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Land and Water Australia and South West Development Commission

Groundwater and Surface Water Interactions in the Fractured Rock Areas of the South West of Western Australia

June 2010

INFRASTRUCTURE | MINING & INDUSTRY | DEFENCE | PROPERTY & BUILDINGS | ENVIRONMENT

Contents

Table Index

Figure Index

Appendices

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Executive Summary

GHD was contracted to undertake works by the National Program for Sustainable Irrigation through the grant, *2nd Round 2008 National Program for Sustainable Irrigation, Western Australia* and the South West Development Commission to undertake investigations into surface and groundwater interactions in the Wilyabrup and Warren-Pemberton agricultural regions. The primary objective of this work was to further understand the nature of the surface and groundwater interactions in the Wilyabrup region, Margaret River and Smith Brook catchment, Manjimup. These catchments were selected as they are both reliant on reliable water supplies to sustain established agricultural and viticultural systems.

Based on a review of common methods used for investigating surface and groundwater interactions, GHD adopted a holistic approach to this investigation and used a combination of low cost methods to understand surface and groundwater interactions in two catchments in the south west of Western Australia. The approach considered a range of factors that have the potential to influence surface and groundwater interactions and provide a reasonable interpretation of the processes occurring at both a catchment and sub-catchment scale.

Baseflow contribution to the Wilyabrup Brook was known to be minor based on field observations and communications with DoW staff. This was confirmed through a combined geomorphic and baseflow separation analysis by GHD which indicated that the Wilyabrup Brook is a surface water and interflow dominated system with minor baseflow influence driven largely by the prominence of duplex soils.

Similarly, surface and groundwater interactions in the Smith Brook catchment were determined to be limited to the stream reach only. It was concluded the Smith Brook catchment is largely a surface and interflow dependent system, with minor baseflow contributions.

There appears to be good connectivity of surface water flows and some groundwater flows (interflow) to both the Wilyabrup and Smith Brook and that these connections should be managed to ensure their sustainability. Areas recharging both superficial and deep groundwater should also be carefully managed to ensure their connectivity to these systems is maintained. Areas most likely to recharge to these water systems are shallow and deep sands, located in the upper catchment reaches.

Under *The Rights in Water and Irrigation Act, 1914*, both a surface and groundwater licence is required for some dams that receive inputs from surface water and underground water. In the case of both the Wilyabrup and Smith Brook catchments, baseflow contributions to streamflow are low. It is therefore fair to assume that underground water intercepted by some dams is likely to be interflow, not baseflow. Given the strong linkages between surface water and interflow, it a reasonable argument that surface water and groundwater be combined as one surface water license.

There is also a strong argument to reconsider the definitions of surface water and underground water within the current act and whether these terms are applicable to all areas of the state, or whether specific acts are required regionally. In the case of the south west of Western Australia, the strong linkages between surface and groundwater make licensing difficult and in this case, combining these two water licenses into one may solve many water licensing issues. At the very least, it would streamline and simplify the licensing process and make interpretations by the public easier.

1. Introduction

GHD was contracted to undertake works by the National Program for Sustainable Irrigation through the grant, *2^{nd} Round 2008 National Program for Sustainable Irrigation, Western Australia* and the South West Development Commission investigate surface and groundwater interactions in fractured rock areas of the south west regional of Western Australia. The areas studied were, the Wilyabrup and Warren-Pemberton agricultural regions.

A key stakeholder involved in the project was the Department of Water (DoW) who provided technical input and assistance to GHD. Other organisations supporting this work were the Whicher Water Resources Management Committee, the Margaret River Wine Association and Warren Donnelly Water Advisory Committee. The primary objective of this work was to further understand the nature of the surface and groundwater interactions in these important agricultural and viticultural regions and therefore contribute to the water planning and allocation already underway.

Specifically, this report entails the component of works undertaken in the Wilyabrup catchment, located in the south west of Western Australia, near the town of Cowaramup and Smith Brook catchment located in the south west of Western Australia immediately south of the town Manjimup. These catchments were selected as they are both reliant on reliable water supplies to sustain established agricultural and viticultural systems. These catchments are characterised as fractured rock environments, where sub-surface water movement is typically rapid and groundwater recharge is limited as a result.

These works are presented as case studies in order to further describe surface and groundwater interactions in the south west of Western Australia and provide a framework for future studies in this region particularly where fractured rock environments dominate.

Conducted in a context of declining rainfall patterns and rising temperatures, concurrent with ongoing demands for reliable water supplies to sustain established agricultural and horticultural systems, the outcomes and possible future work emerging from this investigation will provide important insight as to the hypotheses and associated investigations required to continually improve water planning and allocation in fractured rock environments.

1.1 Background

Surface and groundwater behaviour within the south west of WA varies according to local hydrological, geological and climatic conditions. Annual rainfall within the region is high, in the order of 1000 mm, with most rain falling within winter months (DoW 2008). High rainfall combined with local geological conditions and the prominence of duplex soils throughout the region generate large volumes of surface water runoff. Historically these waters have been captured and harvested in dams by landowners for general farm use including irrigation and stock use. Recent monitoring by the DoW of surface and groundwater use by landowners within some catchments has led to restrictions on surface water use. This was realised through water allocation decisions that limited surface water use by some landowners.

Similarly, landowners are keen to continue to better understand the status of surface and groundwater and their interactions in order to manage important factors such as risk (reliable and sustainable water supply sources); environmental allocations (ensuring the local environment does not deteriorate due to a lack of water) and the possibility of over allocation leading to a review of existing licence allocations.

Farm dams, hobby dams and aesthetic dams exist within the region and act as an inhibitor to surface flows. Farm dams within the Avon Catchment in the wheat belt farming district of Western Australia were found to withhold 14% of flows of the Avon River based on a landscape storage density of 3.28 ML/km^2 (GHD 2008), highlighting the impact they can have on surface water flows. Further, the reduction in surface water flows caused by the increased number of dams in a catchment has implications on the Ecological Water Requirements (EWR) of a river or stream. EWR refers to the minimum flows required within a water course to maintain the ecological integrity of that stream. Flows falling below the EWR have the potential to negatively impact the in-stream aquatic environment and the adjoining riparian vegetation. Thus the regulation of surface water use, which often occurs in the form of on stream dams that reduce downstream surface flows, is important for the ecological integrity of streams.

Groundwater can also contribute to stream flow. Where the groundwater levels occur above the topographic level of the base of the stream, inflow into the stream from groundwater can maintain the flow even if surface water runoff has ceased. Baseflow is often defined as sustained low flow in a river during dry weather conditions, generally all contributed by groundwater. In Western Australia a number of dry season streamflows rely on baseflow to allow streams to continue flowing and often support ecological water requirements' of the streams. Any abstraction of groundwater in these baseflow areas through bores or a reduction of groundwater recharge through surface activities that impacts on the groundwater levels near these streams therefore has the potential to reduce baseflow and impact the downstream environment. Fractured rock environments however, add a further dimension to the 'types' of water flowing into dams, streams and other waterways, notably, 'interflow' or 'throughflow' is one such feature.

Interflow may be defined as the rapid lateral flow of semi-deep water that lies above the saturated soil zone, often a feature of duplex soils and fractured rock environments. The interaction between surface and groundwater is the basis of this study and may be considered in this study as 'interflow'.

The uneven allocation of surface water can also impact other users. For example, a large on stream dam located at the top of a catchment may reduce downstream flows to a point where downstream landowners may be unable to capture and use surface water because flows within that reach of a stream fall below the EWR. Therefore both surface water and groundwater use needs to be carefully managed to ensure supply to all landowners and the longevity of natural streams.

The increase in demand for water is leading to a change in focus on water as a resource within the region. This shift in attitude has led to debate as to the definition of what water is and how it should be sustainably managed. Specifically the separation of surface water and groundwater has implications to landowners' water availability and environmental requirements. Agreed definitions of surface water, groundwater, baseflow and interflow will lead to a better understanding of water allocations and how they can be better managed.

2. Literature Review – Surface and Groundwater Interactions

2.1 Introduction

Surface water sources in viticulture, agriculture and horticultural regions in the south west of Western Australia are becoming close to being fully allocated with irrigators looking to groundwater sources to supplement supply. As this occurs, it becomes increasingly important to be able to properly define, quantify and manage water resources in the area.

In the past, it has been common practice to independently assess and manage surface water and groundwater resources. However, in areas such as south west Western Australia which demonstrate strong linkages between surface and groundwater in fractured rock environments, it is beneficial that a conjunctive water management approach be taken. In order to successfully undertake a conjunctive water management assessment, all possible approaches require consideration and careful contexting.

2.2 Overview of Approaches

This section provides a literature review summarising available techniques for the assessment of surface water and groundwater interactions. These interactions are included in the wider assessment phase of a conjunctive water management approach, which typically includes the investigation of:

Surface Water: Streams, wetlands, dams and estuaries: Aspects such as flow duration and dynamics, water quality, extraction regimes, water storage capacity, associated ecosystems, land use impacts and climate variability may be investigated.

Groundwater: Investigation may include aquifer geometry, geological and stratigraphic details, hydraulic properties, extraction regimes, recharge and discharge mechanisms, groundwater dependant ecosystems and land use impacts.

Surface Water-Groundwater Interactions: The dynamics of water flow between aquifers and surface water features and the implications for water quantity and quality and linked ecosystems.

In general terms, the assessment phase is carried out to acquire baseline information describing the spatial and temporal characteristics of surface water and groundwater systems of a catchment, and their interactions. Assessment most often includes analysis of existing data sets such as climate parameters (rainfall and evaporation), topography, surface drainage, geology/geomorphology, land use, surface and groundwater water levels and water quality.

Following the collation of baseline catchment data, information gaps are identified and specific studies to fill these gaps and clarify key catchment water processes may be initiated. Available techniques for assessing surface water and groundwater interactions are summarised and reviewed below.

2.2.1 Field Observations

Direct observation is the simplest available method for characterising interactions between surface water and groundwater. A field survey can be useful early in an assessment to identify areas needing further investigation. Typically, field observations are useful for showing where groundwater seepage is occurring, but are unable to provide quantitative information on seepage flux. Other observable indicators of surface water-groundwater interactions include mineral precipitates such as manganese and iron oxides as a result of exposure of anoxic groundwater, carbonate precipitates indicating groundwater with high levels of dissolved carbon dioxide and calcium carbonate, and changes in water colour and odour indicative of contaminated or different quality groundwater.

2.2.2 Seepage Measurement

Seepage measurement is one of the few available methods for directly quantifying surface water-groundwater interactions. The Australian National Committee on Irrigation and Drainage (ANCID) has commissioned several studies detailing techniques and best practices for channel seepage quantification and management (ANCID 2001a, 2001b, 2003). Inflow-Outflow methods are discussed, by which a water balance approach is taken comparing stream flow at two channel locations, with the difference assumed to be a result of interaction with groundwater. This method was not recommended due to the difficulties in accurately measuring stream flow. Point measurements were also discussed in the ANCID reviews, whereby seepage meters are installed at discrete locations along a streambed. This method is considered accurate for short lengths of stream, but many meters are needed for longer reaches as seepage is often highly spatially variable (Kaleris, 1998).

2.2.3 Hydrograph Analysis

One of the most common methods for quantification of surface water-groundwater interactions is numerical analysis of a time-series record of water levels or water flow. Stream hydrographs are routinely kept as a management tool for surface water resources and so data are generally readily available. Smakhtin (2001) provides a review of the current understanding of low flow hydrology, and mechanisms by which surface water and groundwater are interchanged. Chapman (1999) compared a number of one-, two- and three-parameter algorithms for identifying groundwater components of stream hydrographs, concluding that the subjectively fitted two-parameter algorithms more consistently provided plausible results than either the one- and three-parameter algorithms which are fitted purely objectively. Most commonly used in Western Australia is Chapman’s (1991) one-parameter algorithm (e.g. Varma 2002).

2.2.4 Hydrometrics

If hydraulic conductivity and the hydraulic gradient are known for a length of stream, Darcy’s Law defining the flow of water in a porous medium may be applied to calculate the flux of water between a surface water feature and groundwater (Sophocleous 2002). The most common field method for measuring hydraulic gradient is the installation of a network of piezometers (Baxter *et a*l. 2003). Pressure transducers and data loggers installed in the piezometers or pressure probes buried in the saturated subsurface may be an option for observing temporal variations in hydraulic head. Numerous methods are used for estimating hydraulic conductivity, including seepage meters and infiltration tests (ANCID 2008), pump tests of installed bores or piezometers, and grainsize analysis (Vukovic & Soro 1992).

2.2.5 Hydrochemistry & Tracers

Interpretation of the chemical constituents of water can provide insights into stream-aquifer connectivity. A number of naturally occurring dissolved constituents may be used to track and quantify the movement of groundwater, including major ions such as calcium, magnesium and chloride, stable isotopes of oxygen and hydrogen and radioactive isotopes such as radium and tritium (Cook 2003). In some instances, heat or water temperature may be used to identify surface water infiltration (Anderson 2005). Artificial tracers such as bromide or a visible dye may also be introduced in known quantities to a water system and their movement subsequently monitored to evaluate the extent to which an aquifer interacts with surface water features (Scanlon 2002).

2.2.6 Modelling

Following collection of baseline and field data, it may be useful to construct a model to describe and predict interaction between surface water and groundwater. A surface-groundwater model consists of two elements: a conceptual model summarising the key catchment processes, dependencies and impacts of the water resource; and a predictive model which is a mathematical tool representing the governing mathematical equations, boundary conditions and catchment parameters.

Predictive models may be either analytical or numerical in nature. Analytical models directly solve the partial differential equations governing the flow of water, while numerical models use mathematical approximations and iterative techniques to solve the same equations. Common numerical models include MIKE SHE, MODFLOW (Harbaugh et al. 2000) and SWMM (US EPA). Middlemis (2001) provide guidelines for modelling groundwater flow in Australia.

Groundwater models provide a scientific and predictive tool for determining appropriate solutions to water allocation, surface water – groundwater interactions, landscape management or impact of new development scenarios. However, if the modelling studies are not well designed from the outset, or the model doesn’t adequately represent the natural system being modelled, the modelling effort may be largely wasted, or decisions may be based on flawed model results and long term adverse consequences may result. The use of these guidelines will encourage best practice and help avoid potential problems.

The conceptual model forms the foundation for further field investigations as well as the development of predictive models. These are essentially mathematical models or simple tools that contain equations that represent the physical processes of water movement in a catchment. Encapsulating the hydrological processes using governing mathematical equations, boundary conditions and estimates of catchment parameters can provide a powerful predictive tool.

The conceptual model outlines the dominant processes and underlying simplifying assumptions to be implemented by the predictive model. It is important to clarify the complexity of the solution required, as an oversimplified model may not be adequately robust and an over-complex model may be costly, time-consuming and have intractable data requirements. The level of conceptualisation and requirements of the predictive model depends on the management objectives, available resources and field data and the legal and regulatory framework (Bear *et al,* 1992).

Mathematical models can vary in form and complexity and include analytical, analytical element, boundary integral and numerical techniques.

2.3 Summary

Whilst each method described above can, in its own right, provide an insight into surface and groundwater interactions in a given setting, a holistic approach will provide supporting information from more than one approach to provide a more robust understanding of surface and groundwater processes and thus their interactions. This approach has been recognised by the Department of Water for the development of Ecological Water Requirements (EWR) for many years as outlined in Section 3.2 in Statewide Policy No. 5 – *Environmental Water Provisions Policy for Western Australia (2000).* Further, the cost of each method should also be considered. Methods involving seepage measurement, numerical modelling and the use of tracers and chemical analysis can be expensive. Consequently a range of low cost options that make use of low cost, readily available resources can provide a methodology to comprehensively assess surface and groundwater interactions.

