater prospects'. A limit of 4000 mg/L salinity was used to filter the dataset, based on stock water tolerance, and 10 bores are presented in Figure 7-5 and summarised in Table 7-1.

The prospective bore locations are heavily centred around the Darkan and Beaufort palaeochannels, but this is possibly an indication of the rigour of the drilling programs undertaken for the palaeochannels, rather than a fair representation of the distribution of potential groundwater sources. But it is likely that the best groundwater prospects are in these palaeochannels as they represent the most significant groundwater targets.

Table 7-1 Groundwater Bore Details

	Location		Total Depth	Bore Owner
Bore ID	**Easting**	**Northing**	**(mBNS)**	
TOW5	470585	6287554	44	DAFWA
TOW6	470700	6287500	40	DAFWA
08DD08I	494149	6316834	60	DAFWA
RC07D98	469954	6301064	14	DAFWA
01WR05I	494503	6315194	11	DAFWA
1419 F87 West Arthur	496641	6287654	14	DWER
BOS3	497312	6285397	52	DWER
BOS10	495911	6283135	47	DWER
BOS11	497318	6286532	36	DWER
TOW4	466330	6285027	67	DWER

The analysis points to a lack of meaningful drilling data to identify suitable areas to explore for additional groundwater supplies. To assist with future decision making we would encourage the Shire and farmers to complete bore logging and testing as per the DWER Rural Water Note 05 – *Simple Pumping Tests for Farm Bores* (Appendix B) for any new bores constructed, or any bores looking to be upgraded or integrated into the community supply.

Ideally the new data would be captured by either the DWER Water Information Reporting database or the DAFWA groundwater database, but failing this the Shire should at least keep a copy of all records for future analysis.

7.3.2 Darkan Palaeochannel

The AEM mapping completed by CSIRO in 2009 appears to have been very effective at mapping the orientation and quality (salinity) of the palaeochannel resource.

From a discussion with Dr Tim Munday at CSIRO he indicated that they have recently acquired new inversion software, which is more powerful than the software used in the 2009 data analysis. While it is not expected to change the results greatly, the Shire could take the opportunity to get CSIRO to re-run the 2009 AEM dataset using the new software to further refine the mapping.

This mapping does not provide an indication of yield, which can only be proved up by drilling, but it does significantly narrow down potential drilling sites by targeting the fresher water. Based on the available mapping (Figure 3-11) there appears to be good prospects for fresh water south and east of the tannery pumping site, along the northern section of Bunce King Rd approaching Dardadine Rd south, and in the north-south section of the palaeochannel south of South Rd.

As mentioned in the previous section, a test pump should be completed and recorded for any new bores constructed as per RWN 05 (Appendix B).

7.3.3 Beaufort Palaeochannel

The Beaufort palaeochannel is approximately 60 km long and while there has been a significant amount of exploration in the Boscabel and Towerinning areas, the orientation of the palaeochannel and the groundwater quality is not well understood. From Figure 7-5 the highest estimated yield of a fresh water supply is found at bore TOW 4, located immediately north-east of the Haddleton Nature Reserve.

To locate the orientation of the palaeochannel and quality of the resource we suggest that AEM mapping is completed, like the mapping completed for the Darkan Palaeochannel. This mapping is particularly important for the Duranillin townsite water supply where the identification of any fresh groundwater in the palaeochannel would be very valuable.

The Great Southern Development Commission (GSDC) is currently leading a project regarding the Beaufort Intensive Ag Precinct with assistance from Dr Richard George from DPIRD. From discussions with Richard George, there is renewed interest in the Beaufort area, and industry/corporates are keen to get some AEM mapping of the palaeochannel completed.

Indicative pricing for a 25 km x 10 km grid is $250,000 for 500 m flight line spacing or $400,000 for 250 m flight line spacing, with the reduced flight line spacing providing higher resolution imagery.

We recommend the Shire liaise with GSDC to work up a proposal for the AEM mapping of the Beaufort Palaeochannel, ideally for the full length, but if this is not feasible, we suggest mapping from bore TOW 7 (Figure 7-2) east to the Shire boundary (an approximate 25 km x 14 km grid).

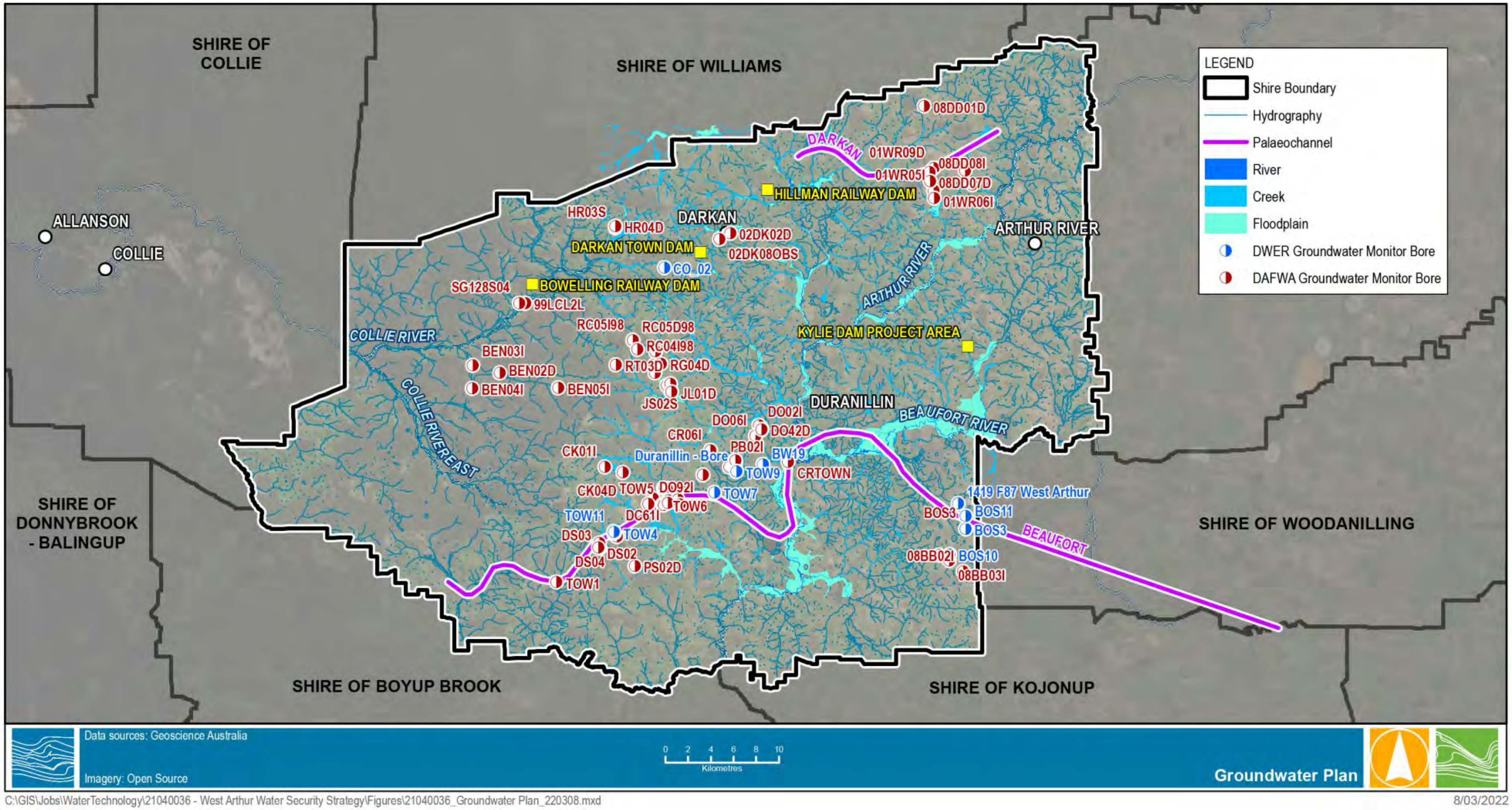


Figure 7-2 Groundwater Bores and Monitoring Sites

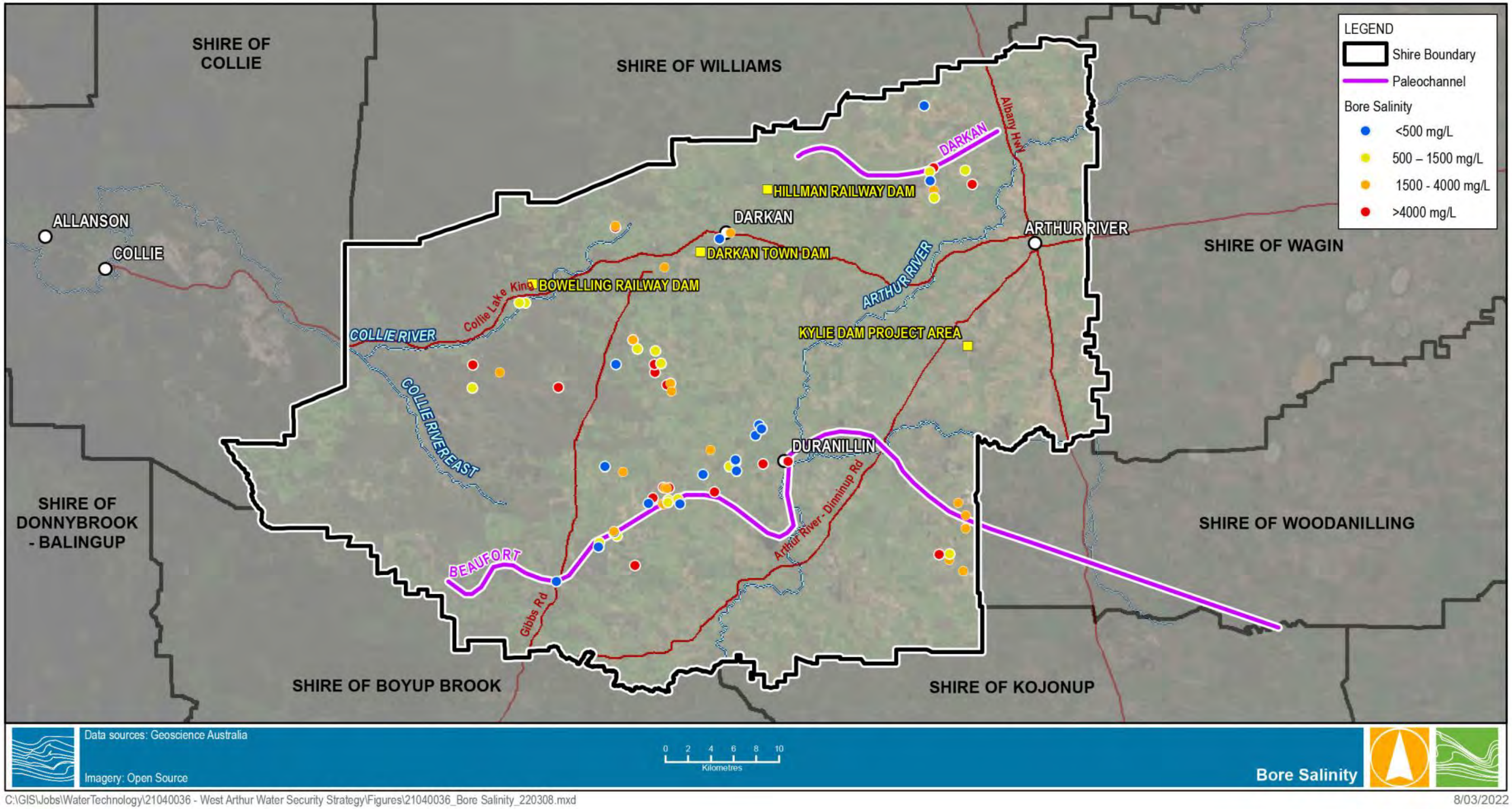


Figure 7-3 Groundwater Bore Salinity

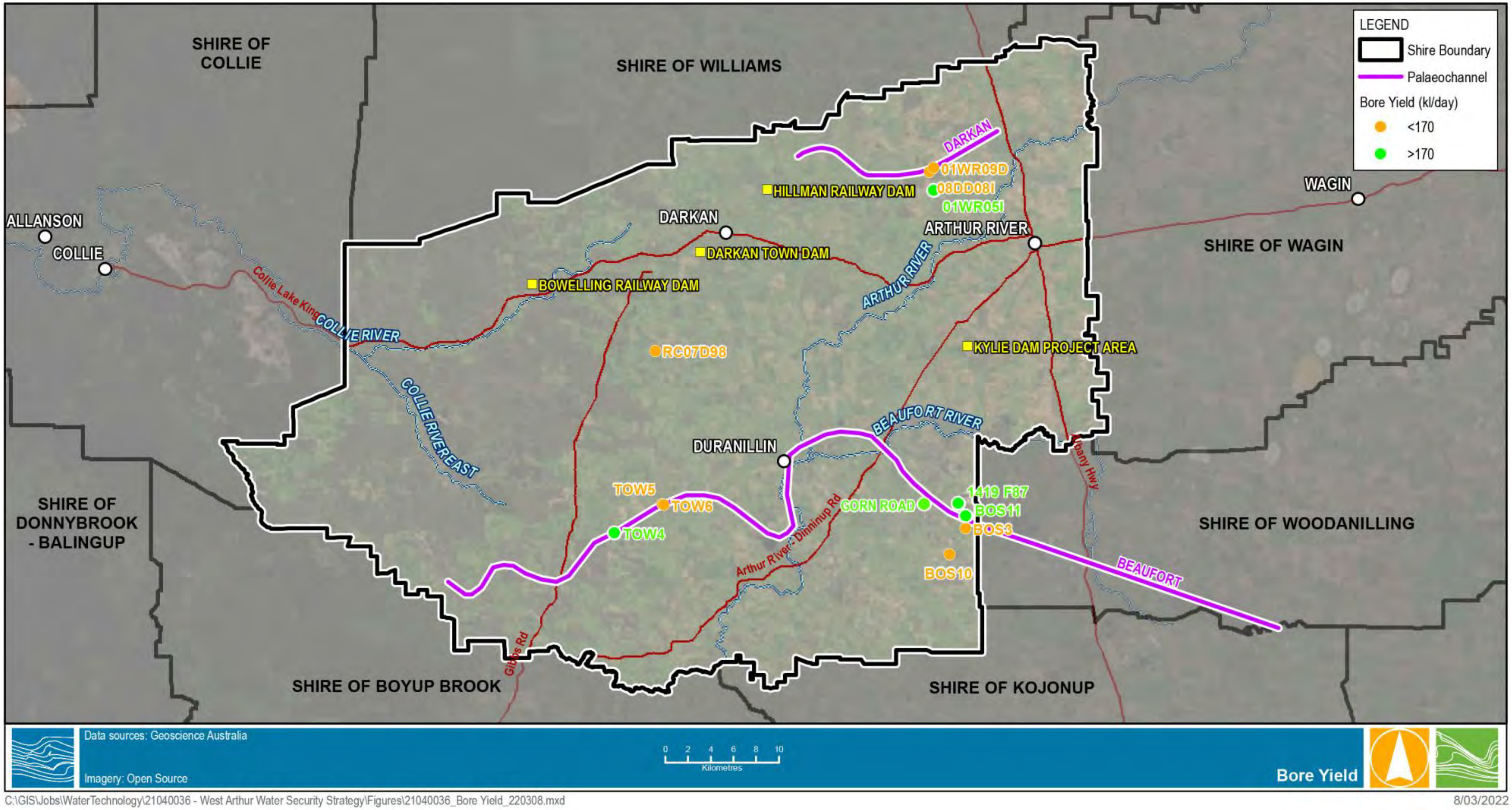


Figure 7-4 Groundwater Bores with a Yield Estimate

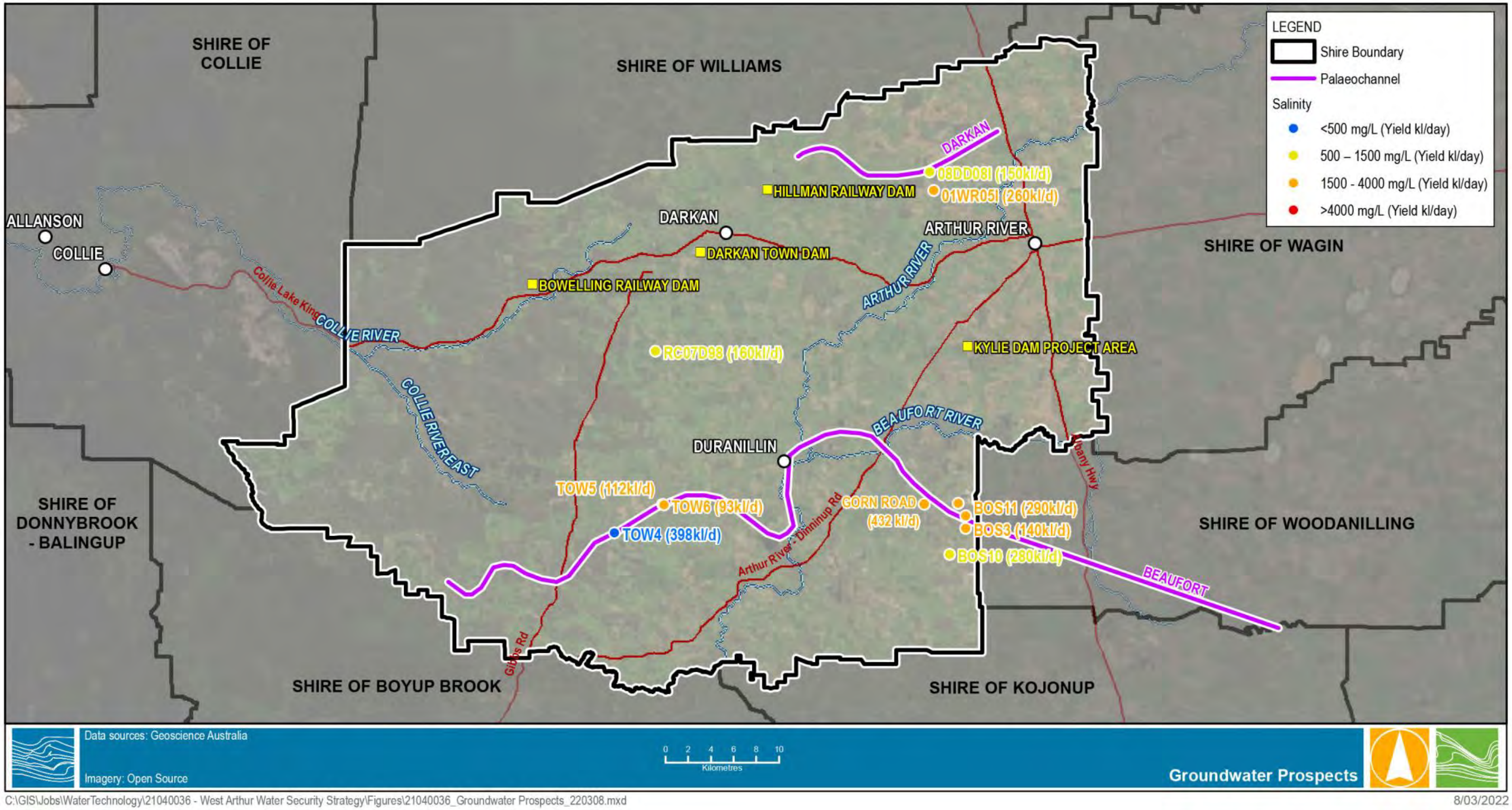


Figure 7-5 Groundwater Supply Prospects

7.4 Challenges and Constraints of Adaptation

7.4.1 Data

The most significant challenge to adaptation is currently a lack of data – flow data, water level data, groundwater test pumping data and water use data (meters). Without at least a basic level of data many assumptions need to be made and it is not possible to accurately assess the water demand, water use efficiency and supply reliability.

7.4.2 Water Use Efficiency

The first action to address a supply deficit is to improve water use efficiency, water conservation and water reuse. By reducing demand it is possible to free up water for other uses, or at least delay expenditure on new water supplies.

The most significant improvements in water efficiency will likely come from the irrigation systems in Darkan drawing from the Town Dam.

7.4.3 Flexible Supply

Surface water and groundwater supplies alone will not secure adequate water into the future. Water supply flexibility in an integrated network is the key to making use of the most cost-effective water while it is available, supplemented with higher cost water when required.

This approach is particularly relevant for the Duranillin Town supply, where four water sources blended together (rainwater tanks, groundwater, dam water and produced water) should be able to provide a reliable supply.

7.4.4 On Farm Water Supply Management

Getting farmers organised on farm to improve the reliability of their supplies will offset the biggest risk to water supply within the Shire – stock water.

The priority is for farmers to check the available water yield of their supplies based on the 2030 climate, and either adjust their stocking rates to match or find more water. This activity should be done as part of the normal business planning process. Appendix C includes Rural Water Note 02 (DWER, 2007) and Assessing Reliability of Farms Dams (DPIRD, 2003) to provide some guidance.

8 RECOMMENDATIONS

8.1 Priority Projects for Stage 2

This report completes the Stage 1 scope of works to assess the estimated water demand and assess the current water supplies. The following priority projects have been identified to allow a first pass feasibility assessment and options short list to be developed as part of the Stage 2 scope of works.

8.1.1 Community Forum

- We recommend a community forum is held to present the results of this investigation and seek input into the water supply projects for development.

8.1.2 Beaufort Palaeochannel AEM

- We recommend the Shire liaise with GSDC to work up a proposal for the AEM mapping of the Beaufort Palaeochannel, ideally for the full length, but if this is not feasible, we suggest mapping from bore TOW 7 (Figure 7-2) east to the Shire boundary (an approximate 25 km x 14 km grid).
- Following the AEM survey, a desktop assessment will be required to interpret the data and identify the most prospective groundwater supply locations for drilling and testing.

8.1.3 Refinement of Darkan Palaeochannel AEM

- While it may not change the results greatly, we recommend that the Shire take the opportunity to get CSIRO to re-run the 2009 AEM dataset using the new 2020 software to further refine the mapping. This will ensure the Shire and landholders are working with the best available mapping when targeting bore locations.
- Following completion of Darkan palaeochannel AEM refinement, we recommend that Water Technology liaise with Dr Richard George and complete a desktop assessment to interpret the data and identify eight prospective groundwater supply locations for drilling and testing, with the appropriate exploration sequence provided.

8.1.4 Emergency Stock Water

- We recommend that the Shire encourage as many farmers as possible to access farm water auditors through the Farm Water Supply Planning Scheme. Additional communication (newsletters, Facebook) and low cost (or free) training workshops around reliable water storage design tools are also encouraged.
- Noting the bore drilled at Hillman Rd in 2016 which is not yet equipped, Water Technology recommends test pumping of the Rees Rd, Gorn Rd and Hillman Rd bores to confirm the long-term pumping rate (or safe yield) and confirm the correct pump size for each bore.
- We recommend each of the bores is fitted with a meter which is read every 3 months as well as measuring the bore salinity every 6 months, with the data stored in one central file within the Shire.
- An additional 1,200 kL/day of supply capacity needs to be developed for emergency stock water to bring the overall supply up to 2,000 kL/day (assuming that the Kylie Dam project will be completed in the next few years and excluding the Growden Place standpipe due to water cost). With no significant dam projects available, all of the water will need to be provided by groundwater. It is expected that somewhere between 3 to 8 bores will be required to reach this supply and we propose the Darkan Palaeochannel as the most likely source of this supply.

8.1.5 Darkan Town Dam

- We recommend that the Shire fit a water meter to the Darkan Town Dam offtake and Nangip Creek pump station and read the meters at least once per month.
- We recommend the installation of a water level staff gauge into the town dam and Nangip creek semi-permanent pool (pump station) which is read once per week.
- We recommend survey of the Town Dam to confirm its capacity.
- Once the above data is available, we recommend a desktop analysis to calibrate the catchment runoff coefficients.
- We recommend a water efficiency review be completed for all the irrigation systems connected to the town dam. The audit will look into the correct sprinkler spacing and operating pressures, damaged sprinklers, wind drift and the irrigation schedules.
- To progress the second dam concept, we recommend a preliminary model of the stormwater pipe system is constructed to test the runoff volume generated using the dry 2030 climate to get an indication on the size and preferred location of the dam.

8.1.6 Duranillin Town Water

- We recommend a survey of residents water use (water consumption breakdown) and analysis on the size of rainwater tank required to meet each residents demand, assuming water carting over summer.
- We recommend an assessment of the Town dam, including current condition, survey of the dam capacity, catchment mapping, runoff analysis using 2030 climate data and options to expand the dam (if any).
- We recommend that the Shire liaise with GSDC to work up a proposal for the AEM mapping of the Beaufort Palaeochannel with a view to installing a new bore close to town.
- We recommend a preliminary CAPEX and OPEX assessment for a WaterGen unit (Watergen | Water from Air) with consideration given to the 30 L/day (individual homes) and 200 to 6000 L/day (centralised) units.

9 FUNDING OPPORTUNITIES

9.1 WA State Government Funding

The WA State government funding opportunities are administered by the Department of Water and Environmental Regulation under the State Rural Water Plan.

9.1.1 Farm Water Supply Planning Program

The program aims to address the significant number of dryland farms that rely partially on water carted from public supplies off-farm, by encouraging landholders to invest in water supply planning into an overall water management strategy for the property (or neighbourhood) water supply initiatives.

Recipients receive a subsidy to engage a technically competent farm water planner to provide a comprehensive plan to improve reliability, improve water management and provide technical solutions to address current and future water supply needs.

The program includes landholders whose properties are connected to a piped water supply.

9.1.2 Community Water Supply Program (CWSP)

The Community Water Supply Program provides grants to encourage rural local governments and farmland community groups to plan and construct improved community water supplies.

The program is to assist farming communities who have limited options for improving their on-farm supplies and whose livelihood depends on the availability of water from off-farm. It focuses on developing off-farm supplies in contrast to on-farm improvements (promoted under the Farm Water Supply Planning Program). Utilisation of on-farm supplies is strongly encouraged and community projects should be seen as a supplement to these water sources that contribute to the overall reliability of supply.

The program helps needy communities provide new water supplies for a wide range of uses, from emergency drinking water for livestock to supplementary water supplies for rural towns. It offers grants to develop additional sources of water to satisfy domestic, crop spray and livestock requirements where benefits are available to the broader community, which greatly assists emergency responses.

Active participation by the community and local government in the projects approved under this program is essential. In addition, it is desirable that management of the new water supplies and maintenance of associated infrastructure be the responsibility of the local community.

For projects resulting in significant direct benefit to individuals, a minimum community contribution of one-third of the construction cost is required.

Those projects that are revenue earning can be funded by Water Corporation.

The program specifically excludes assistance for intensive farming industries including horticulture, aquaculture and viticulture, and intensive animal enterprises such as dairies, piggeries and feedlots. Water requirements for these industries are predictable, more consistent and are more easily planned for in the business development stage.

9.1.3 Agriculture Area (AA) Dams

Over 600 AA dams were constructed during the development of the agricultural region and have contributed to emergency water supply during periods of water deficiency.

While many of these facilities continue to play a key role in maintaining regional water security, there are now a large number that have been superseded by other water resources and are no longer in frequent use by the farming community or government agencies.

A network of strategic AA dams is presently being secured throughout many parts of the dryland agricultural area and these supply points will be maintained to provide sources of emergency water, which can be accessed by farmers in times of serious on-farm water deficiency.

9.2 Commonwealth Government Funding

Access to Commonwealth Government funding should be discussed with the Department of Water and Environmental Regulation, Great southern Development Commission (GSDC) and your local federal member of parliament.

9.2.1 National Water Grids Connection Funding

In Early 2021, the Australian Government announced the National Water Grid Connections funding pathway through the $3.5 billion National Water Grid Fund. Up to $20 million dollars of funding is made available for each state and territory with an Australian Government contribution of up to $5 million per project.

The National Water Grid is a series of region-specific systems that will help build resilience to drought and support regional prosperity. The National Water Grid Connections funding pathway is delivering targeted water infrastructure projects which are brought forward and co-funded by the State Government.

The Community Water Supply Program and the Agriculture Area Dams are two projects which make up WA's National Water Connections Grid package and it is this funding that was secured for the Kylie Dam project.

9.2.2 Future Drought Fund (Drought Resilience Funding Plan)

The Future Drought Fund is a $5 billion fund that will administer $100 million per year of grants from 2020 onwards. The funding is focused on capacity building with a range of technology, innovation, R&D and planning initiatives underway.

One of the initiatives is the Climate Services for Agriculture Program (CSA) which is running a pilot in four agriculture regions across Australia, including the WA Sheep-Wheat Belt. The platform is designed to allow farmers to get a regional perspective on climate risk and will be complemented by the Drought Resilience Self-Assessment Tool (DRSAT). The DRSAT will allow farmers to add farm-scale data producing a farm-scale picture of climate risks, resilience and areas for attention.

A second initiative is the Regional Drought Resilience Planning. In WA this program is being coordinated by DPIRD to prepare plans for the Wheatbelt, Mid West and Great Southern. DPIRD has engaged the Regional Development Commissions to roll out the plans.

Figure 9-1 presents a summary of the funding commitments of the Future Drought Fund to 2024, with $81.5 million still to be allocated.

While there are no direct funding opportunities for the Shire through this program, there are many initiatives which will provide valuable resources to famers and the community to prepare for the changing climate and the impact to water resources, and Water Technology encourage the Shire to engage with the program where opportunities arise.

TABLE 1 Overview of Future Drought Fund programs

Themes	Program	Program overview	Funding to 2023–24 ($'000)	Economic	Environmental	Social
Harnessing innovation	Drought Resilience Research and Adoption Program	Investing in collaborative research, development, extension and adoption and commercialisation activities	121,053	●	●	●
Better risk management	Farm Business Resilience Program	Supporting learning and development for famers in strategic business management, farm risk management, natural resource management and personal and social resilience	75,965	●	●	●
	Regional Drought Resilience Planning	Supporting regions to develop drought resilience plans	40,853	●	●	●
Better climate information	Climate Services for Agriculture	Delivering an interactive digital platform, bringing together a variety of climate information specifically for farmers and the agricultural sector	15,000	●	●	●
	Drought Resilience Self-Assessment Tool (DRSAT)	Delivering an online tool that will enable farmers to assess their exposure to drought and other climate risks	10,000	●	●	●
More resilient communities	Networks to Build Drought Resilience	Building capacity and capability of community organisations to support drought preparedness	7,750			●
	Drought Resilience Leaders	Enabling leaders to support their communities to meet the future challenges arising from drought and changing climate	11,450	●	●	●
Better land management	NRM Drought Resilience Drought Resilient Agricultural Landscapes	Trialling and adopting transformational on-ground practices, approaches and systems to mitigate the future effects on a region's agriculture and broader landscapes	36,429	●	●	
Total			**318,500**			

Figure 9-1 Future Drought Funds Expenditure Commitments to 2024

21040036_R01v02.docx

10 REFERENCES

Anand, R. R. and Gilkes, R. J. (1984) Weathering of hornblende, plagioclase and chlorite in meta-dolerite, Australia: Geoderma, v. 34: p. 261-280.

Anand, R. R. and Gilkes, R. J. (1987) Muscovite in Darling Range bauxitic laterite: Australian Journal of Soil Research, v. 25: p. 445-450

Anand, R. R., Gilkes, R. J., Armitage, T. M., and Hillyer J. W. (1985) Feldspar weathering in lateritic saprolite: Clays and Clay Minerals, v. 33, no. 1, p. 31-43.

Bettenay, E., Russell, W. G. R., Hudson, D.R., Gilkes, R. J., and Edminston, R. J., 1980, A description of experimental catchments in the Collie area, Western Australia: Commonwealth Scientific and Industrial Research Organisation, Australian Division Land Resources Management, Technical Paper no. 7, 36p.

Brockman, H. (2006), Hillman and Narrogin zones (Blackwood zones 8 and 9): rapid catchment appraisal. Department of Primary Industries and Regional Development, Western Australia, Perth. Report 309.

Bureau of Meteorology Climate Online Portal. Accessed 15 November 2021.

Clarke, C. J., George, R. J., Bennett, D. L. and Bell, R. W. (2000) Geologically related variations in saturated hydraulic conductivity in the regolith of the western wheatbelt of Western Australia and its implications for the development of dryland salinity: Australian Journal of Soil Research, v. 38: p. 555-567.

Cody, S. J. (1994) Explanatory notes for the hydrogeological map and groundwater database of the Dumbleyung Land Conservation District, Western Australia Geological Survey, Record 1994/7, 43p.

Commander, D. P., Smith, R. A., Baddock, L. J., Prangley, C. J. and Perry, A. (1996), Transient electromagnetic surveys for groundwater exploration in Tertiary sediments: Western Australia Geological Survey, Annual Review 1995-96, p. 111-117.

CSIRO & Bureau of Meteorology 2007, Climate change in Australia technical report 2007, Commonwealth Scientific and Industrial Research Organisation, Canberra.

CSIRO 2009a, Surface water yields in south-west Western Australia: a report to the Australian Government from the CSIRO South-West Western Australia Sustainable Yields Project, Commonwealth Scientific and Industrial Research Organisation, Canberra.

CSIRO 2009b, Groundwater yields in south-west Western Australia: a report to the Australian Government from the CSIRO South-West Western Australia Sustainable Yields Project, Commonwealth Scientific and Industrial Research Organisation, Canberra.

Department of Primary Industries and Regional Development Interactive Groundwater and Salinity Map for the South-West Agricultural Region Online Portal. Accessed 13 October 2021.

Government of Western Australia, Department of Premier and Cabinet (2007) State Water Plan 2007

Department of Water (2010) Rural Water Plan.

Department of Water (2007) Rural Water Note 02 – Understanding Water Supply Reliability

Department of Water (2007) Rural Water Note 05 – Simple Pumping Tests for Farm Bores

Department of Water (2015) Selection of Future Climate Projections for Western Australia. Water Science Technical Series Report WST 72.

Department of Water and Environmental Regulation (2018) Wellington Reservoir Modelling: Re-evaluating Yield and Salinity Levels Under a Drying Climate. Surface Water Hydrology Series HY37.