3. Case Study Approach

3.1 Overview

Based on a review of common methods used for investigating surface and groundwater interactions, GHD adopted a holistic approach to this investigation and used a combination of low cost methods to understand surface and groundwater interactions in two catchments in the south west of Western Australia. The approach considered a range of factors that have the potential to influence surface and groundwater interactions and provide a reasonable interpretation of the processes occurring at both a catchment and sub-catchment scale.

In order to deliver a better understanding of the hydrological processes occurring at a catchment scale to Government, stakeholders and landowners, GHD prepared a conceptual interpretation of water movement processes occurring within the Wilyabrup and Smith Brook catchment's through a combined methodology of desktop analysis and field observations. This contributed to the ongoing improved understanding of the definition of what water is and how it is separated into its various components, those being surface water, groundwater and interflow; and what the implications may be with respect to water allocation licenses within the region. The definition of baseflow and interflow and the separation from surface water flow was an important step in defining water as a resource.

For the purposes of the report the following definitions are used to define the different underground water sources.

Interflow could be described as a 'semi-deep' water flow as it is above the saturated groundwater zone (vadose zone). It is characterised by water that infiltrates the subsurface and moves both vertically and laterally typically occurring above discontinuous impermeable layers, before discharging either onto the surface or into other water bodies. These layers are likely to vary and may include materials such as weathered bedrock, alluvial and colluvial soils and also fractured bedrock in areas of bedrock highs. Flow is generally rapid along essentially unsaturated flow paths and ephemeral.

Baseflow is defined as sustained low flow in a river during dry weather conditions, generally contributed entirely by groundwater, particularly in areas without bank storage.

3.2 Water Licensing

The Rights in Water and Irrigation Act 1914 (RiWI 1914) regulates the take and use of surface and groundwater in Western Australia. The following definitions describe surface and groundwater from a licensing perspective.

A surface water licence describes water taken from a watercourse, whilst a groundwater well licence describes water taken from underground. Underground water includes both interflow and baseflow.

The Wilyabrup catchment is proclaimed for both surface water and groundwater under the Busselton – Capel Groundwater Area Cape to Cape North Subarea, whilst the Smith Brook catchment is proclaimed for surface water only under the Warren River and Tributaries Surface Water Area. Water licensing in these catchments will be discussed later on in the report.

3.3 Summary

The approach used by GHD to define water interactions in the Wilyabrup and Smith Brook catchment will consist of a holistic approach that can be summarised by:

1. *Field observations of surface water movement at critical points;*
2. *Geomorphological interpretation of the catchment through Digital Elevation Models (DEMs);*
3. *Spatial distribution analysis of soils and geology;*
4. *Hydrologic analysis at sub catchment level;*
5. *Hydrogeological assessment including groundwater analysis;*
6. *Baseflow assessment of surface water flow data;*
7. *Water Balance analysis to identify water behaviour within the catchment; and*
8. *Assessment of overall surface / groundwater interactions.*

Further, the processes undertaken by GHD to investigate water within the Wilyabrup and Smith Brook catchments may provide an indication of appropriate methodology for the future investigation into surface water and groundwater interactions for the south west region of Western Australia.

4. Case Study 1 – Wilyabrup Catchment

4.1 Background

Wilyabrup Brook is located in the south west of Western Australia between Gracetown and Yallingup, near the town of Cowaramup and is approximately 20 km in length. The Wilyabrup catchment lies within the Whicher area and is a proclaimed catchment with an area of approximately 8,920 ha. The catchment is drained by Wilyabrup Brook, which originates west of the Dunsborough Fault and flows north-west before discharging to the Indian Ocean at the catchment outlet.

The land use in the catchment is primarily viticulture and approximately 75% of land has been cleared for this purpose. A number of dams have been constructed along the course of the Brook to assist with water requirements associated with viticulture (Figure 1). It has been reported by DoW (2008) that the impact of these dams on the water balance of the catchment has yet to be quantified, but is likely to be significant.

Figure 1: Example of viticulture and farm dam in the Wilyabrup catchment

4.2 Field Observations

A field assessment was undertaken on the 2nd July 2009. The catchment was traversed, assessing dam and stream conditions. The condition of streamflow was also assessed with advice from a local DoW representative. The following is a summary of findings from the field assessment:

- Connection between groundwater and farm dams was observed in the north east upper catchment area by evidence of fresh tannin dam water with continuous supply;
- Groundwater seeps, interpreted as interflow were observed on hill slopes at Woodlands gauging station;

- It was advised that streamflow occurs during the summer months at Woodlands gauging station by DoW representatives indicating baseflow contribution; and
- Bedrock was observed within the stream reach at Woodlands gauging station.

Figure 2: Bedrock observed at the base of the river at Woodland Gauging Station.

4.3 Geomorphologic Assessment

The catchment geomorphology varies based on the catchment position. The top of the catchment (~135 mAHD) is characterised by gently sloping undulating hills draining into low sloping valley floors (drainage lines), whilst the lower part of the catchment is characterised by steeper sloping hills leading into fairly incised valley floors which leads to the catchment outlet at the Indian Ocean. The greater incision of the valley floors is common in western margins of catchments in the south west of Western Australia and is driven by increased rainfall, stream flow and changes in geology. This is illustrated in Figure 3 where steeper slopes are more evident in the lower Wilyabrup catchment.

A digital elevation model (DEM) of the catchment was generated from 5 m contours and is presented in Appendix A.

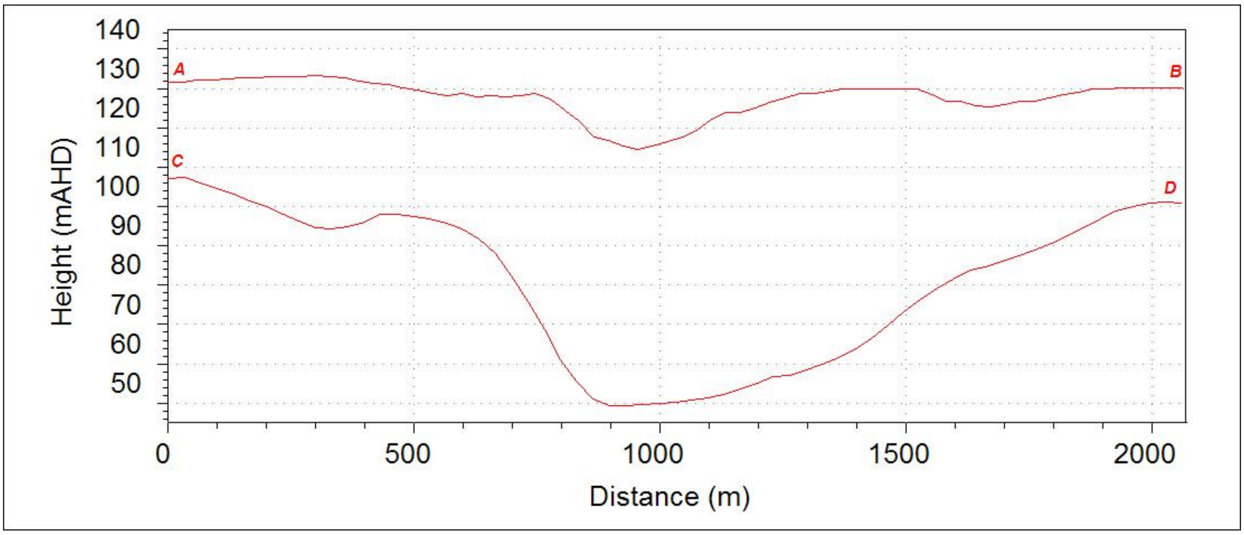

Figure 3: **Profiles across drainage lines in upper (A-B) and lower (C-D) Wilyabrup catchment**

4.4 Geological and Soils Assessment

4.4.1 Geology

The Wilyabrup catchment area sits on the Leeuwin-Naturaliste Ridge to the west of the Dunsborough Fault. Figure 4 details the geology encountered in the Wilyabrup area and presents a longitudinal conceptualisation of the geology beneath the Wilyabrup Brook Catchment.

The Wilyabrup catchment area crosses two distinct physiographic areas, namely the Leeuwin-Naturaliste Ridge to the west and the Blackwood Area to the east.

The Leeuwin Naturaliste Ridge extends from Cape Naturaliste in the north to Cape Leeuwin in the south and extends up to 6 km inland from the coast. The ridge is composed of Precambrian crystalline rocks capped by laterite limestone (Tamala Limestone) and sand.

Precambrian age granitic gneiss and medium grained granulite are seen to outcrop in the catchment area. The granitic gneiss is a pink biotite rock which is usually well foliated. The medium grained granulite is granitic in composition and well foliated and banded. The granulite makes up the majority of the Precambrian in this region and is greater than 600 m in thickness (GSWA, 1967).

Lateritic profiles also outcrop, particularly on hilltops and are associated with hillside seeps in areas where the laterite is exposed at the ground surface on a hillside.

The coastal Limestone is Late Pleistocene in age and unconformably overlies the crystalline Precambrian rocks. The limestone is thought to reach thicknesses of up to 150 m in areas (GSWA, 1967) however a thinner thickness is expected in the catchment based on exposed crystalline rock. The limestone consists primarily of eolian calcarenite but contains minor occurrences of fossil soil and beach conglomerate.

The Cowaramup System is the dominant landform of the catchment and overlays both the Pleistocene and Cretaceous landforms. The majority of stream lines in the catchment occur within the system and stream bed sediments have been reported to consist of boulders, silty, clayey sand and fresh to slightly weathered bedrock.

Granite outcrops occur on the stream beds where erosive processes have cut to appropriate depths. These outcrops become more common towards the coast and were observed along the stream bed near Woodlands gauging station.

The Leederville Formation, Cretaceous, onlaps the Leeuwin Ridge on the eastern side of the catchment. The Leederville underlies the superficial Treeton regolith-landform and the Spearwood regolith-landform (DoW, 2008) and occurs at the surface at some locations in the area where it is weathered and laterised (DoW 2009).

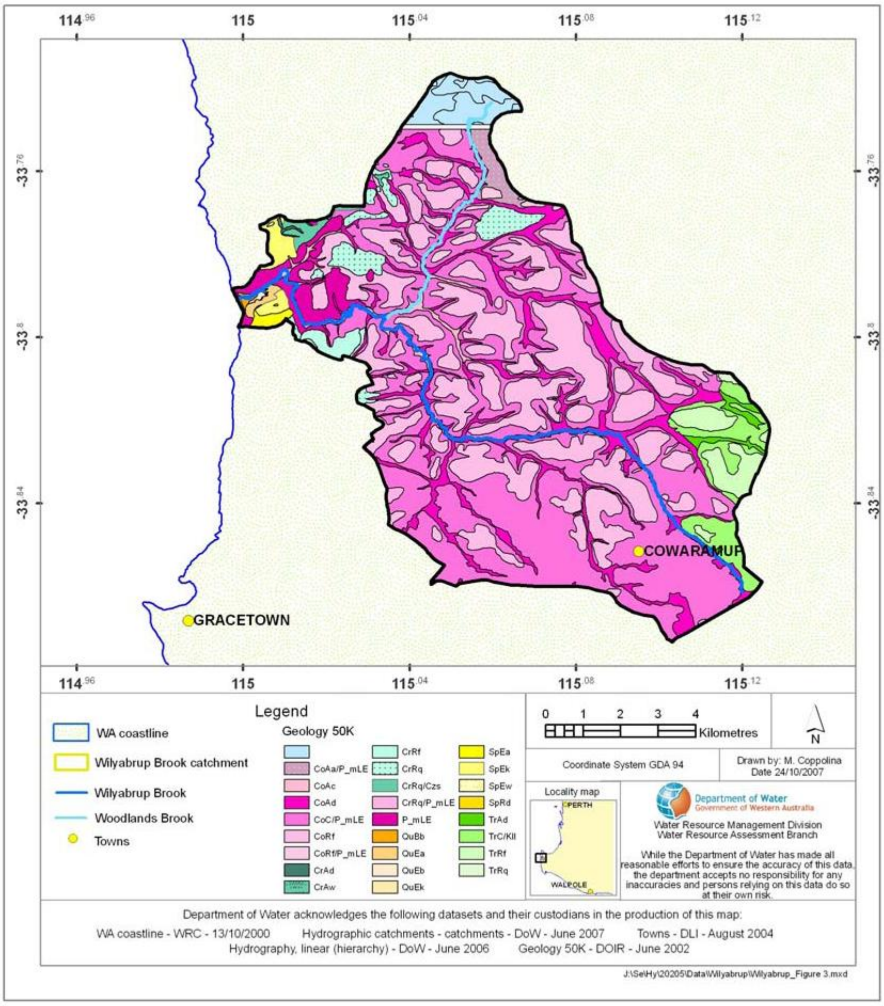

Figure 4: Wilyabrup Region Geology (DoW, 2007)

4.4.2 Soils

Soils within the Wilyabrup catchment are separated into three broad types according to landscape position. Deep sands tend to be prominent at the top of the catchment, whilst duplex soils in the form of gravelly sands over clay dominate the mid to lower slopes. Heavier loamy soils are common on valley floors associated with drainage lines.

The prominence of duplex soils throughout the catchment is likely to influence seepage and interflow contributions to streams. Further, the prominence of duplex soils was increased upon analysis of groundwater bore lithological record. It was found even deep sands located at the top of the catchment contained significantly thick clay layers up to 4 m below sand at starting depths ranging from 2 – 6 m. The distribution of major soil types across the Wilyabrup catchment is presented in Appendix A, whilst a detailed description of soils within the Wilyabrup catchment is presented in Table 1.

Table 1: Detailed description of Wilyabrup catchment soils

Soil	Unit	Description
Gravelly Duplex	216CoCOd2	Flats and gently sloping rises (gradients 0-5%), with deep bleached sands
Shallow Sands	216CoCOi	Flats and gentle slopes (gradients 0-5%), with some laterite outcrop and shallow gravelly sands over laterite
Deep Organic Sands	216CoCOw	Poorly drained flats and depressions with deep organic stained sands
Deep Sands	216CoGL(d)	Flats with deep bleached sands
Deep sands over limestone	216GrGT (2,3,Te,Tee)	Low slopes (2-10%) with deep reddish and yellow brown siliceous sands over limestone
Sand Over Granite	216GrKP	Coastal dunefields, Aeolian sand and limestone rubble over granite. Calcareous deep sands and calcareous stony soils. Coastal heath
Calcareous Sand	216GrKPb	Beaches and foredunes of calcareous sand, along the west coast
Sandy Dunes	216GrKPE(f)	Steep dunes (gradients >20%) on the west coast with deep pale calcareous sands
Loam	216GrWLe3	Low slopes (gradients 5–10 %)
Deep Loam	216WvGLf	Well drained valley flats and floodplains with deep (often red brown loamy) alluvial soils
Mixed Soils	216WvGL3	Slopes (gradients 5-10%) with a variety of soils types
Mottled Soils	216WvGLw3	Slopes (gradients 5-10%) with high water tables and pale grey mottled (Mungite) soils
Gravel	216WvWL	Slopes (gradients (5-15%, ranging 2-30%) and gravelly soils
Shallow gravel over laterite	216WvGLi3	Slopes (gradients 5-10%)with shallow gravel sands over laterite
Shallow bedrock	216WvGLR	Areas dominated by granitic outcrop
Limestone	216GrGTk	Small areas with sinkholes, dolines, limestone scarps and cave entrances
Drainage Line	216WvGLv	Narrow V-shaped often depressions along drainage lines
Swampland	216WvGLvw	Broad U-shaped drainage depressions with swampy floors

4.5 Surface Water Hydrological Assessment

4.5.1 Previous Studies and Investigations

A study has been carried out by the Department of Water (DoW) (2008) which presents a detailed description of rainfall and stream flow analysis in the Wilyabrup catchment area. Reports that document the hydrology of this catchment include:

- Wilyabrup Brook hydrology summary (DoW 2008);
- Surface hydrology of the Cape-to-Cape Region of Western Australia (DoW 2007); and
- Whicher area surface water management plan – Water Resource Allocation and Planning Series, Report No. 19; September 2009.

Data from two stream flow gauges has been analysed in this report. The Woodlands gauge records flow from 82.3 km^2 of the catchment and has been operating since 1973. The second gauge, Juniper, commenced operation in 2004 and records streamflow from a 43.6 km^2 catchment. A generalised South West groundwater areas allocation plan was released by the DoW in 2009 and contains a solid grounding in generalised aquifer characterisation. A detailed description of the geology of the area is presented in the geological memoirs associated with the Busselton and Augusta geological map sheets SI/50-5 and SI/50-9 (GSWA, 1967).

4.5.2 Overview

Flow in the Wilyabrup Brook is seasonal, with the majority of flows occurring during the wet months (May – Oct). Over the period of record, maximum and minimum annual flows have ranged between 51,000 ML and 10,400 ML respectively (DoW 2008).

Surface water flow data is limited to two gauging stations on the Wilyabrup Brook. Woodlands gauging station (downstream) has been operating since 1973 and Juniper gauging station has recently been installed (November 2004) to monitor flow rates in the upper reaches of the Brook. Meteorological data is collected at three stations in the catchment area. Due to the pre-existing nature of hydrological information documented for Wilyabrup Catchment, the existing surface water hydrology of the Wilyabrup Brook as recorded at Woodlands and Juniper gauging stations will not be detailed in this document.

However of relevance to this investigation is the flow duration of the Wungong Brook at both gauging stations. This provides a direct insight to the contribution of baseflow that forms the total flow of the stream. A stream that flows year round is also likely to receive baseflow year round, which will therefore comprise a significant proportion of the total flow. Conversely a stream that flows seasonally is likely to have a much smaller baseflow component of the total stream flow. Flow duration curves for Wilyabrup Brook at both gauging station locations are illustrated in Figure 5.

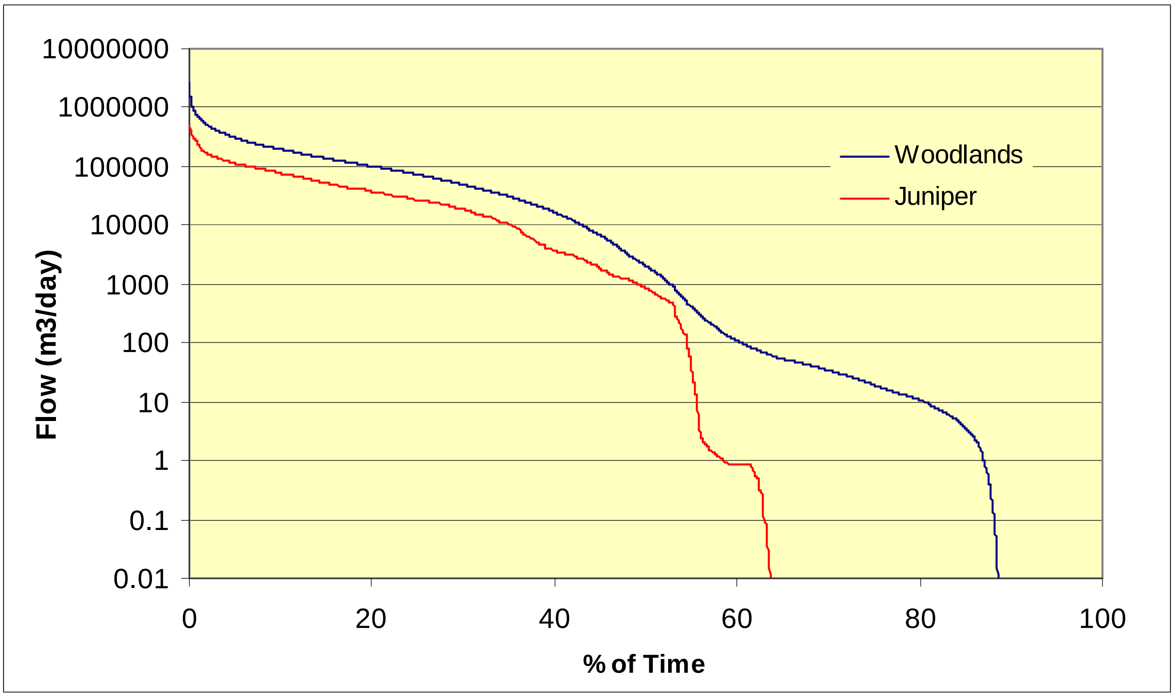

Figure 5: Flow duration curves for Woodlands and Juniper gauging stations

Figure 5 indicates Woodlands, which flows approximately 89% of the time, receives a greater contribution of baseflow than Juniper, which flows for approximately 63% of the time.

The DoW classifies both baseflow and interflow area as 'groundwater' for water allocation licensing purposes within the Wilyabrup catchment as per the *RiWI Act 1914*. Some on stream dams are thought to receive a certain proportion of baseflow where construction has involved excavation below the natural surface. This has created a sump in to which underground water seeps. In these cases, this water is interpreted, licensed and abstracted for use as groundwater. With a limited availability of allocated surface water in the Wilyabrup catchment, there is increased focus on groundwater as a viable water source. However the baseflow component of a stream is important for maintaining the EWR of that stream. Therefore baseflow should be quantified and defined prior to using it as a water source within streams. Further it is not yet well understood whether it is baseflow or interflow that recharges to the Wilyabrup Brook. This will be further investigated in Section 4.7.

4.6 Hydrogeological Assessment

4.6.1 Overview

The Wilyabrup catchment falls into the Busselton Capel Groundwater Area. It does not however fall into any of the management zones defined by DoW (2009). This is probably principally because it appears that the fractured Precambrian crystalline rock of the Leeuwin Complex, which makes up a large proportion of the area, does not play a major role in groundwater supply.

The Leeuwin Complex is found to underlie most of the Wilyabrup catchment. The aquifer is classified as a fractured rock aquifer with groundwater movement limited to the weathered upper horizons and deeper fractured systems in the crystalline basement rocks.

The Tamala Limestone directly overlies the crystalline rock sequence in the South of the area and consists of a sequence of karst channels and conduits. Rapid infiltration of surface water occurs in these areas. The drainage is known to discharge via spring lines along the coast. Water level data is not useful in this area due to a dual porosity system in the limestone and rapid groundwater movement.

A number of boreholes have been drilled in the catchment, most of them shallow, penetrating only the weathered horizons. The majority of private bores in the area are used for watering livestock and tend not to exceed depths of 10 m below ground level (bgl). Groundwater levels were taken in boreholes drilled by the DoW and water levels ranged from 0.0 to 4.6 mbgl. This suggests that the bores are tapping mainly the perched aquifers in the weathered horizon above unweathered crystalline rock. If so, these bores could be tapping ephemeral perched water bodies which have a reduced yield/water level or dry up completely in the dry season.

4.6.2 Groundwater Quality

It has been reported in DoW (2008) and DoW (2009) that groundwater quality is highly varied, even within the individual aquifers underlying the Wilyabrup catchment. Groundwater salinity in the Leeuwin crystalline rock and overlying Tamala Limestone is thought to vary between 100 and 840 mg/L. This is based on results gathered from boreholes drilled by the DoW in the Wilyabrup catchment with a maximum bore depth of 46 m.

Additional monitoring is required to form a more detailed understanding of groundwater quality in the Wilyabrup catchment and its variation for different aquifers.

4.7 Baseflow Assessment

Baseflow is defined as sustained low flow in a river during dry weather conditions, generally all contributed by groundwater and not from surface runoff. In some cases, streams with bank water storage, like meandering rivers can contribute to baseflow. However this is not the case in the Wilyabrup catchment which is defined by steeper sided topography with streams cut into the underlying geology. It is therefore felt that any baseflow in the Wilyabrup catchment will be contributed by groundwater.

In order to determine the importance of baseflow in a water balance it is necessary to do a baseflow separation. In simple terms, the assumption is that baseflow is the water that continues to maintain stream flow throughout the year and is not impacted by runoff or low precipitation.

Previously a hydrograph baseflow separation model was run on Woodlands hydrographs on the Wilyabrup catchment and discussed in DoW (2008). Results of the base flow separation analysis of Wilyabrup suggest that the partitioning uses an average annual baseflow index of 0.512 or 51 per cent, with annual values ranging from 48 to 57 per cent. Monthly analysis of the data revealed that, on average, from September to December baseflow accounted for between 65 and 74 per cent of the total streamflow. The DoW stated that the timing and volume of this baseflow contribution may play an important role in sustaining ecological processes in and along the brook.

Baseflow separation calculations were carried out by GHD using the Smathkin Baseflow Separation Method. Minimum flows in the river were used as baseflow for the calculations. Two gauging stations were used namely 610006 (Woodlands) and 610028 (Juniper). It has been calculated from the baseflow assessment that baseflow may contribute approximately 1 per cent of total annual flow in Wilyabrup Brook at monitoring point 610006 (Figure 6) and no baseflow upstream of 610028. In the case of the Juniper gauging weir, the fact that the stream is dry for most of the summer region suggests that the groundwater level is below the base of the stream and does not contribute to stream flow maintenance.

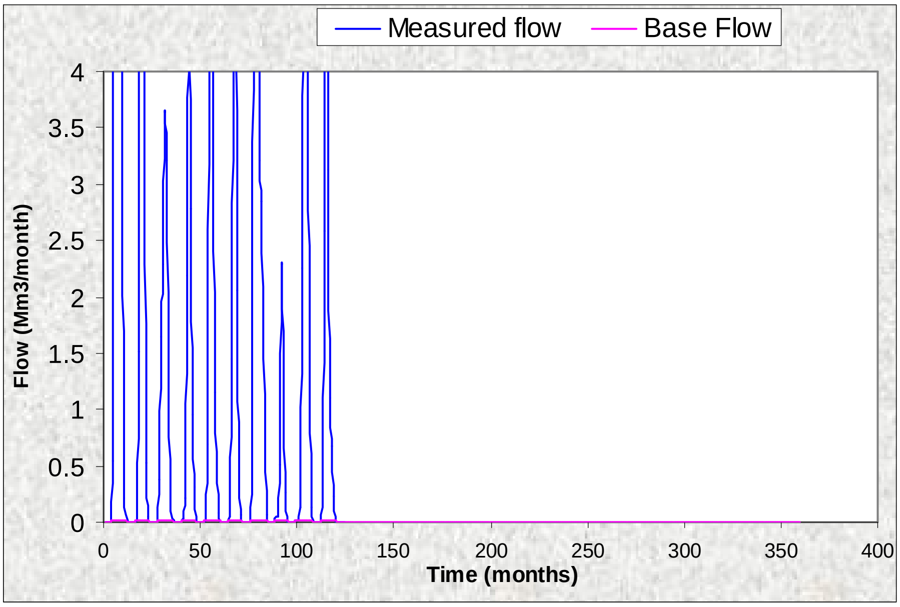

Figure 6: Wilyabrup Baseflow Separations (Woodlands Gauging Station 610006) showing 1 % baseflow for the catchment

Figure 6 show the importance of baseflow to the flow of the river as a percentage to river contribution flow throughout the year. This analysis is based on ten years of water level monitoring data. The graph shows that the contribution by baseflow is 100% over the months of December, January and February but is of relatively no importance in winter months when rainfall runoff is the main contributor to stream flow.

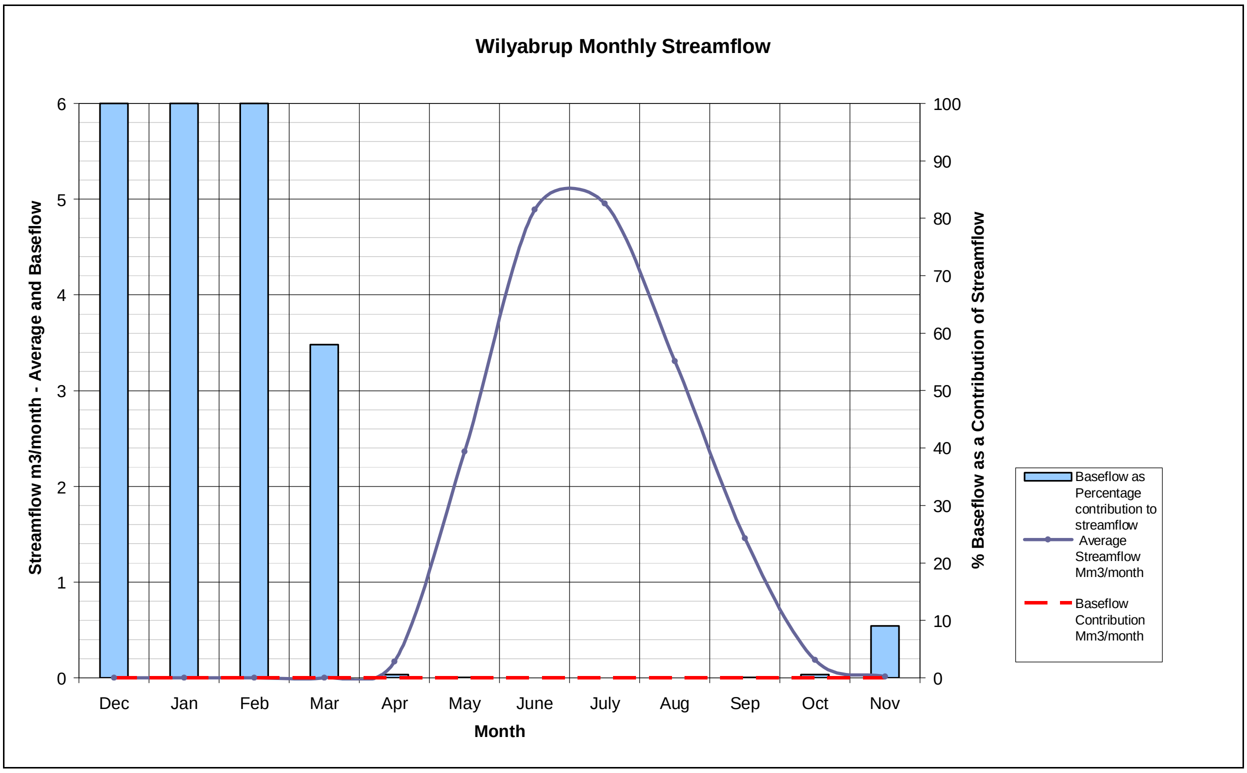

Figure 7: Contribution of baseflow to streamflow as a percentage of total flow (Wilyabrup Catchment monitoring point 610006)

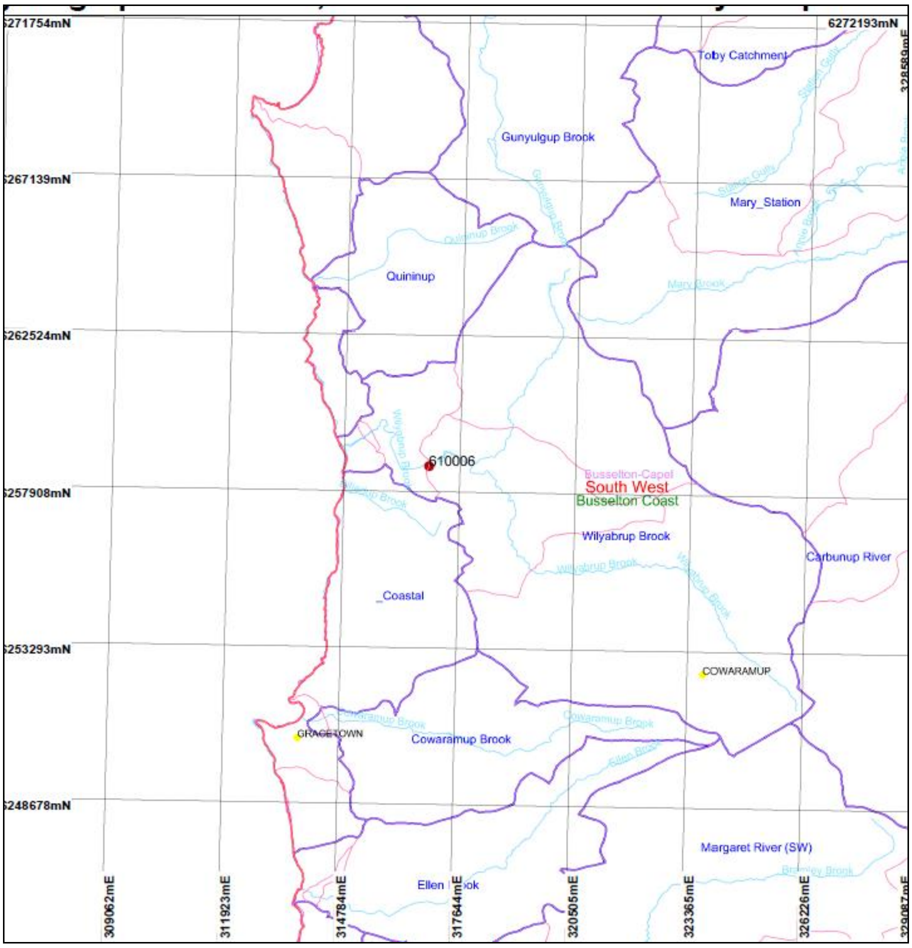

Figure 8: Wilyabrup Catchment with Woodlands Gauging Station (DoW, 2008)

4.8 Water Balance

To provide a more detailed overview of water use within the Wilyabrup catchment, the catchment was broken down into three hydrogeological catchments according to geomorphology, landuse and the location of gauging stations. These catchments are presented in Appendix A.