Department of Water and Environmental Regulation Water Information Reporting Online Portal. Accessed 28 November 2021.

Dobereiner, L., and Porto, C. G. (1993) Considerations on the weathering of gneissic rocks, in The engineering Geology of weak rocks, edited by CRIPPS and others., p.193-205.

Engel, R., McFarlane, D. J. and Street, G. (1987) The influence of dolerite dykes on saline seeps in south-western Australia: Australian Journal of Soil Research, v 25, p. 125-136.

Farmer, D, and Coles, N. (2003), Assessing storage reliability of farm dams. Department of Primary Industries and Regional Development, Western Australia, Perth. Report 245.

Frederiksen, C, Frederiksen, J & Zidikheri, M (2012) Large-scale climatic changes and their attribution, in B Bates, C Frederiksen, & J Wormworth (eds) Western Australia's Weather and Climate, A Synthesis of Indian Ocean Climate Initiative Stage 3 Research, CSIRO and BoM, Australia.

George, R. J. (1992) Hydraulic properties of groundwater systems in the saprolite and sediments of the wheatbelt, Western Australia: Journal of Hydrology, v. 130, p. 251-278.

George, R. J., Cochrane, D. L., and Bennett ,D. L. (1994), Groundwater systems responsible for dryland salinity in the Lake Towerrinning catchment, Western Australia, in Water Down Under Groundwater Papers: Combined 25th Congress of the International Association of Hydrogeologists with the 22nd International Hydrology and Water Resources Symposium of The Institution of Engineers, Adelaide November 1994, p. 355-360.

Hawkes, G. E. (1993) A review of available groundwater data in the Boscabel and Kybellup plain areas: Western Australia Geological Survey, Hydrogeology Report 1993/24 (unpublished).

Hope, P & Ganter, C 2010, ‘Recent and projected rainfall trends in south-west Australia and the associated shifts in weather systems’, in I Jubb, P Holper & W Cai (eds), Managing climate change, Papers from the Greenhouse 2009 Conference, CSIRO Publishing.

Indian Ocean Climate Initiative 2012, Western Australia's weather and climate: a synthesis of Indian Ocean Climate Initiative Stage 3 Research, CSIRO and BoM, Australia.

Intergovernmental Panel on Climate Change 2007a, Climate change 2007: Synthesis report, contribution of Working Groups I, II and III to the Fourth Assessment Report of the

Intergovernmental Panel on Climate Change, in R Pachauri & A Reisinger (eds), IPCC, Geneva, Switzerland, ISBN 92-9169-122-4.

Intergovernmental Panel on Climate Change 2007b, Climate change 2007: physical science basis, S Solomon, D Qin, M Manning, Z Chen, M Marquis, K Averyt, M Tignor & H Miller (eds), contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, ISBN 978-0-521-88010-7.

Johnston C. D., Hurle, D. H., Hudson, D. R. and Height, M. I. (1983), Water movement through preferred paths in lateritic profiles of the Darling Plateau, Western Australia: Commonwealth Scientific and Industrial Research Organisation, Division of Groundwater Research, Technical Paper no. 1, 34p.

McCrea, A. F., Anand, R. R. and Gilkes, R. J. (1990) Mineralogical and physical properties of lateritic pallid zone materials developed from granite and dolerite: Geoderma, v. 47: p. 33-57.

Nahon, D. and Tardy, Y. (1992) The ferruginous laterites, in Regolith exploration geochemistry in tropical and subtropical terrains edited by C.R.M., BUTT and H. ZEEGERS: Handbook of Exploration Geochemistry, 4, Elsevier, Amsterdam, pp. 42 and 537

Prangley, C. J. (1994a) Bore completion report, Lake Towerrinning Catchment Group Palaeochannel Project: Western Australia Geological Survey, Hydrogeology Report 1994/13 (unpublished).

Prangley, C. J. (1994b) Boscabel Palaeochannel bore completion report: Western Australia Geological Survey, Hydrogeology Report 1994/11 (unpublished).

Prangley, C. J. (1994c) Manjimup fractured rock drilling project bore completion report: Western Australia Geological Survey, Hydrogeology Report 1994/21 (unpublished).

Prangley, C. J. (1995a) Beaufort Palaeochannel bore completion report TOW 13-40: Western Australia Geological Survey, Hydrogeology Report 1995/43 (unpublished).

Prangley, C. J. (1995b) Darkan Palaeochannel bore completion report TOW 41-44: Western Australia Geological Survey, Hydrogeology Report 1995/51 (unpublished).

Rockwater Pty Ltd, (1990) Proposed tannery site at Dardadine, results of groundwater investigations: Report to Kinhill Engineers Pty Ltd., (unpublished).

Rockwater Pty Ltd, (1992) Results of pumping test on G. White's Bore, Dardadine (unpublished).

Water and Rivers Commission (2000) Hydrogeology of the Blackwood River Catchment, Western Australia. Hydrogeological Record Series Report HG6.

Waterhouse, J. D., Commander D. P., Prangley, C. and Backhouse J. (1995) Newly recognized Eocene sediments in the Beaufort River Palaeochannel: Western Australia Geological Survey, Annual Review 1993-94, p. 82-86.

APPENDIX A
DARKAN PALAEOCHANNEL AEM RESULTS – CSIRO PRESENTATION

The Dardadine (Arthur River) Palaeochannel Project: Airborne geophysics in support of rural communities in Western Australia

Tim Munday, Jasmine Rutherford, Richard George and Andrew Fitzpatrick

WATER FOR A HEALTHY COUNTRY
www.csiro.au

SOUTH WEST CATCHMENTS COUNCIL

GOVERNMENT OF WESTERN AUSTRALIA

Department of Agriculture and Food

Australian Government

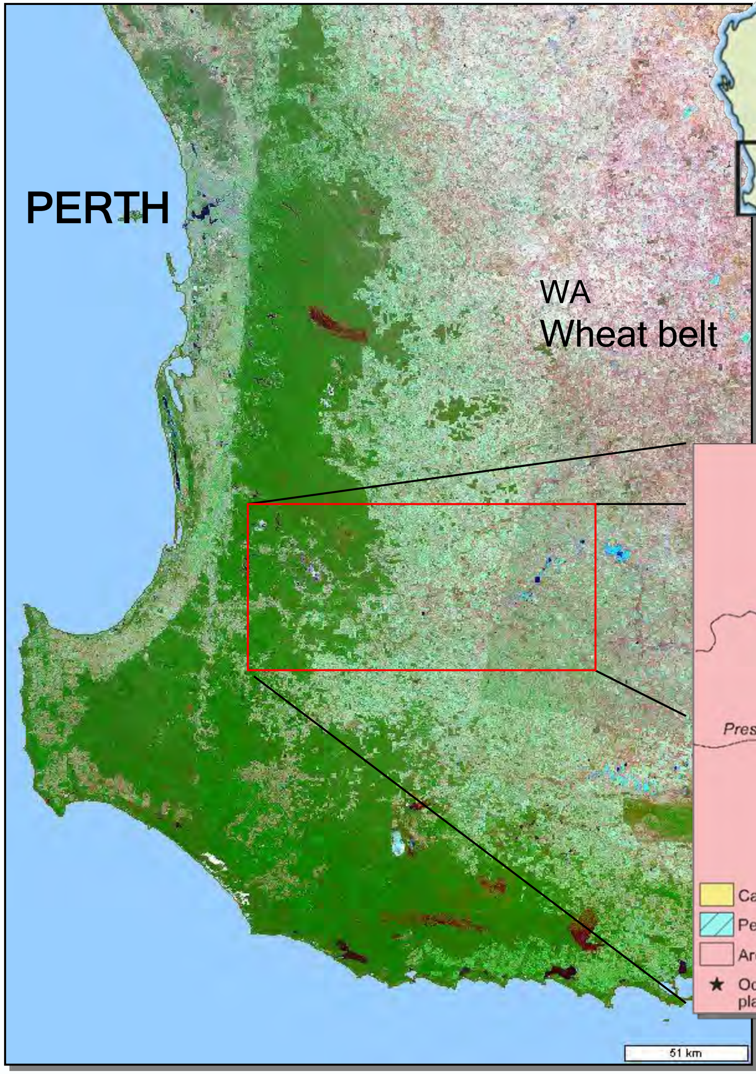
CSIRO

What's the story about?

More specifically:

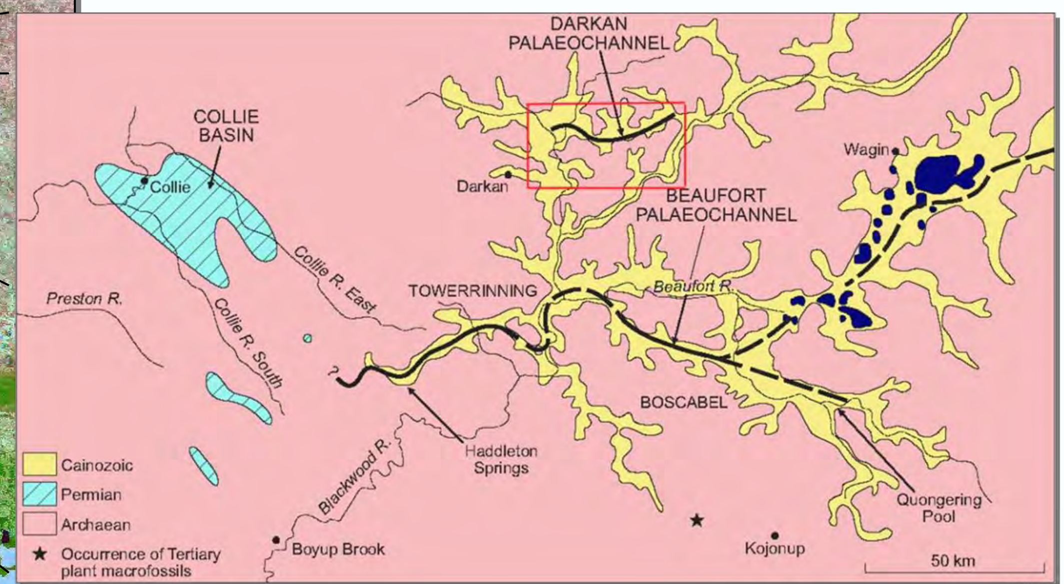
- Case study on the application of AEM data in fine-scale groundwater resource assessment to support local farming community – wheatbelt farm-scale study
- Define the location and quality of available resource linked to Darkan palaeovalley sedimentary sequence
- Drought proof local farmers and offer possible options for local irrigation (pivots etc)

Location



PERTH
WA
Wheat belt
51 km

Northern Territory
Queensland
Western Australia
South Australia
New South Wales
Victoria
Australian Capital Territory
Tasmania



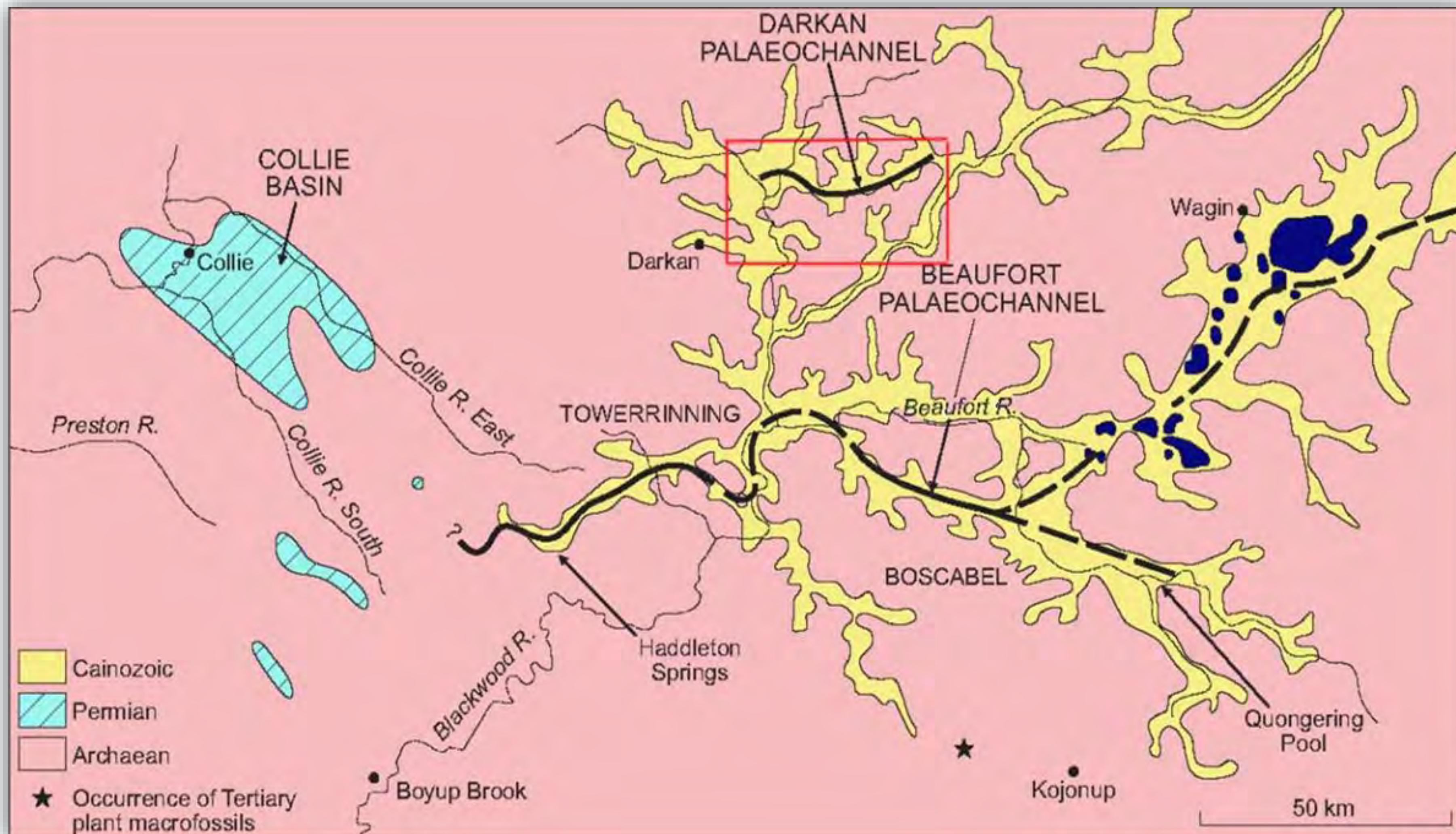
DARKAN PALAEOCHANNEL
COLLIE BASIN
Collie
Darkan
Wagin
BEAUFORT PALAEOCHANNEL
Collie R. East
TOWERRINNING
Beaufort R.
Preston R.
Collie R. South
BOSCABEL
Haddleton Springs
Blackwood R.
Quongering Pool
Cainozoic
Permian
Archaean
★ Occurrence of Tertiary plant macrofossils
Boyup Brook
Kojonup
50 km

Palaeovalleys of Western Australia

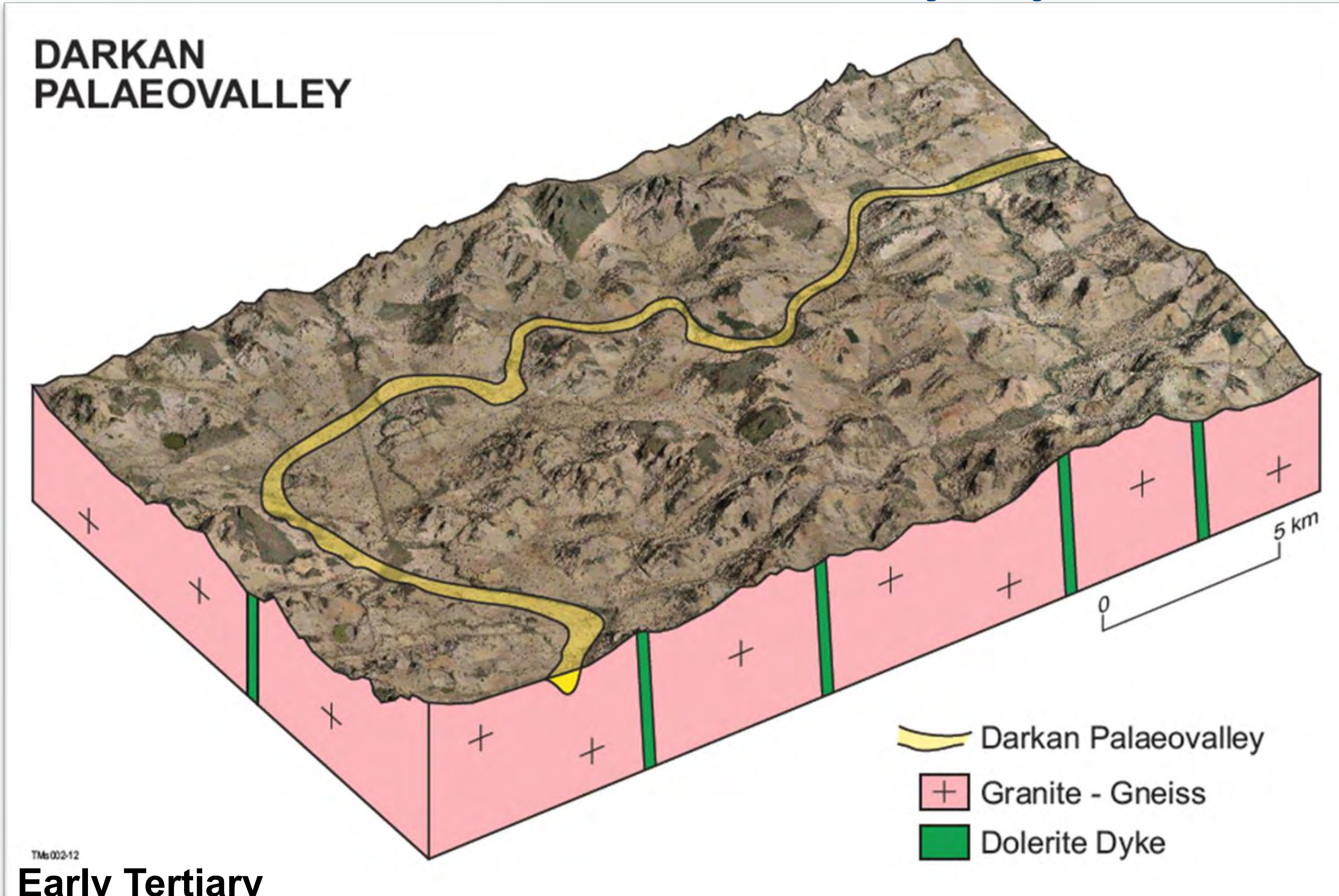
Groundwater in the western Yilgarn is contained in three aquifer systems:

1. *Weathered and fractured Archaean bedrock;*
2. *Basal palaeochannel sands*
3. *Overlying Late Neogene alluvial/colluvial and aeolian sediments which commonly cap the palaeovalleys.*

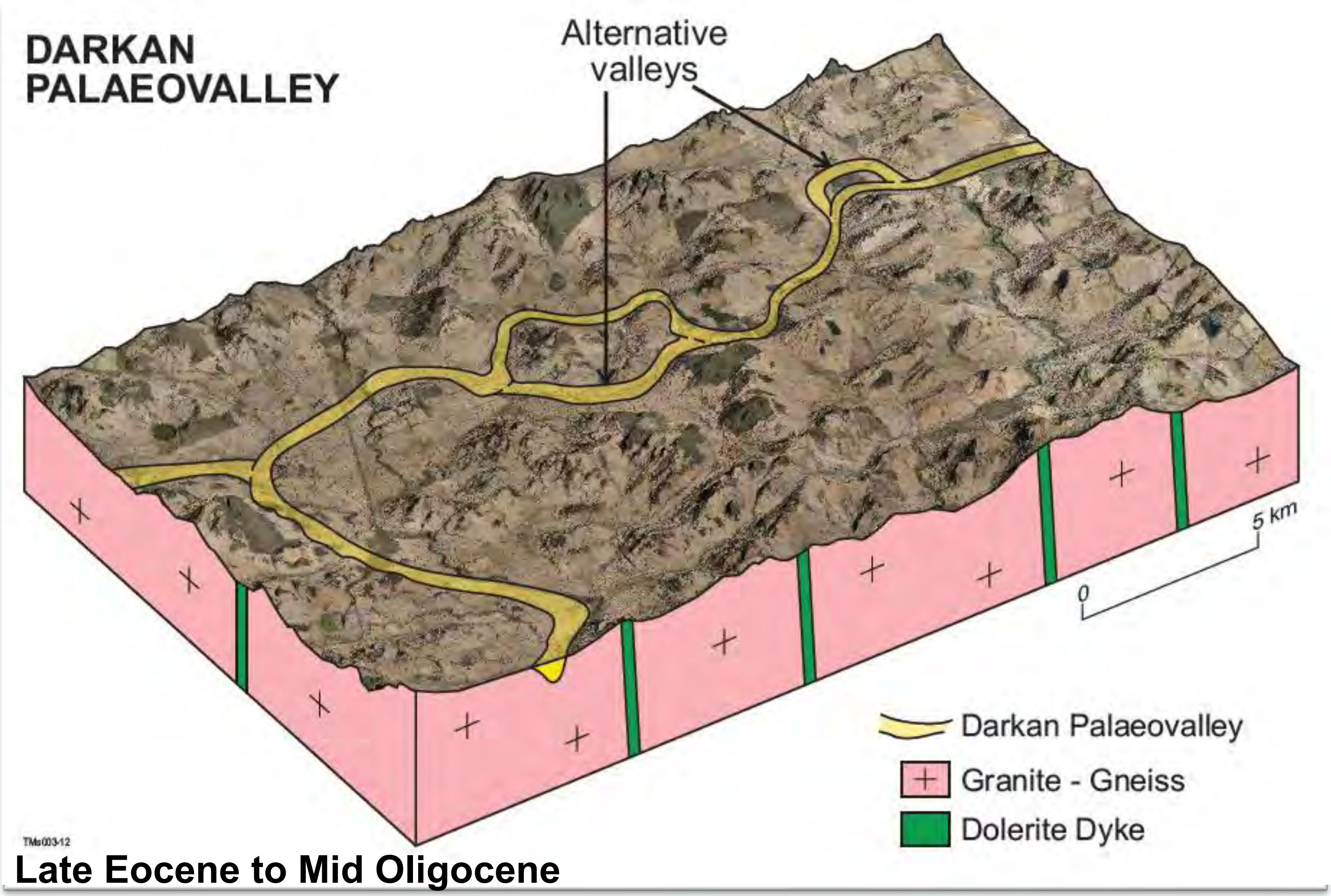
Darkan Palaeochannel



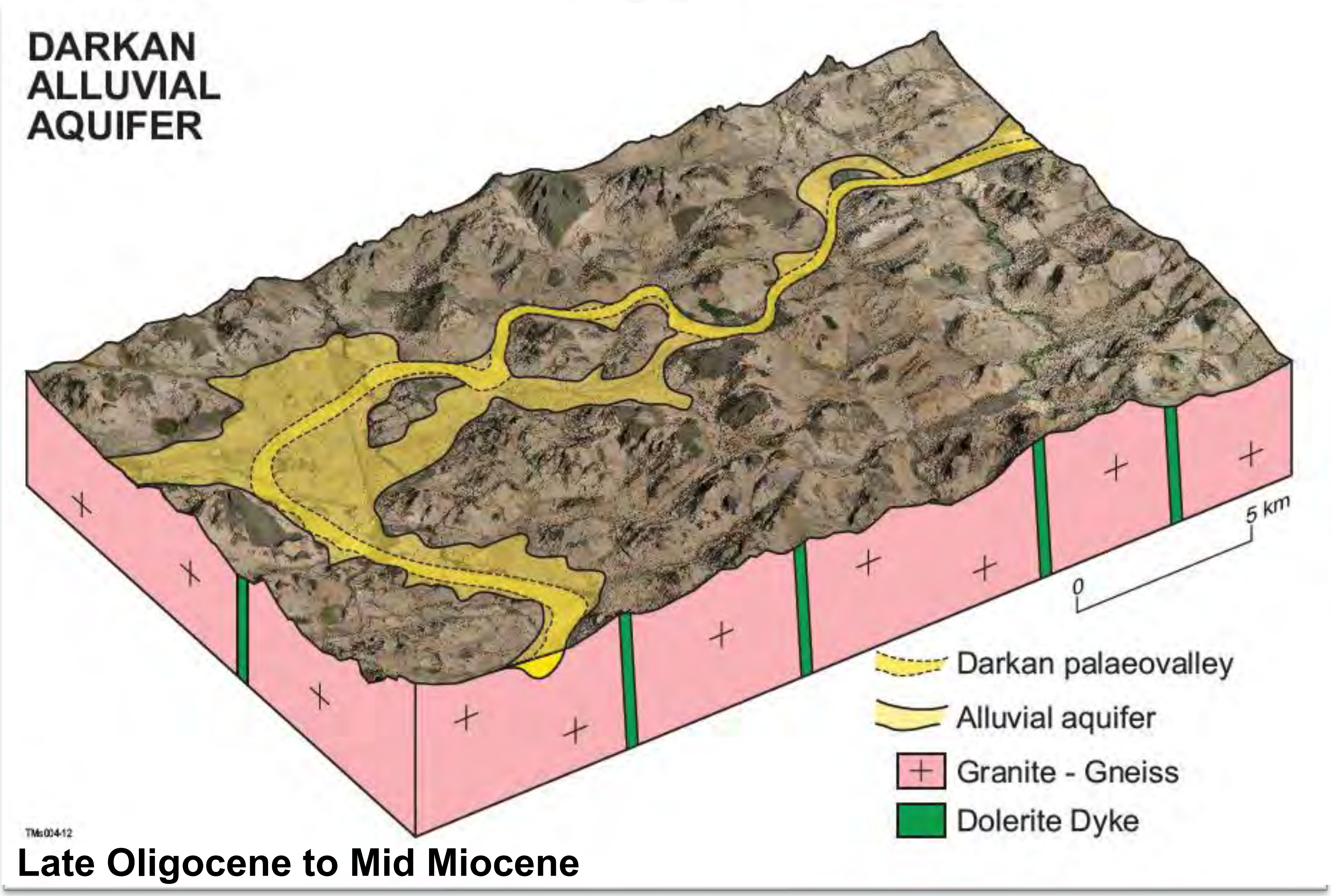
Evolution of Darkan Palaeovalley Aquifer



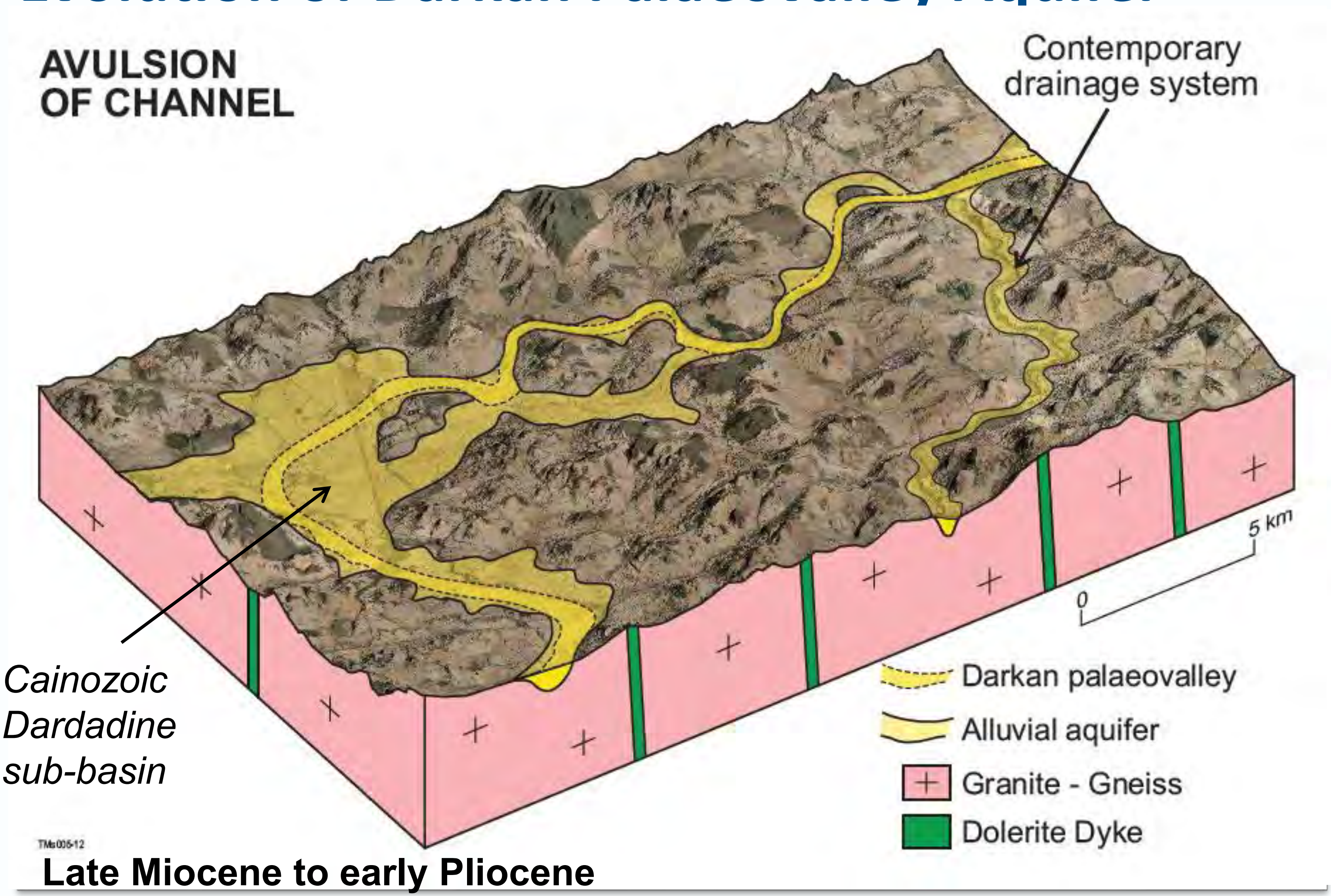
Evolution of Darkan Palaeovalley Aquifer



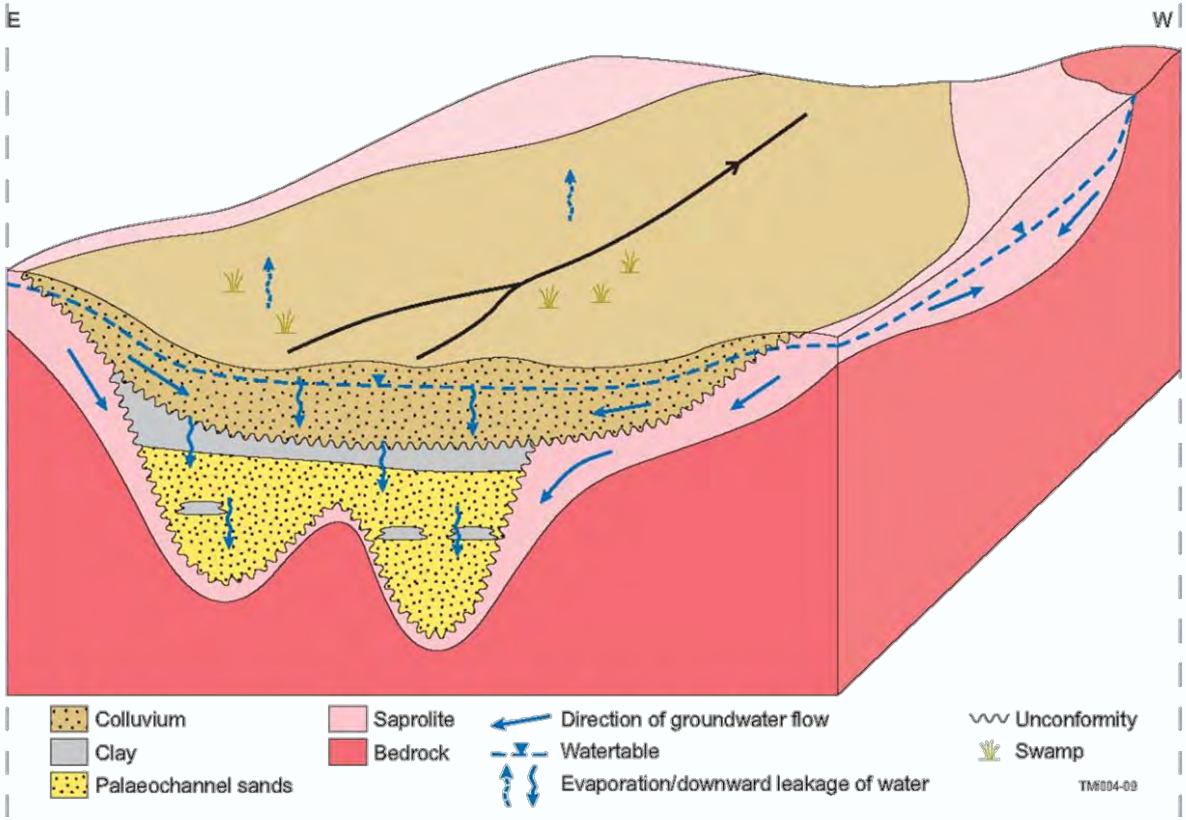
Evolution of Darkan Palaeovalley Aquifer



Evolution of Darkan Palaeovalley Aquifer



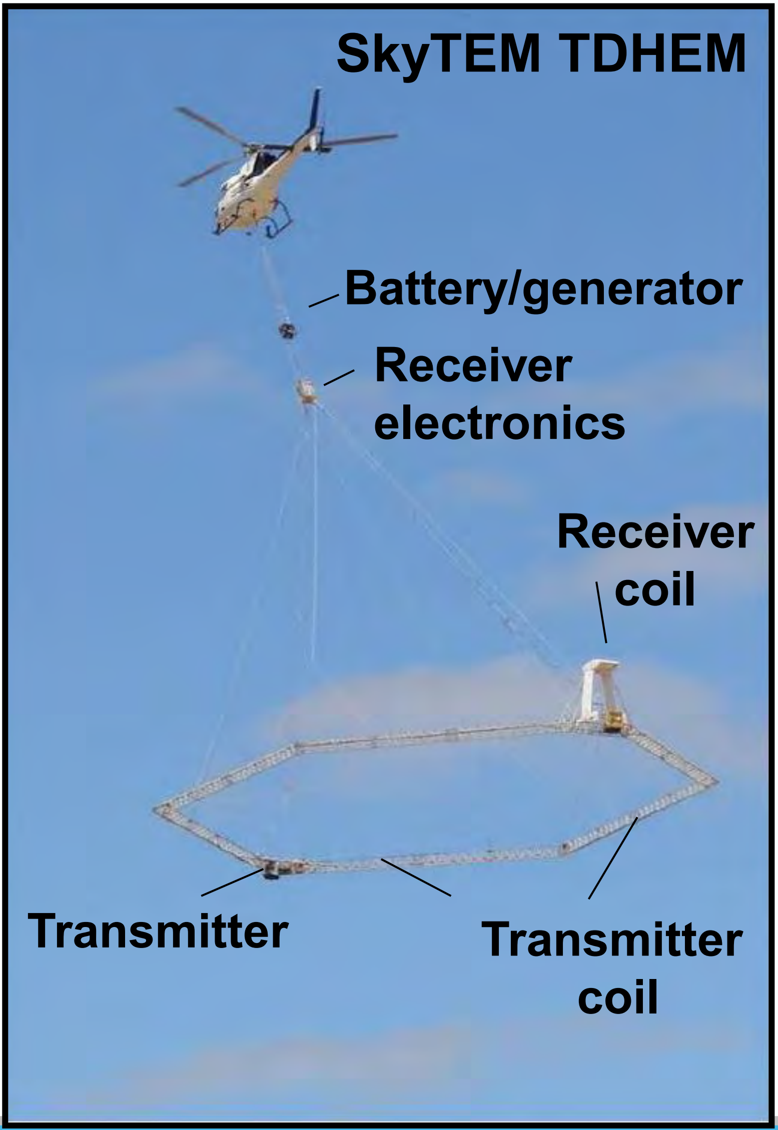
Palaeochannel Target



- Palaeovalley sediments : +/-500 metre-wide channel
- Main sand aquifer is~ 30–45m thick; yields ~ 230–302 m^3/day
- Groundwater salinity is variable - 450 mg/L in the centre, up to 26,000 mg/L on margins (but spatial variation poorly understood!)