The landuse characteristics were calculated using an existing coverage of native vegetation and digitising areas of active viticulture and urban components from aerial imagery interpretation. Areas not comprised of native vegetation or viticulture was deemed as pasture. The urban area within the Southern catchment was also calculated using aerial imagery interpretation.

The characteristics of the three hydrographic catchments delineated within the Wilyabrup catchment are presented in Table 2.

Table 2: Hydrographic catchment landuse characteristics

Catchment ID	Area (ha)	% Native Veg	% Viticulture	% Pasture	% Urban
Western	564	82 %	1 %	17 %	0 %
Central	3,865	22 %	26 %	52 %	0 %
Southern	4,363	20 %	19 %	60 %	1 %

The landuse information in Table 3, together with hydrological parameters estimated for the Wilyabrup catchment, was used as input data into a high level water balance spreadsheet model. The water balance provides an indication of hydrological characteristics within each Wilyabrup sub catchment.

The spreadsheet model is based on a series of coefficients designed to partition rainfall into surface runoff, evaporation and infiltration to groundwater. These coefficients were estimated based on figures from previous water balance models and available local data for each landuse (Table 3).

Table 3 Water balance coefficients estimated for the Wilyabrup catchment

Landuse	Direct Evaporation	Surface Runoff	Input to Root Zone
Native Vegetation	0.2	0.1	0.7
Viticulture	0.1	0.25	0.65
Urban	0.2	0.5	0.3
Pasture	0.075	0.2	0.725

An important component of the water balance was the estimation of evapotranspiration, which was calculated using the following equation and used in conjunction with initial input to root zone volumes to determine total groundwater recharge volumes (Zhang *et al* 1999).

$$\frac{ET}{P} = \frac{1 + w\frac{E_o}{P}}{1 + w\frac{E_o}{P} + \left(\frac{E_o}{P}\right)^{-1}}$$

ET – Evapotranspiration (mm)

P = Precipitation (mm)

E_o = Potential evapotranspiration (mm)

w = Plant available water coefficient (ranges from 0.5 for crops to 2.0 for forest)

Potential evaporation (E_o) was calculated using the Priestley and Taylor (1972) method:

$$\mathrm{PET} = \frac{\alpha}{\lambda}\frac{\Delta}{\Delta + \gamma}(R_n - G)$$

R_n – Net radiation (MJ m^{-2} day^{-1})

G – Soil heat flux (assumed to be 0)

Δ - Slope of the vapour pressure – temperature curve (kPa K-1)

Y – Latent heat of evaporation (~2.5×10^6 J mm-1)

a - Empirical factor of 1.26

The water balance is presented below in Table 4 and was calculated with the following assumptions:

- Monthly rainfall data was used from BOM site 9636 Cowaramup. The 1989 year (1085 mm) best matched the average annual rainfall (1057 mm) over the period of record and was used as input data;
- An annual irrigation rate to viticulture was assumed to be 1.5 ML/ha/yr based on supplied irrigation data;
- The net recharge was calculated as: *Net recharge = (groundwater recharge + surface water runoff) – water captured for viticulture irrigation;*
- Landuse areas calculated through spatial analysis of supplied and digitised layers;
- Plant available water coefficients were applied based on land use estimates for each subcatchment;
- Net radiation data was sourced from the Bureau of Meteorology website for Busselton (Site: 009515).

Table 4: Water balance for the Wilyabrup Catchment – Current Case

Inputs	**Catchment**			
	Western	**Central**	**Southern**	**Total**
Rainfall (1065 mm/year)	6,120	41,943	47,347	95,410
Water captured for viticulture irrigation*	8	1,507	1,243	2,750
Total inputs	**6,128**	**43,450**	**48,590**	**98,160**
Outputs	**Western**	**Central**	**Southern**	**Total**
Evaporation and Evapotranspiration	5,403	33,357	37,513	76,273
Surface Water Runoff	725	8,011	9,114	17,850
Groundwater Recharge	0	2,082	1,963	4,045
Total outputs	**6,128**	**43,450**	**48,590**	**98,168**
Net Groundwater Addition	***717***	***8,586***	***9,834***	***19,137***

* An average annual irrigation rate of 1.5 ML/ha was assumed based on supplied catchment irrigation data

The modelled water balance results were validated by comparison to known values for the Wilyabrup catchment. It is currently known 363 ML of groundwater are abstracted annually, whilst 2, 626 ML of surface water storage are currently licensed. These figures combined, correspond reasonably well with the total water captured for viticulture irrigation (2,750 ML). Further, the combined annual modelled surface water runoff of 17,125 ML for the Central and Southern catchments also matches well to the average annual measured streamflow of 18,955 ML at Woodlands gauging station over the period 1997 – 2008.

Groundwater recharge represents approximately 4 per cent of total water inputs to the Wilyabrup catchment. Evaporation and evapotranspiration account for between 77 and 99 per cent of total water inputs to the Wilyabrup. Modelling indicates evapotranspiration is a dominant process, particularly in naturally vegetated catchments such as the Western catchment where groundwater recharge is zero.

4.8.1 Landuse Change Scenario

A landuse change scenario was modelled within the water balance model. Based on the relative unknown nature of future landuse changes within the catchment, one simple landuse change was modelled. Recent advice indicated that there is increasing pressure on viticulture due to reduced profit margins as a result of tough financial times and this may lead to the future reduction of the area established to viticulture in the region. Consequently, this water balance scenario assumes viticulture does not exist within the catchment and that the areas of land previously used for viticulture are planted for agroforestry.

The results of the water balance landuse change scenario are presented in **Error! Reference source not found.**.

Table 5: Water Balance for the Wilyabrup Catchment – Landuse Change Scenario

Inputs	**Catchment**			
	Western	**Central**	**Southern**	**Total**
Rainfall (1065 mm/year)	6,120	41,943	47,347	95,410
Water captured for viticulture irrigation*	0	0	0	0
Total inputs	**6,120**	**41,943**	**47,347**	**95,410**
Outputs	**Western**	**Central**	**Southern**	**Total**
Evaporation and Evapotranspiration	5,404	35,547	39,579	80,530
Surface Water Runoff	716	3,375	7,765	11,856
Groundwater Recharge	0	21	3	24
Total outputs	**6,120**	**41,943**	**47,347**	**95,410**
Net Groundwater Addition	***716***	***3,396***	***7,768***	***11,880***

The variation in the total water balance figures for the current case and landuse change scenario resulted in changes to:

- Captured water for irrigation;
- Evaporation and evapotranspiration;
- Surface water runoff; and
- Groundwater recharge.

Groundwater recharge will reduce from 4,045 M to 24 ML/yr, which represents the most significant reduction within the water balance. This is driven primarily by increased evapotranspiration losses through reforestation. Surface water runoff will also reduce significantly due to the lower surface water runoff coefficient associated with forestry (0.1) when compared to viticulture (0.25).

Consequently it can be inferred that the effect of exchanging viticulture with forestry is likely to reduce streamflow in the Wilyabrup Brook by approximately 34 per cent. The net groundwater recharge is also likely to decrease by approximately 38 per cent.

It is therefore important to take into consideration landuse change within the catchment. Increasing forested land cover within the catchment is likely to reduce both streamflow and groundwater recharge. Consequently these changes should be taken into consideration through revised surface and groundwater allocations for the catchment.

4.9 Discussion

This investigation has been undertaken to generate a conceptual understanding of surface water and groundwater interactions in the Wilyabrup Brook catchment. The hydrology of Wilyabrup Brook catchment is well understood with stream flow data dating back to 1973 and a number of climate stations positioned within the catchment area. This data has allowed for the generation of hydrographs and a comparison of stream flow to rainfall data.

On a regional scale the geology of the Bunbury Augusta area is well understood. A DoW WIN database search has revealed that most boreholes in the catchment area are less than 10 m deep. Geological logs are some what scarce for boreholes in the catchment area. It is understood that deeper bore data (>20 m) is likely restricted to work carried out by the DoW.

The hydrogeological properties of local individual aquifer units have not been discussed in the provided documentation. It is believed that a reasonable understanding of the more regional hydraulic properties is available in the wider literature. These values are useful for catchment based water balance modelling however more site specific values of hydraulic conductivity and hydraulic gradient are desirable in the vicinity of Wilyabrup Brook in order to generate an improved conceptualisation of the surface water groundwater interactions in that area and to carry out Darcian flow calculations.

Groundwater chemistry in the Wilyabrup Brook catchment is summarised in the available documents and in the wider literature however, more detailed groundwater quality data is required for a number of reasons. Firstly, it may be possible to type the groundwater from the individual aquifers in the catchment allowing for an assessment of the degree of connectivity between water bodies and an assessment of the degree of homogeneity within the individual units especially those which are considered the more significant contributor to groundwater flow. Secondly, depending on the hydrochemical signature of the underlying aquifer and that of the surface water, techniques can be applied on a local scale to separate base flow from stream flow. This may allow for a secondary confirmation calculation of base flow separation if required.

The baseflow separation analysis undertaken by GHD has yielded significantly different results to those generated by DoW (2008). This is due to the different methods used for baseflow separation and different objectives of the analysis. The Smakhtin method adopted here separates baseflow only and does not account for interflow. The method used by DoW measures slow stream flow from all sources, including interflow for the purposes of maintaining EWR. Consequently, GHD's baseflow contribution at Woodlands gauging station was 1 %, compared to between 48 to 57 % as calculated by DoW. This variance indicates a significant contribution of interflow to total stream flow.

The information provided within this report including field observations and groundwater recharge percentages of approximately 4 per cent of total catchment water inputs supports GHD's estimate of baseflow (excluding interflow) contribution to Wilyabrup Brook. All information points towards the Wilyabrup catchment being a surface water and interflow dependant catchment, with minor contributions from baseflow.

The prominence of duplex soils throughout the catchment, including soil layers classified by DAFWA as deep sands indicates the process of interflow is likely to contribute largely to surface water runoff and consequently streamflow. Groundwater level information taken from WIN bores indicates extremely shallow groundwater in many bores of < 1 mBGL, however the location of the majority of these bores is on drainage lines. Further, it is unclear as to whether it is the actual groundwater level or superficial water being measured.

From these findings it appears there is a distinct separation of surface water and interflow from baseflow in the Wilyabrup catchment. Current water allocations consider groundwater a component of some large dams in the Wilyabrup catchment that are excavated below the natural surface, which has implications for groundwater and surface water licensing. Interflow, which is classified as groundwater, is a dominant process in the catchment. The technical definition of the term describes sub surface water movement, however this water is often expressed at the ground surface as a seep, which changes the classification of this water from underground water to surface water.

In some examples, water licenses are required for both surface water and groundwater where both surface and underground water feed into some dams. It seems unnecessary to require two water licenses for water that is abstracted from the same source. Consequently there is a strong argument to combine both surface and groundwater licenses in this case, making no distinction between the two.

A conceptual interpretation of surface and groundwater interaction within the Wilyabrup catchment is presented in Figure 9.

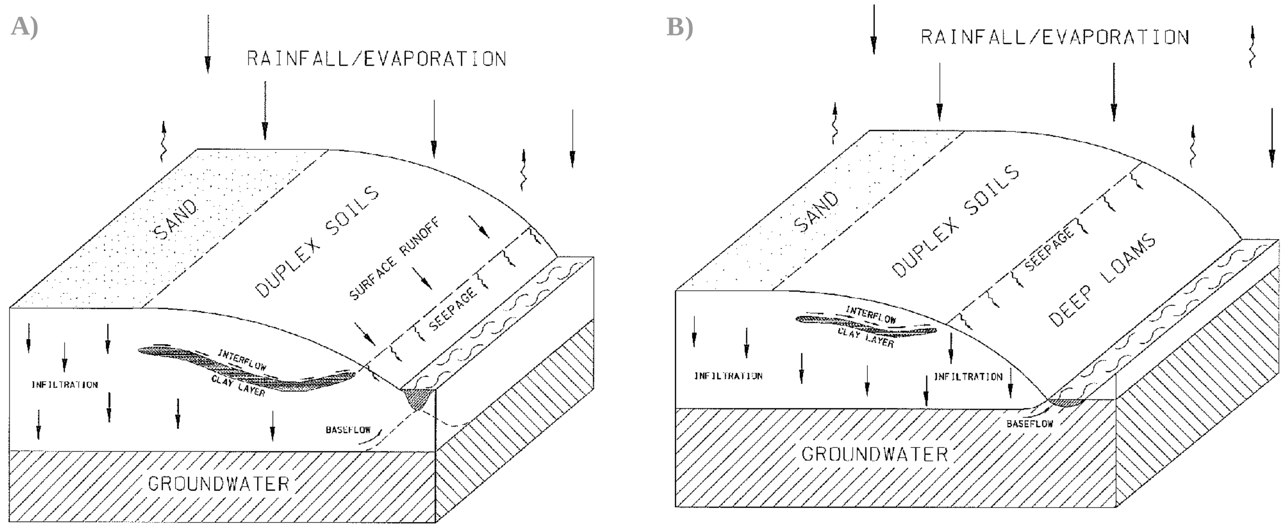

Figure 9 Conceptual interpretation of the surface and groundwater interaction in the Wilyabrup catchment.

Concept a) is representative of surface and groundwater interactions upstream of Juniper gauging station. Here baseflow does not occur which is represented by the lack of groundwater interception at the stream reach. Groundwater seeps are likely to occur close to the stream reach as a result of the proximity of duplex soils to streams. Concept b) is representative of the catchment area immediately upstream of Woodlands gauging station and downstream towards the catchment outlet. Here the more incised nature of the catchment has eroded the landscape in some cases to bedrock, resulting in the interception of groundwater. Consequently, baseflow forms a component of total streamflow in these areas of the catchment.

More supporting information is required to support the argument of combining both surface and groundwater licences in the Wilyabrup catchment. It is noted such a change in water licensing would have implications for other catchments in the region and may require changes to local policies.

5. Case Study 2 – Smith Brook Catchment

5.1 Background

Smith Brook catchment is located in the south west of Western Australia immediately south of the town Manjimup. The catchment is elongated with a length of approximately 17 km and has a total area of 10,436 ha. Smith Brook is the main drainage line running in a south south-easterly direction through the catchment and discharges at the catchment outlet to the Warren River.

Smith Brook catchment receives an annual average rainfall of 917 mm based on rainfall history at Manjimup rainfall station 9573 (1975 – 2006). Agricultural activity within the catchment is mixed and includes avocados, viticulture and mixed vegetables such as potatoes. More recently there has been a shift towards tree farming, with *Eucalyptus globulus* the most common species farmed for timber.

Figure 10 Example of on stream dams and viticulture

5.2 Field Observations

A field assessment was undertaken on the 3rd July 2009. Both the Smith Brook and the neighbouring Lefroy catchments were visited to assess dam and stream conditions and also to discuss water allocation issues with local landowners. The condition of streamflow was also assessed with advice from a local DoW representative. The following is a summary of findings from the field assessment:

- Groundwater seeps, interpreted as interflow were observed on hill slopes in the Lefroy catchment;
- Dams regularly run dry in the summer period upstream of Middlesex gauging station (Figure 11)
- It was advised that streamflow maintenance occurs during the summer months at Middlesex gauging station by a landowner indicating baseflow contribution (Figure 11);

Figure 11 Field photographs of a dry dam in winter and Middlesex gauging station

Figure 12: Photographs of interflow / infiltration water perched on clays decanting onto surface

5.3 Geomorphologic Assessment

The geomorphology does not vary significantly within the Smith Brook catchment. Profile cross sections across the Smith Brook at varying locations within the catchment illustrate similar slopes and degrees of valley incision (Figure 13; Appendix B). This is likely a result of fairly uniform rainfall across the catchment, which is not significantly affected by coastally driven rainfall or rain shadows.

A digital elevation model (DEM) of the catchment was generated from 5 m contours and is presented in Appendix B.

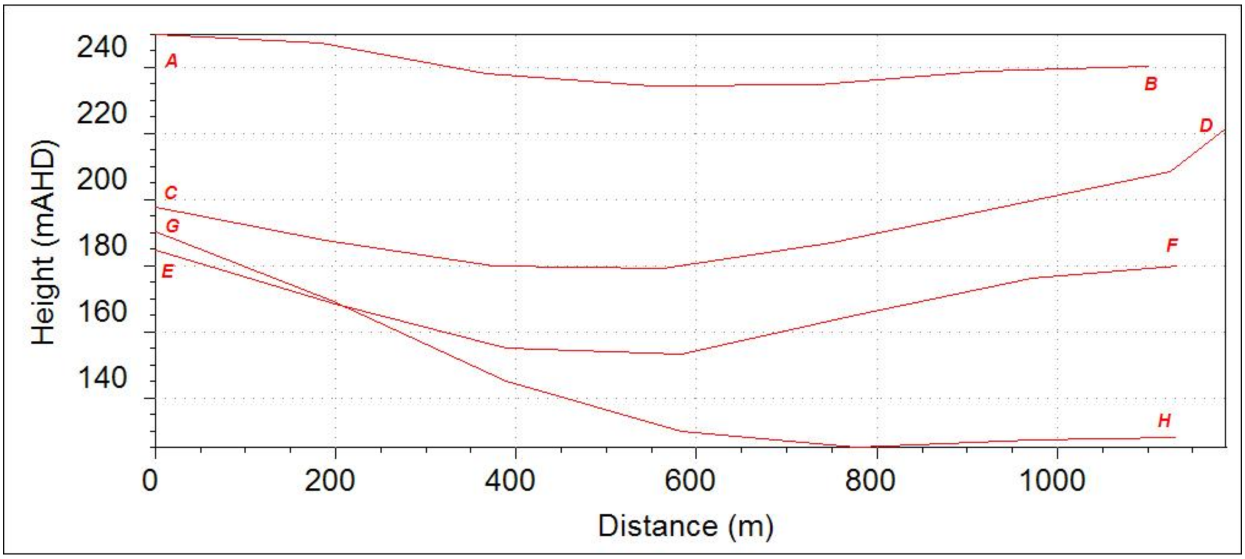

Figure 13 Cross section profiles across Smith Brook

5.4 Geological and Soils Assessment

5.4.1 Geology

The Smith Brook catchment area overlies the Archaean Yilgarn Craton which consists predominantly of gneiss within the catchment area. This gneiss is typically composed of quartz, feldspar and biotite. The meta-sediment is generally well banded and is amphibolite to granulite facies in grade. Other minor rock types in the Yilgarn Craton include banded iron formation, amphibolite and small lenses of quartz mica schist (DoE, 2004). Quartzite and quartz veining are also common in the basement rock and is seen to outcrop within the Archaean gneiss, which is also evident in bore logs.

A number of bores were drilled for the DoW in the 1990s, one of which (WIN ID: 11927174) is located close to Smith Brook approximately 7 km from the Warren River. The borehole was drilled to a total depth of 107 m. A moderately weathered quartzite reportedly occurs between ground level and 26 m below ground level (mbgl). The degree of weathering decreases with depth and is non existent below 59 mbgl. Quartzite it reported to occur to the base of the hole (107 mbgl).

Various Cainozoic and Quaternary surficial deposits form a veneer over the Archaean basement. A predominantly massive laterite is found at the surface over the majority of Smith Brook catchment. The laterite includes overlying pisolitic gravel with minor latherized sand. It is thought that the laterite formed over a broad time-span in the Tertiary. The laterite has chiefly developed by the in situ weathering of underlying rocks. It varies from massive to cemented, with either a pisolithic or vesicular texture, to loose, uncemented pisolites. Colluvial deposits are abundant along the stream line of Smith Brook (GSWA, 1984).

5.4.2 Soils

There are five major soil types within the Smith Brook Catchment. The catchment is characterised by sandy gravels located in the upper catchment areas that grade into a combination of gradational soils and sandy, loamy and gravelly duplex soils. The gravelly duplex unit is largely associated with subcatchment divides, whilst the gradational unit is largely confined to minor drainage lines and also includes some duplex soils. The duplex nature of the majority of soils within the Smith Brook catchment supports the potential for a surface water dominated catchment as a result of shallow water storage above clay lenses. This is likely to contribute to streamflow through interflow processes. The spatial distribution of soils in the Smith Brook catchment is illustrated in Appendix B, whilst a more detailed description of the soils within the catchment is provided in **Error! Reference source not found.**.

Table 6 Detailed Smith Brook catchment soils description

Soil	Unit	Description
Loamy Gravels	254DwCL(Yn,WH)	Gently undulating rises over sedimentary deposits, relief 5-15 m, slopes 1-5%. Soils are loamy gravels and sandy gravels.
Sandy Gravels	254DwBe	Broad, gently sloping (3-15%) divides on laterite, soils are sandy gravels and loamy gravels.
Gradational Soils	254PvPM	20 to 40 m deep. Flat to gently sloping floors. Few channels. 3 to 10 deg. Smooth slopes. Red or yellow gradational soils, not calcareous with some red duplex soils.
Gravelly Duplex	254PvCR(y,b);DwCRb	Gravelly yellow duplex soils; jarrah-marri forest; Brown gravelly duplex soils and red earths; karri-marri forest.
Sandy Duplex	254PvCRd	Sandy yellow duplex soils; marri-jarrah forest

5.5 Surface Water Hydrological Assessment

5.5.1 Previous Studies and Investigations

Whilst detailed investigations have been undertaken for the adjacent Lefroy catchment, no detailed investigations have been published for the Smith Brook catchment, although it is noted the catchments display similar landuse and hydrological characteristics. Smith Brook catchment is characterised by numerous on-stream large farm dams used for irrigation. Whilst the impact of these dams has not been measured on the hydrology of the Smith Brook, it is known that on-stream dams have a negative effect on downstream flows.

5.5.2 Overview

To date there is no known reported hydrological information for Smith Brook. The hydrology of the neighbouring Lefroy Catchment was recently investigated by the DoW (2008), which provides an insight as to the hydrological behaviour or the Smith Brook catchment, however geological, geomorphologic and landuse differences are also likely to result in differences in stream flow characteristics. Consequently an overview of the Smith Brook hydrology is provided.

Recorded surface water flow data in the Smith Brook catchment is limited to three gauging stations. The period of record at all locations is not current and the most recent complete annual record of stream gauge is in 2007, although prior to that is in 1999. A summary of the flow characteristics of gauged flow data is provided in **Error! Reference source not found.**. Flow data is limited to relatively short periods of record, with no reliable data available from 1999. DoW (2008) reported that flows from approximately 1999 – 2004 in the Lefroy catchment lie well below the long term (1952 – 2004) and short term (1975 – 2004) mean. Consequently hydrological inferences drawn from flow data from the Smith Brook catchment may be an overestimate of actual results.

Table 7 Smith Brook catchment gauging station characteristics

Catchment ID	Area (ha)	% Native Veg	% Agriculture	% Forestry	% Pasture	% Urban
Northern	2941	31	4	3	56	3
Central	7081	42	5	8	45	0
Southern	364	87	0	0.5	12.5	0
Research Station	52	86	0	2	12	0

Flow duration curves were also generated for all gauging stations over their period of record to provide an indication of the contribution of baseflow to total annual stream flow at these locations (Figure 14). Results indicate Picketts Road gauging station flows for 100% of the time, indicating baseflow during the dry summer period is responsible for stream flow maintenance. Middlesex gauging station flows for 98 % of the time, again indicating a baseflow contribution over the summer period. Manjimup Research Station however, is shown to flow only 45 % of the time and runs dry over the summer period, indicating there is no baseflow contribution to the stream. It should be noted Manjimup Research Station catchment is a tributary of Smith Brook and is mostly comprised of native vegetation (86 %). Consequently, the mean annual yield of 0.55 ML/ha from this catchment is indicative of the mean annual yield from areas covered by native vegetation.

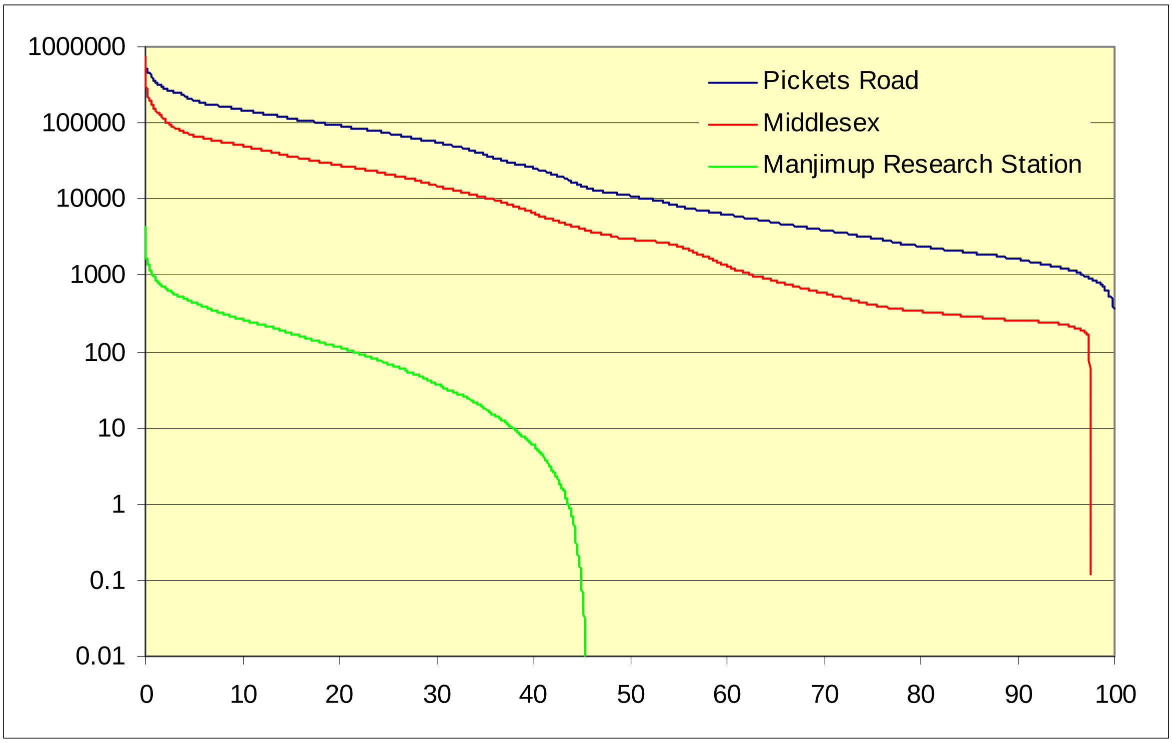

Figure 14: Flow duration curves for Smith Brook gauging stations

Figure 14 indicates interactions between surface and groundwater are likely, but restricted to the main stream reach of Smith Brook. Surface and groundwater interactions are not likely in heavily vegetated catchments such as Manjimup Research Station. Here it is likely that evapotranspiration processes maintain deeper groundwater levels, restricting interaction with surface water. Consequently it is likely that agricultural practices are responsible for interactions between surface water and groundwater, particularly in the upper catchment

5.6 Hydrogeological Assessment

5.6.1 Overview

Groundwater occurs mainly in the weathered profile and in the fractures and joints of the gneiss basement rocks. The weathered rock aquifer is considered to have local to intermediate groundwater flow patterns and are considered to have limited potential as a groundwater resource.

Groundwater in the neighbouring Lefroy Brook catchment occurs mainly in the permeable zones of weathered gneissic rocks. These weathered profiles are thought to vary in thickness from 5 to 30 m. Groundwater flow is typically localised with aquifer recharge occurring through direct rainfall infiltration. Numerous pockets of quartzite and quartz veins occur in the central and south-eastern areas of Lefroy Brook catchment and these form high yielding fractured rock aquifers that can store significant quantities of groundwater (DoW 2008). The overlying Tertiary laterite is not thought to contain significant quantities of groundwater.

The degree of groundwater and surface water interaction in Smith Brook is believed to vary both spatially and temporally. It is stated in the literature that groundwater flow is typically localised in the weathered aquifer, thus the degree of interaction between the two bodies is also likely to be highly localised with significant baseflow in areas at certain times of the year and minor/no baseflow in other areas.

A borehole drilled close to Smith Brook for the DoW in 1994 shows the weathered bedrock to extend to a depth of approximately 26 mbgl. A water level of 6.6 mbgl was taken from this bore in March 1994. This further reinforces the theory that localised groundwater flow is likely common in the Smith Brook catchment. This borehole was found to yield >285 m^3/day which makes it a significant resource. Generally there appears to be little groundwater development in the Smith brook catchment and the users appear to rely mainly on surface water.

5.6.2 Groundwater Quality

The weathered bedrock aquifer is thought to contain groundwater of a moderate salinity with readings thought to be less than 1000 mg/L TDS. Salinity values in the fractured quartz vein/quartzite fractures are thought to be lower with values not expected to exceed 500 mg/L TDS (DoW, 2008).

Groundwater quality measurements were taken while drilling borehole WIN ID: 11927174. Groundwater salinity was found to range from 78 to 300 mg/L and a pH value of 4.8 was recorded. Although groundwater is slightly acidic, a maximum salinity value of 300 mg/L suggests a fresh water source.

5.7 Baseflow Assessment

It is understood that no previous baseflow separation has been carried out on Smith Brook. Four stream flow gauging stations are located within the Smith Brook catchment. Of these four stations, two are noted as being located on tributaries of Smith Brook while the other two are located on Smith Brook. Pickettt's Road gauging station covers the largest area of the catchment (101 km^2) however records only exist between 1995 and 2000.