CSIRO

AEM System & Survey Characteristics



Transmitter loop: 16x16m^2, four turns, area 313m^2

Peak current: Low Moment - 40 Amps
High Moment - 95 Amps

Time range: LM: 11.8 - 1140µs (20)
HM: 47 - 8800 µs (24)

Flight configuration: Dual mode

Acquisition speed: ~ 75km/hr

Nominal altitude of loop: ~60m agl

*Nominal footprint: ~80-100+m**

Terrain clearance: ~30m

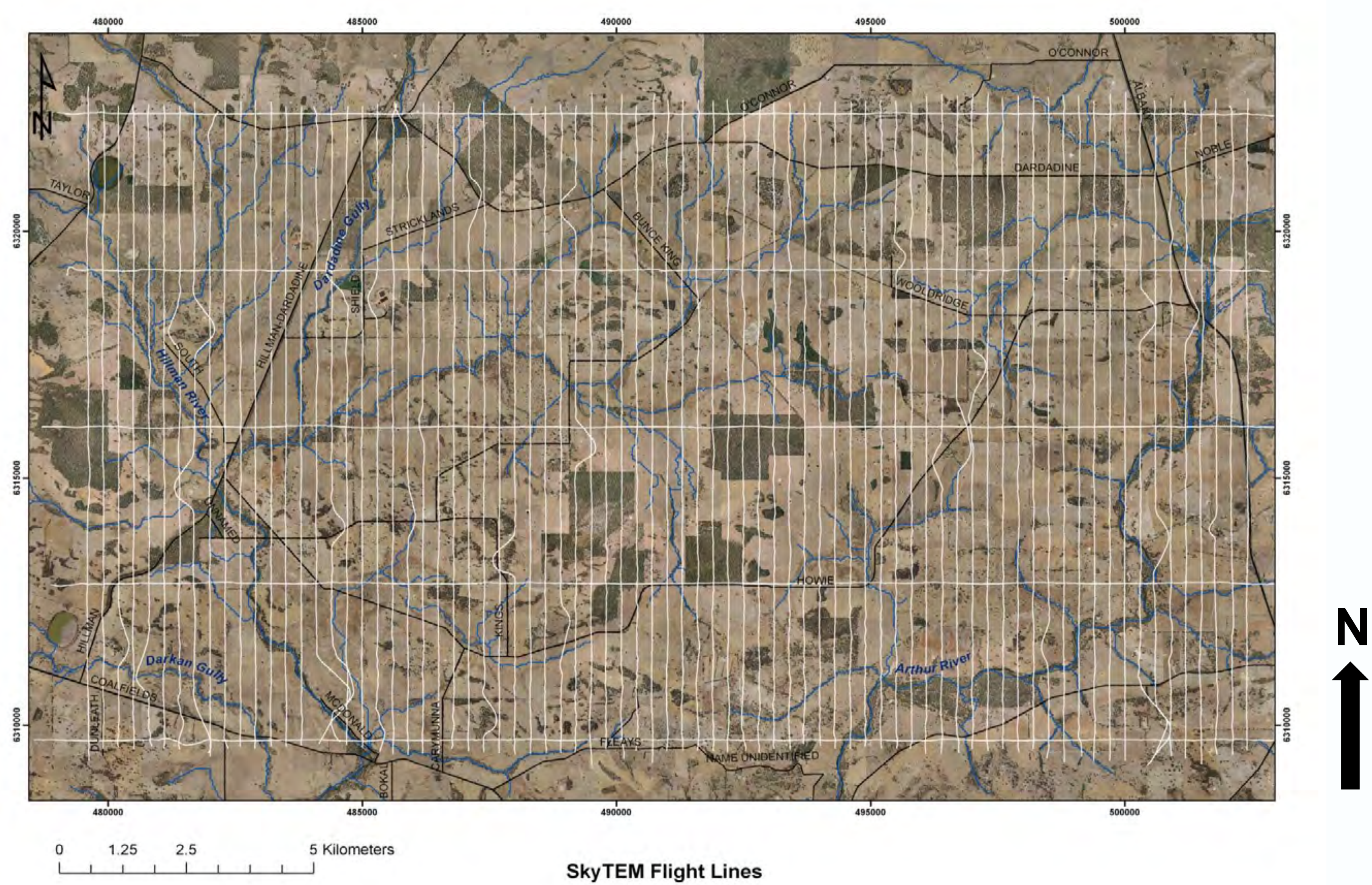
Line orientation: 000-180

Line spacing: 300m

Acquisition Date: 11-21st June 2008

Total Line kms: 1127

Flight Line Map

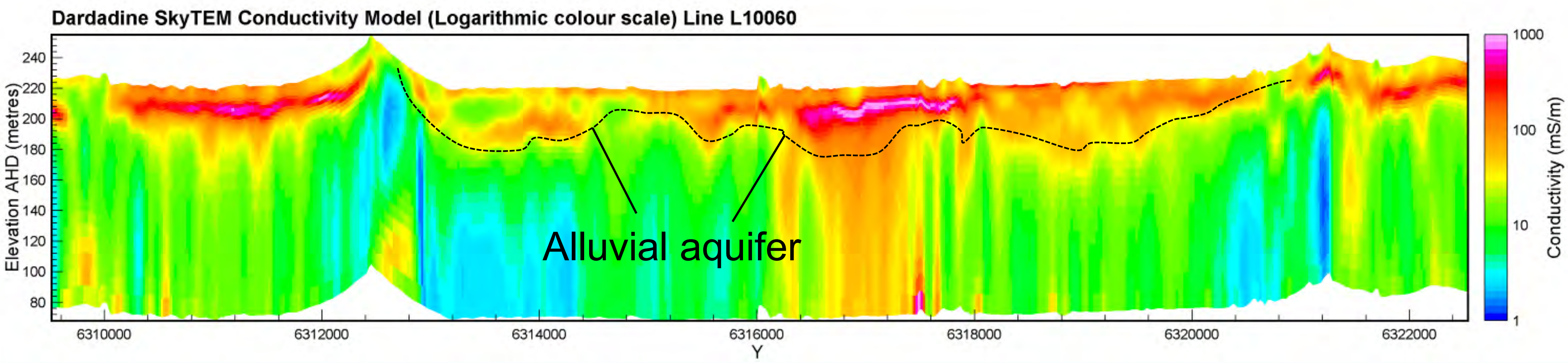


Why SkyTEM?

1. Calibrated – no need to think about levelling, or post - acquisition calibration
2. Near surface sensitivity for groundwater quality variations in alluvial aquifer
3. Enough power to see to basement in highly saline thick alluvial sequences

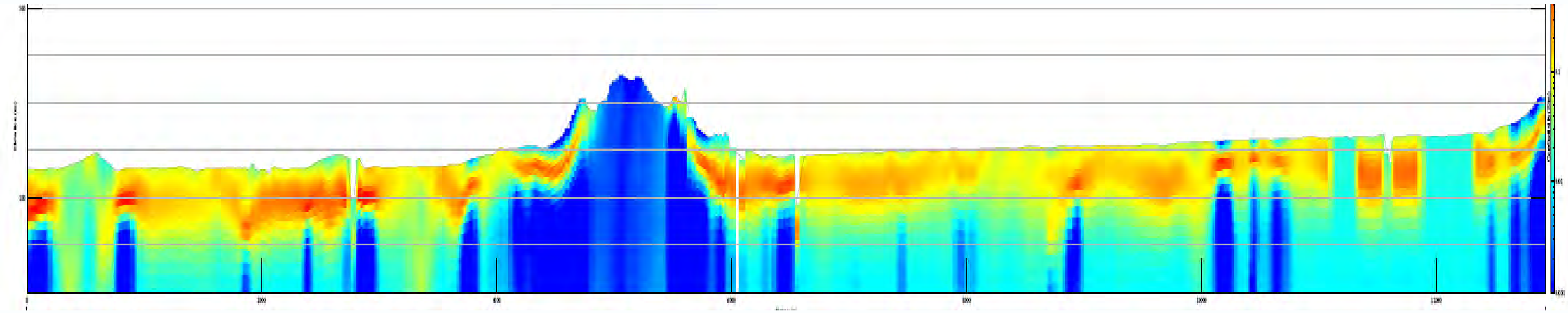
Interpretation

- We employed a fast approximate inversion (iTEM) (*Christensen et al 2009*)
- The inversion was integrated with the lateral parameter correlation method – smooth model sections and maps
- Method has been demonstrated to be very accurate with comparisons of model sections from the fast and the conventional inversion shows very little difference

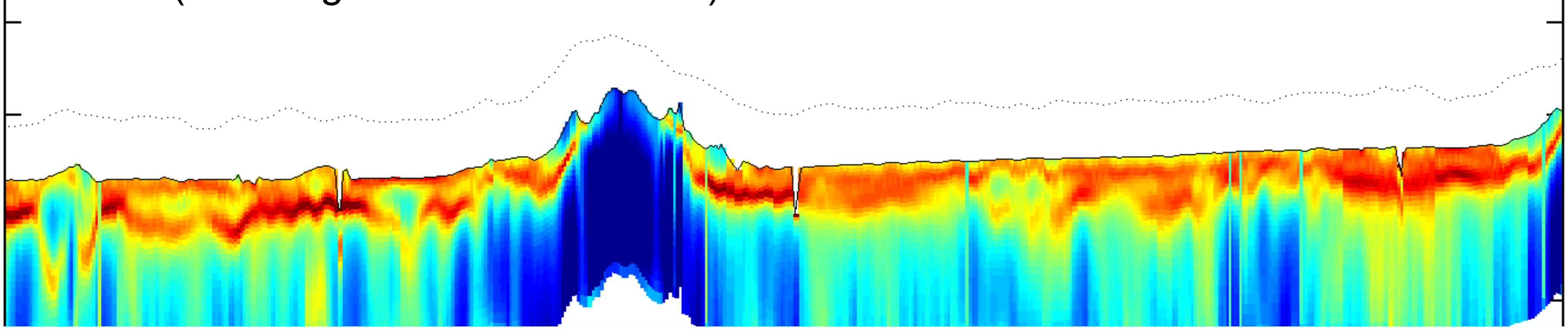


Interpretation

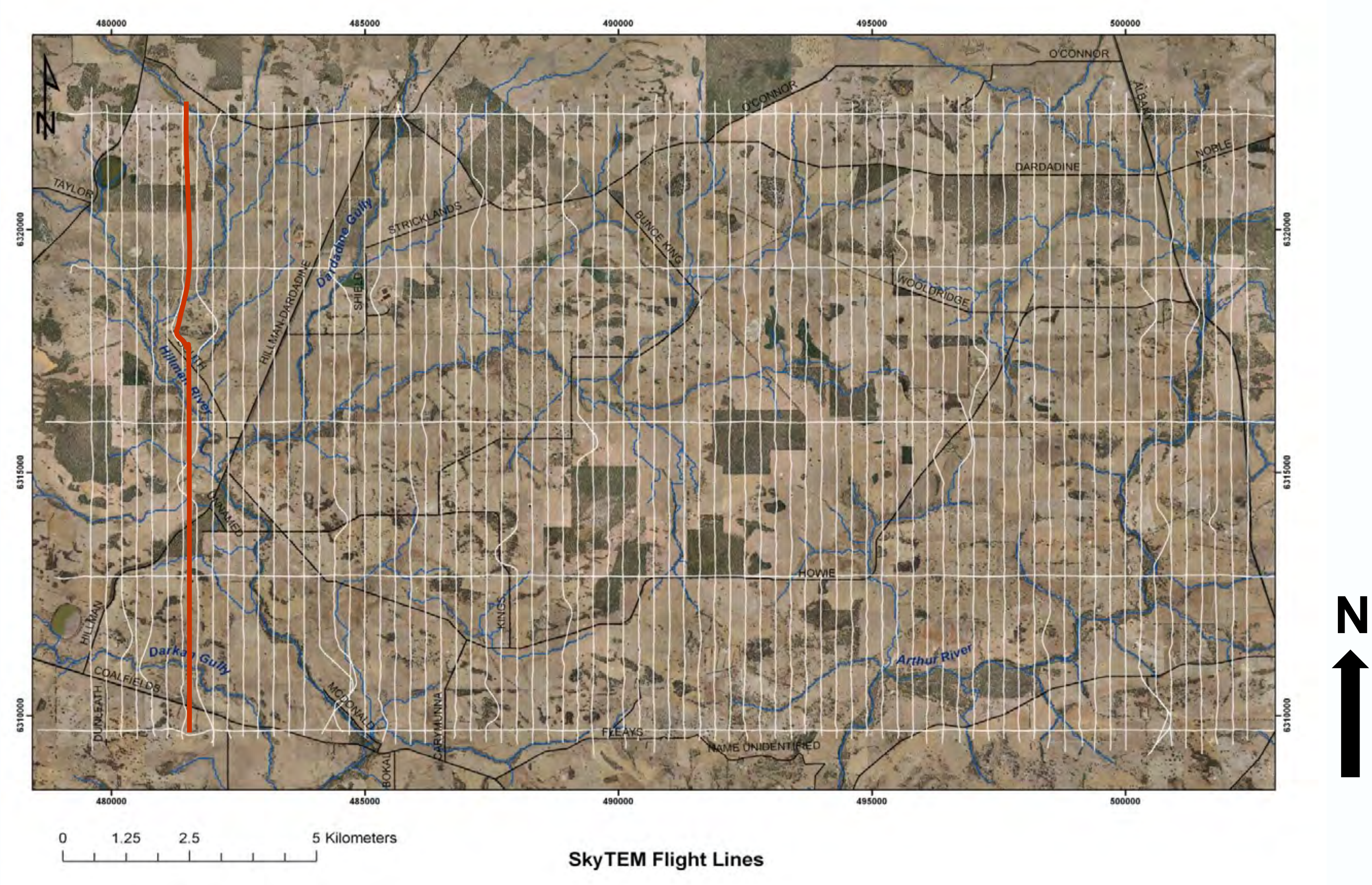
GA SBS LEI of High moment only



iTEM (Both High and Low moment)



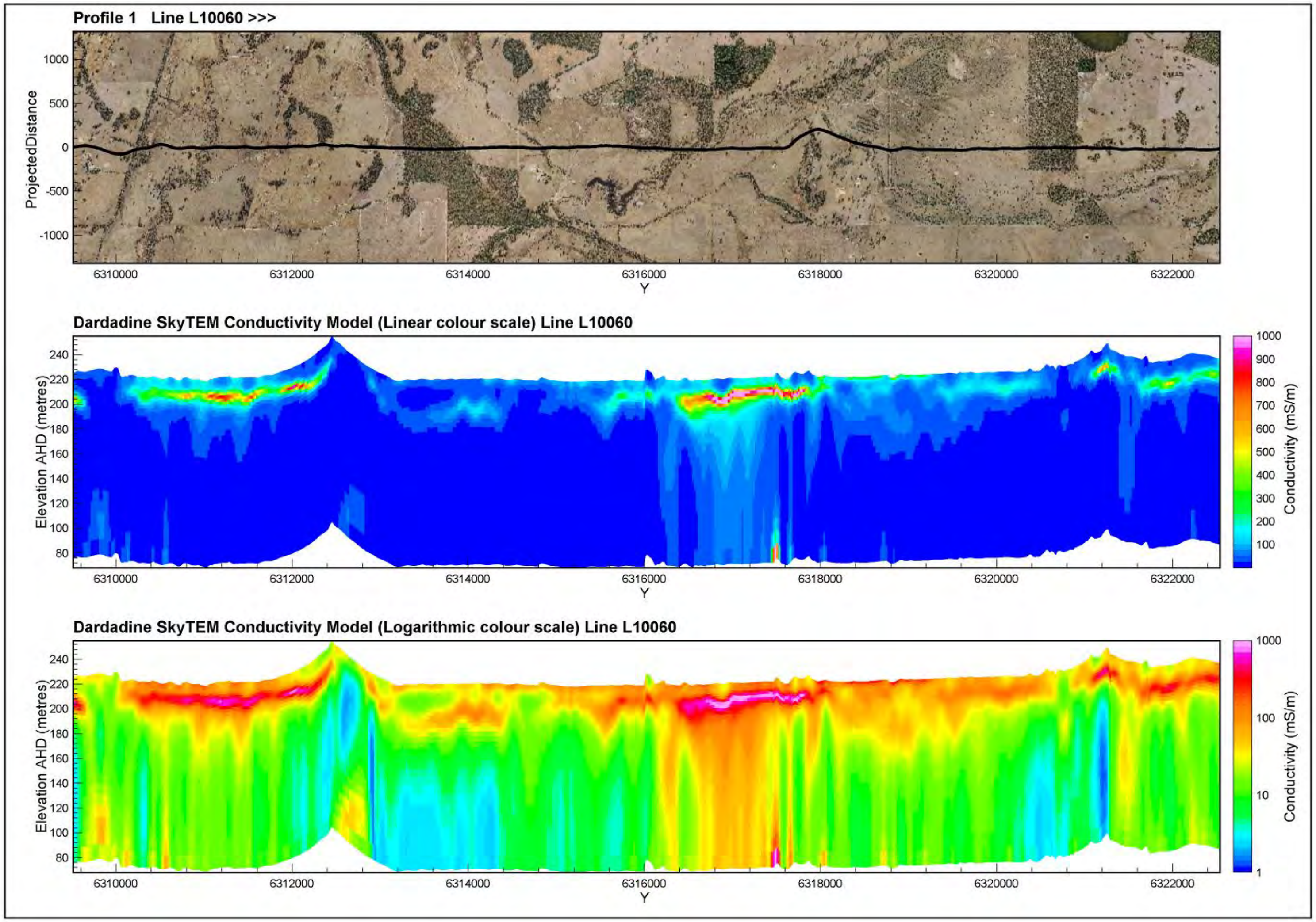
Flight Line Map – type section



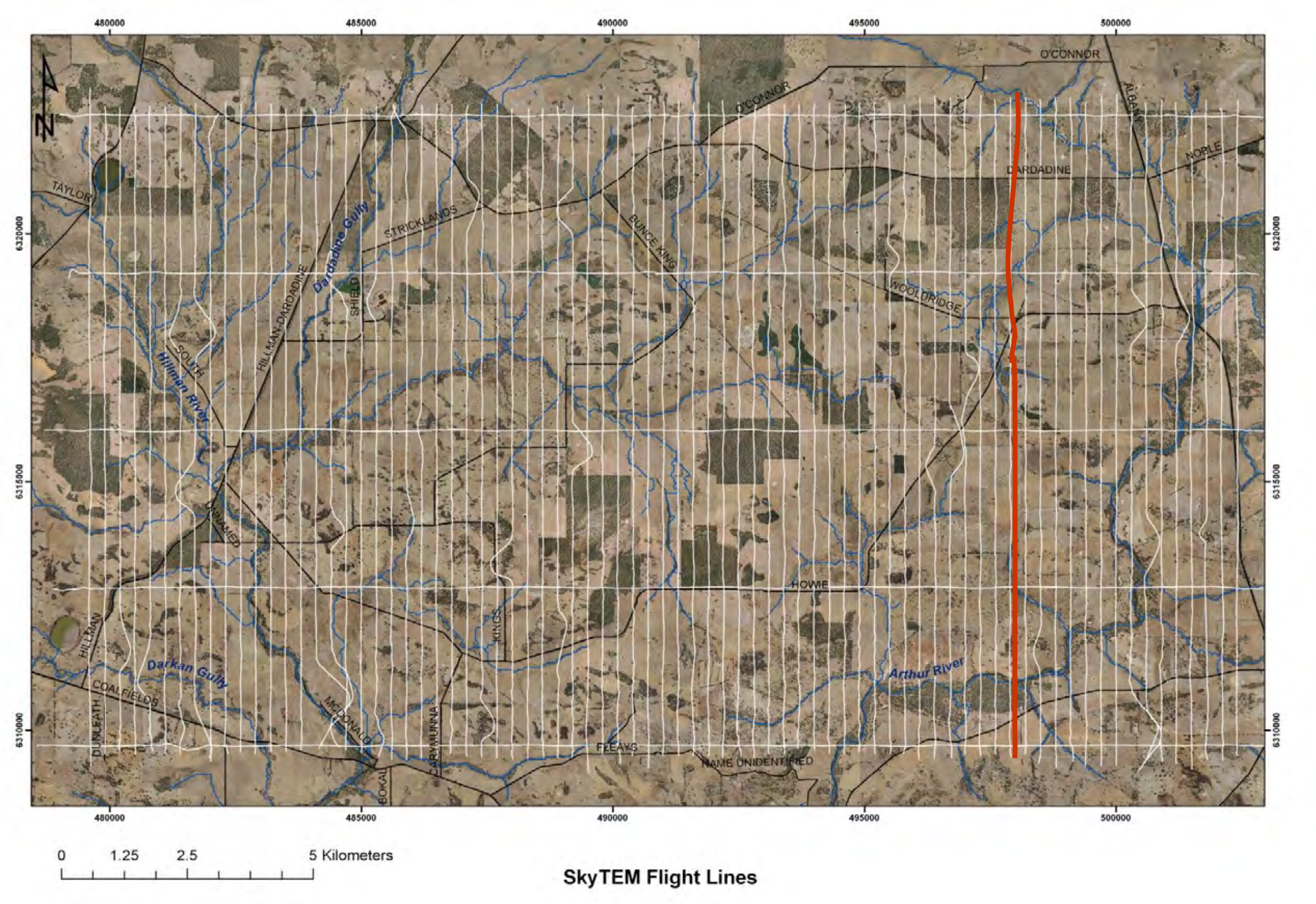
Conductivity-depth sections for each flightline

South

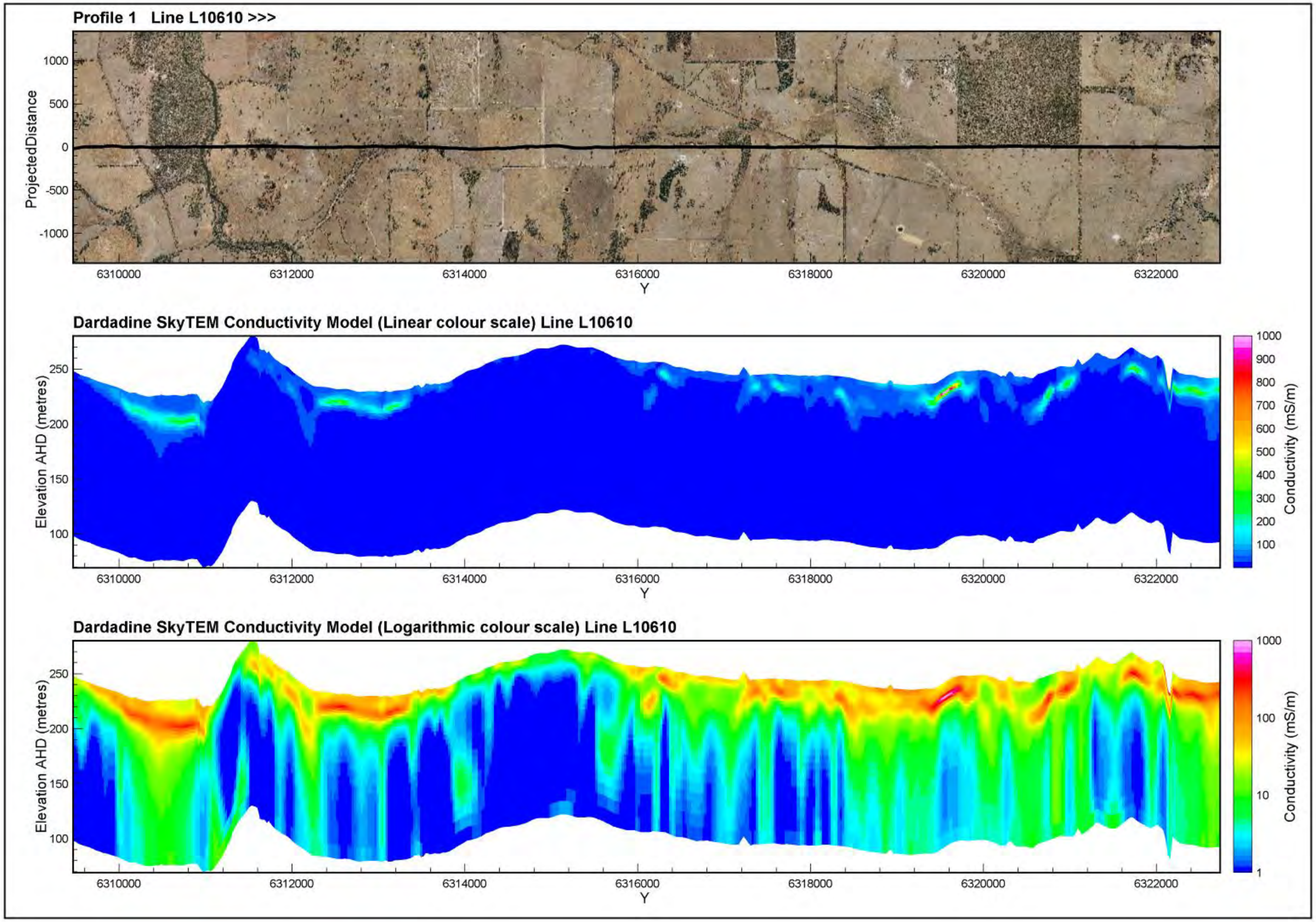
North



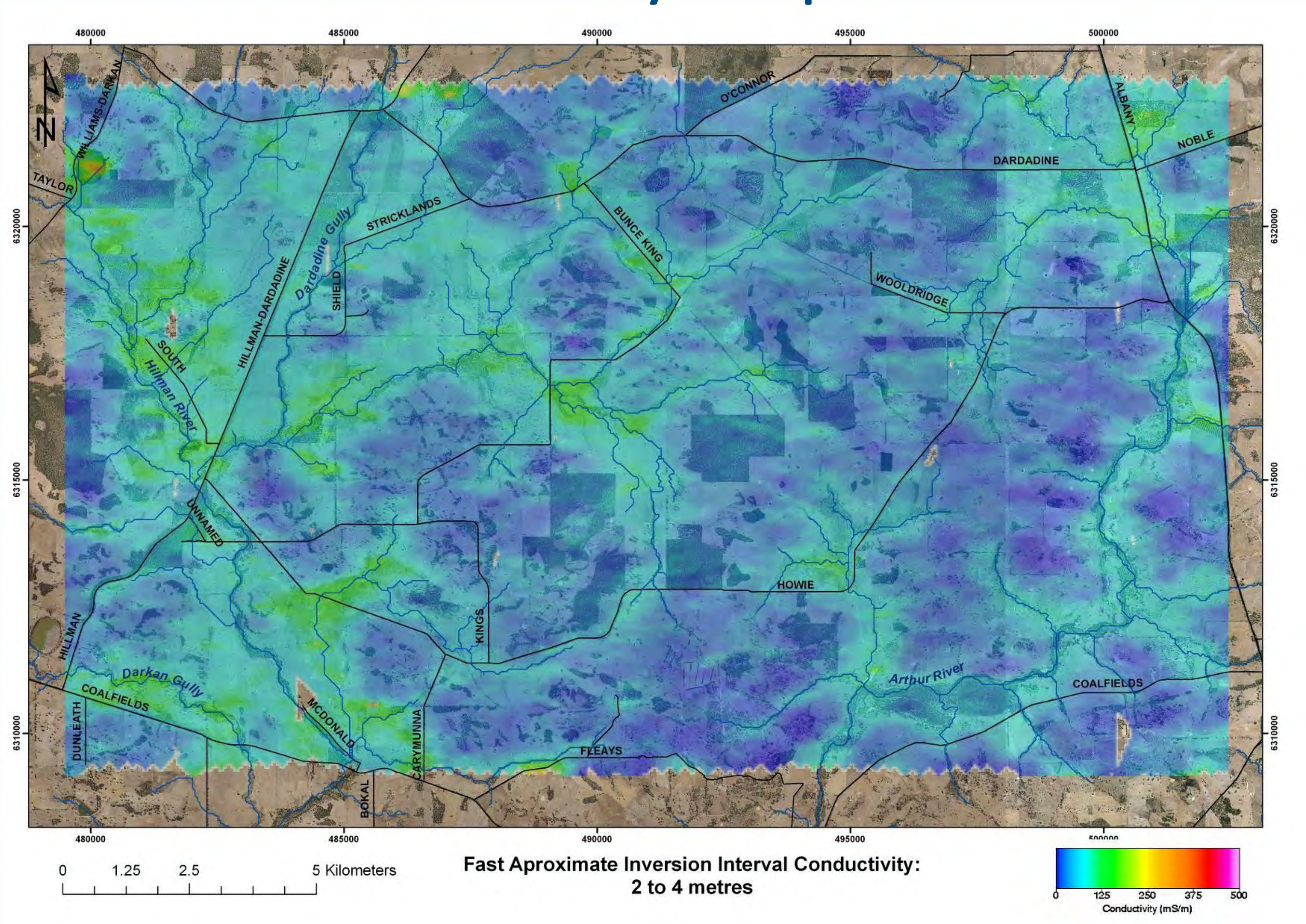
Flight Line Map



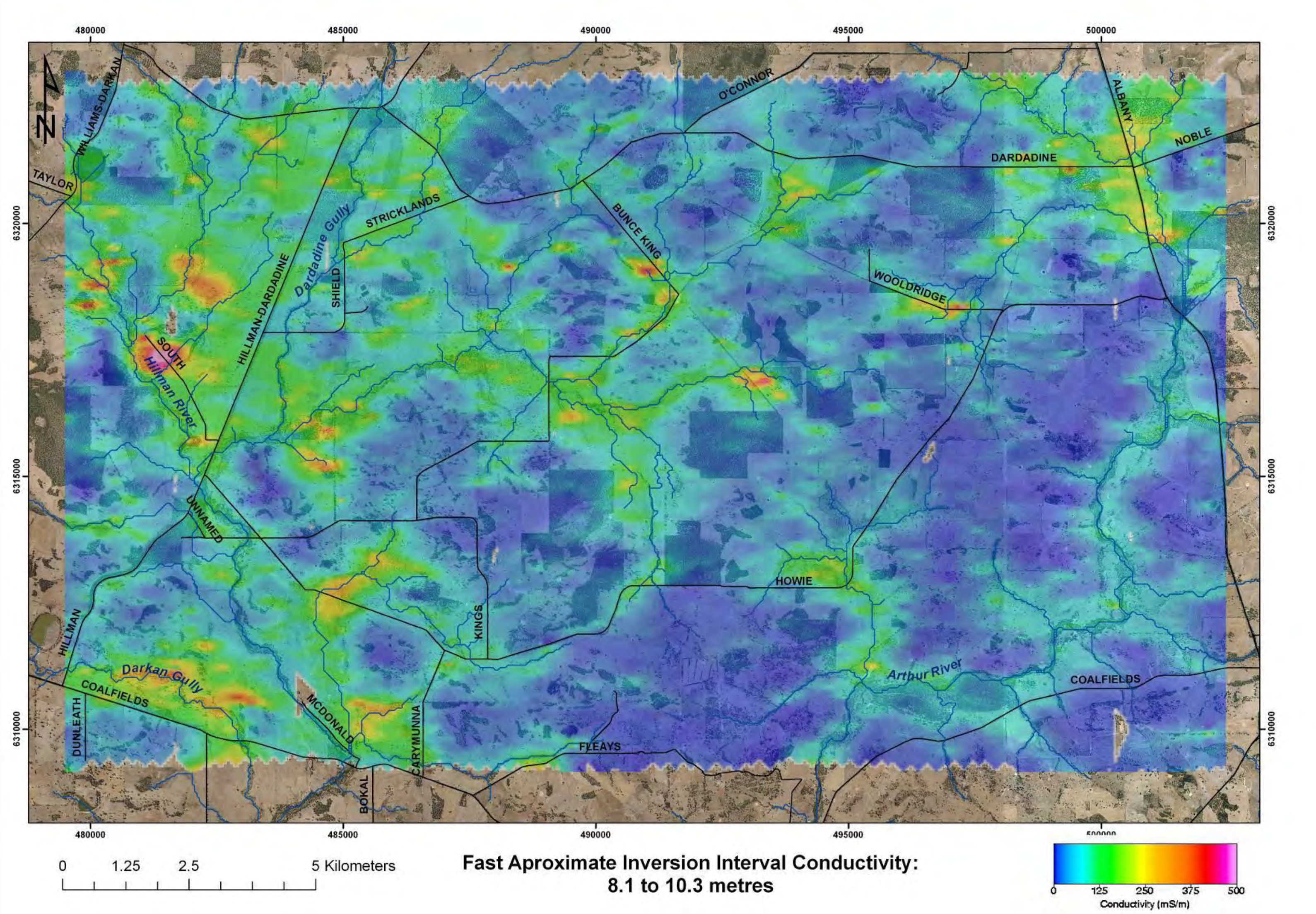
Conductivity-depth sections for each flightline