An example year (1997) has been chosen to demonstrate the relationship between rainfall and stream flow within the Smith Brook catchment, Figure 15. Stream flow can be seen to be directly proportionate to rainfall with increased rainfall resulting in increased run off. One exception is seen in July where a drop in rainfall resulted in an increase in stream flow when compared to the previous month. The exact reason for this is unclear however it is possible groundwater is likely a significant contributing factor to the maintained flow rates seen during this month where run off is negligible. Significant summer flow rates such at that seen in January 2008 (89,869 m^3) when rainfall is negligible (12 mm) also suggest significant baseflow.

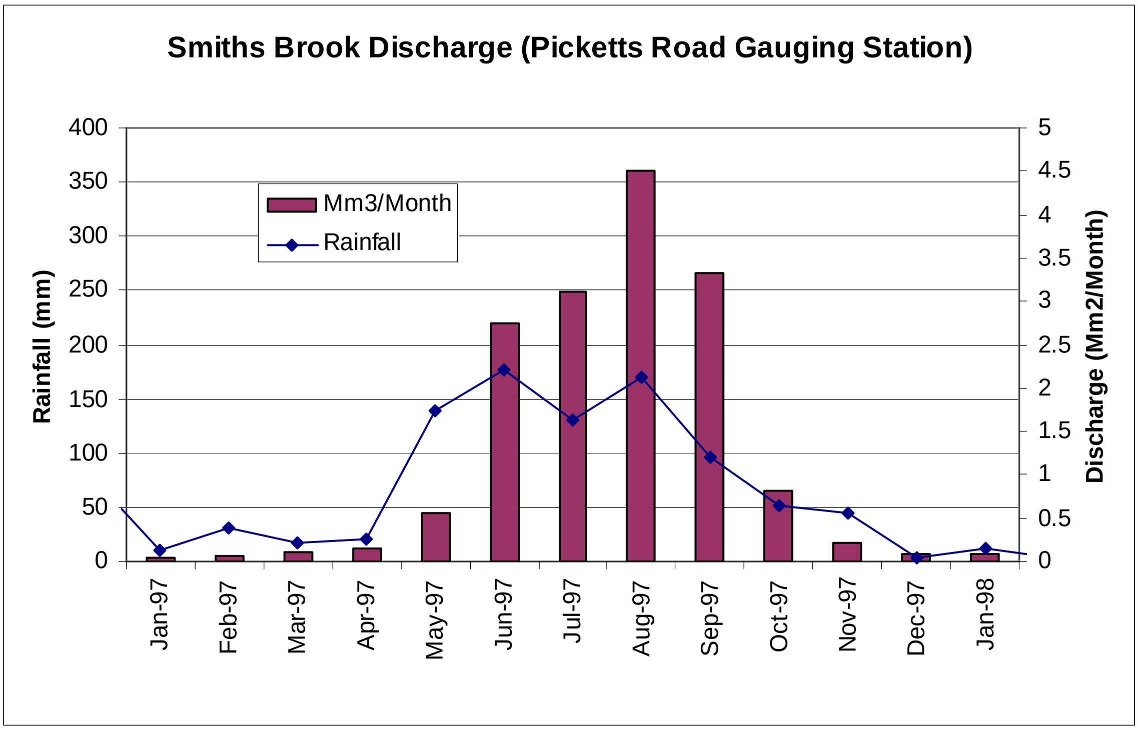

Figure 15: Smith Brook Annual Discharge and Rainfall (1997)

Two baseflow separations using the Smathkin Method were done for Smith Brook Stream, one at Picketts Road and one at Middlesex.

They are illustrated in Figure 16 and Figure 17.

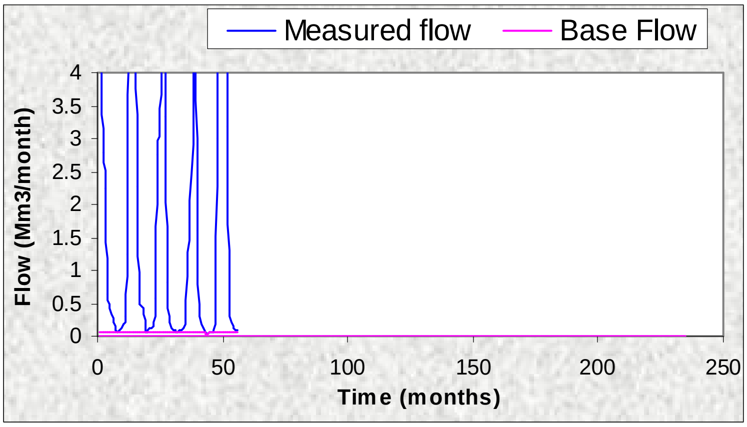

Figure 16: Middlesex (Baseflow Separation showing 3% of total flow)

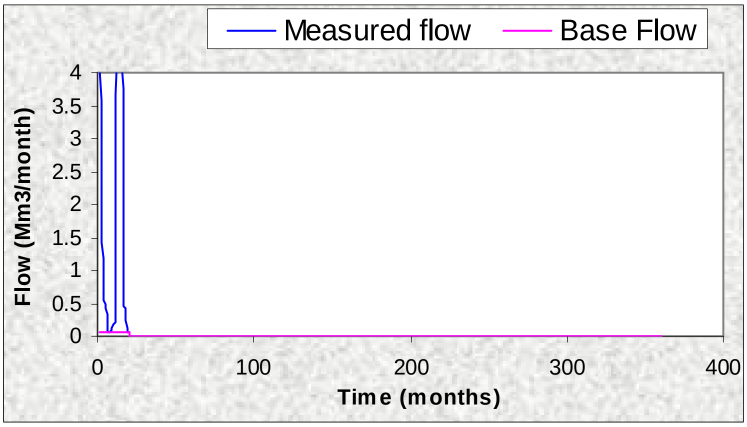

Figure 17: Pickett's Road (Baseflow Separation) showing data limited to 24 months) and 3% baseflow contribution

The baseflow separations show that the contribution of baseflow to total streamflow appears to be in the order of 3 per cent for both the Pickett's road and Middlesex gauging stations. From this it appears that there is little change in the hydrodynamic regimes as regards to baseflow throughout the catchment area assessed between the two stations.

The importance of baseflow to the rivers is shown in the following two graphs (Figure 18 and Figure 19). As can be seen in the Middlesex Streamflow analysis, baseflow contributes significantly to the monthly streamflow flow of the river in the dry months with high contributions of 66% in December and 85% in January and 57% in February. In the winter rainfall months it can be see that in May, June, July August and September monthly baseflow is generally less than 3% of total flow.

In the Pickett's Road analysis, monthly baseflow contributes 19% in December, 89% in January and 77% in February. Again in the dry winter months baseflow contribution to monthly streamflow is between 1-4%.

A fairly significant difference can be seen in comparing the percentage baseflow contribution to streamflow in December for Picketts Road (19%) and Middlesex (66%). This is more than likely related to the fact that there is more runoff remaining lower down in the catchment that is contributing a more significant percentage to streamflow thereby reducing the percentage contribution by baseflow.

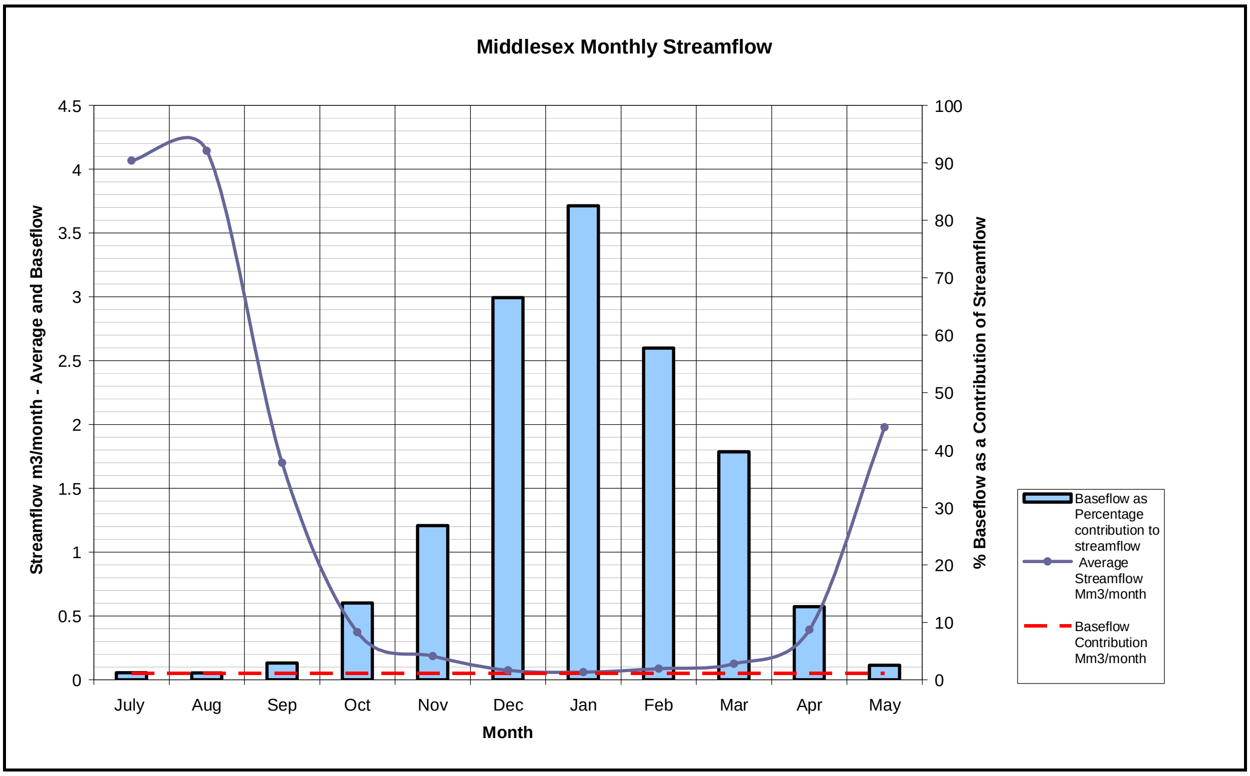

Figure 18: Middlesex baseflow as a percentage of total streamflow

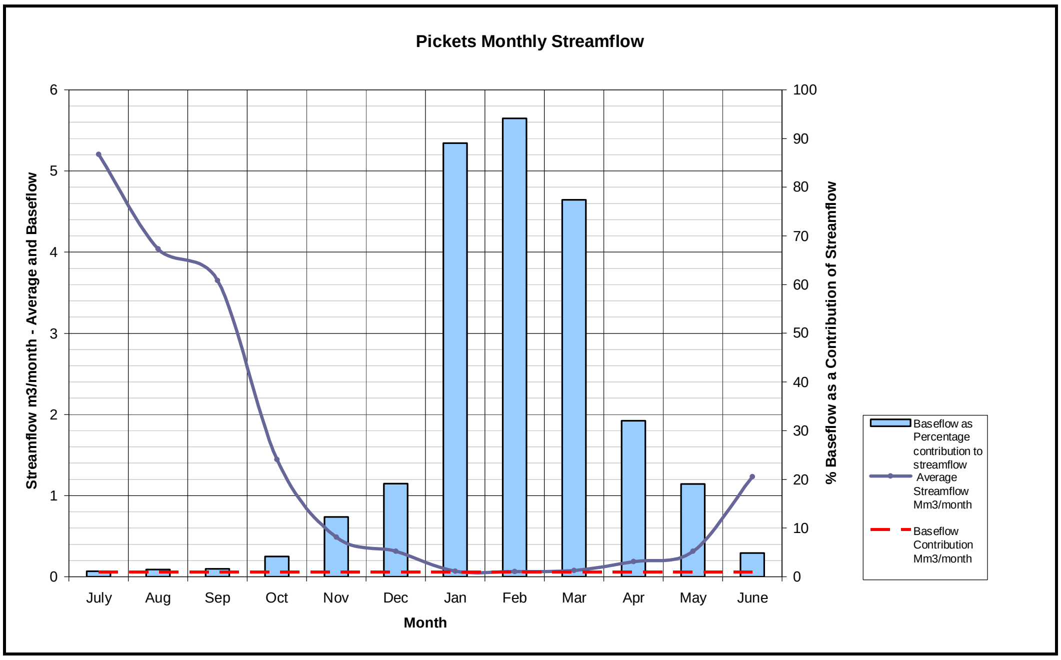

Figure 19: Pickett's Road baseflow as a percentage of total streamflow

5.8 Water Balance

To provide a more detailed overview of water use within the Smith Brook catchment, the catchment was broken down into three hydrogeological catchments according to geomorphology, landuse and the location of gauging stations. These catchments are presented in Appendix B. The landuse characteristics were calculated using an existing coverage of native vegetation and digitising areas of agriculture and agroforestry from aerial imagery interpretation. Areas not comprised of native vegetation agriculture or agroforestry were deemed as pasture.

Table 8 Smith Brook catchment landuse breakdown

Catchment ID	Area (ha)	% Native Veg	% Agriculture	% Forestry	% Pasture	% Urban
Northern	2941	31 %	4 %	3 %	59 %	3 %
Central	7081	42 %	5 %	8 **%**	45 %	0 %
Southern	364	87 %	0 %	0.5 %	12.5 %	0 %
Research Station	52	86 %	0 %	2 %	12 %	0 %

The landuse information in **Error! Reference source not found.**, together with hydrological parameters estimated for the Smith Brook catchment, was used as input data into a high level water balance spreadsheet model. The water balance provides an indication of hydrological characteristics within each Smith Brook sub catchment.

The spreadsheet model is based on a series of coefficients designed to partition rainfall into surface runoff, evaporation and infiltration to groundwater. These coefficients were estimated based on figures from previous water balance models and available local data for each landuse (**Error! Reference source not found.**).

Table 9 Water balance coefficients estimated for the Smith Brook catchment

Land use	Direct Evaporation	Surface Runoff	Input to Root Zone
Native Vegetation	0.2	0.1	0.7
Agriculture	0.1	0.25	0.65
Urban	0.2	0.4	0.4
Pasture	0.075	0.2	0.725
Forestry	0.2	0.1	0.7

An important component of the water balance was the estimation of evapotranspiration, which was calculated using the following equation and used in conjunction with initial input to root zone volumes to determine total groundwater recharge volumes (Zhang *et al* 1999).

$$\frac{ET}{P}=\frac{1+w\frac{E_o}{P}}{1+w\frac{E_o}{P}+\left(\frac{E_o}{P}\right)^{-1}}$$

ET – Evapotranspiration (mm)

P = Precipitation (mm)

E_o *= Potential evapotranspiration (mm)*

w = Plant available water coefficient (ranges from 0.5 for crops to 2.0 for forest)

Potential evaporation (E_o) was calculated using the Priestley and Taylor (1972) method:

$$\mathrm{PET}=\frac{\alpha}{\lambda}\frac{\Delta}{\Delta+\gamma}(R_n-G)$$

R_n *– Net radiation (MJ* m^{-2} *day*$^{-1}$*)*

G – Soil heat flux (assumed to be 0)

Δ *- Slope of the vapour pressure – temperature curve (kPa K-1)*

Y – Latent heat of evaporation (~2.5x10^6 *J mm-1)*

a - Empirical factor of 1.26

The water balance is presented below in Table 10 and was calculated with the following assumptions:

- Monthly rainfall data was used from BOM site Manjimup No 9573. Rainfall was selected using the 1980 rainfall year (923 mm) which closely matched the annual average (917 mm) over the period of record (1975-06);
- An annual irrigation rate to viticulture was estimated to be 1.5 ML/ha/yr based on supplied irrigation data from the Wilyabrup catchment near Cowaramup;
- The net recharge was calculated as: *Net recharge = (groundwater recharge + surface water runoff) – water captured for irrigation;*
- Landuse areas calculated through spatial analysis of supplied and digitised layers;
- Plant available water coefficients were applied based on land use estimates for each subcatchment;
- Net radiation data was sourced from BOM site for Manjimup (Site: 009573).

$$\frac{ET}{P}=\frac{1+w\frac{E_o}{P}}{1+w\frac{E_o}{P}+\left(\frac{E_o}{P}\right)^{-1}}$$

ET – Evapotranspiration (mm)

P = Precipitation (mm)

E_o *= Potential evapotranspiration (mm)*

w = Plant available water coefficient (ranges from 0.5 for crops to 2.0 for forest)

Potential evaporation (E_o) was calculated using the Priestley and Taylor (1972) method:

$$\mathrm{PET} = \frac{\alpha}{\lambda}\frac{\Delta}{\Delta + \gamma}(R_n - G)$$

R_n *– Net radiation (MJ m*$^{-2}$ *day*$^{-1}$*)*

G – Soil heat flux (assumed to be 0)

Δ *- Slope of the vapour pressure – temperature curve (kPa K-1)*

Y – Latent heat of evaporation (~2.5x10^{6} *J mm-1)*

a - Empirical factor of 1.26

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- The net recharge was calculated as: *Net recharge = (groundwater recharge + surface water runoff) – water captured for irrigation;*
- Landuse areas calculated through spatial analysis of supplied and digitised layers;
- Plant available water coefficients were applied based on land use estimates for each subcatchment;
- Net radiation data was sourced from BOM site for Manjimup (Site: 009573).

Table 10: Smith Brook water balance current state (values in ML/yr)

Inputs	**Catchment**				
	Northern	**Central**	**Research Station**	**Southern**	**Total***
Rainfall (1013 mm/year)	27,169	65,414	480	3,363	95,946
Water captured for irrigation*	176	531	0	0	707
Total inputs	**27,345**	**65,945**	**480**	**3,363**	**96,653**
Outputs	**Northern**	**Central**	**Research Station**	**Southern**	**Total***
Evaporation and Evapotranspiration	21,855	53,778	426	2,984	79,043
Surface Water Runoff	4,727	9,976	54	378	15,135
Groundwater Recharge	763	2,191	0	0	2,954
Total outputs	**27,345**	**65,945**	**480**	**3,363**	**96,653**
Net Groundwater Addition	***5,314***	***11,636***	***54***	***378***	***17,382***

Inputs	**Catchment**				
	Northern	**Central**	**Research Station**	**Southern**	**Total***
Rainfall (1013 mm/year)	27,169	65,414	480	3,363	95,946
Water captured for irrigation*	176	531	0	0	707
Total inputs	**27,345**	**65,945**	**480**	**3,363**	**96,653**
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Groundwater Recharge	763	2,191	0	0	2,954
Total outputs	**27,345**	**65,945**	**480**	**3,363**	**96,653**
Net Groundwater Addition	***5,314***	***11,636***	***54***	***378***	***17,382***

» ** excludes the Research Station inputs*

The water balance indicates an average total of 96.6 GL is used within the Smith Brook catchment annually. Based on estimates of irrigation rates to active agricultural areas (1.5 ML/ha/yr), 707 ML of surface water is captured in dams and used for irrigation. Water licensing in the Smith Brook is yet to be undertaken. Consequently, these figures provide a good starting point for future surface water allocations in the catchment.

Validation of the model can be partly checked by comparing modelled surface water runoff to measured surface water runoff volumes. Modelled surface water runoff at the base of the Central catchment and including inputs from the Northern catchment (14,703 ML/yr) compared well to the mean annual flow for Pickettts Road gauging station (13,360 ML/yr).

Direct groundwater recharge within the catchment is estimated at 3% of total inputs. Evaporation and evapotranspiration account for between 80 and 89 % of total water inputs on a sub catchment scale. This is due to the large areas covered by both native vegetation and forestry.

5.8.1 Landuse Change Scenario

A landuse change scenario was modelled within the water balance model. Based on the relatively unknown nature of future landuse changes within the catchment, one simple landuse change was modelled only. Advice from local landowners indicated agroforestry was becoming a more common farming practice in the region due to low profit margins on products such as mixed vegetables.

Consequently, the area currently used for agriculture was assumed to be used for the purpose of agroforestry. The results of the water balance landuse change scenario are presented in Table 11.

Table 11: Smith Brook water balance Landuse Change Scenario (values in ML/yr)

Inputs	**Catchment**				
	Northern	**Central**	**Research Station**	**Southern**	**Total***
Rainfall (1013 mm/year)	27,169	65,414	480	3,363	95,946
Water captured for irrigation*	0	0	0	0	0
Total inputs	**27,169**	**65,414**	**480**	**3,363**	**95,946**
Outputs	**Northern**	**Central**	**Research Station**	**Southern**	**Total***
Evaporation and Evapotranspiration	22,089	54,365	426	2,984	79,023
Surface Water Runoff	4,564	9,485	54	378	14,481
Groundwater Recharge	516	1,564	0	0	2,080
Total outputs	**27,169**	**65,414**	**480**	**3,363**	**95,946**
Net Groundwater Addition	***5,080***	***11,049***	***54***	***378***	***16,561***

Inputs	**Catchment**				
	Northern	**Central**	**Research Station**	**Southern**	**Total***
Rainfall (1013 mm/year)	27,169	65,414	480	3,363	96,426
Water captured for irrigation*	0	0	0	0	0
Total inputs	**27,169**	**65,414**	**480**	**3,363**	**96,426**
Outputs	**Northern**	**Central**	**Research Station**	**Southern**	**Total***
Evaporation and Evapotranspiration	22,089	54,365	426	2,985	79,865
Surface Water Runoff	4,564	9,485	54	378	14,481
Groundwater Recharge	516	1,564	0	0	2,080
Total outputs	**27,169**	**65,414**	**480**	**3,363**	**96,425**
Net Groundwater Addition	***5,080***	***11,049***	***54***	***378***	***16,561***

** excludes the Research Station inputs*

Results indicate a landuse change from agriculture to agroforestry will increase the net groundwater addition for the catchment. This is due to higher evapotranspiration associated with denser vegetation.

Surface water runoff is only slightly affected by the change in landuse, due primarily to the relatively small areas of land taken by active agriculture (4-5%) in the Northern and Central catchments.

Consequently the reductions in groundwater recharge as a result of increased evapotranspiration are not significant.

Agroforestry is currently practiced within the catchment, representing approximately 6.3 % of the total Smith Brook catchment area. Exchanging current active agricultural areas (not pasture) with agroforestry is therefore unlikely to have a significant impact on stream flow. Slight reductions in groundwater recharge will be expected, however these changes are unlikely to be significant based on the relatively small areas currently used for active agriculture. Expanding agroforestry practices into areas currently used for pasture is likely to have a greater impact on reducing both streamflow and groundwater recharge. Further, groundwater levels may also reduce, which may also reduce the baseflow contribution to streamflow, further reducing total streamflow.

5.9 Discussion

This study has been undertaken to generate a conceptual understanding of surface water groundwater interactions in the Smith Brook catchment using a holistic approach of simple, low cost methods.

The hydrology of Smith Brook catchment is moderately well understood with stream flow data dating back to 1988 at Middlesex gauging station and 1995 in the lower catchment Picketts Road station.

On a regional scale the geology of the Pemberton-Irwin Inlet area is well understood however further information is desirable on a local catchment scale relating to strata thicknesses and lateral extent. The thickness of the weathered bedrock is known at one location however its lateral continuance is critical to identify localised flow systems.

The hydrogeological properties of local individual aquifer units have not been discussed in the provided documentation. It is believed that a reasonable understanding of the more regional hydraulic properties is available in the wider literature. These values are useful for catchment based water balance modelling however more site specific values of hydraulic conductivity and hydraulic gradient are desirable in the vicinity of Smith Brook in order to generate an improved conceptualisation of the surface water groundwater interactions in that area and to carry out Darcian flow calculations.

Groundwater chemistry in the Smith Brook catchment is summarised in the available documents however, more detailed groundwater quality data is required for a number of reasons. Firstly, it may be possible to type the groundwater from the individual aquifers in the catchment allowing for an assessment of the degree of connectivity between water bodies and an assessment of the degree of homogeneity within the individual units especially those which are considered the more significant contributor to groundwater flow. Secondly, depending on the hydrochemical signature of the underlying aquifer and that of the surface water, techniques can be applied on a local scale to separate base flow from stream flow. This may allow for a secondary confirmation calculation of base flow separation if required.

GHDs calculation of baseflow indicated a 3 % contribution to total annual flow at both Middlesex and Pickettts Road gauging stations. Calculations of baseflow at the Manjimup Research Station gauging station concluded baseflow does not contribute to total streamflow. This is supported by the flow duration curves for this gauging station, which indicated the stream flowed for only 43 % of the time.

Figure 20 provides a conceptual interpretation of surface and groundwater interactions in the Smith Brook catchment.

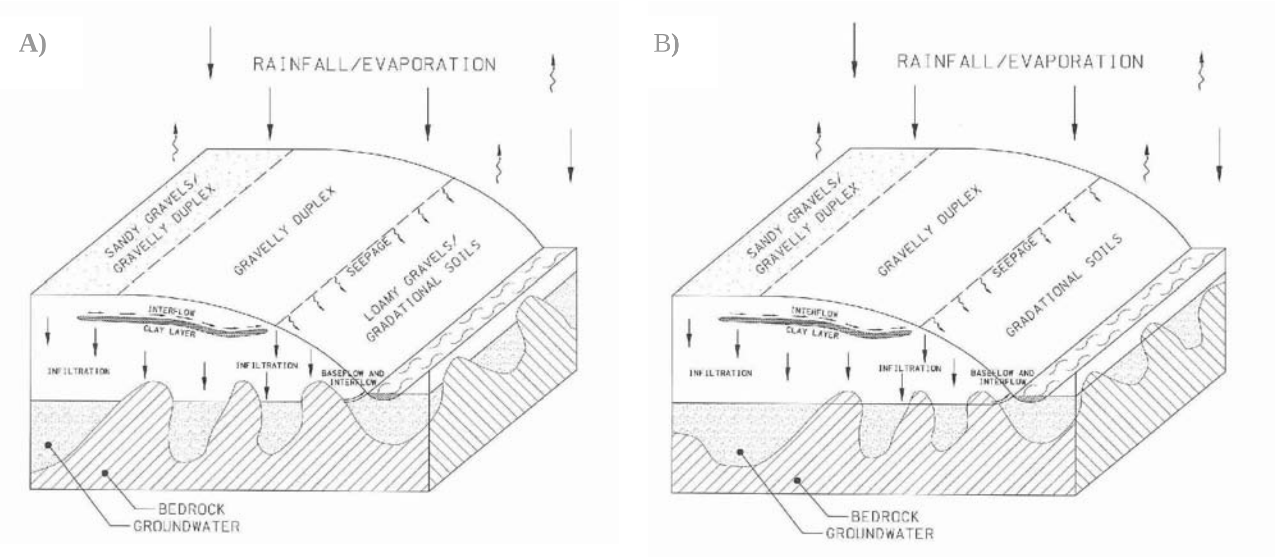

Figure 20: Conceptual interpretation of surface and groundwater interactions in Smith Brook catchment

Concept a) and b) are both conceptually similar with respect to the interactions of surface water and groundwater. Baseflow contributions were calculated at 3 % of total annual flow for Middlesex and Pickettts Road gauging stations. The spatial distribution of soils at each gauging station is the only variation between the two concepts. Concept a) is representative of the catchment area above Middlesex gauging station, whilst Concept b) is representative of the catchment area below Middlesex gauging station.

Both concepts illustrate the presence of duplex soils which are also present in the sandy soils at the top of the catchment. Water balance outputs indicate direct groundwater recharge comprises approximately 2.5 % of total catchment water inputs (rainfall + irrigation). The baseflow analysis, supported by flow duration curves for flow data from the three gauging stations within the catchment indicate there is some connection between surface water and groundwater, but is likely restricted to the stream zone only.

However, excluding this immediate area, surface water and groundwater are largely independent with minor groundwater recharge as a result of duplex soils generating interflow. Whilst hillside seeps were not identified specifically within the Smith Brook catchment, they were observed in the neighbouring Lefroy Brook catchment, which is not geomorphologically dissimilar, indicating hillside seeps are also likely to occur in the Smith Brook catchment. Consequently, interflow input into stream zones is likely to be a common process occurring within the Smith brook catchment.

For water licensing to be undertaken within the Smith Brook catchment, it is recommended the Middlesex and Picketts Road gauging stations should be recommissioned to provide streamflow volumes in order to monitor the impacts of allocations across the catchment. Further, landuse changes within the catchment should also be monitored as they will likely impact streamflow and groundwater recharge, which will have implications for water allocations and their impact on the catchment water balance.

6. Conclusions

6.1 Interpretation of Water Interactions

The interactions between surface water and groundwater were investigated within the Wilyabrup and Smith Brook catchments. This was undertaken through a combined desktop and field investigation approach. The contribution of baseflow to total streamflow provides an insight into the surface and groundwater interactions within a stream. In both catchments, baseflow (excluding interflow) was found to have only a minor contribution to total streamflow. Baseflow calculations by DoW (2008) were significantly higher, but included interflow and were used with the objective of separating low and high flows from an EWR perspective. Consequently, comparisons between the two methods should be considered carefully.

Baseflow contribution to the Wilyabrup Brook was known to be minor based on field observations and communications with DoW staff. This was confirmed through a combined geomorphic and baseflow separation analysis by GHD which indicated that the Wilyabrup Brook is a surface water and interflow dominated system with minor baseflow influence driven largely by the prominence of duplex soils.

Duplex soils support a superficial layer of water and are often are expressed down gradient as a hillside seeps. These hillside seeps are favourable to processes such as interflow. Interflow can in turn be expressed as surface water through a hillside seep. The expression of this water occurs when interrupted by features including:

» Geological barriers;

» Physical barriers (i.e. roads); and

» Natural streams.

It was apparent these seeps contributed to the total streamflow of the Wilyabrup Brook and therefore needed to be quantified. It is currently accepted that this water is classified as groundwater, due to the fact that it originates from under the ground surface. However this water is closely linked to surface water and in some cases, its classification changes between surface and groundwater. The fact that interflow is so closely associated with surface water supports the argument that surface water and groundwater could be combined under the one water license in these fractured rock environments.

It was apparent in the Wilyabrup catchment that baseflow contribution to streamflow increased towards the bottom of the catchment, resulting in annual streamflow towards the Wilyabrup Brook inlet trending towards ephemeral flow in the upper reaches of the catchment; fed by surface water runoff and interflow. The lack of baseflow as the total stream flow at both gauging stations, indicated that interflow comprised a significant proportion of total streamflow, together with surface water runoff. Thus the Wilyabrup catchment is a surface water and interflow flow dependent system, strongly supported by the prevalence of duplex soils and shallow bedrock across the catchment, particularly in the upper catchment areas.

Similarly, surface and groundwater interactions in the Smith Brook catchment were determined to be limited to the stream reach only. It was concluded the Smith Brook catchment is largely a surface and interflow dependent system, with minor baseflow contributions.

Further, there appears to be good connectivity of surface water flows and some groundwater flows (interflow) to both the Wilyabrup and Smith Brook and that these connections should be managed to ensure their sustainability. Areas recharging both superficial and deep groundwater should also be carefully managed to ensure their connectivity to these systems is maintained. Areas most likely to recharge to these water systems are shallow and deep sands, located in the upper catchment reaches. Ensuring the landuse of these areas is not negatively impacted by development including urbanisation and forestry will enhance recharge to sub-surface water systems.

The hydrologic processes occurring in the Wilyabrup catchment are largely mirrored in the Smith Brook catchment. Whilst geomorphologically they are different, the distribution of soil type is similar, both strongly influenced by the presence of duplex soils.

6.2 Implications for Water Allocations

Surface water allocations are almost fully allocated within the Wilyabrup and Smith Brook catchments. This has forced landowners to turn their attention to groundwater in order to create more usable water for farm use. In some cases in the upper Wilyabrup catchment, farm dams are thought to intercept groundwater. DoW has therefore estimated the contribution of groundwater to that dam by using known groundwater level information to allocate an annual groundwater volume for farm use to that landowner. This water, even though it is represented above the ground surface in the dam, is classified as groundwater and is therefore allocated as such.