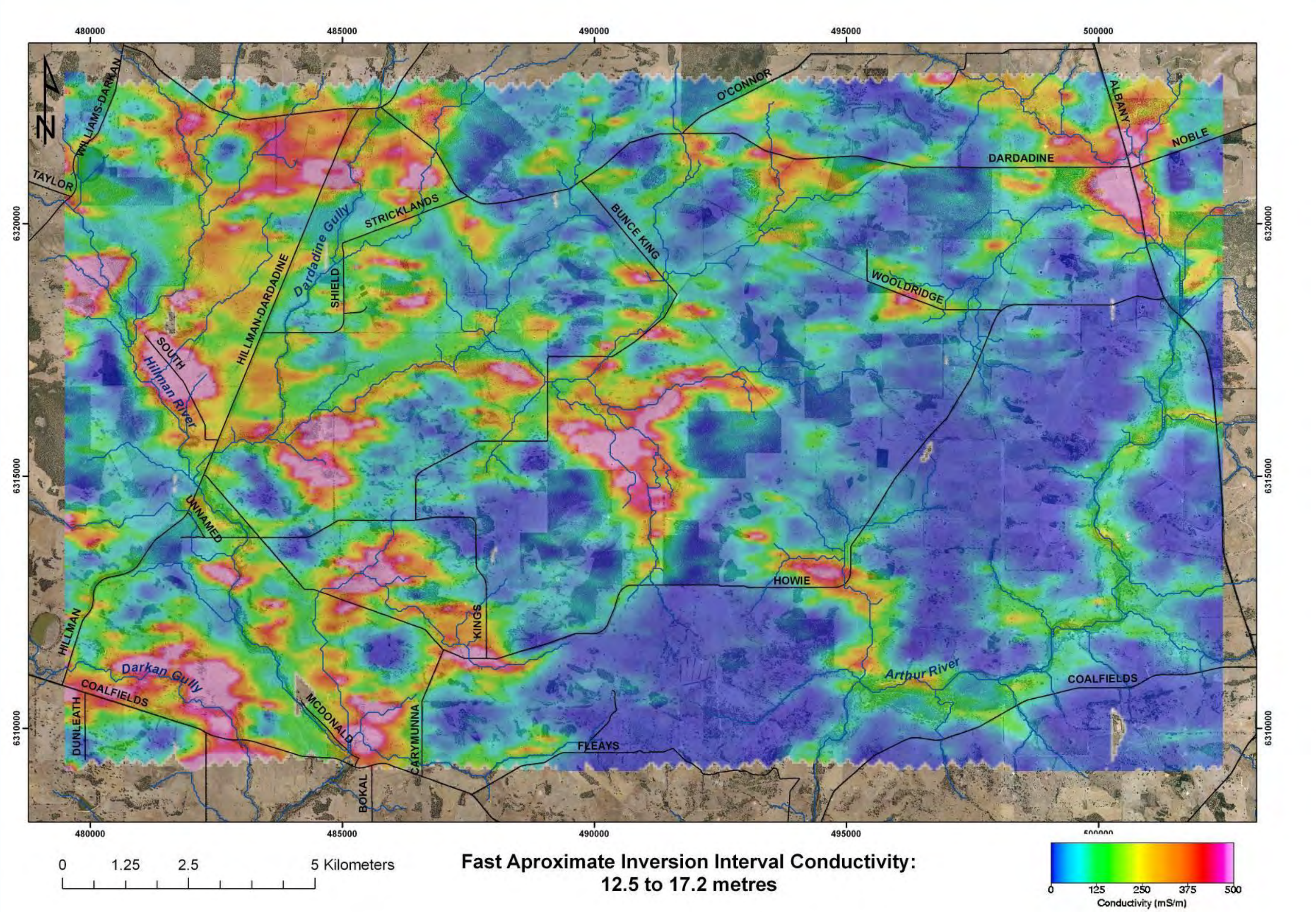
interval Conductivity Maps: 2-4m



interval Conductivity Maps: 8-10m

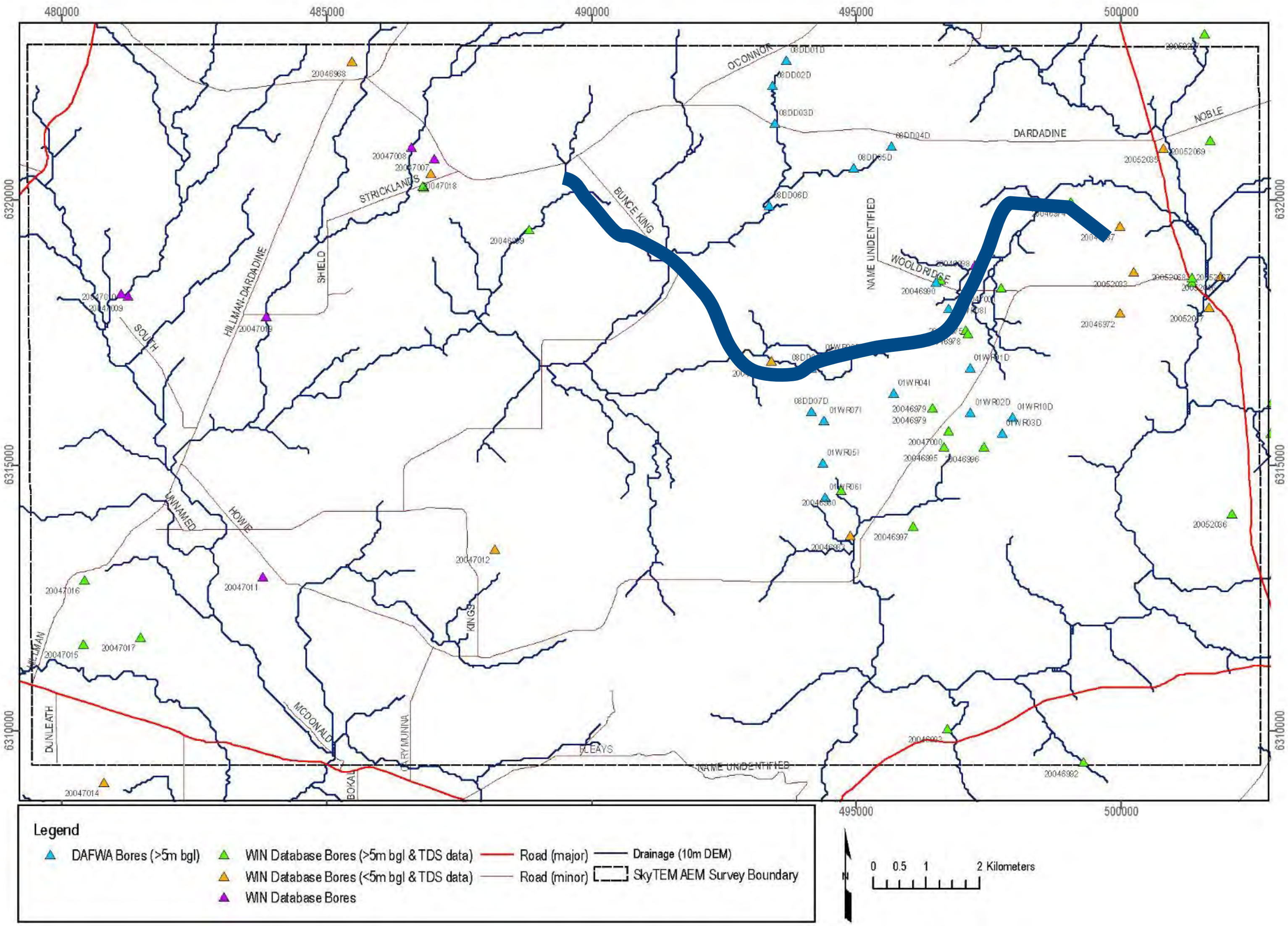


Interval Conductivity Map: 12-17m



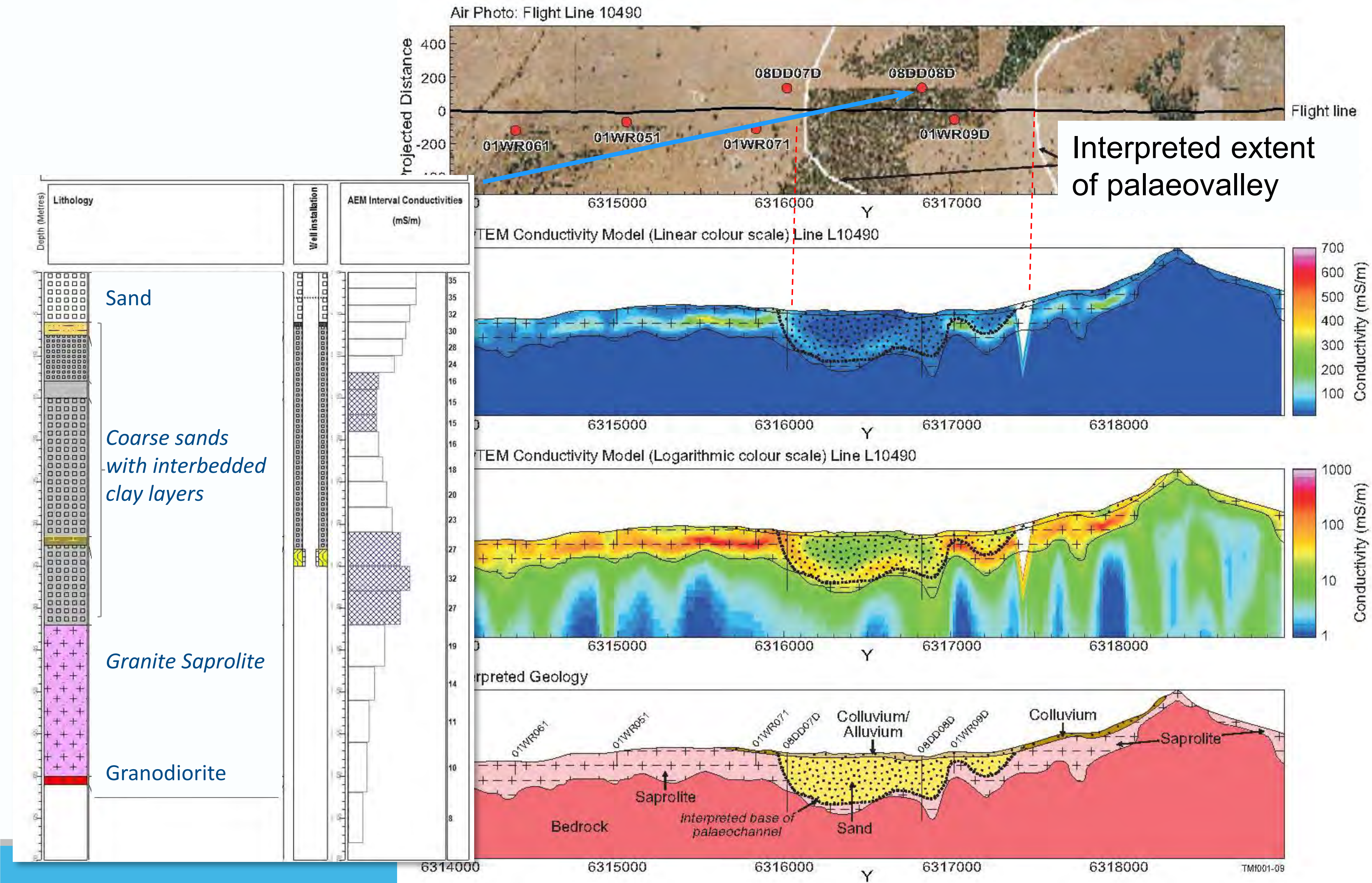
CSIRO

Existing Bore Data – local extent interpreted

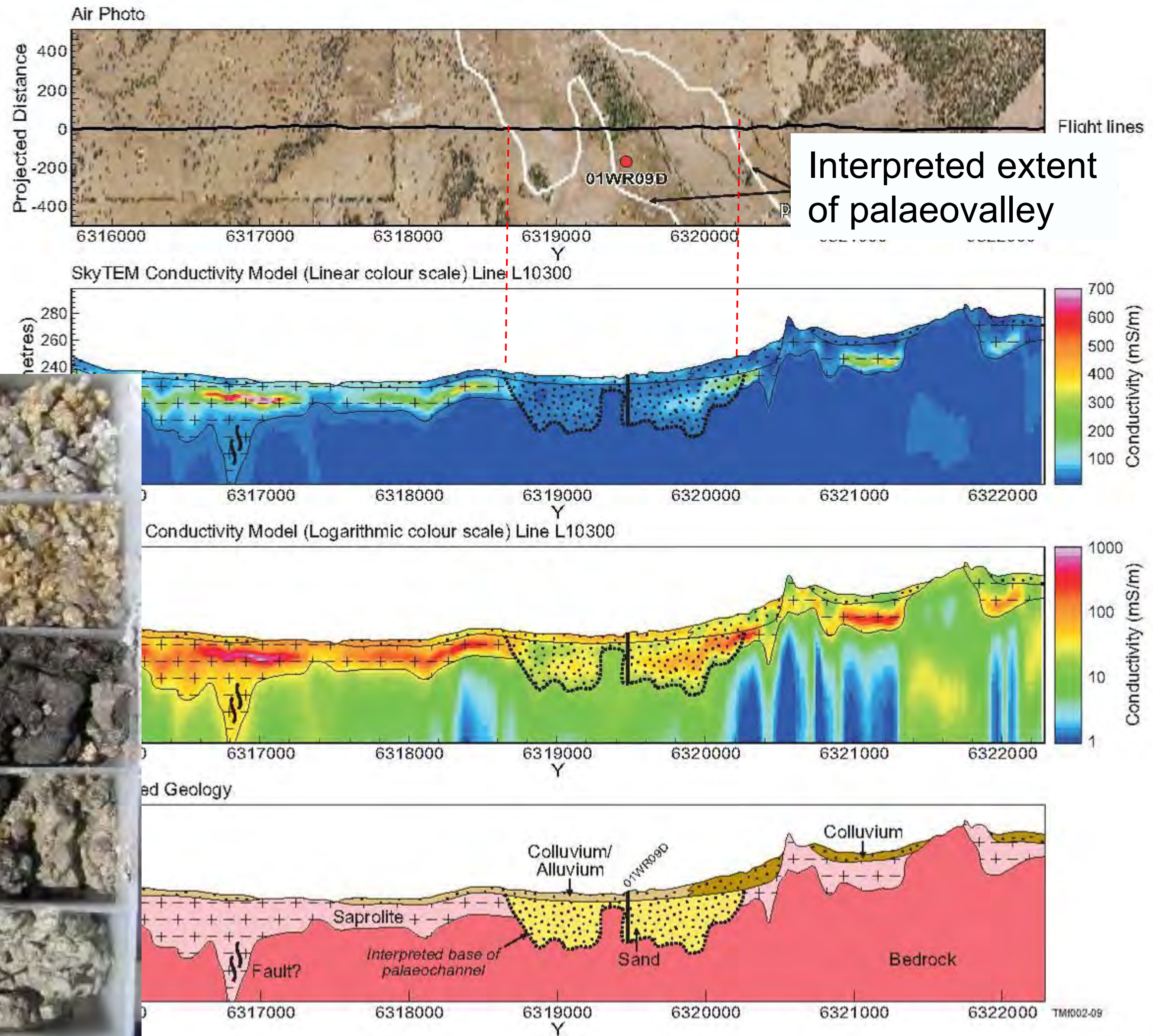


Interpret AEM Sections

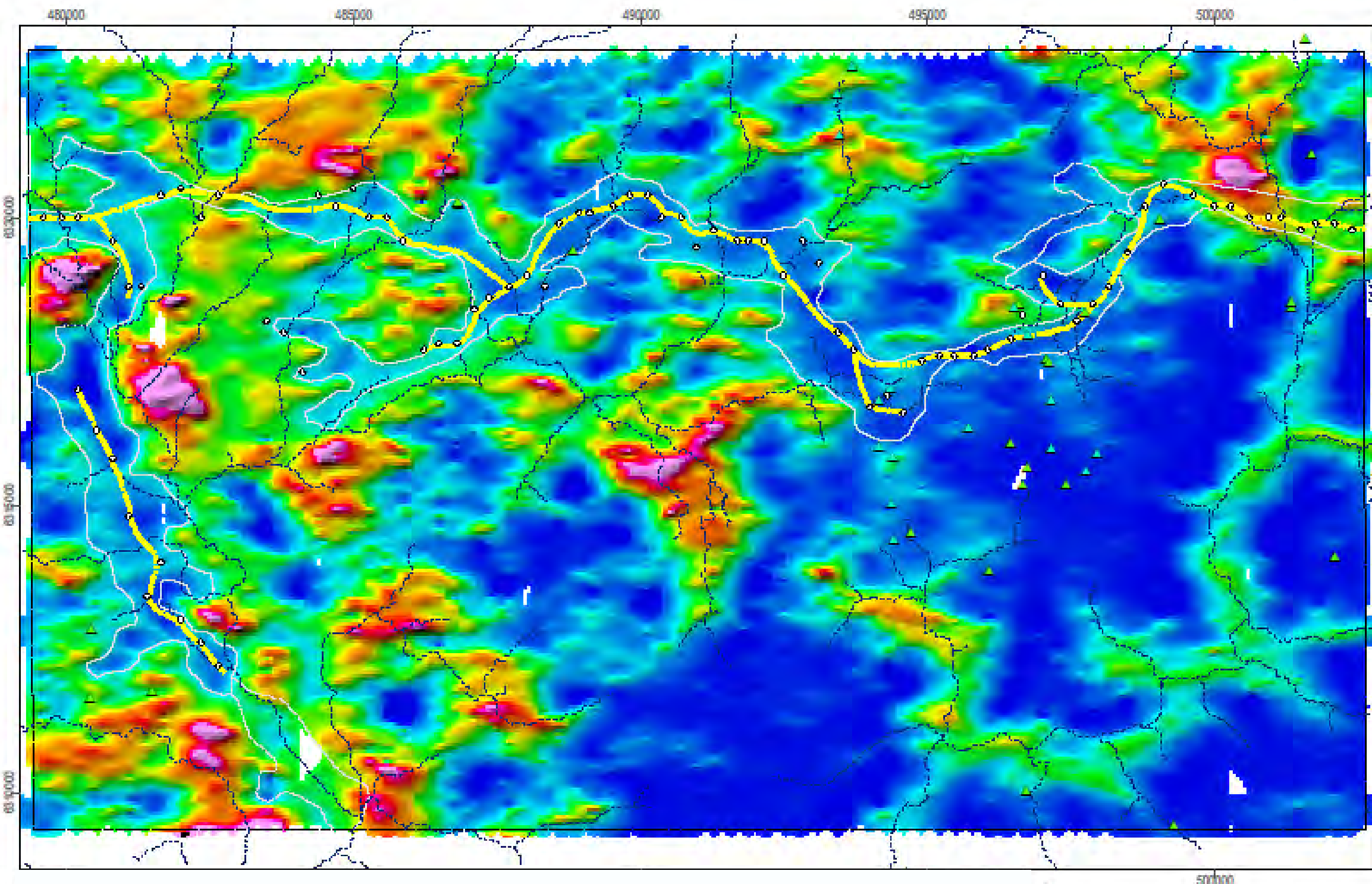
Finding the palaeochannel



Finding the palaeochannel



Mapping the palaeovalley thalweg



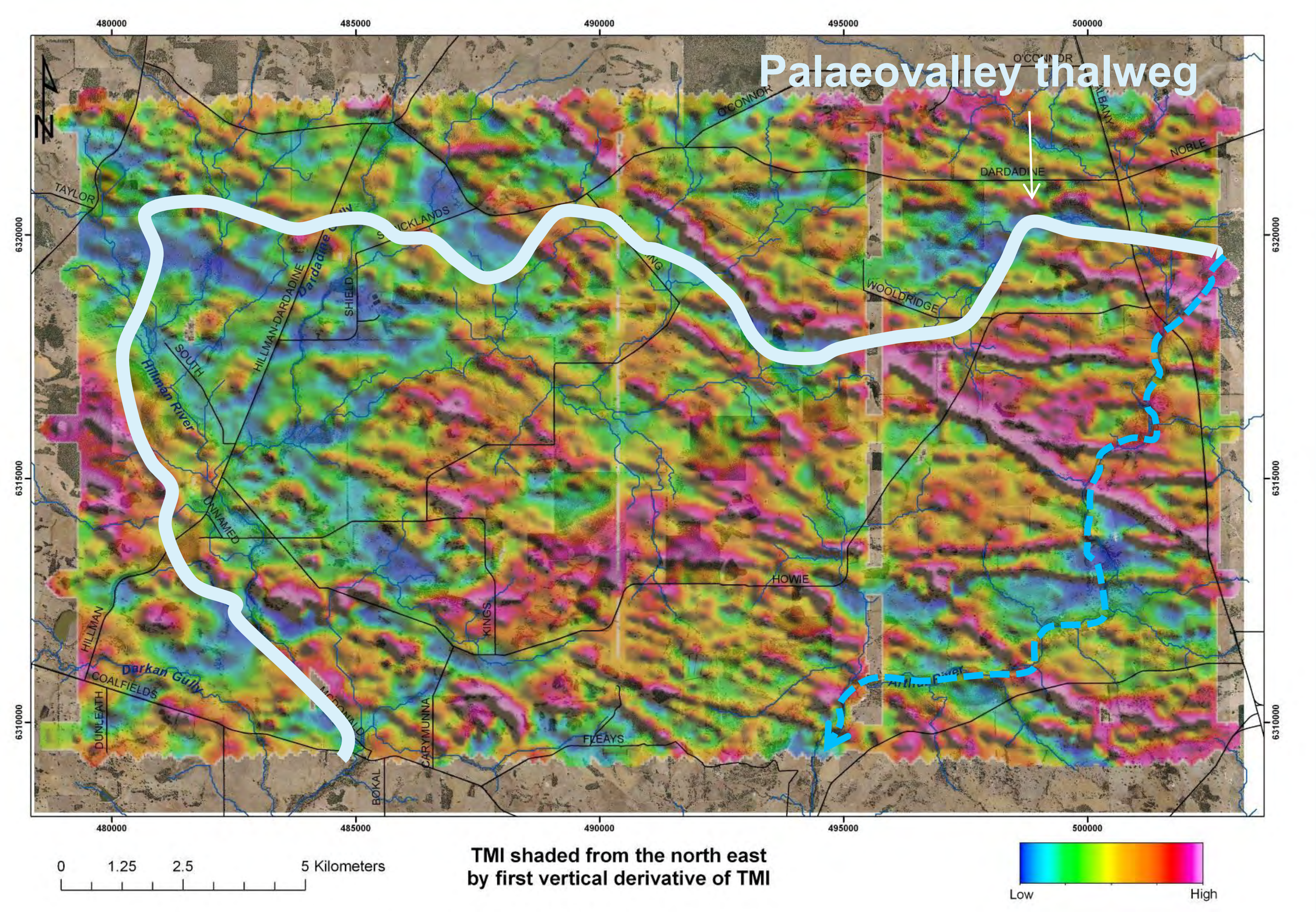
○ Thalweg position on flightline
Thalweg interpolated

Palaeovalley extent

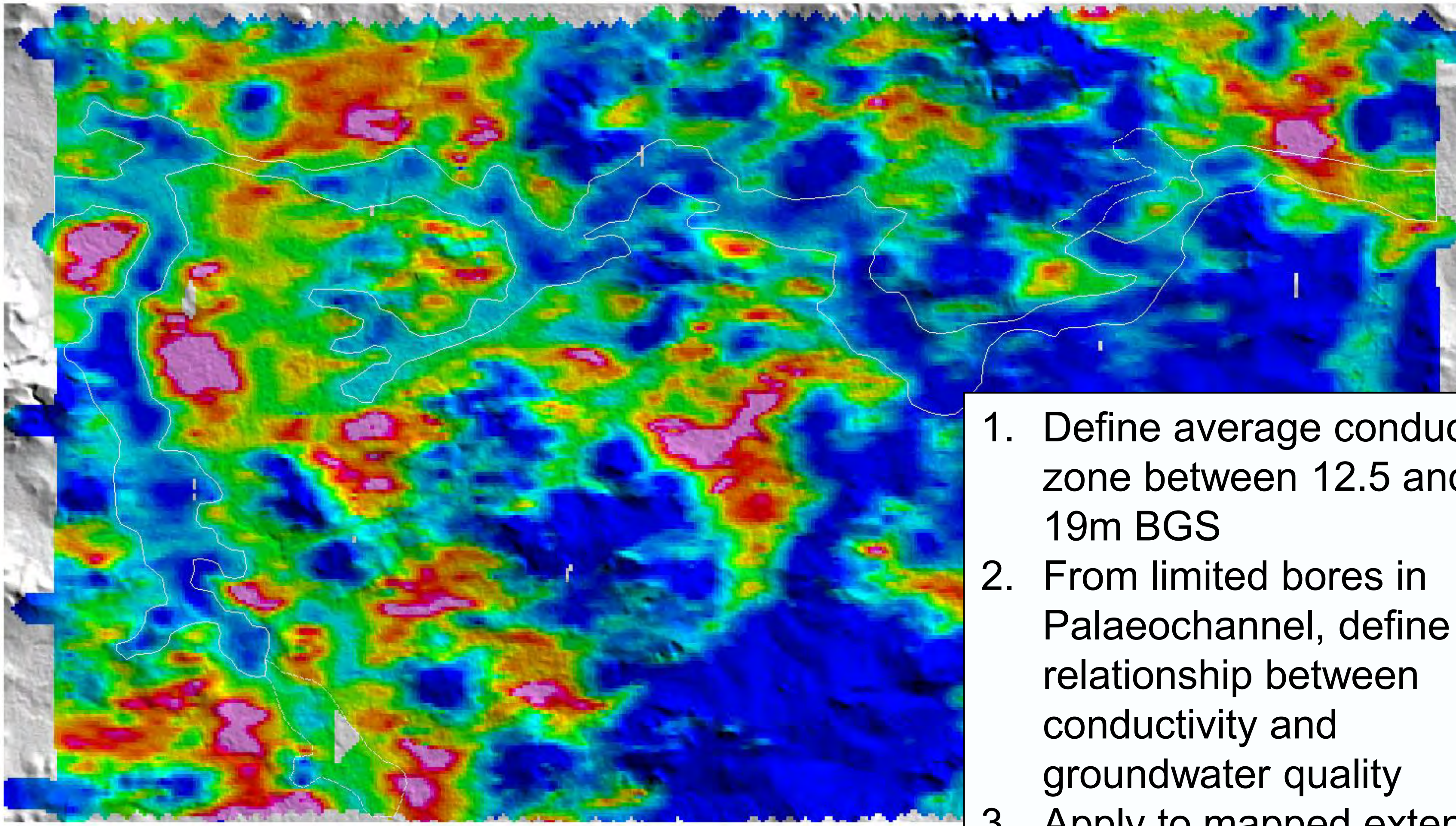
0 0.5 1 2 Kilometers

Conductance (S)
0 125 250 375 500

Magnetics ...a small digression...

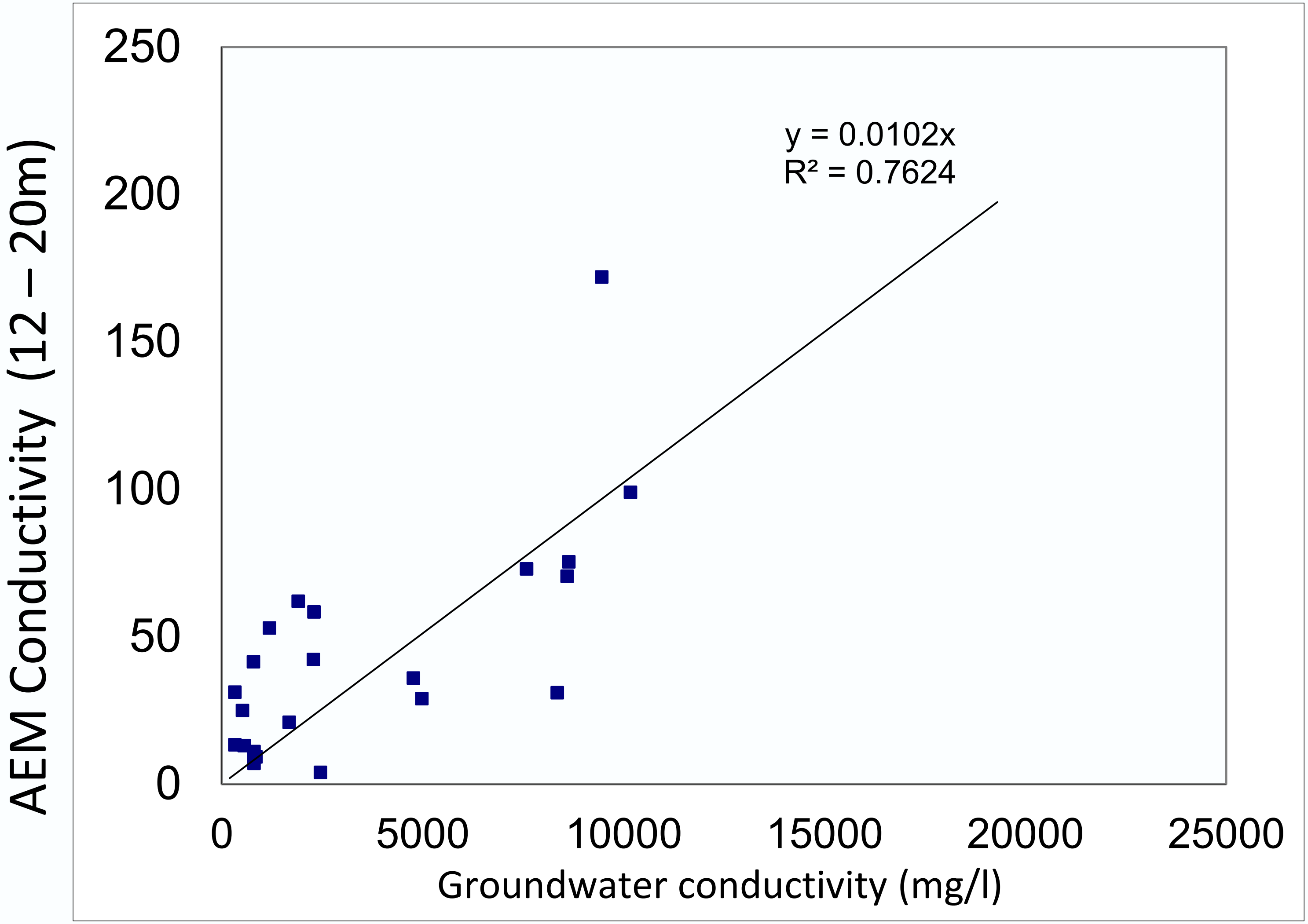


Water table - ~ 10-12m below ground surface

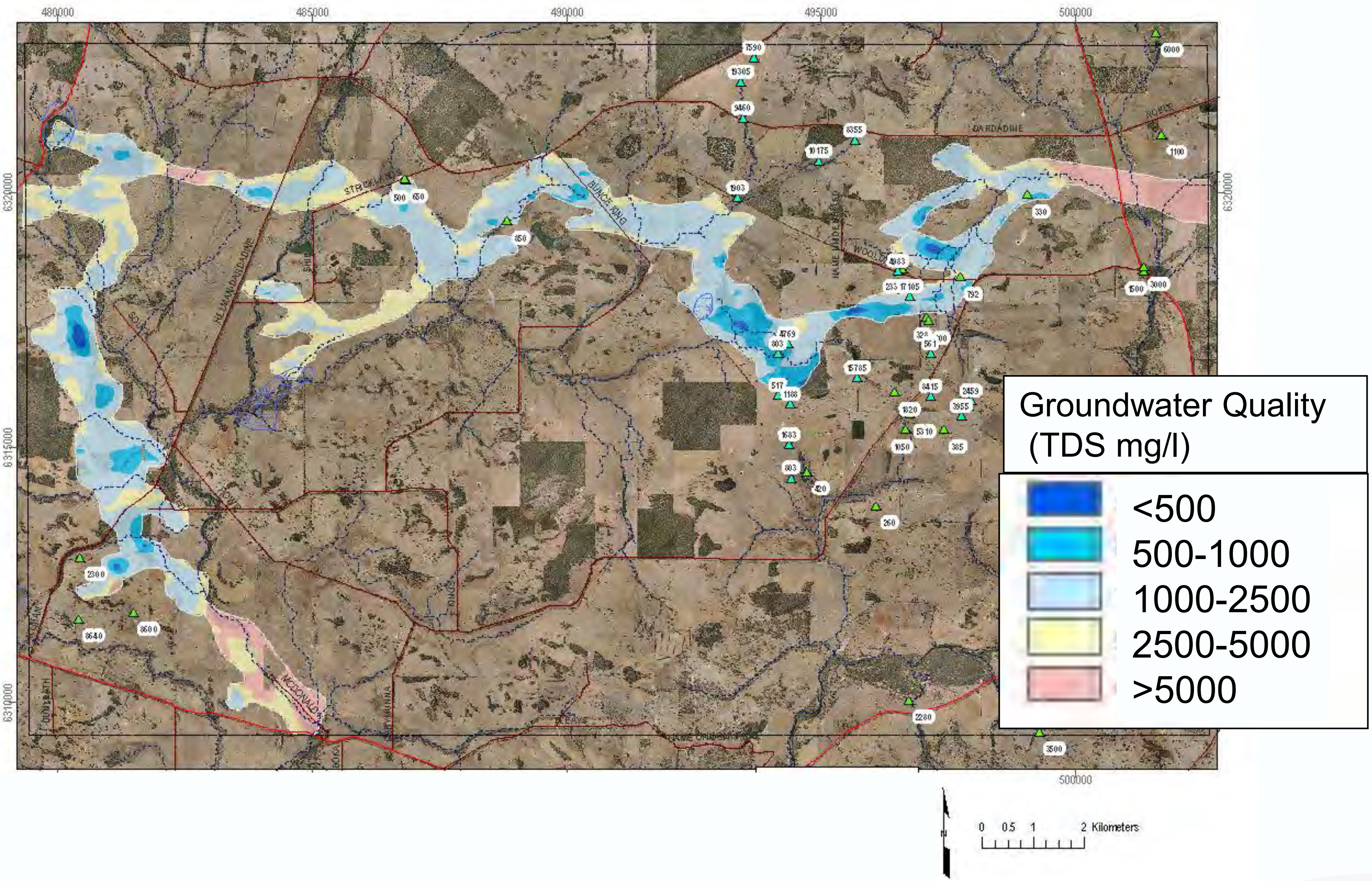


1. Define average conductivity zone between 12.5 and 19m BGS
2. From limited bores in Palaeochannel, define relationship between conductivity and groundwater quality
3. Apply to mapped extent of palaeovalley

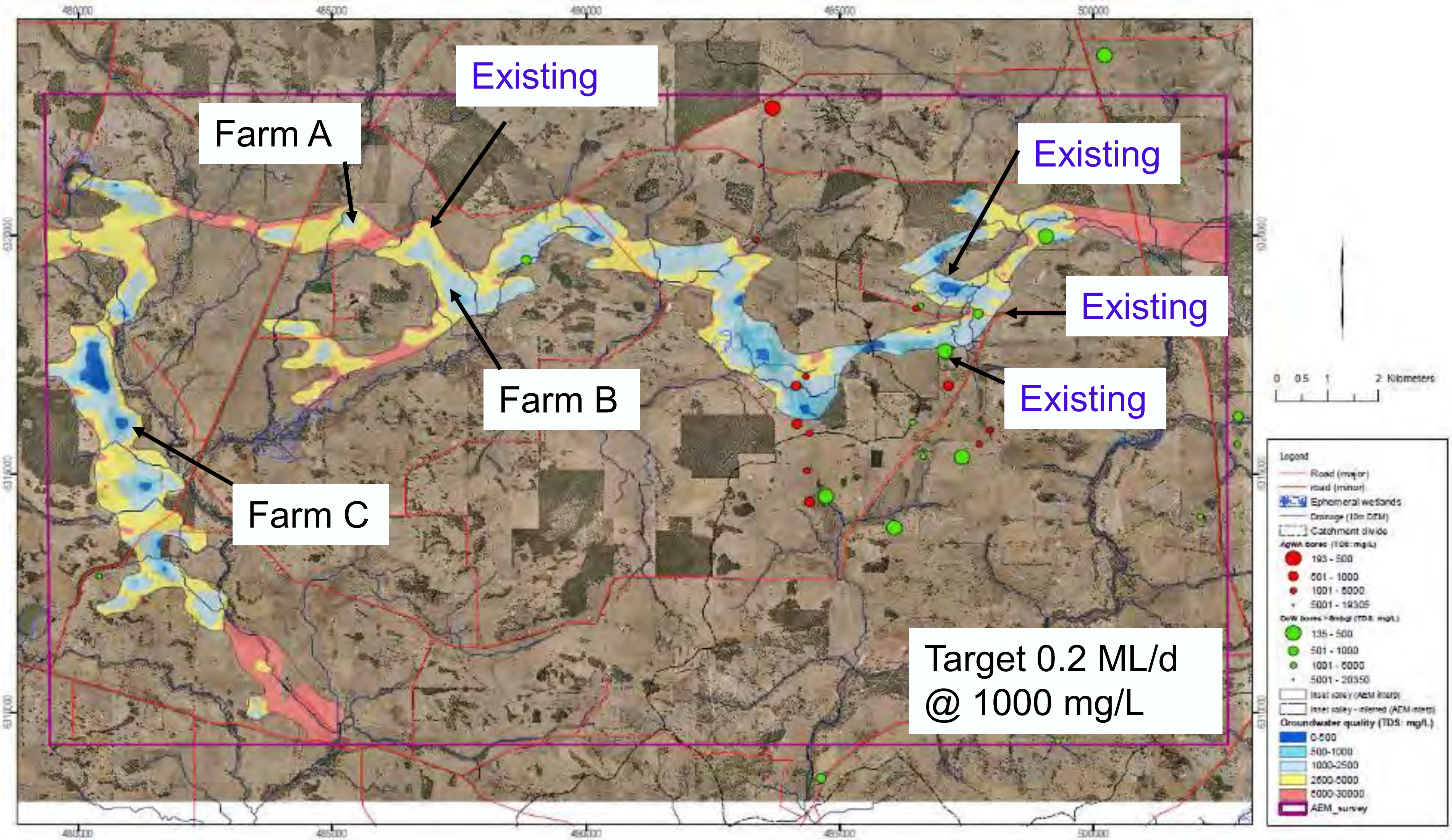
Relationship



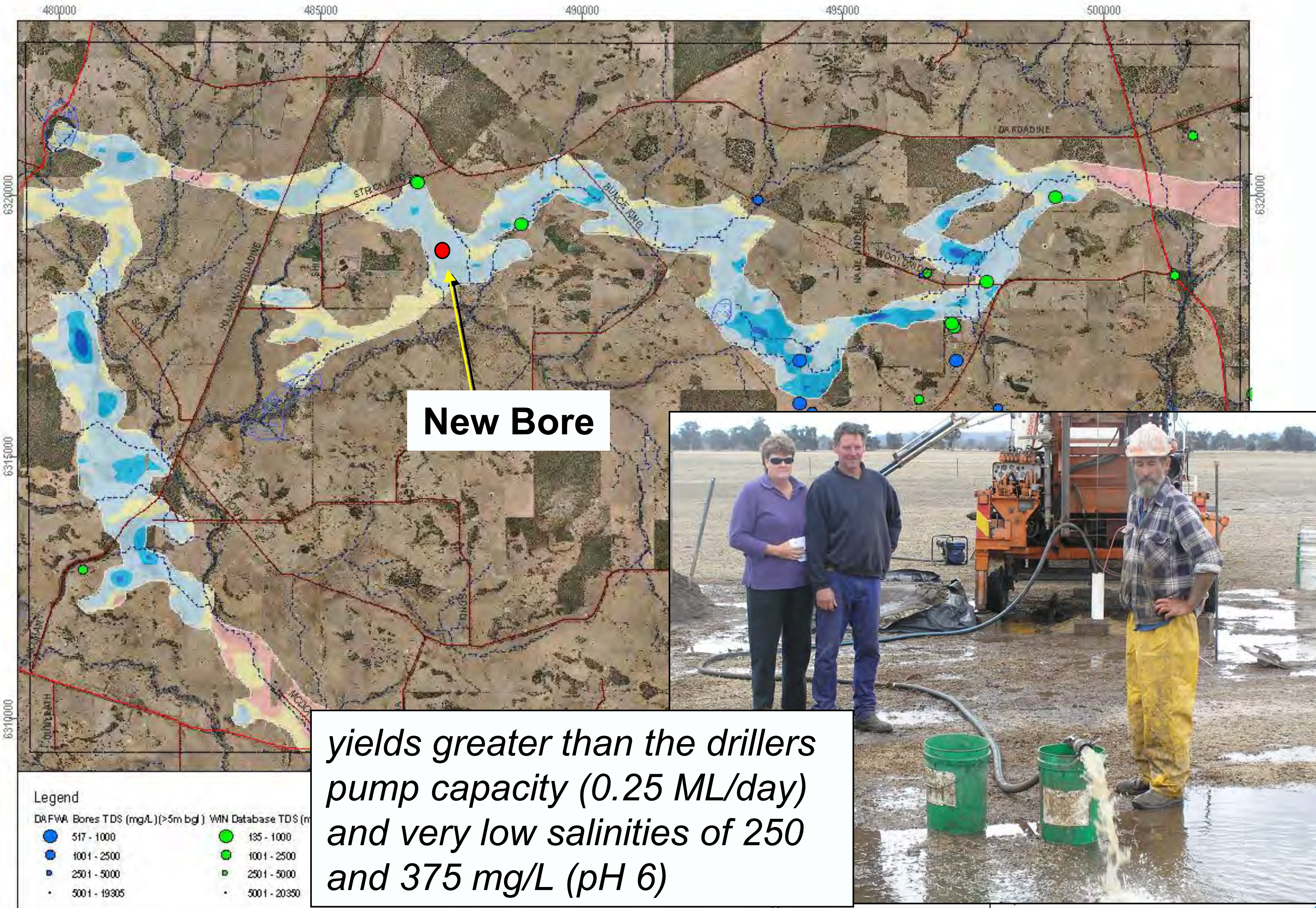
TDS of Palaeochannel Sand Aquifer



...interpreted aquifer & its salinity



Results

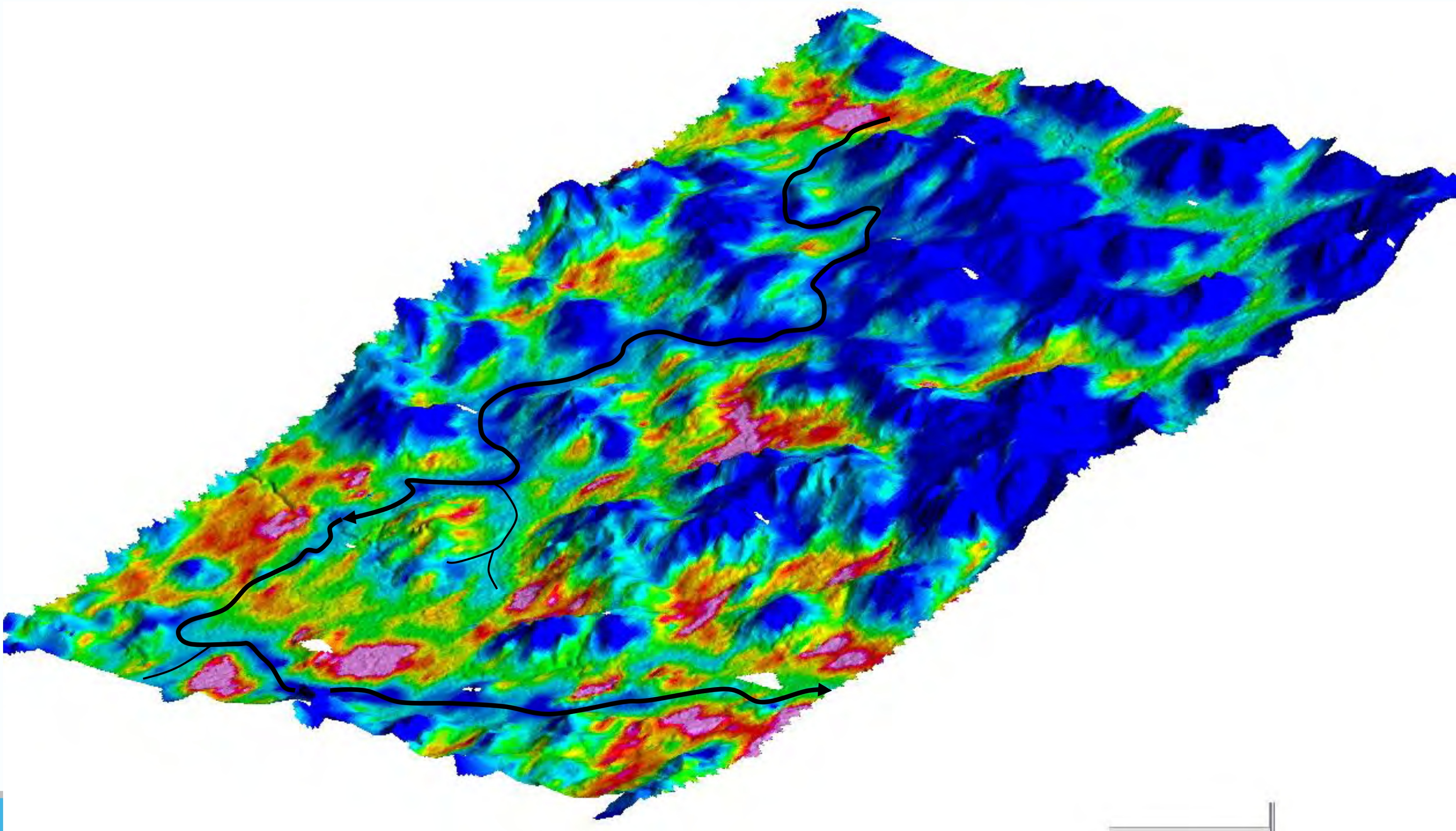


yields greater than the drillers pump capacity (0.25 ML/day) and very low salinities of 250 and 375 mg/L (pH 6)

Results

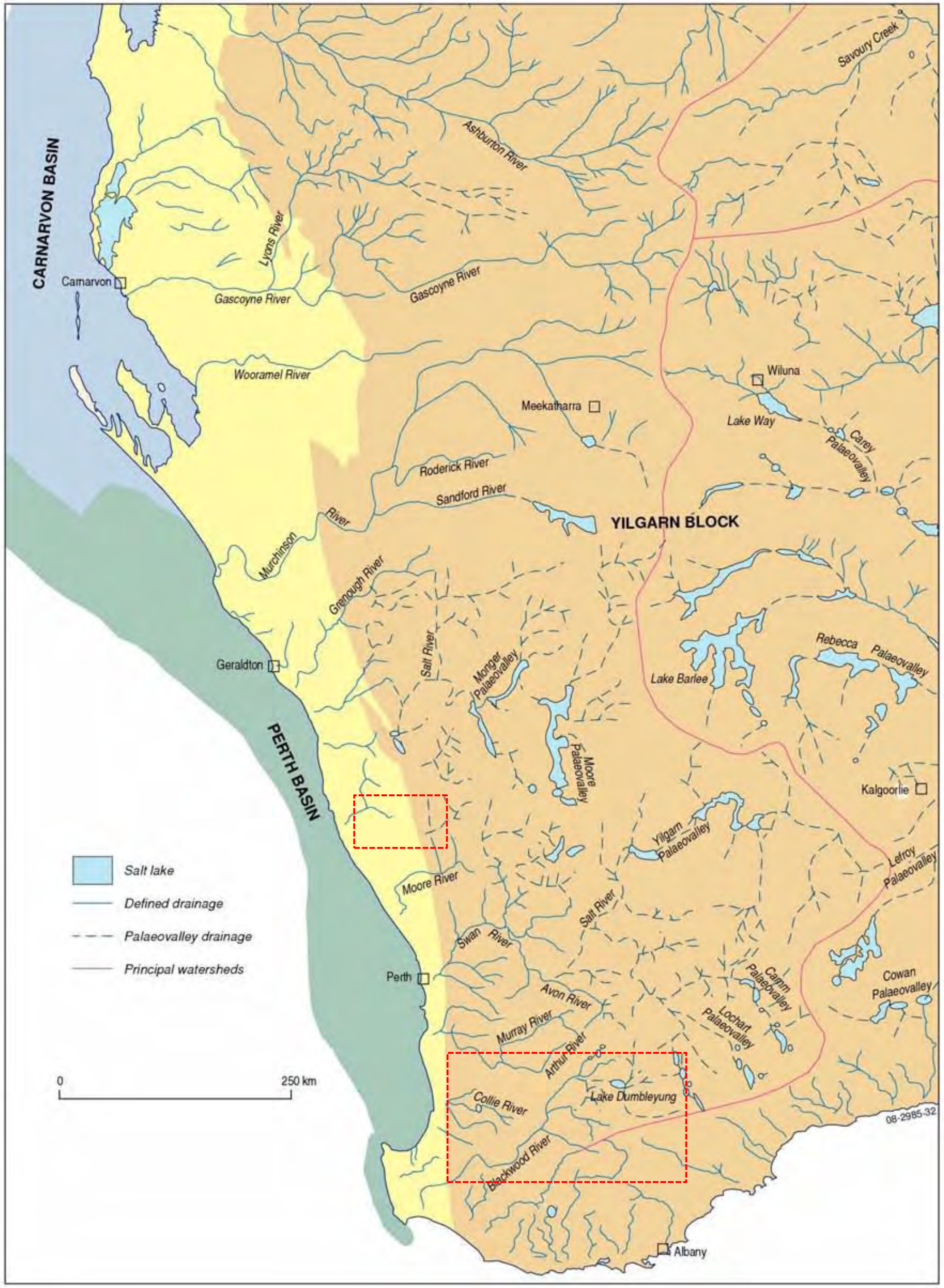
Good yield low salinities of ~500mg/L (pH 6)

Dryland salinity



Relative success- New Area

North Perth Basin



Summary

1. The orientation of the Darkan Palaeochannel has been defined
2. The estimated quality of groundwater in the palaeochannel has been determined
3. Potential new fresh groundwater resources have been delimited
4. Ground investigations (drilling) confirm the resource identified
5. The extent of dryland salinity, particularly in the lower landscape areas has also been defined
6. Small, targeted surveys can assist in farm-scale water resource assessment, for drought proofing and supplementation of existing supply

Thank you

Tim Munday

CSIRO Earth Science and Resource Exploration

t +61 8 6436 8634

e tim.munday@csiro.au
w www.csiro.au

Ground Conductivity Maps

What do AEM systems measure?

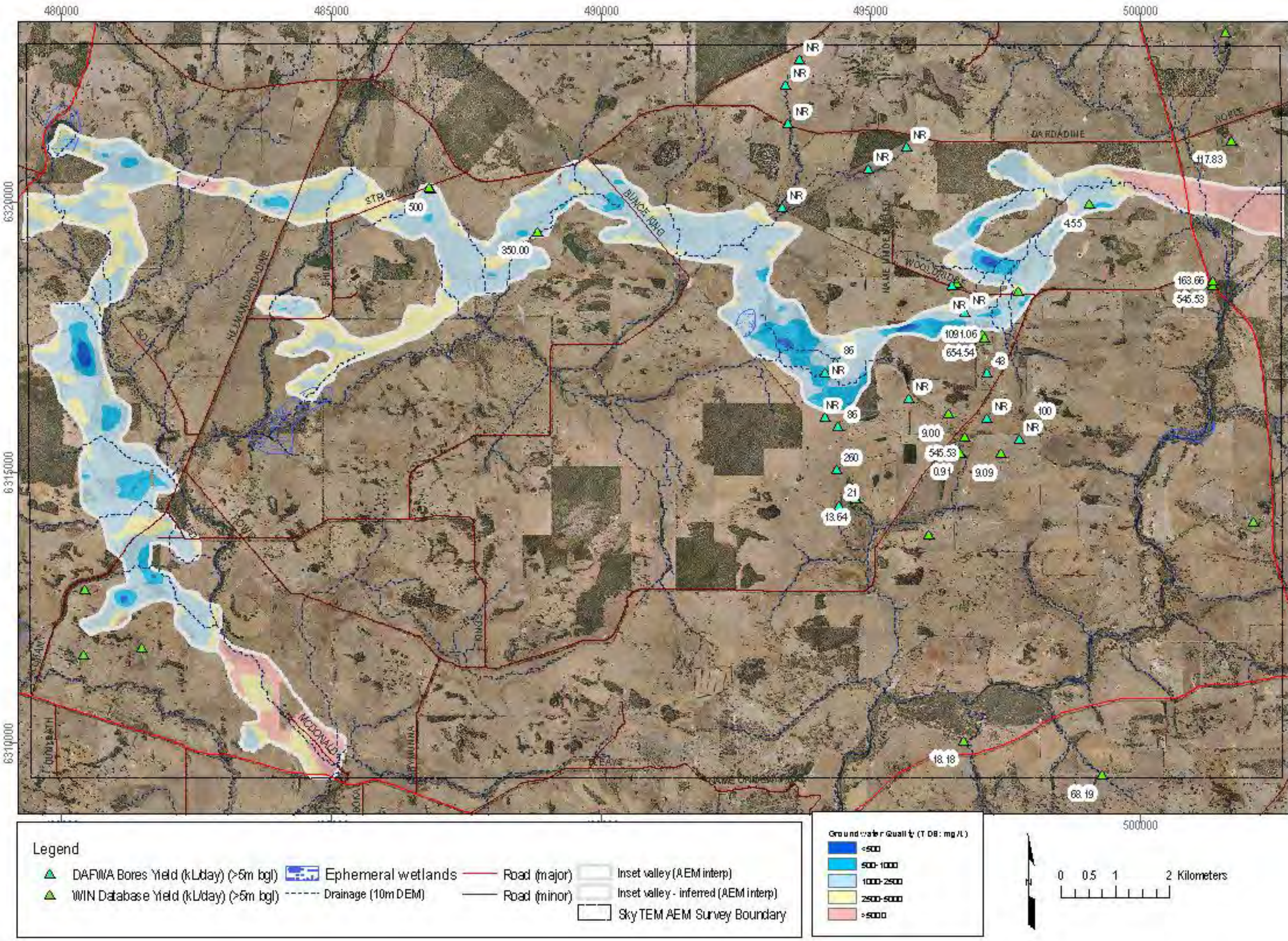
Technically:

- AEM measures a response that is a function of the electrical conductivity of the subsurface

Practically:

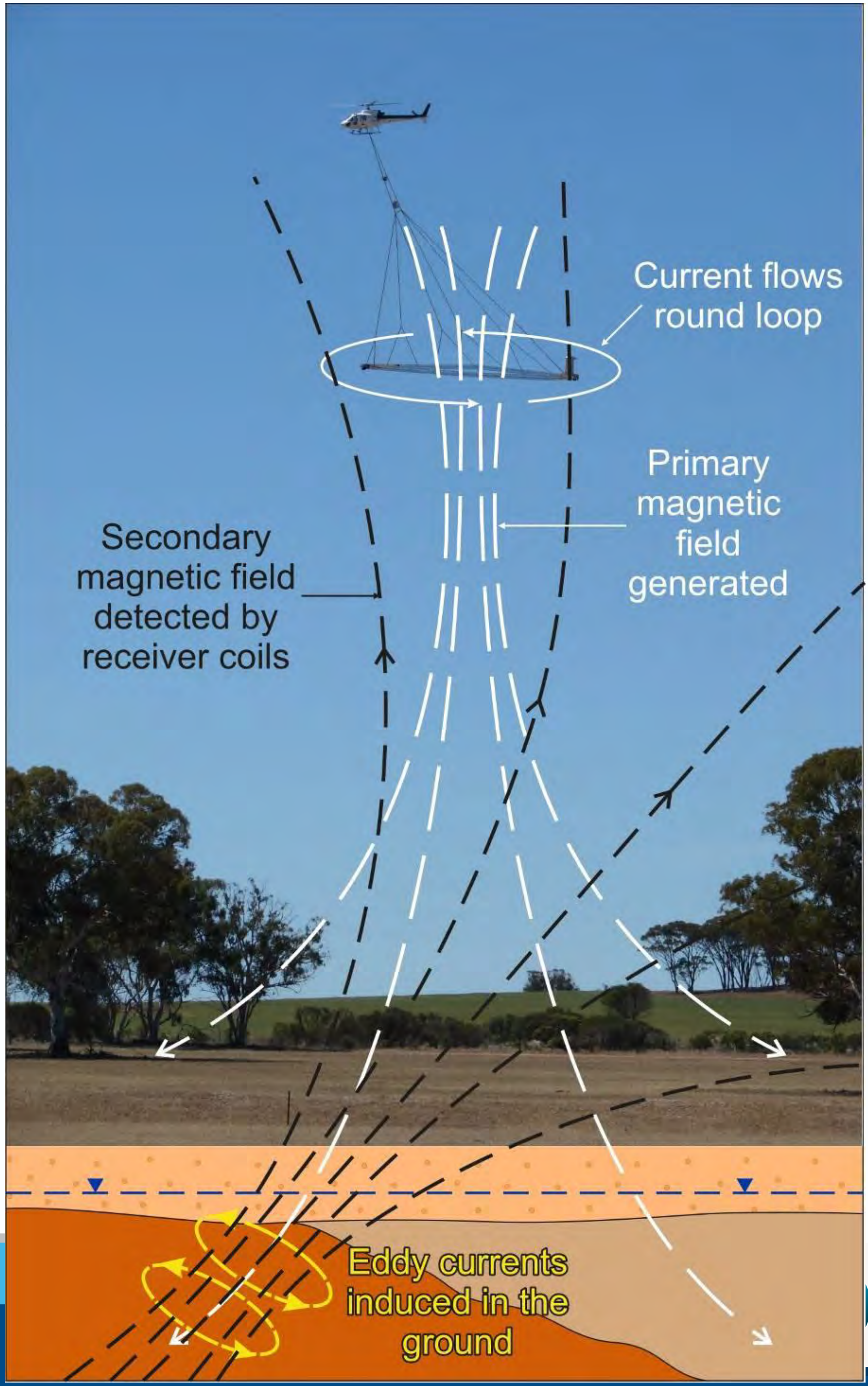
- Spatial patterns based upon conductivity contrasts *in the sub-surface sediments*
- Electrical conductivity (not just salt, or water, but a range of factors), however mostly a function of the first two..

Yield


480000
485000
490000
495000
500000
6320000
6315000
6310000
500
350.00
117.83
455
163.66
545.53
1091.06
654.54
86
48
100
9.00
545.53
0.91
9.09
260
21
13.64
18.18
68.19
NR
DARDADINE
Legend
DAFWA Bores Yield (kL/day) (>5m bgl)
WIN Database Yield (kL/day) (>5m bgl)
Ephemeral wetlands
Drainage (10m DEM)
Road (major)
Road (minor)
Inset valley (AEM interp)
Inset valley - inferred (AEM interp)
SkyTEM AEM Survey Boundary
Groundwater Quality (TDS: mg/L)
<500
500-1000
1000-2500
2500-5000
>5000
N
0 0.5 1 2 Kilometers

CSIRO

How does it work?

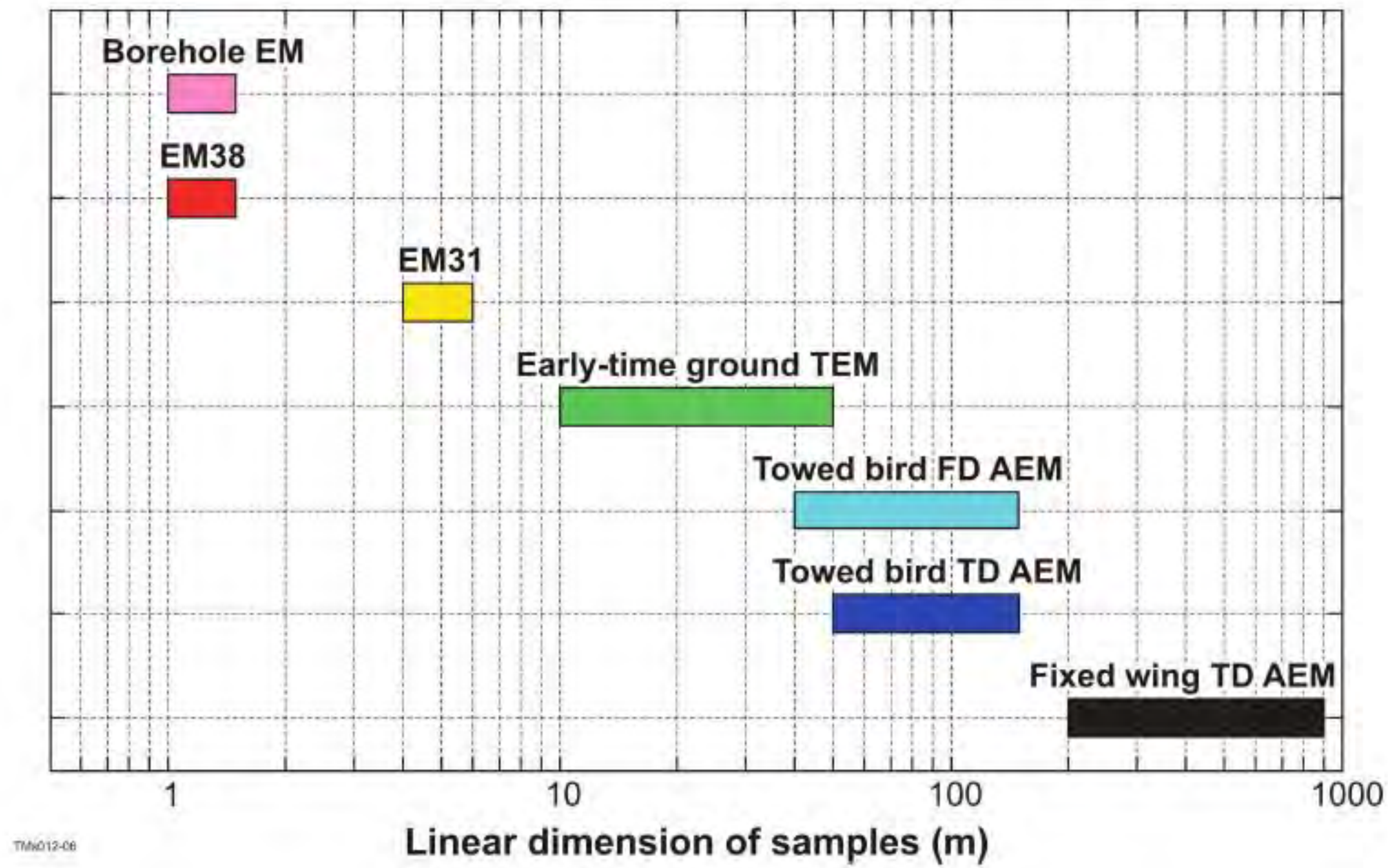



27-30
30-33
33-36
36-39
39-42

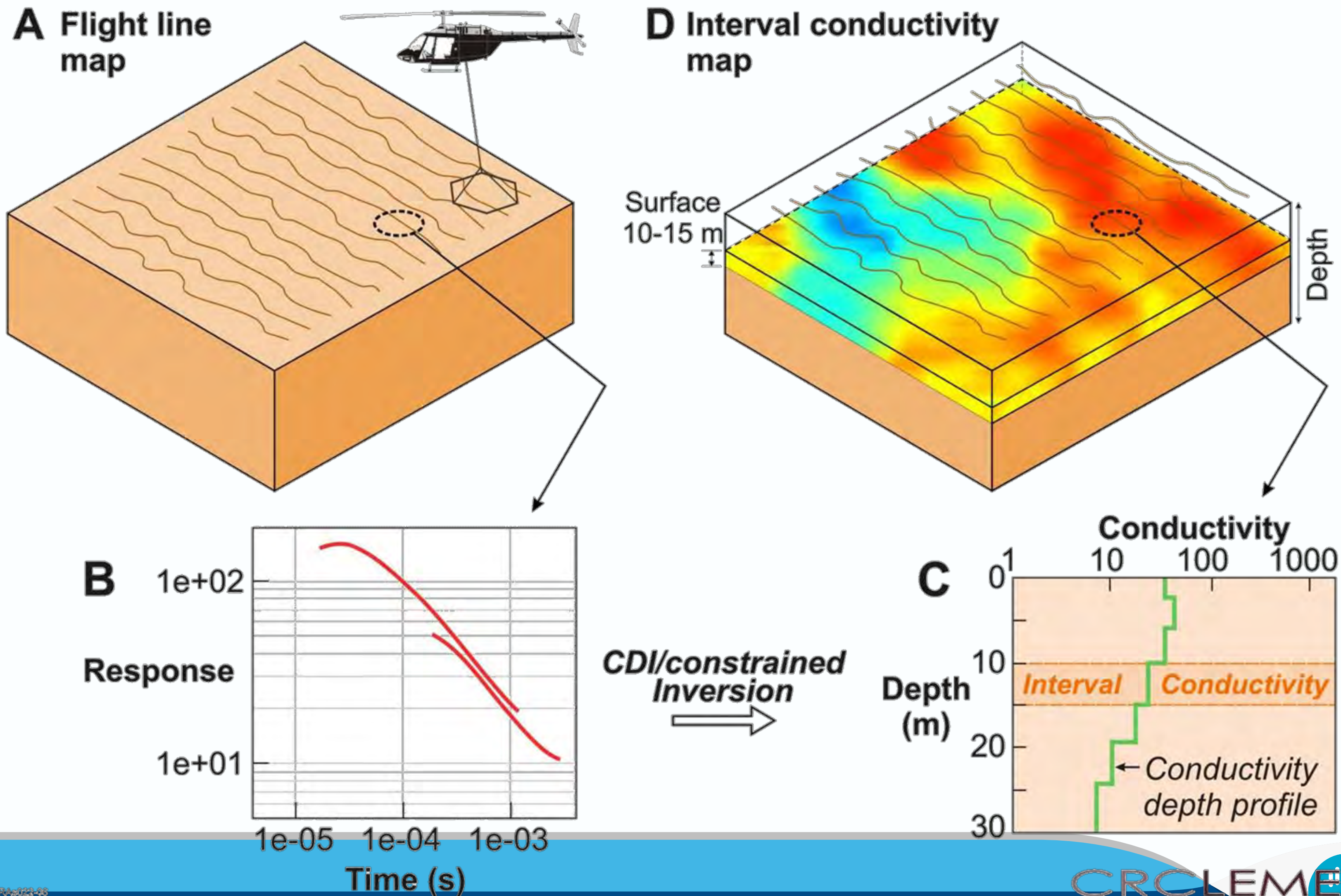

Farm A


Farm B

Resolution – Lateral weighted response



Producing a conductivity model of the ground



APPENDIX B
RURAL WATER NOTE 05 – TEST PUMPING FOR FARM BORES

Department of Water
Government of Western Australia

ISSN 1835-1573

Rural Water Note RWN 05

Simple Pumping Tests for Farm Water Bores ◻ September 2007

Ground water supplies are derived from deep bores, shallow bores, wells and soaks.

The available supply from a bore is usually assumed to be the same as the driller's estimate when it was first drilled.

The safe yield of the supply needs to be estimated by conducting a simple pump test after the bore is completed.

Once the bore has been in service for a while, most people estimate the supply by observing how many stock it can support and converting this to a daily flow.

Supplies from other bores may be limited by the size of pump used to extract the water.

If you have a new bore or are unsure of the safe yield of an existing bore, a driller's estimate is a poor way to estimate the available supply from the bore. Many people confuse this estimate with the long-term supply or safe yield of the bore, which could vary by as much as 50 per cent from the original estimate. The only true method of assessing a bore is to conduct a simple pump test on it.

How to do a pump test

A pump test measures changes in the water level of a bore during long-term pumping. By looking at the response, you can determine a safe pumping rate.

Measure the water level in the bore before you start the pump test. If the bore has been in recent use, let it recover to a static or stable level before proceeding. The driller's records should tell you the depth of water when drilled, along with the bore and casing depths.

Set up a pump and pump the supply at the estimated rate for at least eight hours at a continuous rate equal to either the driller's estimate or the rate at which you hope to extract water from the bore.

After the start of pumping, measure the drawdown (water level in the bore) every five minutes for the first half hour, every half hour for the next two hours and hourly for the rest of the test. Record the results carefully; you can draw them on graph paper to view the response.

If this pumping rate can be maintained without using more than two-thirds of the available drawdown then this is a reasonable estimate. If the drawdown is more than or less than two-thirds of the available drawdown, adjust the pumping rate accordingly. This will give a reasonable estimate of the amount of water you can safely draw from a ground water supply (bore, well or soak).

If you have a supply you have been drawing on for some time, you will already have a good idea of the volume of water you can draw based on experience. Just be sure the capacity of the pump is not the limiting factor.

Measuring water levels in bores and recording results during the pump test

This can be difficult during a pump test, particularly at the beginning of the test or if pumping equipment is of a similar diameter to the casing.

Department of Agriculture and Food
Government of Western Australia

Department of Water
Government of Western Australia

Record times as close to the recommended intervals if possible and use a stopwatch if available to record the exact time you measure the water level.

Try to measure the depth as accurately as possible. Plotting the results on a graph (time vs depth) will allow you to visually interpret the results.

The depth to water in the bore can be measured using a tape measure with an attachment that will make a noise signal or gives some indication when it touches the water surface. Try a bath plug, flat circular disc such as a fox whistle or an indicator stick. If possible, measure and record the depth of water from ground level.

During the test, make sure that any water pumped from the bore is disposed of as far away as possible from the bore. If water can re-enter the system being pumped, the results will not be meaningful.

Contact details

Rural Water Planning
Department of Water
www.water.wa.gov.au
ruralwater@water.wa.gov.au
Tel: 1800 780 300 (freecall)

APPENDIX C
FARM DAM RELIABLITY GUIDANCE

Department of Water
Government of Western Australia

ISSN 1835-1573

Rural Water Note RWN 02

Understanding Water Supply Reliability – September 2007

In dryland agricultural areas of Western Australia, seasonal rainfall fluctuations necessitate the design of reliable on-farm water supplies so that farming enterprises can continue in low rainfall years.

Reliability is a term used to express how often the user of a system is prepared to allow a water supply storage system to fail. The more reliable the system required, the greater the need for precision design and construction – and the more expensive it is to install and maintain.

Reliability is normally expressed as a percentage or as an expected failure frequency. For example, a system with a reliability of 50 per cent has a 50 per cent chance of success in any given year; and, of course, a 50 per cent chance of failure. This may be also expressed as a one-in-two failure rate (ie 1:2 years).

A system with 90 per cent reliability has a 90 per cent chance of success in any given year and the failure rate (10%) may be expressed as one-in-ten (ie 1:10 years). Note that it is possible for a system with a 90 per cent reliability rating to fail more than one year in succession (when we get two or three, one-in-ten year events in succession), but in the long run it will average out to one failure every 10 years.

The level of reliability required often depends on the impact that system failure will have on those affected and the cost associated with failure. Some farmers may be prepared to accept a failure of a system once every five years – others only once every 20 years.

Consideration needs to be given to the type of agricultural enterprise, with the importance of water resource reliability increasing as the degree of agricultural intensification rises. In an intensive farming system, such as cattle feedlots or piggeries, where water consumption is high and forward contracts or other business agreements exist, access to a secure reliable water supply is paramount.

Farm water supplies for broadacre enterprises are designed with a nominal reliability rating of at least 90 per cent. However, many on-farm water supplies are rated only as 50 to 70 per cent reliable, resulting in a heavy draw on the public scheme during relatively low average rainfall years.

Carting water generates high costs to the community to maintain the supply and a high cost to the farmer in both dollars and time. A 20 per cent improvement in reliability of on-farm water supplies will benefit the public and the farming community, releasing public funds to create and maintain community and emergency off-farm water supplies.

Further information

Designing for Reliable Water Supplies. Farmnote 72/2004. Department of Agriculture and Food, Western Australia.

Farmer, D. and Coles, N. May 2003. *Assessing Storage Reliability of Farm Dams.* Resource Management Technical Report 245, Department of Agriculture and Food, Western Australia.

Contact details

Rural Water Planning
Department of Water
www.water.wa.gov.au
ruralwater@water.wa.gov.au
Tel: 1800 780 300 (freecall)

Department of Agriculture and Food
Government of Western Australia

Designing for reliable water supplies

Technical Report · April 2004

Neil A. Coles
University of Leeds

No. 72/2004

Department of Agriculture
Farmnote

Designing for reliable water supplies

By Neil Coles, Senior Research Officer, South Perth

In the dryland agricultural areas of Western Australia seasonal fluctuations in rainfall necessitates the design of reliable on-farm water supplies so that the farming enterprises can continue to function in years with low rainfall. Suitably designed storage such as dams, raintanks and soaks or adequately defined and equipped bores are required to ensure supply for livestock, crop spraying and domestic use. To ensure reliability, two measures are required; what is the expected demand? and what is the storage capacity? Linkages between these two measures are the capacity to control demand and the cost of maintaining reliability of supply. This assumes that the water collection and storage strategy also ensures water quality is maintained.

The costs of designing and maintaining a reliable supply are dependent on the acceptable level of risk a landholder is willing to take, based upon the losses incurred if the supplies fail versus the cost of meeting long-term demand under low rainfall conditions. To understand the nature of this relationship the concept of reliability needs to be explained.

Reliability in design

Reliability is a term used to express how often you are prepared to accept the failure of a system, in this case a water supply. This term, reliability or rate of failure, is determined by balancing the costs associated with development to a certain capacity against the negative costs of system failure. These include both the rate (i.e. number of times) and the length of time that a system remains ineffective. The negative costs may include the cost of livestock agistment or replacement and carting water to maintain supply.

Reliability is usually expressed in terms of a percentage or as a failure rate in a given number of years (i.e. 1 in 10 or 90 per cent). For example, if a system has a reliability of 50 per cent it has a 1 in 2 chance of being successful in any given year, or a 50:50 failure rate. This could be expressed as one failure rate every two years based on the long-term average. A system with a reliability of 90 per cent has a 90 per cent success rate in a given year or a 10 per cent chance of failure. This system would be expected to fail once in ten years in the long term, however it is possible for such a system to fail more than one year in succession, where two or three one-year in ten events occur together. Note the long-term average will still rate the system as a 1:10.

Such an event occurred during 2001/02 drought, where systems were designed to provide continuous supply during little or no rainfall for twenty-two months (1:10) failed due to the extended dry period.

The level of designed reliability required is determined by how often those affected are prepared to pay for the cost of failure. Some landholders may be prepared to accept a water supply failure rate of one in five years, others may design for one in twenty years. The more reliable the system is required to be, the more care must be taken with the planning, design and construction. For systems that have a high dependence, like water supplies, the cost increases and the level of reliability also increases.

On-farm water supplies need to meet or exceed a 90 per cent reliability rating. This may be achieved through dams, raintanks, groundwater or access to the public piped-water scheme. Due to the long-term cost of maintaining the piped-water supply, it is expected that landholders will develop reliable on-farm supplies and only access the scheme during low rainfall years when on-farm systems have failed. At present many on-farm supplies would fall into the 50-80 per cent reliability rating. Although the overall rating within the dryland agricultural areas has lifted in the last eight years due to funds provided under the Farm Water Grant Scheme, further investment is required.

Estimating livestock carrying capacity of farmland

The total livestock carrying capacity of farmland is dependent on the average annual rainfall and available feed for livestock (given adequate water supplies). If the normal (based on an average number for previous years) livestock carrying capacity is not known, an estimate can be made based on an allocation of:

- 1 DSE per pasture-hectare for every 70 mm of average, annual rainfall. In areas of rainfall greater than 500 mm, for improved pasture, the carrying capacity may be as high as 2 DSE per hectare.
- 1-1.5 DSE per cropped hectare for stubble utilisation.

Note: A DSE is defined as a 45 kg non-lactating sheep in forward-store condition during summer, on a maintenance diet of sub-clover or better pasture.

Evaluating existing supplies

The understanding of the development of long-term reliable supplies is dependent on the understanding of the critical relationship between water-harvesting potential, storage capacity and demand. A number of simple software programs are available from the Department of Agriculture that will enable landholders to evaluate their existing farm-water resources and plan for future demand.

Dam volume - How large? How small?

Dams need to be designed to cater for the expected demand plus losses from evaporation and a limited (or acceptable) amount of leakage (<1.5 mm/ day or <0.5m/a). By necessity, dams and other short-term water-management or attenuation structures need to be at least 2 m deep. The size of the dam is often dictated by the landscape and soil conditions.

Initially we will consider dam volumes, shape and demand. Table 1 provides an indication of dam performance relative to shape, with round dams providing the best dam volume, cost-benefit relationship. In the eastern wheatbelt annual evaporative losses can exceed 2 m and can vary from 1.8 m to 2.8 m depending on location. Therefore a dam requires a minimum of 2 m of depth before consideration can be given to livestock, irrigation or domestic demand.To assess performance of an existing dam the reader is referred to Technical Report 245 (Farmer and Coles 2002).

Table 1. Percentage of volume in upper 2.0 m.

Volume (m^3)	Volume (%)		
	Round	Square	Rectangular (1.5L:1.0B)
1000	82	87	92
2000	71	79	79
3000	65	69	70
4000	60	65	65
5000	58	61	61
6000	56	59	59

To understand the relationship between cost, volume and supply reliability, let us consider a dam designed to supply 500 DSE that is restricted in depth to 5 m and relies on farmland catchment. This relationship is plotted in Figure 1. The graph clearly indicates that as the volume increases so does the cost proportionally, however the change in reliability levels out after the volume reaches 6000 m^3. This demonstrates that constructing a dam larger than 6000 m^3 (that is depth limited) does not give a good return on supply improvement relative to the cost of construction. In this limited example, $7400 is invested in increasing the dam volume from 6000 to 10000 m^3 but the supply reliability is only improved by 2.5 months. Increasing dam size is not reflected as an increased reliability, particularly at sites where the depth of the dam is restricted. In this case, the increase in the surface area required to increase volume counts against the dam's reliability due to evaporative losses, and demonstrates the relationship between size, shape, depth, cost and reliability.

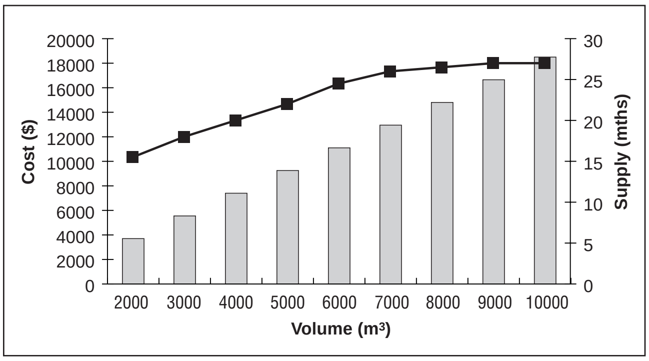


Figure 1. Comparison of construction cost versus reliability of water supply

Raintank system

Roof raintank systems are not subject to evaporation and therefore the rainfall regime, demand and roof area dictates the size of the rainwater tank required to ensure a reliable supply. Raintank (V2) is a simple model used to evaluate existing systems and future design requirements. The roof area is rated against the rainfall using a 1-2 mm threshold and a known volume of storage. The threshold is used to allow for different roof designs, covering (i.e. tiles etc.) losses caused by faulty guttering and down-pipes, or incorrect pipe-sizing, and builds in a margin of safety in predictive response. Raintank (V2) is available from the Department of Agriculture.

Domestic water supplies

Domestic water includes all amenities in the house including showers, toilet, laundry and kitchen use. The amount of water needed can be approximated to 150 L/day per person for up to four people in one house, then 100 L/day for any additional persons. The most efficient way to collect high-quality water is to channel the rainwater that falls onto the available roof areas into storage tanks. Other sources such as groundwater and dam water can be used for laundry, toilet flushing and gardens, depending on the rate of supply and water quality. Domestic water is less than 15 per cent of the water used in agricultural areas, but it is often the first impacted upon by low rainfall, system failure or transfer to other uses such as livestock or crop spraying.

Domestic water is used in a variety of ways and has the greatest impact on the quality of life on the farm. About 40 per cent of all domestic water is used inside the home, the rest is used outside the home, mostly in the garden. Inside the home, about 30 - 40 per cent of water is used in the shower/bath, 30 per cent in the laundry, 20 per cent in toilets and the remaining 10 - 20 per cent in other indoor areas, including the kitchen. So to maintain quality of life aspects, it is important to design a reliable, domestic water-supply that will meet the demand for both quantity and quality.

Crop-spraying requirements

The crop-spraying requirements in each year will vary according to the distribution of crop/pasture on each farm within each shire. Crop-spraying requirements are based on the number of applications per year (usually 3); the rate of water mixed with the chemical to be applied (35–50 L/ha) multiplied by the area of land sprayed (hectares) each year. For example, the crop-spraying requirements for canola is about 160 L/ha per season. The quality of water that can be used for spraying varies depending on the pesticide or herbicide to be applied.

Roof raintank systems designed to meet crop-spraying requirements should ensure that the volume of water is available for the whole cropping program, and to account for the fact that the water is likely to be drawn in a short time-period that does not allow for rainfall recovery (see Raintank FN 64/2004). Factors affecting water quality include pH, muddiness, salinity, hardness and organic matter content and these can impact on the effectiveness of the spraying application.

Groundwater supplies

One of the main concerns with groundwater supplies is that they are often viewed as limitless supplies which will not change over time. Supplies derived from groundwater can vary seasonally in both water quality and quantity available. Salinity levels can rise significantly and bores can often dry up. Before developing a reticulation system, the groundwater source should be properly tested. Groundwater is usually derived from two sources, either deep regional aquifers accessed by a bore or a well; or shallow perched aquifers which may be accessed using a bore, well or excavated soak.

Water intake per DSE (or per head of livestock) is related to the intake of dry matter. The more moisture supplied by the feed, the lower the need for drinking water. The DSE allocation for bore water is dependent on the bore yield, water quality and the capacity of the existing bore pump.

Different classes of livestock can tolerate different qualities of water, and considerable differences exist between individual animals and their tolerance to saline drinking water (Luke 1987). Water intake for livestock grazing on *non-saline* pastures varies with the concentration and type of salt present. Livestock tolerance to saline water increases if the stock are accustomed to it, have restricted access to water, are on green feed, are dry (i.e. not lactating), and on a maintenance-feed intake, rather than a growth diet (Southorn 1995).

The daily drinking allocation for peak periods during summer, (when only dry feed is available) has been modified to account for maximum daily average temperatures during January and February. The peak drinking rate has also been adjusted for wastage (assumed to be 20 per cent of peak) associated with inefficiencies within the delivery system (i.e. evaporation from troughs, spillage, etc.). Salinity factors have been derived to account for higher drinking rates resulting from increased soluble salts. The values given in Table 2 should only be used as a guide and are considered to be a minimum requirement. Where the salinity of the water supply is known, the values should be utilised to evaluate bores for the design of water-supply systems based on available groundwater, pumps and reticulation systems. Water with a salinity above 1900 mS/m Unit ? is generally not recommended for continuous use by livestock and should not be assessed as useable water.

Livestock that have a proportion of saltbush in their diet, require good quality water. In general, the higher the proportion of saltbush in their diet, the less salt the animal can tolerate in the drinking water. If high-quality water is available, then adult sheep will consume approximately twice the water than sheep grazing on sub-clover pastures. For diets based on a saltbush-pasture mix then water qualities above 1200 mS/m should be avoided.

Table 2. Peak demand estimates [L/Hd/day] during summer.

	Maximum daily sheep drinking rates in summer			
	Factored[1] drinking rates			
Water Salinity[2] (mS/m)	**Fresh**	**600**	**1200**	**1900**
Locality	**Litres per head per day**			
Albany	3.2	3.9	4.5	5.5
Bencubbin	6.4	7.7	9.0	10.9
Brookton	5.9	7.1	8.3	10.1
Corrigin	5.9	7.1	8.3	10.1
Cranbrook	3.8	4.6	5.4	6.5
Dalwallinu	6.7	8.0	9.4	11.4
Dandaragan	6.3	7.5	8.8	10.6
Dwellingup	4.9	5.9	6.9	8.3
Esperance	5.6	6.7	7.9	9.5
Geraldton	5.7	6.9	8.0	9.8
Goodlands	6.8	8.1	9.5	11.5
Holt Rock	5.9	7.1	8.3	10.1
Hyden	6.1	7.3	8.5	10.4
Jerramungup	6.0	7.3	8.5	10.3
Katanning	5.0	6.1	7.1	8.6
Kellerberrin	6.3	7.6	8.9	10.8
Kondinin	6.1	7.3	8.5	10.4
Lake Grace	5.6	6.7	7.8	9.5
Lake King	5.2	6.3	7.3	8.9
Manjimup	4.4	5.3	6.2	7.5
Merredin	6.3	7.5	8.8	10.6
Moora	6.3	7.5	8.8	10.6
Mukinbudin	6.6	7.9	9.3	11.2
Mullewa	7.1	8.6	10.0	12.1
Munglinup	4.5	5.4	6.3	7.7
Narembeen	6.1	7.3	8.5	10.4
Narrogin	5.2	6.3	7.3	8.9
Newdegate	5.7	6.9	8.0	9.8
Norseman	5.7	6.9	8.0	9.8
Northam	6.3	7.5	8.8	10.6
Perenjori	7.3	8.8	10.2	12.4
Ravensthorpe	4.7	5.6	6.6	8.0
Rocky Gully	3.7	4.4	5.1	6.2
Salmon Gums	5.0	6.1	7.1	8.6
Scaddan	4.4	5.2	6.1	7.4
Southern Cross	6.6	7.9	9.3	11.2
Three Springs	7.3	8.8	10.2	12.4
Wagin	5.2	6.3	7.3	8.9
Wialki	6.6	7.9	9.3	11.2
Wongan Hills	6.4	7.7	9.0	10.9
York	6.4	7.7	9.0	10.9

1. Daily drinking allocation has been modified by accounting for average maximum daily temperature and waste (20 per cent) factors. Particular attention should be given to the fact that different classes of livestock tolerate varying qualities of water (Luke 1987).
2. To convert mS/m to mg/L TSS multiply by 5.5; to convert mS/m to gr/gl TSS multiply by 0.385.

Reference

Farmer, D. and Coles, N.A. ,2003. Assessing the storage reliability of farm dams. *Tech. Rep.245 Dept. of Agric. WA*. ISSN 0729-3135.

Luke, G., 1987. Consumption of water by livestock. *DRM Tech. Rep. 60*. Western Australia Department of Agriculture.

Southorn, N., 1995. *Farm Water Supplies: Planning and Installation.* Inkata Press, Sydney. NSW.

1-5-2003

Assessing storage reliability of farm dams

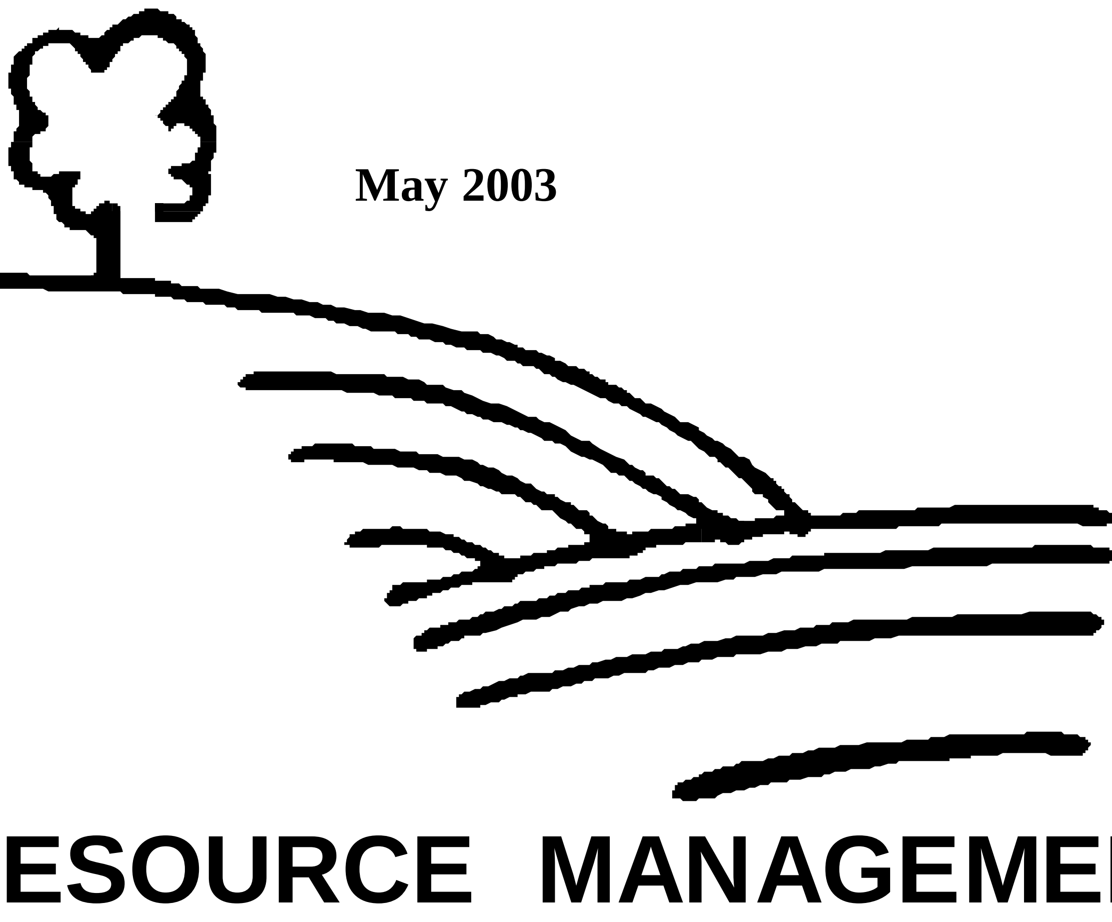
D Farmer

N Coles

Department of Agriculture
Government of Western Australia

ASSESSING STORAGE RELIABILITY OF FARM DAMS

By Darren Farmer and Neil Coles



May 2003

RESOURCE MANAGEMENT TECHNICAL REPORT 245

ISSN 1039-3205

Resource Management Technical Report 245

Assessing storage reliability of farm dams

Darren Farmer and Neil Coles

May 2003

Department of Agriculture
Government of Western Australia

Disclaimer

The contents of this report were based on the best available information at the time of publication. It is based in part on various assumptions and predictions. Conditions may change over time and conclusions should be interpreted in the light of the latest information available.

Contents

Introduction

During periods of low rainfall, dams with farmland catchments receive limited run-off. Dams with improved catchments normally receive minimal run-off. Any dam water then becomes a limited resource and needs to be managed effectively. Alternative water sources or management strategies will need to be considered *before* the water runs out.

This report provides information on a method to estimate the volume of water in a farm dam and to determine how long this water will last. It is intended to answer the question *"roughly how long will it be before the water in this dam will no longer provide a reliable supply?"*

Some of the important aspects to consider when calculating losses from farm dams under conditions of low rainfall are:

- due to sloping sides, the volume of water is less with each 1 m of depth, *i.e. a dam at one quarter its maximum depth holds significantly less than one quarter of its total capacity*;
- unless regularly maintained, farm dams generally accumulate sediments in the bottom 1.0-1.5 metres. This can cause a significant reduction in the expected volume of water stored in the dam;
- water quality generally decreases as dam depth decreases due to increased biological activity, evaporation and residual accumulation (e.g. salt concentration).

To estimate how long the water will last, data concerning demand and losses is required to begin water planning and budgeting. The most important facts to establish are:

(1) the volume of water in the dam;

(2) the expected demand on that water (i.e. rate of use) by livestock or domestic use; and

(3) critical losses (evaporation and leakage).

These methods are intended to provide the landholder with an indication of water supply over short periods only (i.e. in the order of 4-20 weeks). Should a more accurate estimate be required then the land owner should consult a hydrologist or Land Conservation Officer (LCO) at the Department of Agriculture.

1. Assessing remaining water supply

The first step in assessing the reliability of a water supply is to estimate the volume of water in the dam. Often, the depth has been reduced due to siltation. This means that you may not be able to guess the volume of a dam based on the constructed depth. This is particularly important during low rainfall years or periods where dam volumes are low. To calculate the volume and rate of loss. the geometry and dimensions of the dam are required.

1.1 Collecting information at the dam site

The following information should be collected (see Figure 1):

- length and width (rectangular dam) or diameter (circular dam) for the *surface of the water contained in the dam*;
- the depth of water *to the top of the sediment* (i.e. mud layer) in the bottom;
- the slope of the dam sides (batter slope) or batter.

Instructions on how to obtain these are contained in Appendix D**.**

Note: Where water quality is in doubt it may be necessary to collect a water sample in a clean plastic or glass bottle. Salinity and acidity measurements can be conducted at Department of Agriculture offices. For other water quality measurements contact the WA Chemistry Centre.

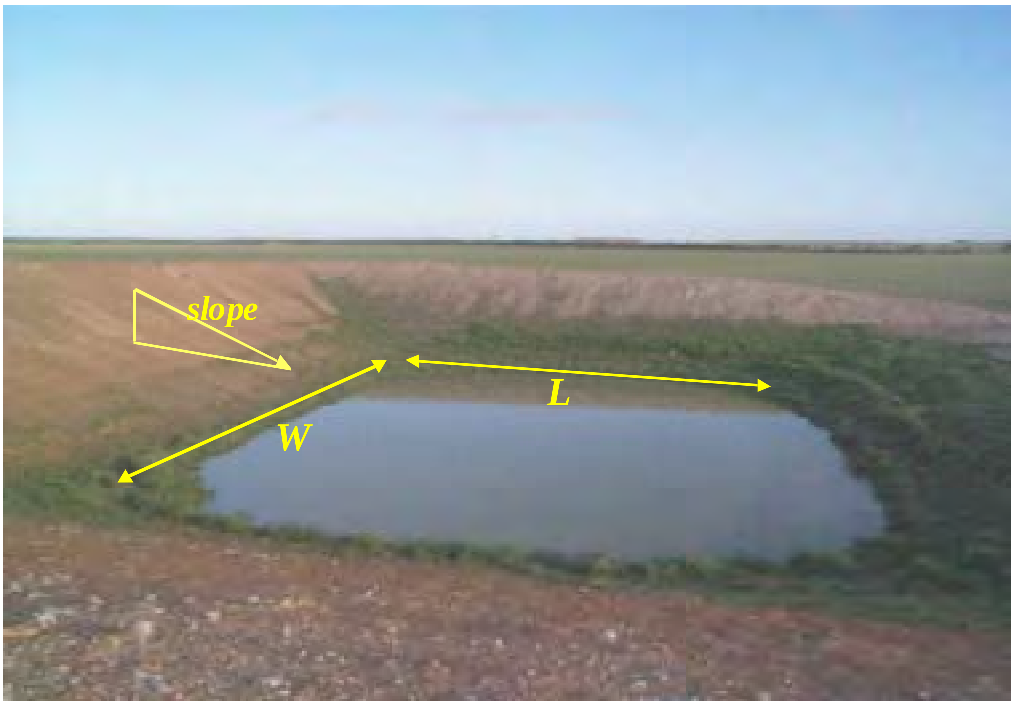


Figure 1: Measurements needed related to dam (in addition to water depth)

It is important to confirm that the water depth is measured as the distance between the surface of the water and the top of any sediment in the dam (see Appendix D).

This is because in most cases, water below 0.2 m cannot easily be accessed by stock or extracted by pumping, and is usually of poor quality.

It is recommended that the reader refer to the appendices (listed) in order to become familiar with measuring dam properties and obtaining the surface area and remaining water volume for a given depth.

Calculating the surface area and volume

The Department of Agriculture provides easy-to-use computer software that can estimate dam volumes from the basic information indicated in Figure 1. Alternatively, use the graphs in Appendix A, or the equations in Appendix B.

The most important information is the water surface area at measured depths and the change in volume with depth. A worksheet and explanation for manual calculation of these is in Appendix B.

When calculating values it is important to understand that as the water depth in the dam decreases, the length and width will decrease at a rate proportional to the batter slopes. The rate of reduction for a dam with a 1:3 batter is shown in Figure 2.

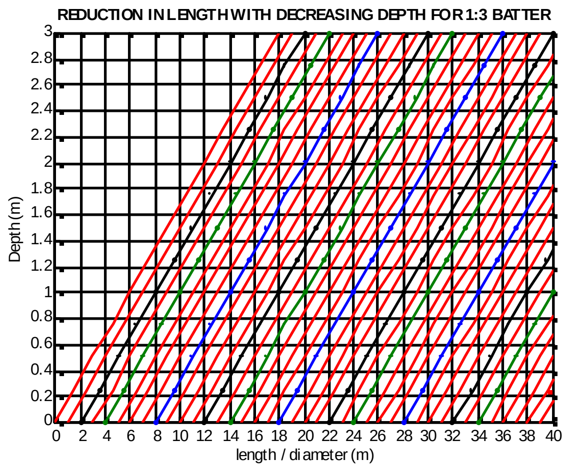
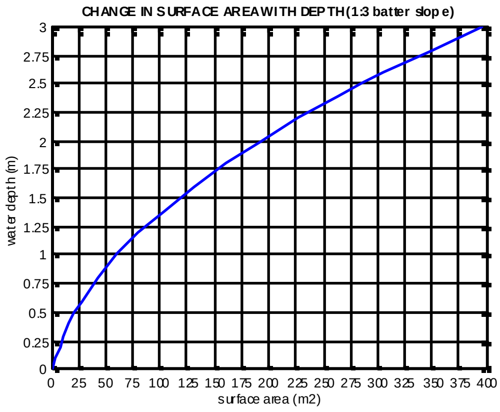


Figure 2. Reduction in length with depth for a dam with batters of 1:3

For example a farm dam has a length of 10 m when the water is 1.2 m deep. Locate 1.2 m and 10 m on the graph. Follow the lines across and upward to the point where they intersect. Follow along the closest diagonal line to this point to determine change in length as depth increases or decreases (e.g. *at 0.6 m deep the length will be 6.4 m while 1.6 m deep would give a length of 12.4 m*). The same can be done for width. Full size graphs for dams with 1:3 and 1:2 batters are in Appendix A.

Once the length has been resolved for a given depth, it is possible to determine the surface area at depth, and hence the volume. Figure 3 illustrates the change *in surface area with depth*. The ratio is important as it impacts upon the volume of water lost to evaporation. Figure 4 shows that *volume will decrease more quickly as the depth of water in the dam decreases*.



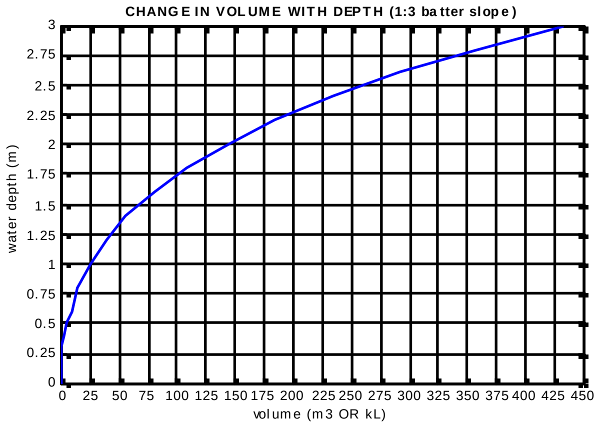


Figure 3. Decrease in surface area and stored volume with depth for a dam with water surface dimensions of 10 m x 8 m at 1.2 m depth (W=0.8 L) and 1:3 batters

Plotting volume versus depth clearly demonstrates the effect that changing depth has on the volume of available or stored water. For example, at a depth of 1.5 m the dam only stores a volume of 65 m^3. This is much less than half of the 432 m^3 when the dam is 3 m, or twice as deep (*i.e. half the depth yet only 15% of the capacity*).

These graphs give surface area and volumes for dams of a specific design. For accuracy in determining the surface area and volumes of other dams, run a series of calculations and compile a table (e.g. Table 1).

Table 1: Example dimensions for a rectangular dam with water surface 10 m x 8 m at 1.2 m deep and batter slopes of 1:3.

Depth (m)	Surface area (m^2)	Volume (m^3 or kL)
0.2	8.0	1.0
0.4	16.6	3.4
0.6	28.2	7.8
0.8	42.6	14.8
1.0	59.8	25.0
1.2	80.0	39.0

Due to the strong relationship between depth, slope, length, surface area and volume it is necessary to carry out all calculations, regardless of method. The long-hand or manual approach, and Dam Volume Calculator program are discussed in Appendices B and C.

Charts are provided for 1:3 and 1:2 batter slope dams in Appendix A. Information from these should be used with caution as some water below 0.2 m may be unavailable due to poor quality. Refer to Example 1 in Appendix B. The volume at a constructed depth of 1.2 m is 39 m^3. The volume of the low quality portion below 0.2 m is 1 m^3. This means that there is only an available volume of 38 m^3.

2. Estimating demand volumes

To estimate demand, include all water that will be removed from a dam. This can include losses due to evaporation, leakage, livestock water use and water that is pumped for on-farm or domestic use.

2.1 Evaporation

Evaporation depends on temperature, humidity, wind, the surface area of water and orientation of the dam. Hot, dry, windy days will cause greater water loss than cold still days. Similarly, evaporation is usually much lower in the winter than that experienced during summer. *Average monthly evaporation rates for various districts are included in Appendix E.* This table should be used to obtain an average evaporation value for the nearest station to your location.

To calculate the evaporative loss use the following equation:

Equation 1 $$\mathrm{EVAP\,(m^3)} = \mathrm{SurfAREA} \times \frac{\mathrm{dEVAP}}{1000} \times n\_days$$

where:

SurfAREA is the surface area of the water in the dam in m^2;

dEVAP is daily evaporation rate obtained from Appendix E and converted to mm/day by dividing by the days in the month; and

n days is the number of days over which the total evaporative loss is calculated.

Since evaporation is dependent upon various factors it is recommended that calculations be checked regularly against what is actually happening in terms of changes in depth of water in the dam over a seven day period.

2.2 Livestock water use

Livestock water use is discussed in detail by Luke (1988) and sheep drinking rates for various agricultural centres are included in Appendix F.

Livestock drinking rates are based on a dry sheep equivalent (DSE) which is defined as a 45 kg dry (i.e. non-lactating) sheep in forward store condition during summer on a maintenance diet of sub. clover or better pasture. Pigs (free range) and cattle/horses consume water at rates equivalent to 2 and 10 DSE respectively.

During a low rainfall year the lack of winter pasture often necessitates hand-feeding, or feeding alternative herbage. A minimum water requirement of 2 L/head/day is suggested for stock under these circumstances (Luke 1988).

Where water supplies have higher salt concentrations, or where stock are being sustained on alternative feed, such as saltbush, then water consumption has been found to be much higher (Table 2).

Table 2: Typical sheep drinking rates with increased salt content

Total soluble salts (mg/L)	Consumption factor compared to tabulated DSE rates (sF)
Fresh water	1
3,500	1.2
7,000	1.4
10,500-14,000	1.7-2.8

To calculate livestock demand, first estimate the number of DSEs that have access to the water supply. Use the tables in Appendix F to estimate the expected water demand for sheep in your locality. Determine the potential salt concentration and read the correction factor from Table 2 or Appendix F.

Equation 2 $$STOCK\ (m^3) = \mathrm{n}DSE's \times \frac{\mathrm{dRATE}}{1000} \times \mathrm{sF} \times \mathrm{ndays}$$

where:

nDSE is dry sheep equivalent;

dRATE is the value obtained from Appendix F (L/DSE/day);

sF is the salt factor from Table 2 above; and

ndays is the number of days over which the volume is being computed.

2.3 Domestic and other water use

Water extracted from farm dams for low quality domestic use, gardens or spraying is usually pumped from the dam. The rate at which this occurs is dependent on the system in use, the pump extraction rate and the length of time the pump operates. A best guess estimate is required for daily extraction volumes in kilolitres/day or cubic metres/day. As many people estimate water volumes in units other than m^3 or kL a set of conversion factors is provided in Table 3.

Table 3: Conversion rates for various volume measures

Volume unit	Conversion factor
Cubic metre (m^3)	1 m^3 = 1 m^3
Litre (L)	1 L = 0.001 m^3
Kilolitre (kL)	1 kL = 1 m^3
Gallon	1 gal = 0.00454 m^3
Cubic yard	1 cu. yd= 0.76455 m^3
Cubic foot	1 cu. ft = 0.028316 m^3

If a pump is being used the volume consumed can be estimated by multiplying the pump rate by the time over which the pump is run.

Example 1. A 300 L/hr pump is run for 5 hours each day to top up an auxiliary house tank that is used for non-drinking purposes (e.g. toilet, shower, vegetable garden). Assume that this rate is applicable after head losses have been accounted for (refer to pump literature to assess head loss).

300 L/hr X 5 hrs = 1500 L
1 litre = 0.001 kL

Convert L to kL
1500 X 0.001 =1.5 kL
Volume required for 30 days
30 X 1.5 = 45 kL

Example 2. A 600 kL/day pump is run for 6 hours to transfer water.

Calculate fraction (f) of day;
6 hours = 6/24 hrs = 0.25 day,
Volume of water transferred is:
=fday X pump rate
= 0.25 X 600 = 150 kL/day

When calculating the volume required it is best to list all the expected uses and then try to estimate how much water will be needed on each occasion. Once this has been established, simply multiply the single instance volume by the number of days that the volume of water might be required during the period of estimation.

The total external water demand is the sum of all water that is being extracted. Care must be taken to ensure that volumes are converted to the same units and the time period being considered. This will generally be per week or per month. To ensure consistency with dam storage all volumes should be converted to m^3.

3. Determining reliability of supply

Total demand is simply the sum of all water requirements. In essence, if there is sufficient water in the dam to meet these requirements then the supply is termed reliable. If the demand is predicted to exceed the stored water capacity at any time the supply is termed unreliable and alternate measures will need to be taken such as reducing demand or carting water. The supply evaluation process is summarised in Figure 4.

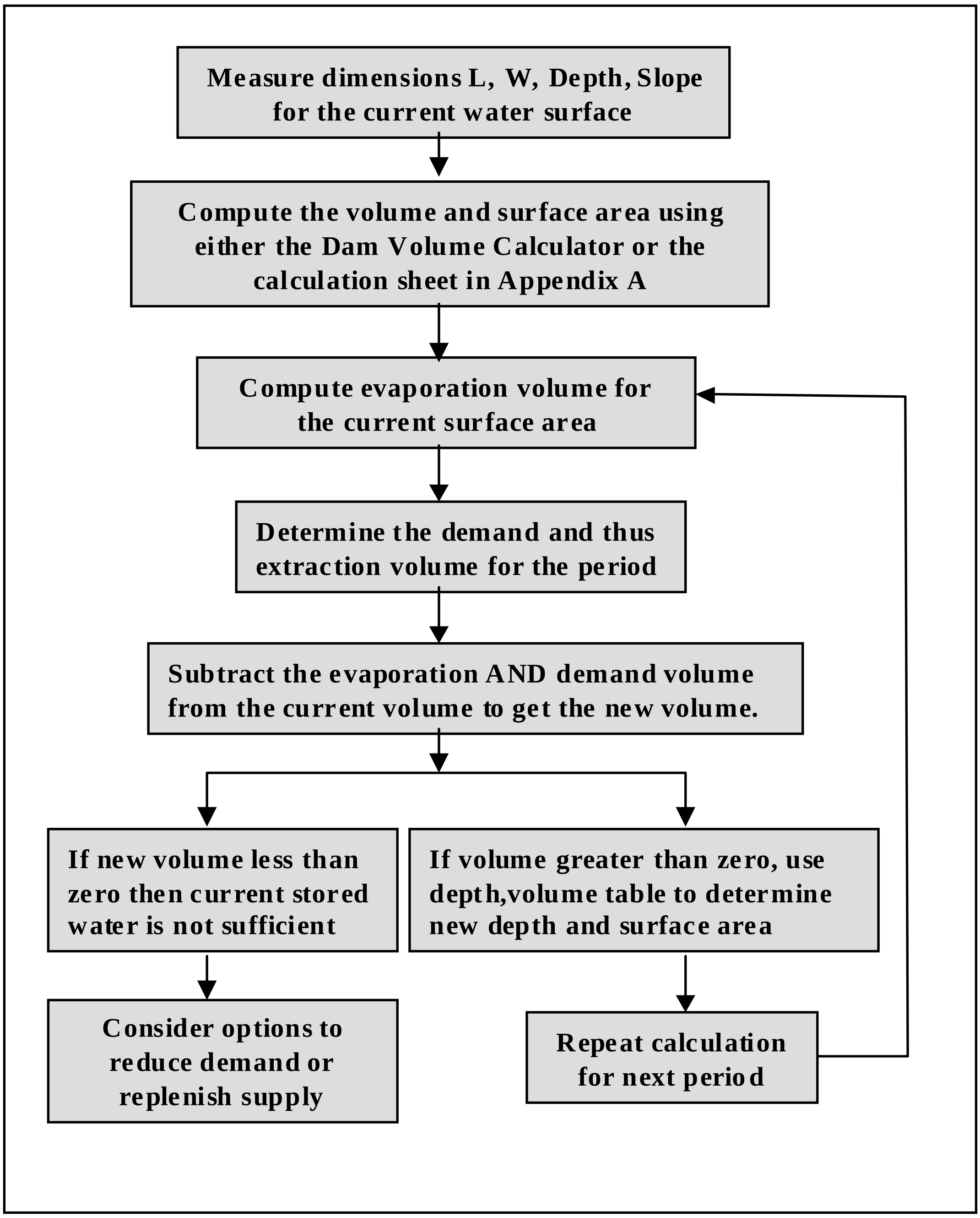


Figure 4: Calculation process for determining the reliability of a farm dam over a period of 1-4 months (assuming no inflow during the period)

The steps involve those discussed in Sections 1 and 2: visiting the dam site; collecting the right measurements; determining the stored water volume; rating available water against expected demand for a designated period.

The reliability of the estimation will be influenced by the time frame over which the demand is calculated. At smaller periods (e.g. a week) the updating of surface area will tend to produce more realistic estimates of the evaporated volume. For many purposes however fortnightly or monthly computations are sufficient.

Example 3. The rectangular dam shown in Figure 1 (and referred to in Figures 2 and 3, and Table 1) is required to support 200 sheep and supply 3000 L of water per fortnight to the homestead. The dam is in the Lake Grace district and the month is May during a low rainfall year in which the dam has yet to receive substantial run-off.

Field inspection found the water surface was 10.0 m x 8.0 m and 1.2 m deep. The dam has a batter slope of 1:3.

Calculations to assess reliability of dam for May

(i) From Table 1 the volume of water available is 39 m^3 and surface area is 80 m^2 (see example in Appendix B).

(ii) From Appendix E evaporation from dams at Lake Grace in May is typically 69 mm/month or 69/31 = 2.2 mm/day.

EVAP (m^3) = SurfAREA x dEVAP/1000 x n_days (Equation 1)

80 x (2.2/1000) x 31days = 5.5 m^3/month

(iii) Livestock use is 2 L/day/DSE due to hand feeding and there are 200 sheep. The water in the dam is slightly brackish (est. 2000 mg/L)

STOCK (m^3) = nDSEs x dRATE/1000 x sF x ndays (Equation 2)

2 x (200/1000) x 1.1 x 30 =13.2 m^3/mth

(iv) Domestic requirement is 3,000 L per fortnight or about 6 m^3/mth

(v) Total demand is therefore:

5.5 + 13.2 + 6.0 = 24.7 m^3 during May

(vi) At the and of May therefore…

new Vol = old Vol – demand

= 39 m^3 – 24.7 m^3 = ***14.3 m^3***

Looking up volume of 14.3 m^3 in Table 1 we find that this is associated with a depth of approx. 0.8 m (i.e. at the end of May the dam will have dropped by 0.4 m if there had been no inflow during that time).

Calculations to assess reliability of dam for month of June

(vi) The new surface area is approx. 43 m^2 and June evaporation is 43 mm (1.4 mm/day).

EVAP (m^3) = SurfAREA x dEVAP/1000 x n_days (Equation 1)

43 x (1.4/1000) x 30 days = 1.8 m^3/mth

Assuming the stock demands remain the same:

Demand = 1.8 + 13.2 +6 =21 m^3/mth

(vii) Since the demand volume exceeds the available volume (i.e. 21 >14.3), then it is likely that the dam will fail in the next month.

Even if 6 kL for the house supply is taken from another source the livestock and evaporation losses will still result in dam failure by the end of June.

It is probable that the water level will not drop to exactly 0.8 m. It may be more or it may be less. Hence it is important that actual water levels are monitored over the period. With regular monitoring of dam water levels it should be possible to refine water use and supply estimates.

4. Maximising limited water supplies and promoting efficient recovery

Excess run-off and recharge in agricultural areas are prime causes of waterlogging and salinity. In some cases, the same farms that are exposed to these problems also experience water shortages regularly.

In the eastern wheatbelt low rainfall periods can occur every three years, while in other agricultural areas there may only be one significant event per decade.

Water is an essential part of a farming enterprise. It makes sense to plan for low rainfall periods given their frequency. Some farms in Western Australia have a poorly designed infrastructure that does not allow the landholder to take advantage of water harvesting, storage and management techniques that will enable them to develop reliable water supplies. Through good design it is possible to generate and store run-off even in below average rainfall years.

These options exist for landholders that are regularly faced with water shortages;

- cater for existing demand by increasing on-farm storage;
- reduce demand through livestock reduction via sales or agistment;
- reduce home and garden use;
- maximise the harvesting of rainfall through improved catchments and diversion structures;
- develop a maintenance program for existing water supplies to ensure they are operating at optimum storage and collection capacities.

4.1 Increasing on-farm water storage

Increasing available storage on a property is the one step towards improved water supply reliability. Where existing dams fill regularly and excess run-off is not captured, various options exist to site a new dam below the existing dam (i.e. dams in series or double-dams). Effective options include siting a second dam off the drainage line and using the first to keep this dam topped up. Where the second dam is large, banks and roaded catchments can be used to increase the inflow.

Increases in storage should not be limited to earth dams. Efforts should be made to link rain tanks to all available roof areas for domestic or crop spray requirements. The **RAINTANK™** calculator is a simple roof-run-off-storage evaluation program that enables the user to determine how effective their current system is and what size roof or tank is required to improve that system. The software is provided free by the Department of Agriculture and can be obtained from the DRAINWISE website (*www.agric.wa.gov.au/drains*). The calculator is Windows compatible and is designed to assist landholders in matching roof areas to tank sizes for the agricultural areas. Roof materials (e.g. corrugated iron, tiles etc) are capable of harvesting 70 to 80% of rainfall.

For example a 30 m x 10 m galvanised shed offers a catchment area of 300 m^2. During a 10 mm rainfall event this surface, if properly guttered, is capable of yielding 2.0 to 2.2 m^3 (or 2,000 to 2,200 litres) of rainwater suitable for domestic use.

4.2 Maximising water harvesting

A major problem faced by property owners during low rainfall years is that many farm dams fail to fill. This is typically because a large portion of the initial rainfall simply soaks into the ground due to the dryness of the soil profile. Even in high run-off landscapes such as duplex soils and clays, up to 40 mm of rainfall may be required before the soil moisture deficits and detention storages are satisfied and run-off is generated. In deeper profiles and sandy soils this value can be significantly greater. Consequently, vital water supplies are lost and shortages may persist even after significant rainfall.

Roaded catchments

Roaded catchments, located above dams, are essentially compacted areas of hillslope, typically covering about 2 to 5 hectares (e.g. about 30-50 m wide and 70-200 m long), which have been surveyed and compacted to a design grade (0.5–1%). Experience in wheatbelt areas has shown that well maintained roaded catchments can deliver run-off volumes of 40,000-100,000 L from rainfall events as little as 10 mm. A well sited roaded catchment can deliver recharge volumes equivalent to meet one to two months of summer water demand for 1000 sheep from a single summer storm (based on 15-20 mm event and 2-5 ha catchment). The same rainfall event may not yield any significant inflow from a natural catchment.

The potential contribution of a roaded catchment to maintaining viable supplies of water can be assessed using the **DAMCAT-3^{TM}** farm water supply design and assessment program. This software, developed by the Department of Agriculture, is used to match catchment areas to farm dam volumes for a given demand. Local rainfall records are used to assess the reliability of the catchment-dam combination for low rainfall years. DAMCAT-3 can be downloaded from the DRAINWISE website and was developed to run on most Windows platforms.

Roaded banks

An alternative to a roaded catchment is a roaded bank. These are essentially large broad flat-sectioned collector banks 8-20 m across running at grades of 0.5-1% similar in design to contour and level banks used for soil conservation, (which are typically 4-5 m across). The advantage is that, while acting as a collector bank for larger rainfall events, rainwater is also harvested during low rainfall events. In this respect roaded banks have been found to be more readily acceptable than having both water harvesting and soil conservation structures in the same paddock. This reduces the amount of area lost to production.

Opportunities exist to adopt dam designs that promote storage and minimise losses. These include above-ground circular earth or flat batter dams where deep dams are otherwise not possible, and the use of dam liners where local construction materials may be prone to leaking.

Recent research work funded by the Water and Rivers Commission, Department of Agriculture and the Office of Water Regulation has sought to reduce evaporation losses through the use of well sited shelter-belts, wind barriers and alternative dam construction techniques. These methods aim to minimise, or disrupt, water-surface-air interaction and therefore interfere with the uplift of water vapour. Information on windbreaks is available in Farmnote 80/2002.

4.3 Adopting a maintenance program

Combining the engineering concepts with proper design of water harvesting structures can often readily overcome many aspects of limited farm water supplies. However, if these structures are not properly maintained then they become less efficient, and the ability to effectively harvest water is compromised (i.e. the water supply is less reliable).

A regular maintenance program should be adopted for all the dams and roaded catchments on the property. Good design, such as silt traps and piped inlets for dams, can reduce the need for de-silting of the main dam. Weed control and surface grading on the roaded catchment will help maintain its efficiency in low rainfall years.

Further information regarding the improvement and development of on-farm water supplies can be obtained by contacting your local Department of Agriculture or the Drainwise website.

References

Department of Agriculture. (In prep). DAMCAT-3 user documentation.

Department of Agriculture. (In prep). RAINTANK user documentation.

Hauck, E.J, and Coles, N.A. (1995). 'Farm water supply reference data for raintanks and surface water.' Unpublished report, Department of Agriculture.

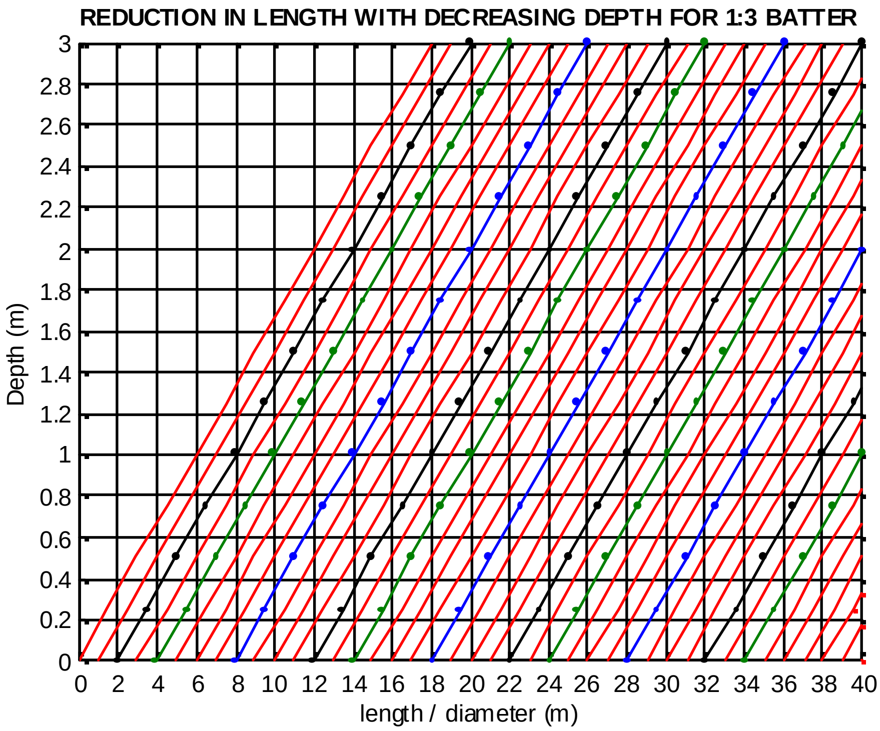
Laing, I.A.F. (1985). Improved catchments for farm dams. Journal of Agriculture WA. 26: 67-69.

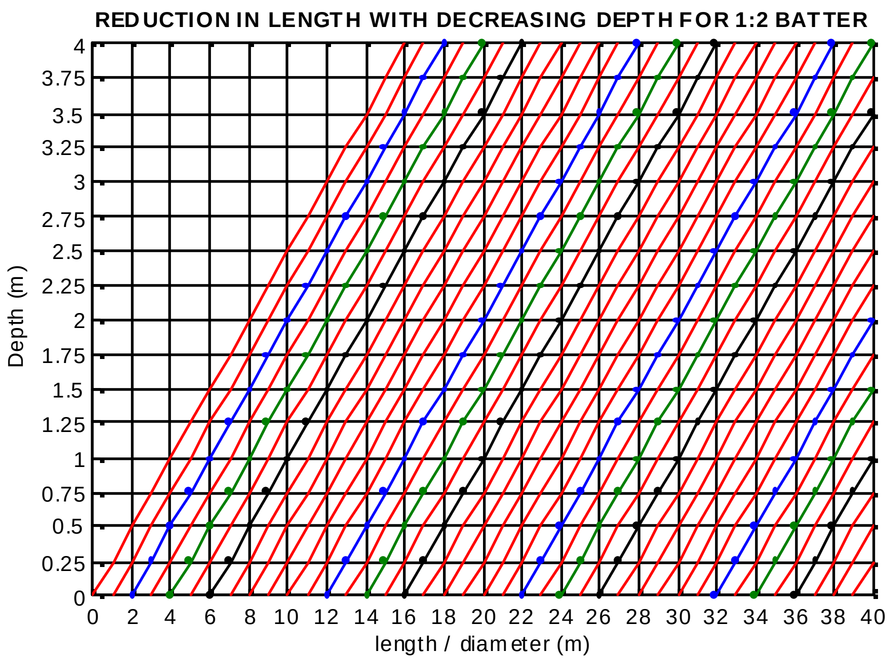
Laing, I.A.F. (1981). Evaluation of small catchment surface treatments. Australian Water Resources Council Technical Paper No. 61. Australian Government Publishing Service, Canberra.

Luke, G.J., Burke, K.L., O'Brien, T.M. (1988). 'Evaporation data for Western Australia', Resource Management Technical Report 65, Department of Agriculture.

Luke, G.J. (1988). 'Consumption of water by livestock'. Resource Management Technical Report 60, Department of Agriculture.

Appendix A
Charts and graphs for estimating dam storage dimension





Charts 1 & 2: Reduction in the length of the water surface with decreasing depth for farm dams with batter slopes of 1:3 and 1:2 respectively. To use this chart, first identify the current water surface length and depth. Find the closest diagonal line to where these intersect. Move up or down this diagonal line to estimate the increase or decrease in water surface length with increased or decreased depth.

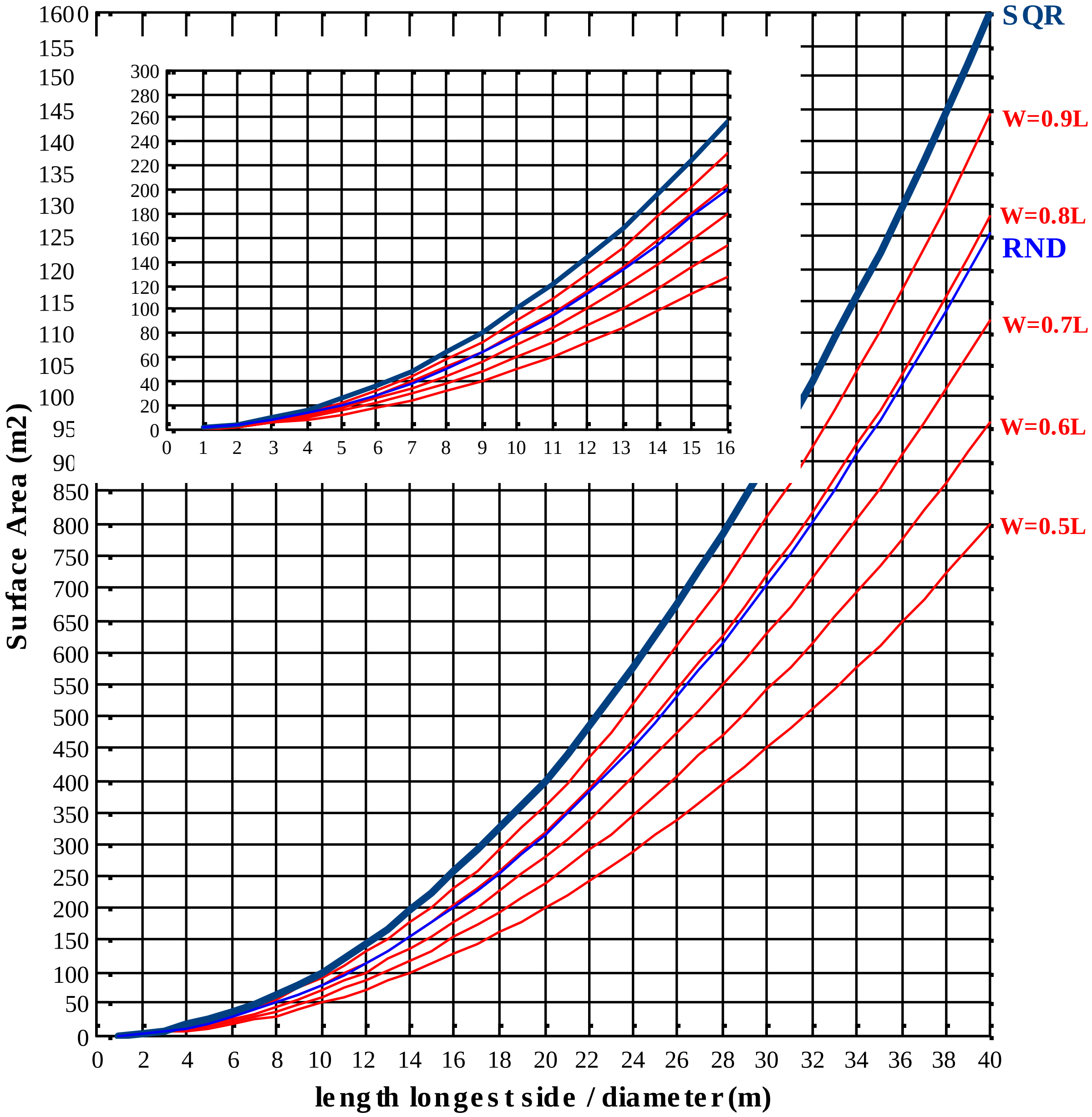
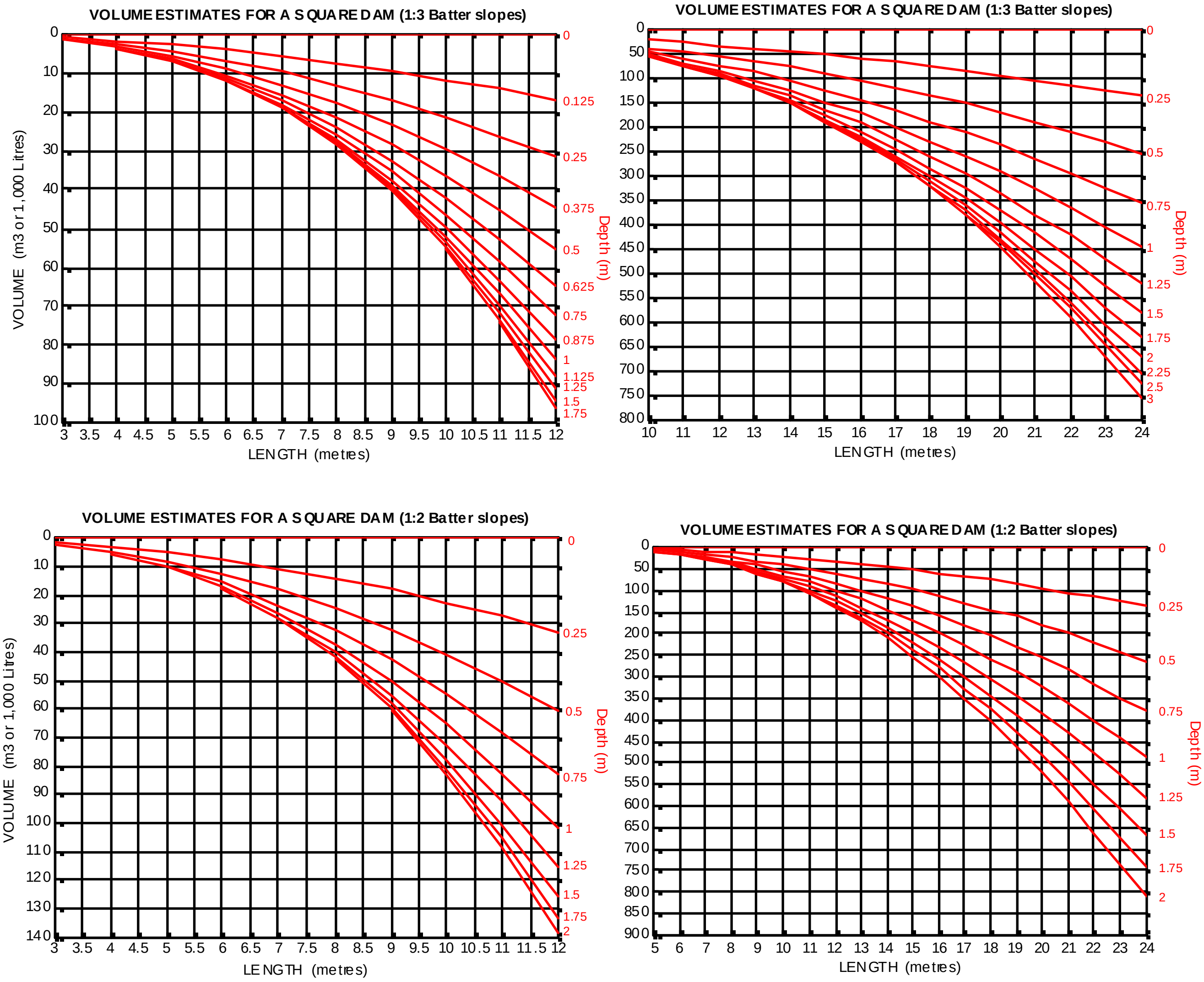
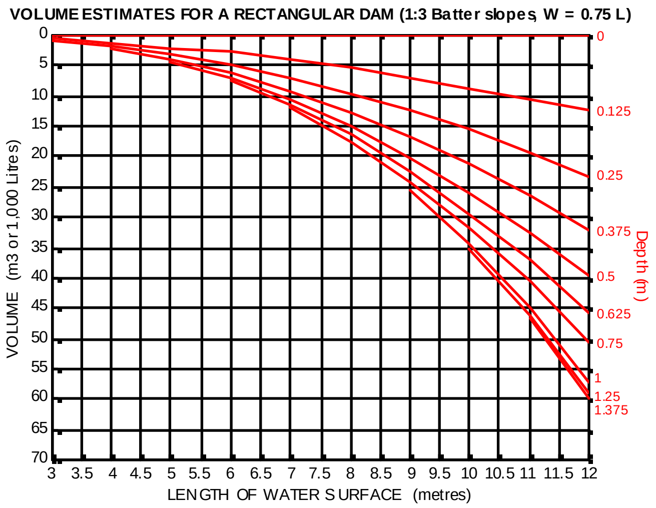
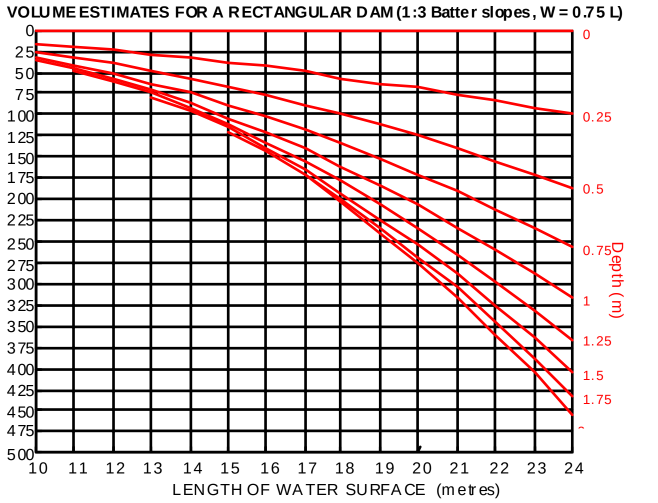


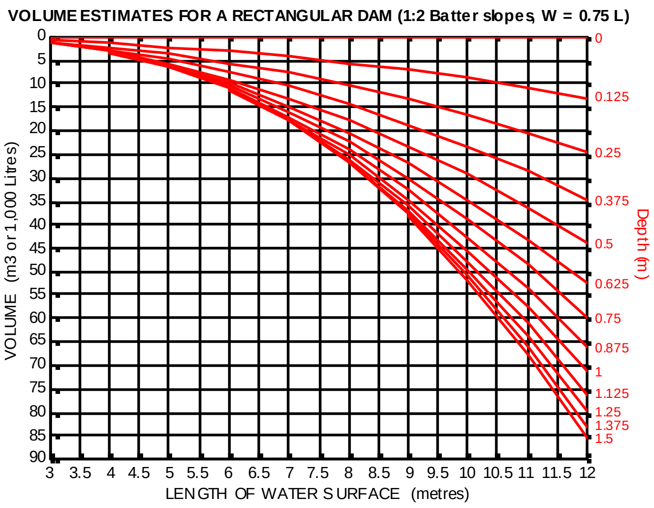
Chart 3: Surface area for varying lengths (of a square dam) and diameters (for a circular dam) of the surface water level in farm dams. Inset shows enlarged section of the lower left of the chart. SQR line is for square dams (i.e. L = W), RND is for circular dams (i.e. L = diameter) and red shows various rectangular configurations (for example W = 0.8 L implies that a dam with L=20 m will have W = 16 m).

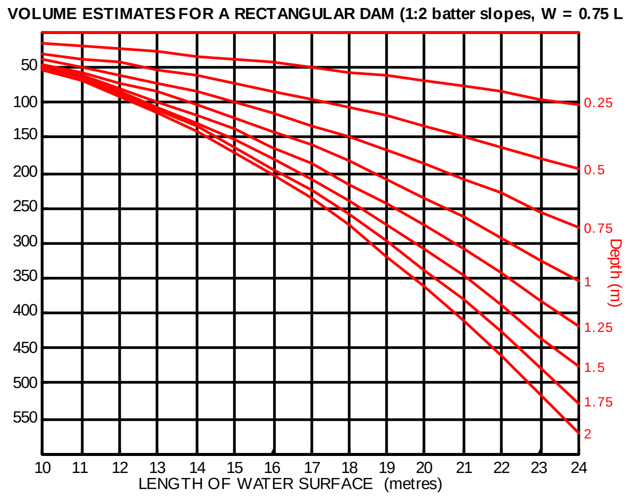


Charts 4, 5, 6 & 7: Length, depth and volume charts for square dams with batter slopes of 1:3 and 1:2.

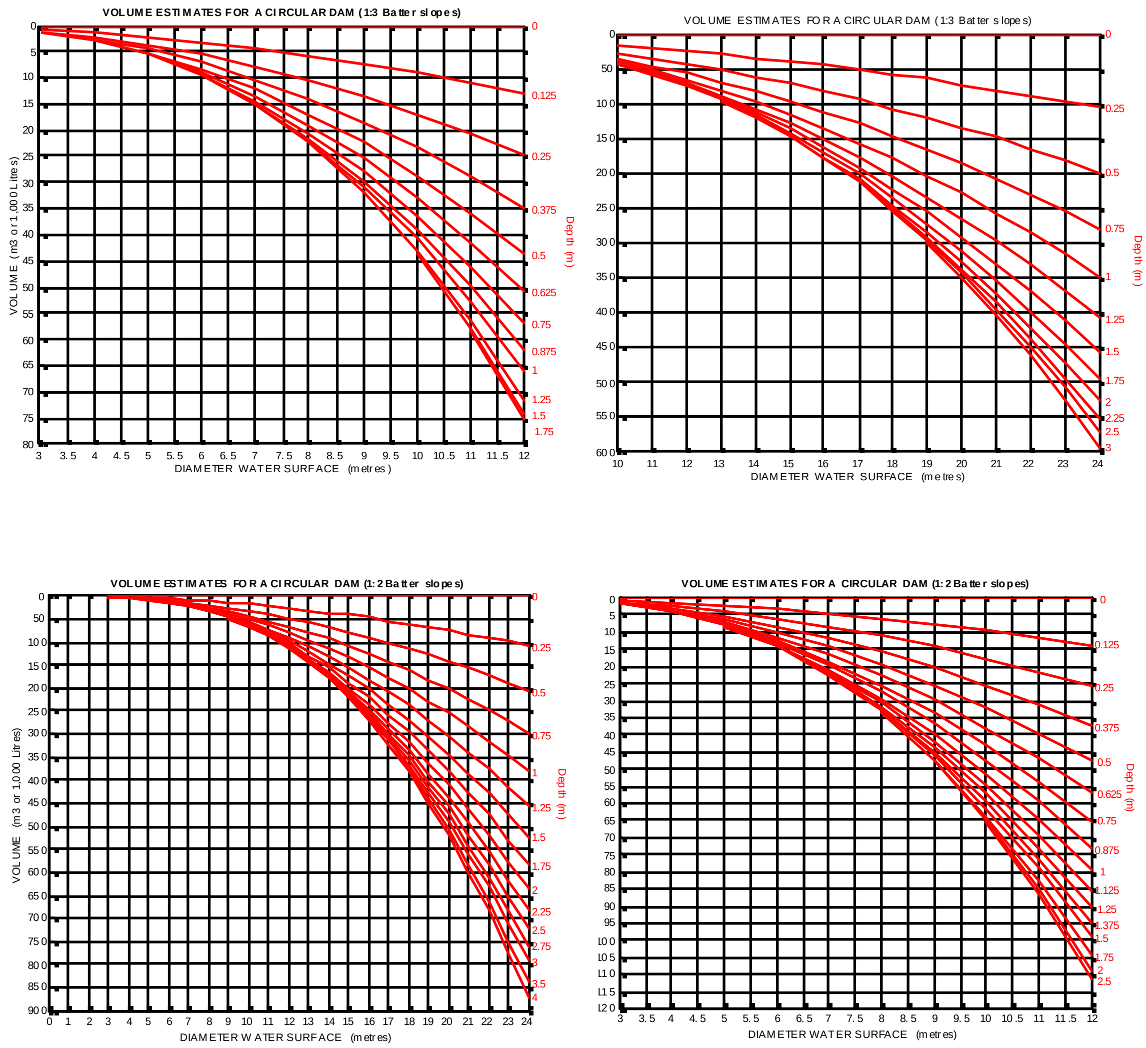






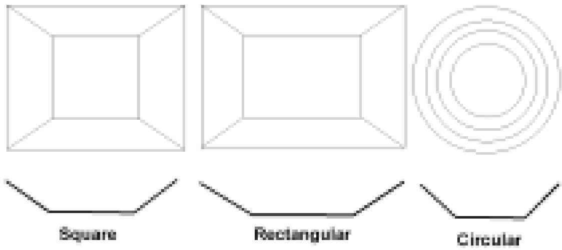


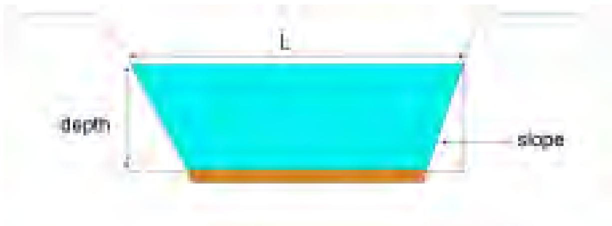
Charts 8, 9, 10 & 11: Length, depth and volume charts for rectangular dams with batter slopes of 1:3 and 1:2 and L:W ratio of 0.75.



Charts 12, 13, 14 & 15: Length, depth and volume charts for circular dams with batter slopes of 1:3 and 1:2.

Appendix B
Computing dam volume and surface area





Dam volumes can be estimated using calculations applicable to the geometric shapes they most closely resemble. The simplest shapes are square, rectangular and circular. The cross-section of all three types is trapezoidal (see above). The valley dam or gully wall dam is not considered here.

For a trapezoid, knowing the length, depth and slope is sufficient to calculate any other dimension (see Appendix D for how to calculate depth, length and width). For dam volumes the base is the only remaining unknown.

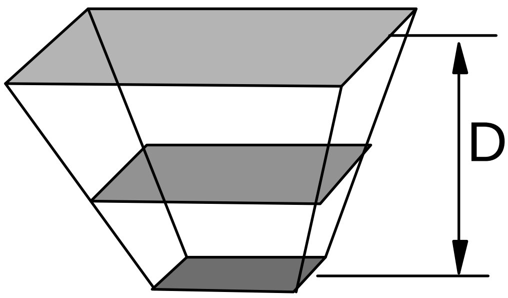
If we express slope in the form 1 m rise for every x m, then the term 1-in-3 (or 1:3) means that we have a 1 m rise for every 3 horizontal metres. A 1:3 ratio gives the value of 3 for slope, for the purposes of these calculations. See Appendix D for more.

To determine the length and width of the dam base:

Base_L = Length - 2 x (Depth x Slope)

Width_L = Width - 2 x (Depth x Slope)

Since the dam is assumed to be a regular shape (i.e. constant batter slope) then the following formula is used to calculate the volume.



$$VOL = \frac{D}{6}(\ AR_{top} + 4\ AR_{mid} + AR_{base})$$

Where AR_{top}, AR_{mid} and AR_{base} are the surface areas of the top, middle and base of the dam, respectively.

This method requires three cross-section areas to be known - the surface, base and mid-sections. *Note that the mid-section area IS NOT simply the average of the surface and base*. The mid-length and width must each be computed:

$$\text{Mid\_L} = \text{Length} - 2 \times \left(\frac{Depth}{2} \times \text{Slope}\right)$$

$$\text{Mid\_W} = \text{Width} - 2 \times \left(\frac{Depth}{2} \times \text{Slope}\right)$$

Areas are calculated using the formulae:

for square and rectangular dams:

AREA = Length x Width

for circular dams:

R = radius = diameter divided by 2

AREA = R x R x 3.1415926

Example: Rectangular dam

Dam water surface measures 10 m x 8 m, slope is found to be 1:3 and the water depth is 1.2 m. Compute the volume of water.

AR_{top} = surface area = 10 x 8 = 80 m^2

Base_L = 10 – (2 x (1.2 x 3)) = 2.8 m

Base_W = 8 - (2 x (1.2 x 3)) = 0.8 m

AR_{base} = 2.8 x 0.8 = 2.24 m^2

mid_L = (10+2.8)/2 = 6.4m

mid_W = (8+0.8)/2 = 4.4m,

AR_{mid} = 6.4 x 4.4 = 28.2 m^2

VOL = (1.2/6) x (80 + (4x28.2) + 2.24)

= 39.0 m^3

Volume of water is 39.0 m^3

Example: Circular dam

Diameter of dam at water surface measures 10 m (R=d/2 = 5 m). Slope is found to be 1:3 and water depth is 1.2 m. Compute the volume of water.

AR_{top} = surface area = R x R x 3.1415926 = 5^2 x 3.14 = 79 m^2

Base_d = 10 – (2 x (1.2 x 3)) = 2.8 m; R = d/2 = 2.8/2 = 1.4 m

AR_{base} = R x R x 3.1415926 = 1.4^2 x 3.14 = 6.2 m^2

Mid_d = 10 – (1.2x3) = 6.4m; R = d/2 = 6.4/2 = 3.2 m

AR_{mid} = 3.2^2 x 3.14 = 32.2 m^2

VOL = $D/6(AR_{top} + 4AR_{mid} + AR_{base})$ = 1.2 m/6 (79 + 4(32.2) + 6.2)m^2

= 42.8 m^3

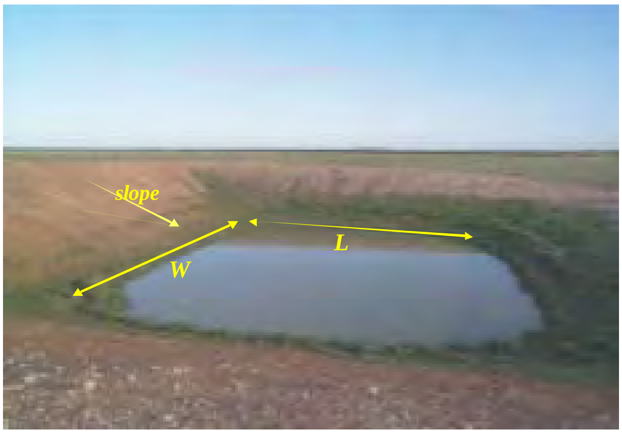
Volume of water is 42.8 m^3

Appendix C

Using the Dam Volume Calculator to assess water supply reliability of a farm dam

The Dam Volume Calculator computes volumes and unknown dimensions for regularly-shaped farm dams. It allows a range of questions relating to the design of new dams and the water supply assessment of existing dams to be answered.

Data required (should be in metres)



The first step is to obtain the data required to assess the dam. For an existing dam, such as that shown above, it is necessary to know the **length** and **width** of the water surface, the **depth** of the water and the **slope** of the batters. A summary of methods used to obtain these can be found in Appendix D.

Setting up the Dam Volume Calculator

Run the Dam Volume Calculator, and select the appropriate dam geometry (square, rectangular or circular). For existing dams it is necessary to select the '**solve for bottom dimensions'** mode (since slope, depth and surface dimensions are known).

Enter the field measurements in the appropriate boxes. If the depth measurement penetrated the bottom sediment enter the sediment thickness otherwise use the default value. The *actual* water depth and *maximum depth should both be the same for the first run.* Enter an appropriate value for daily evaporation (see Appendix E) and select the desired volume units.

Check that the data has been entered correctly and then press **COMPUTE**. The dimensions of the base have now been computed. If the water depth is set the same as the dam depth then the data in the lower part of the output screen will correspond to the current water surface.

The base dimensions should be recorded on a sheet of paper because to calculate the capacity or volume above the current depth it will be necessary to change to the mode to ***'Solve Top'***.

Assessing volumes as water levels fall

After completing the initial calculation it is only necessary to change the water depth value to calculate the remaining volume as the storage declines. After entering a new depth press **COMPUTE** to calculate the new volume.

Water budgeting

The Dam Volume Calculator can assist in determining whether the current volume of water in a dam is sufficient to meet expected demand.

First run the Dam Volume Calculator as described for the current water surface level. Record the *volume, surface area* and *evaporation losses* on a sheet of paper.

Next determine the total amount of water that is required for the period of interest (i.e. week or month). This should include all water for livestock, farm and domestic use. Ensure this value is in the same units as those set for the Dam Volume Calculator (e.g. M^3).

The computed evaporation loss is for one week. If the period of interest is greater than a week then the value must be multiplied appropriately (e.g. if the period of interest is one month then multiply by 4 to obtain a close approximation).

Enter the figures from the Dam Volume Calculator and what has been determined to be the demand into the following equations:

Total Demand = VOL water needed + VOL evaporated

New Dam VOL = Current Dam VOL – Total Demand

If the total demand exceeds the current volume then the dam will fail within the time period assessed if no rainfall occurs.

As it is not possible to directly compute the new depth with the calculator, the best approach is to create a table of depths and volumes at 0.1-0.2 m intervals from the current depth down to 0.2 m (similar to Table 1). Once the ***'New Dam Vol'*** has been determined look up the corresponding depth value in the table, enter this new depth in the water depth box and press **COMPUTE.** Repeat the process for the next period.

N.B. Evaporation reduces as the dam water level drops. Hence it is advisable not to exceed time periods of one month for each iteration.

Appendix D
Obtaining storage volume information for a farm dam

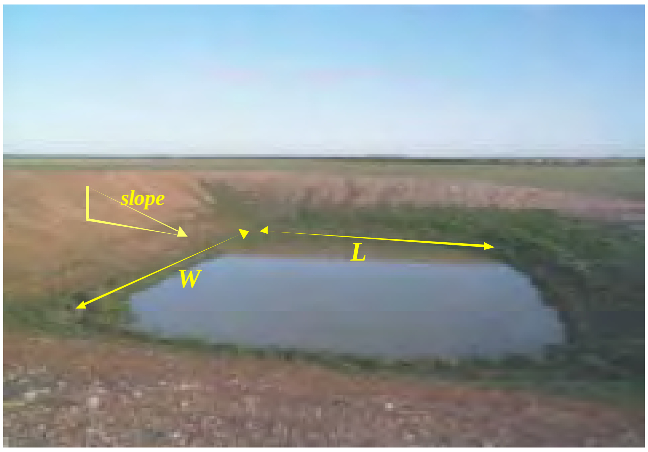


Figure D1: Measurements that should be taken when inspecting a farm dam (in addition to water depth)

When determining the dam reliability it is important that the dam be inspected and measured. Visually estimating water volume is not good enough to obtain a reliable assessment of the projected dam performance. To obtain the best estimate of the existing dam volume it is necessary to determine the following dimensions:

Square or rectangular dam: Length, Width, Depth, Batter slope

Circular dam: Diameter, Depth, Batter slope

Note: To use the information in this report all measurements should be in metres.

1. Measuring the current water surface area

For dams with rectangular or square shapes it is simply a case of measuring the length and width as shown in Figure 1.

Surface area = Length x Width

For circular dams it is necessary to measure the diameter. The radius is half of the diameter. The surface area is then calculated using:

Radius = Diameter divided by 2

Surface area = Radius x Radius x 3.1416

2. Determining dam depth

When determining the water supply capability in dams with low water volumes it is essential the dam depth be physically measured. Depth boards should not be assumed to be zeroed to the base of the dam as sediment may have accumulated in the dam. However once calibrated (i.e. compared to actual measurements) they can provide a valuable role for monitoring.

The easiest way to measure dam depth is to use a weighted wooden or aluminium pole. Hold the pole vertically near the centre of the dam using a rope and move it around till the average water level is determined (Figure D2).

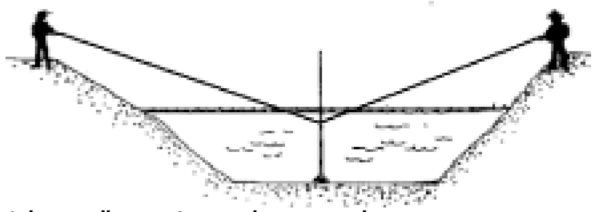


Figure D2: A simple 'dam dipper' can be used to measure water depth. To move the pole, simply pull the rope tight to raise it off the dam floor. A rope with a weight attached and ribboned sections can be used as an alternative to the pole

3. Making a dipper

A simple method of measuring this depth without physically entering the dam is to make a dam dipper. Attach a weight (e.g. a sock or plastic bag filled with sand) to the bottom of the pole. Tie a rope around a wooden pole longer than the expected water depth about half way up. Stand on each side of the dam and, keeping the rope tight, pull the pole out into the middle of the dam.

Keeping the pole upright lower the pole until it rests on the bottom – do not allow it to lie over. Again pull the rope tight (this will raise the pole off the bottom) and carefully drag it to the bank. The water level will be visible on the pole and can be measured using a tape measure. Alternative approaches include using coloured tape (e.g. electrical tape) or paint placed at 0.25 m intervals on the pole so that it can be read while in the water, and using a weighted rope in place of the pole.

WARNING: When measuring depth avoid sinking the base of the pole into the sediment. Water below this mark is not accessible to livestock or pumps and should not be considered. Where sediment is a major problem it may be necessary to attach a flat base plate to the pole.

4. Estimating the dam batter slope

The dam batter slope is needed to determine the rate at which the surface area and volume decreases with depth. This is important since the dam will hold ***less water per metre of depth*** as the dam depth decreases or dries out (see Figure D3 below).

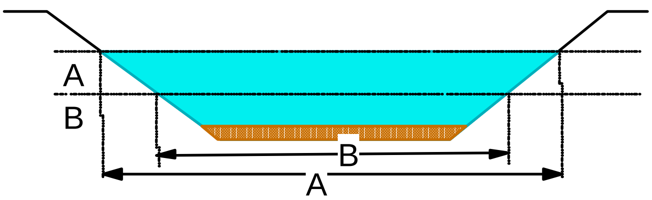


Figure D3: Reduction in storage volume with depth due to sloping dam sides. The width of A is greater than B

The slope can be measured using a builders spirit level, a wooden stake (longer than 1m) and wooden or metal pole more than 2m long. Hammer the stake into the ground at the water's edge. Place one end of the pole UPSLOPE of the stake and raise the pole until it is level (check using the builders spirit level). Use a tape measure to measure the distance ALONG THE LEVEL POLE from the upslope end to the stake (this is the Horizontal Distance). Measure the height of the pole off the ground (the Vertical Distance). See Figure D4.

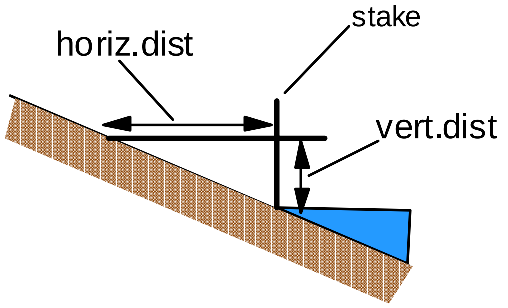


Figure D4: Using a stake, pole and builder's spirit level it is possible to compute the batter slope of a farm dam. Measure the horizontal distance (between the end of the pole and the stake) and the vertical distance (from the pole to the ground at the stake)

Use this information to compute the slope:

$$slope = \frac{horiz.distance}{vert.distance}$$

This formula computes the slope in terms of X metres required to rise 1 m (i.e. 1 in X).

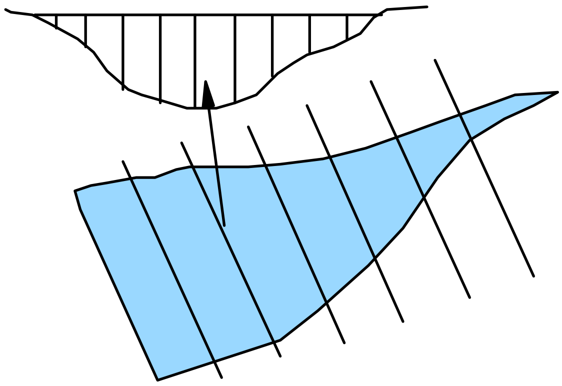
Example:

The slope method is used and the horizontal distance from the end of the pole to the stake is measured at 1.7m. The vertical distance up the stake was measured to be 0.6m.

slope = 1.7m ÷ 0.6m = 2.833 i.e. 1 in 2.8.

5. Determining the profile of irregular dam shapes

Farm dams which do not have a regular geometrical shape must be surveyed. This should be carried out on a grid or cross-sectional basis, ideally using a level or a theodolite. To obtain a rough estimate, sections can be measured by stretching a rope marked at 1 or 2 metre intervals (e.g. using cloth strips or ribbons) and using either a pole or dam dipper to obtain depth readings at each mark on the rope.



The depths are then plotted on graph paper, contoured or gridded using a suitable computer package. Refer to a surveying text-book for information on calculating volumes using cross–section, grid data or contour data.

6. Computing the volume

The Department of Agriculture has developed a computer program that can be used with Length, Width, Depth and Slope to compute the dam volume, surface area and base dimensions automatically. Once solved the software will also allow varying depths and sediment thicknesses to be considered. This program can be obtained from the DRAINWISE website (www.agric.wa.gov.au/drains) or by contacting the Water Resource Group at Department of Agriculture, South Perth.

Manual methods of calculating surface area and volume are discussed in Appendix B.

Appendix E

Estimated monthly and annual evaporation loss from dams in South-West Agricultural Area (mm*)

Station	Ed/Ep**	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Ajana	0.740	293	271	239	160	118	73	73	93	111	182	224	284	2,121
Albany	0.970	213	165	145	88	61	45	47	64	81	102	145	193	1,349
Berk. Valley	0.790	300	270	240	144	92	58	57	75	100	158	218	294	2,006
Brookton	0.790	205	218	184	108	67	40	41	50	79	120	173	232	1,577
Corrigin	0.760	289	228	197	116	69	41	41	55	83	134	184	257	1.694
Cranbrook	0.850	226	195	156	93	56	37	39	51	75	101	149	218	1,396
Dandaragan	0.810	285	237	229	134	91	62	59	78	96	151	213	283	1,918
Donnybrook	0.850	187	158	127	71	53	39	42	53	62	92	126	172	1,182
Esperance	0.930	247	196	179	123	86	59	73	83	106	140	177	236	1,705
Geraldton	0.820	296	276	256	169	123	84	72	92	114	177	229	300	2,188
Gingin	0.830	273	245	214	123	79	54	52	75	94	143	198	266	1,816
Goodlands	0.720	316	281	242	154	95	58	61	78	103	172	223	297	2,080
Holt Rock	0.760	288	215	187	121	73	50	60	67	91	145	192	251	1,740
Jerramungup	0.800	248	179	157	101	66	40	48	60	82	117	155	212	1.465
Kalgoorlie	0.710	306	245	217	141	94	66	73	92	128	192	231	301	2,086
Katanning	0.810	246	191	169	98	53	38	40	51	77	110	161	229	1,473
Kondinin	0.770	291	227	197	120	72	45	46	59	87	138	190	226	1,733
Lake Grace	0.770	274	207	177	113	69	43	43	58	84	125	174	241	1,608
Lake King	0.780	276	203	177	117	73	52	60	69	91	139	182	237	1,676
Manjimup	0.910	192	157	135	78	60	42	50	53	70	91	130	181	1,239
Margaret R	0.960	152	150	66	54	50	45	47	47	50	73	123	164	1,021
Medina	0.870	237	216	182	103	69	53	52	60	87	129	171	227	1,586
Merredin	0.750	315	260	231	138	82	52	55	67	96	165	214	292	1,967
Moora	0.790	289	263	229	136	89	57	55	71	97	152	212	284	1,934
Mt. Magnet	0.680	352	301	265	179	121	78	80	106	138	219	260	324	2,423
Mukinbudin	0.730	319	270	240	146	87	56	62	75	101	172	221	297	2,046
Mullewa	0.720	314	282	244	166	115	69	69	93	114	186	227	299	2,178
Munglinup	0.850	246	190	169	118	79	56	69	76	98	135	177	224	1,637
Narembeen	0.750	297	239	209	125	75	50	51	62	90	150	195	270	1,813
Narrogin	0.830	260	213	180	104	67	41	42	53	82	118	171	237	1,568
Norseman	0.740	278	214	182	125	81	59	69	78	108	158	200	250	1,802
Northam	0.780	285	242	205	117	70	43	44	53	85	130	184	256	1,714
Paynes Find	0.710	338	298	260	169	111	70	73	94	121	199	246	318	2,297
R'nsthorpe	0.830	260	194	169	118	77	55	65	73	93	135	179	226	1,644
Rocky Gully	0.900	213	180	153	87	60	42	48	54	77	98	144	209	1,365
Salmon Gums	0.780	262	202	172	121	80	56	69	75	99	145	187	231	1,699

Station	Ed/Ep**	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Scaddan	0.820	246	191	179	116	79	55	68	76	99	138	180	223	1,650
South. Cross	0.720	313	252	226	139	86	57	65	78	108	175	220	294	2,013
Three Springs	0.740	298	273	239	154	101	59	73	80	105	167	216	286	2,051
Upper Swan	0.840	274	236	202	114	74	52	50	73	92	135	185	254	1,741
Wagin	0.810	253	205	174	100	64	39	41	51	80	114	157	232	1,510
Wialki	0.720	324	280	245	151	94	60	65	82	107	179	228	305	2,120
Wokalup	0.900	209	189	146	80	63	51	50	62	72	102	144	198	1,366
Wongan Hills	0.740	289	258	222	132	81	49	51	65	91	145	202	276	1,861

From: Luke *et al.* 1988

** Tabulated values are mm/month. To obtain daily values, divide by the number of days in the month*

*** Ed/Ep is dam evaporation (Ed) divided by Class A pan evaporation (Ep)*

Appendix F

Livestock drinking rates

Livestock drinking rates are based on a dry sheep equivalent (DSE) which is defined as a 45 kg dry (i.e. not lactating) sheep in forward store condition during summer on a maintenance diet of sub. clover or better pasture. Pigs and cattle/horses consume water at rates equivalent to 2 and 10 DSE respectively.

During a drought year the lack of winter pasture often necessitates hand-feeding and therefore a minimum water requirement of 2 L/head per day was imposed on the sheep drinking rates (Luke 1988). Although this value is too high for most years, design criteria must consider worst case conditions. Greater than normal sheep drinking rates during winter incorporates a safety factor into water supply designs.

N.B. The concept of livestock water used here is highly simplified. Actual water use is highly variable due to seasonal conditions, feed type and water quality. Higher use rates occur as salt content increases.

Table F1. Livestock drinking rates (L/DSE/day) using a minimum of 2.0

Location	J	F	M	A	M	J	J	A	S	O	N	D
Albany	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Bencubbin	3.7	3.5	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.6	3.3
Brookton	3.4	3.3	2.7	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.3	3.2
Bunbury	2.4	2.4	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Corrigin	3.4	3.1	2.6	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.2	2.9
Cranbrook	2.2	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Dandaragan	3.6	3.6	2.9	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.4	3.2
Donnybrook	2.9	2.9	2.4	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.5
Esperance	2.6	2.5	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.2
Geraldton	3.2	3.3	3.0	2.3	2.0	2.0	2.0	2.0	2.0	2.0	2.3	2.8
Goodlands	3.9	3.8	3.4	2.2	2.0	2.0	2.0	2.0	2.0	2.1	2.7	3.4
Holt Rock	3.0	3.2	2.6	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.4	3.2
Jerramungup	2.8	2.7	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.5
Kalgoorlie	3.5	3.2	2.8	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.6	3.3
Katanning	2.9	2.7	2.2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.6
Kondinin	3.5	3.3	2.6	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.4	3.3
Lake Grace	3.2	3.0	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.2	2.9
Lake King	3.0	2.8	2.4	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.1	2.5
Manjimup	2.3	2.2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Margaret River	2.3	2.5	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Merredin	3.6	3.4	2.8	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.5	3.2
Moora	3.6	3.6	2.9	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.4	3.2
Mukinbudin	3.8	3.7	3.1	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.6	3.2

Location	J	F	M	A	M	J	J	A	S	O	N	D
Mullewa	4.1	4.0	3.5	2.5	2.0	2.0	2.0	2.0	2.0	2.2	3.0	3.7
Munglinup	2.6	2.6	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.2
Narrembeen	3.5	3.4	2.9	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.4	3.2
Narrogin	3.0	2.8	2.3	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.7
Norseman	3.3	3.1	2.6	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.5	3.0
Northam	3.4	3.5	3.0	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.5	3.3
Perenjori	4.2	4.0	3.5	2.3	2.0	2.0	2.0	2.0	2.0	2.0	2.9	3.9
Ravensthorpe	2.7	2.5	2.2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.5
Rocky Gully	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Salmon Gums	2.9	2.8	2.4	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.1	2.7
Scaddan	2.5	2.3	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.3
South. Cross	3.8	3.6	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.8	3.5
Three Springs.	4.2	4.0	3.5	2.3	2.0	2.0	2.0	2.0	2.0	2.0	2.9	3.9
Upper Swan	3.5	3.5	3.1	2.2	2.0	2.0	2.0	2.0	2.0	2.0	2.3	3.1
Wagin	3.0	2.8	2.4	2.0	2.0	2.0	2.0	2.0	2.O	2.0	2.0	2.8
Wialki	3.8	3.7	3.3	2.1	2.0	2.0	2.0	2.0	2.0	2.1	2.6	3.3
Wokalup	2.4	2.4	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Wongan Hills	3.7	3.6	2.9	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.6	3.4

From: Luke (1988).

Table F2. Peak water demand estimates per DSE [L/head/day] for water supply designs with corrected rates for water quality

	Maximum daily DSE drinking rates in January/February (Factored[1] drinking rates)			
Water EC[2] (mS/m)	**Fresh**	**600**	**1200**	**1900**
Locality	**L/DSE/day**			
Albany	3.2	3.9	4.5	5.5
Bencubbin	6.4	7.7	9.0	10.9
Brookton	5.9	7.1	8.3	10.1
Corrigin	5.9	7.1	8.3	10.1
Cranbrook	3.8	4.6	5.4	6.5
Dalwallinu	6.7	8.0	9.4	11.4
Dandaragan	6.3	7.5	8.8	10.6
Dwellingup	4.9	5.9	6.9	8.3
Esperance	5.6	6.7	7.9	9.5
Geraldton	5.7	6.9	8.0	9.8
Goodlands	6.8	8.1	9.5	11.5

[1] Daily drinking allocation has been modified by accounting for average maximum daily temperature and waste (20%) factors. Particular attention should be given to different tolerance of water quality by different classes of stock (Luke 1988).

[2] To convert mS/m to mg/L TSS multiply by 5.5; to convert mS/m to gr/gl TSS multiply by 0.385.

	Maximum daily DSE drinking rates in January/February (Factored[1] drinking rates)			
Water EC[2] (mS/m)	Fresh	600	1200	1900
Locality	L/DSE/day			
Holt Rock	5.9	7.1	8.3	10.1
Hyden	6.1	7.3	8.5	10.4
Jerramungup	6.0	7.3	8.5	10.3
Katanning	5.0	6.1	7.1	8.6
Kellerberrin	6.3	7.6	8.9	10.8
Kondinin	6.1	7.3	8.5	10.4
Lake Grace	5.6	6.7	7.8	9.5
Lake King	5.2	6.3	7.3	8.9
Manjimup	4.4	5.3	6.2	7.5
Merredin	6.3	7.5	8.8	10.6
Moora	6.3	7.5	8.8	10.6
Mukinbudin	6.6	7.9	9.3	11.2
Mullewa	7.1	8.6	10.0	12.1
Munglinup	4.5	5.4	6.3	7.7
Narembeen	6.1	7.3	8.5	10.4
Narrogin	5.2	6.3	7.3	8.9
Newdegate	5.7	6.9	8.0	9.8
Norseman	5.7	6.9	8.0	9.8
Northam	6.3	7.5	8.8	10.6
Perenjori	7.3	8.8	10.2	12.4
Ravensthorpe	4.7	5.6	6.6	8.0
Rocky Gully	3.7	4.4	5.1	6.2
Salmon Gums	5.0	6.1	7.1	8.6
Scaddan	4.4	5.2	6.1	7.4
Southern Cross	6.6	7.9	9.3	11.2
Three Springs	7.3	8.8	10.2	12.4
Wagin	5.2	6.3	7.3	8.9
Wialki	6.6	7.9	9.3	11.2
Wongan Hills	6.4	7.7	9.0	10.9
York	6.4	7.7	9.0	10.9

WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

Melbourne
15 Business Park Drive
Notting Hill VIC 3168
Telephone (03) 8526 0800

Sydney
Suite 3, Level 1, 20 Wentworth Street
Parramatta NSW 2150
Telephone (02) 9354 0300

Brisbane
Level 5, 43 Peel Street
South Brisbane QLD 4101
Telephone (07) 3105 1460

Adelaide
1/198 Greenhill Road
Eastwood SA 5063
Telephone (08) 8378 8000

Perth
Ground Floor, 430 Roberts Road
Subiaco WA 6008
Telephone (08) 6555 0105

New Zealand
7/3 Empire Street
Cambridge New Zealand 3434
Telephone +64 27 777 0989

Wangaratta
First Floor, 40 Rowan Street
Wangaratta VIC 3677
Telephone (03) 5721 2650

Geelong
51 Little Fyans Street
Geelong VIC 3220
Telephone (03) 8526 0800

Wimmera
597 Joel South Road
Stawell VIC 3380
Telephone 0438 510 240

Gold Coast
Suite 37, Level 4, 194 Varsity Parade
Varsity Lakes QLD 4227
Telephone (07) 5676 7602

watertech.com.au