Under *The Rights in Water and Irrigation Act, 1914*, both a surface and groundwater licence is required for some dams that receive inputs from surface water and underground water. In the case of both the Wilyabrup and Smith Brook catchments, baseflow contributions to streamflow are low. It is therefore fair to assume that underground water intercepted by some dams is likely to be interflow, not baseflow. Given the strong linkages between surface water and interflow, it a reasonable argument that surface water and groundwater be combined as one surface water license.

There is also a strong argument to reconsider the definitions of surface water and underground water within the current act and whether these terms are applicable to all areas of the state, or whether specific acts are required regionally. In the case of the south west of Western Australia, the strong linkages between surface and groundwater make licensing difficult and in this case, combining these two water licenses into one may solve many water licensing issues. At the very least, it would streamline and simplify the licensing process and make interpretations by the public easier.

In the case where licenses are fully allocated, such as the Wilyabrup, alternative water options require investigation. The use of deep groundwater in areas where baseflow does not contribute to the total streamflow would in theory have little impact on the EWR of that stream reach and an increased volume of that groundwater could be made available though groundwater allocations for farm use. This is particularly applicable to the upper Wilyabrup catchment.

Alternatively, the construction of off stream dams with an enhanced catchment (roaded catchment) is not likely to negatively affect the EWR of the Wilyabrup or Smith Brook. An investigation into the use of roaded catchments in the Avon Arc of the Avon River Basin found a roaded catchment to have a neutral effect on the hydrology of the downstream environment (GHD 2008). The reduced rainfall / runoff threshold of the artificially constructed catchment was found to create sufficient runoff to fill a farm dam to point where it overflowed water to maintain the original hydrologic contributions to the downstream environment.

6.3 Future Studies

The approach used within the case studies of Wilyabrup and Smith Brook catchments to assess surface and groundwater interactions has resulted in improved understanding of surface and groundwater interactions in two isolated catchments which may have wider implications on surface and groundwater interactions for the surrounding region.

A simple holistic approach using low cost methods for assessing interactions at a catchment and sub catchment scale was applied. This assessment concluded the Wilyabrup and Smith Brook catchments, which are fairly typical catchments for the region, are surface and groundwater independent systems. This is likely to have implications for future allocations of both surface and groundwater for irrigation use.

Before the approach used in this assessment is applied to other catchments in the region, the methods used should be reviewed and the results assessed to determine the level of applicability of these methods to other catchments.

It is the opinion of the authors that these methods are useful in assessing catchment and sub catchment scale surface and groundwater interactions and that truthing of these conclusions should be undertaken and comprise detailed on ground investigations.

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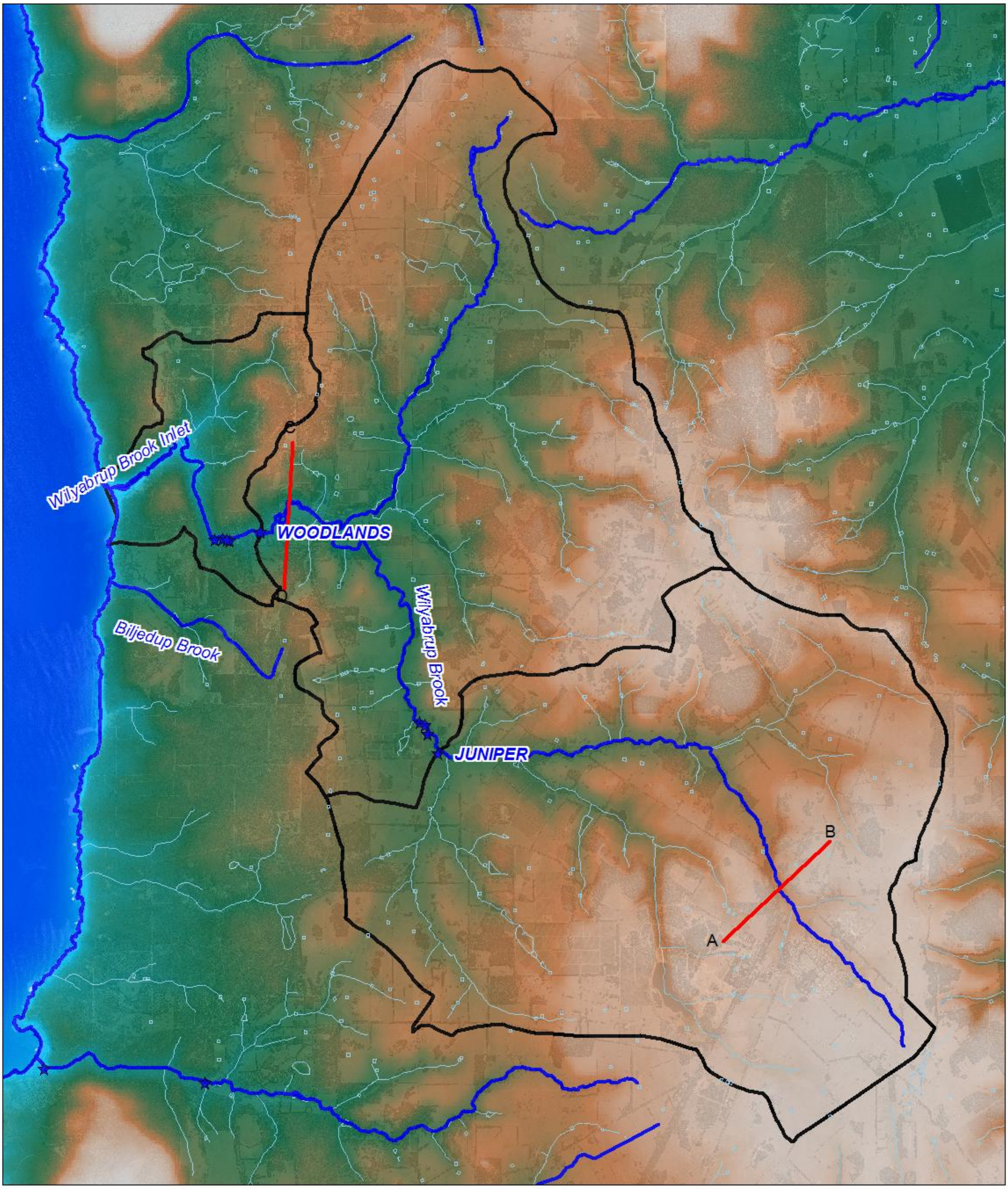
Appendix A

Wilyabrup Catchment Figures



LEGEND

★ Surface Water Sites

— Profiles

— Minor Drainage Lines

— Major Drainage Lines

▭ Hydrographic Subcatchments

■	135	■	100	■	45	■	7
■	122	■	95	■	25	■	5
■	115	■	85	■	15	■	2
■	110	■	70	■	10	■	0

1 0 1 2

Kilometers

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid of Australia, Zone XX

N

CLIENTS PEOPLE PERFORMANCE

Client Name - Natianal Program for Sustainable Irrigation

Project Name - Surface and Groundwater Interactions

Job Number	61-24253
Revision	A
Date	23122009

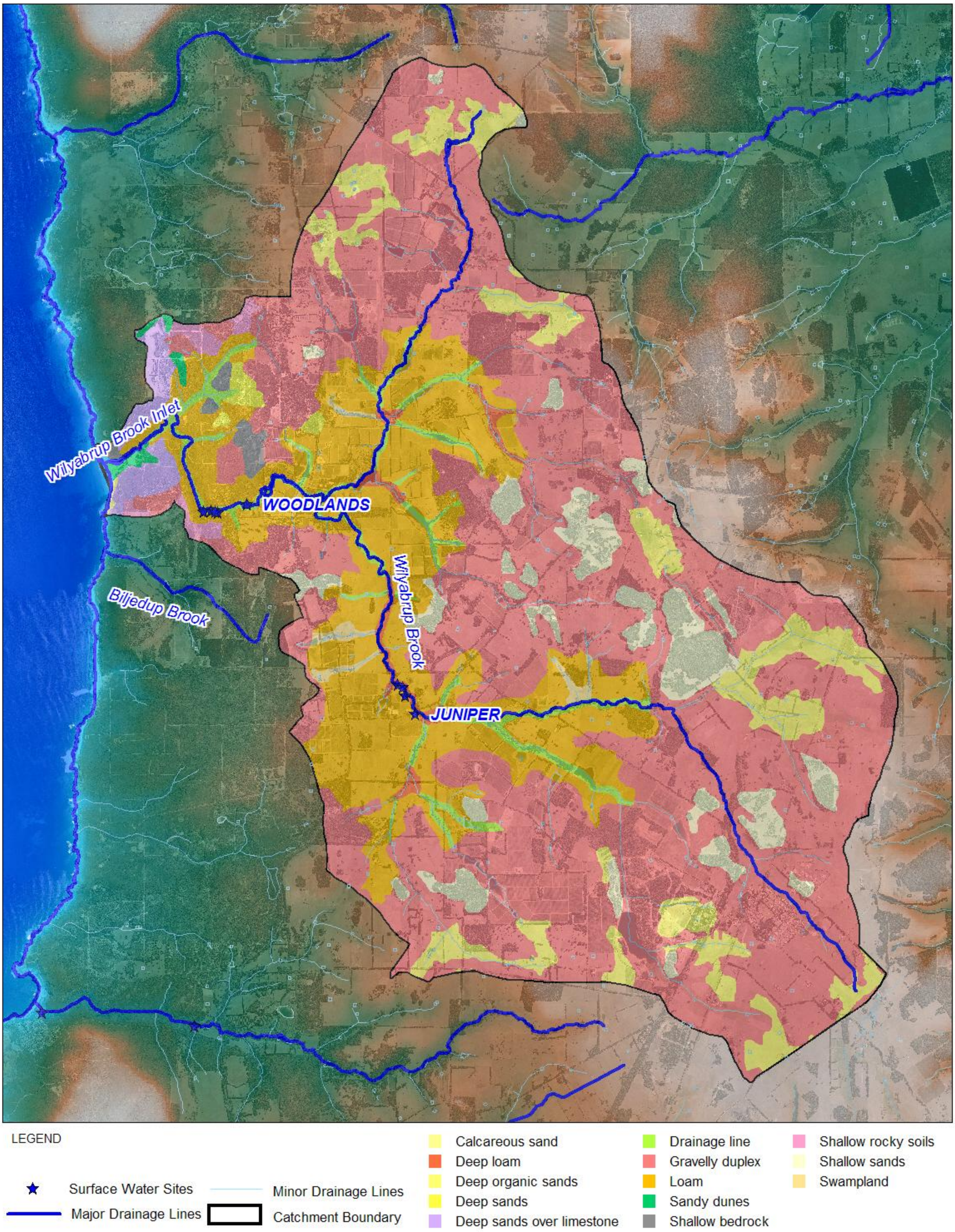
Wilyabrup DEM

Figure 1

G:\Dir\JobNo\WorkspaceName.WOR

239 Adelaide Terrace Perth WA 6004 Australia T 61 8 6222 8222 F 61 8 6222 8555 E permail@ghd.com.au W www.ghd.com.au

Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by: GIS Operator



1 0 1 2
Kilometers

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid of Australia, Zone XX

N

GHD
CLIENTS PEOPLE PERFORMANCE

Client Name - National Program for Sustainable Irrigation

Job Number	61-24253
Revision	A
Date	23122009

Project Name - Surface and Groundwater Interactions

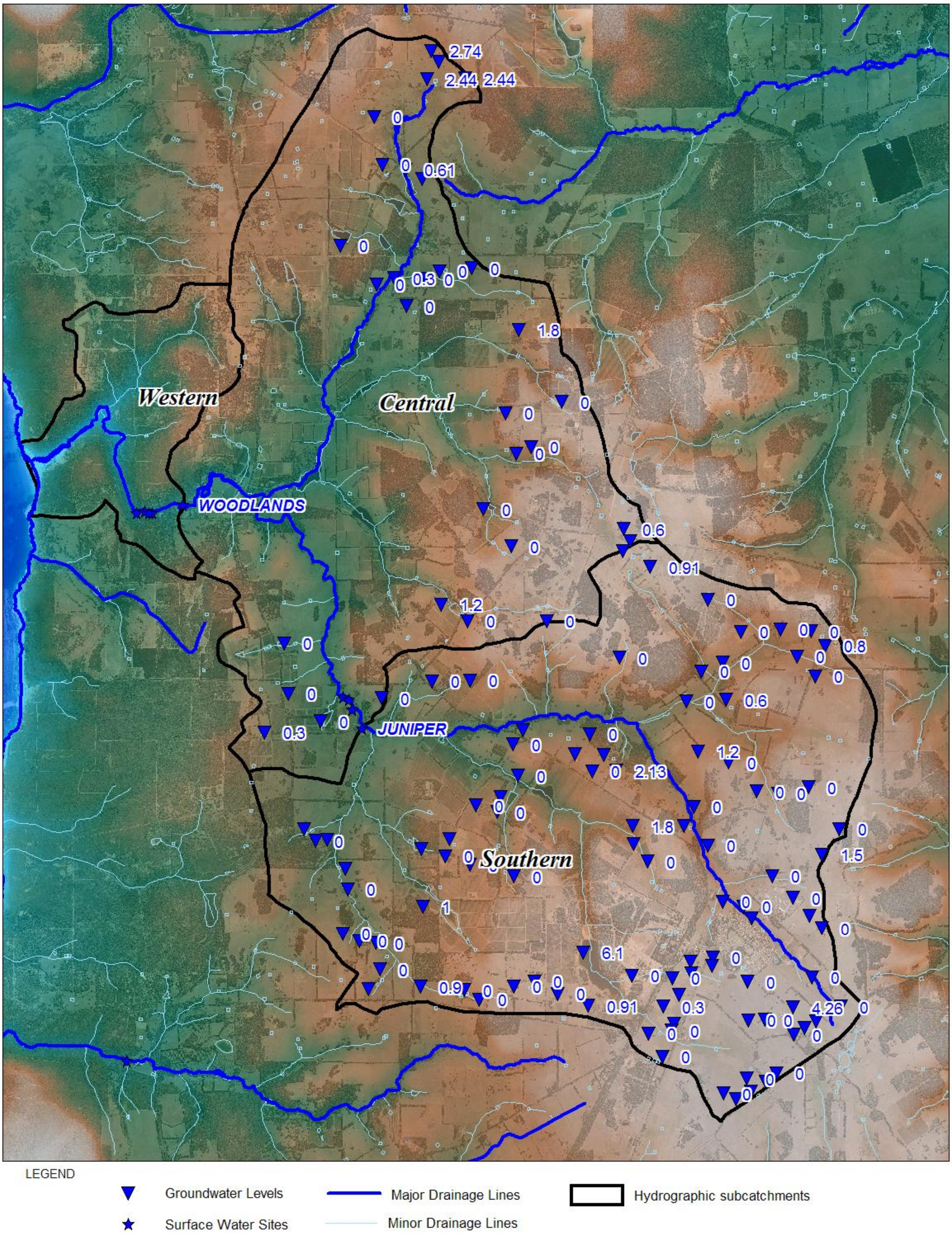
Wilyabrup Soils

Figure 2

G:\Dir\JobNo\WorkspaceName.WOR

239 Adelaide Terrace Perth WA 6004 Australia T 61 8 6222 8222 F 61 8 6222 8555 E permail@ghd.com.au W www.ghd.com.au

Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by: GIS Operator



1 0 1 2
Kilometers

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid of Australia, Zone XX

N

CLIENTS PEOPLE PERFORMANCE

Client Name: National Program for Sustainable Irrigation
Project Name: Groundwater and Surface Water Interactions
Wilyabrup groundwater

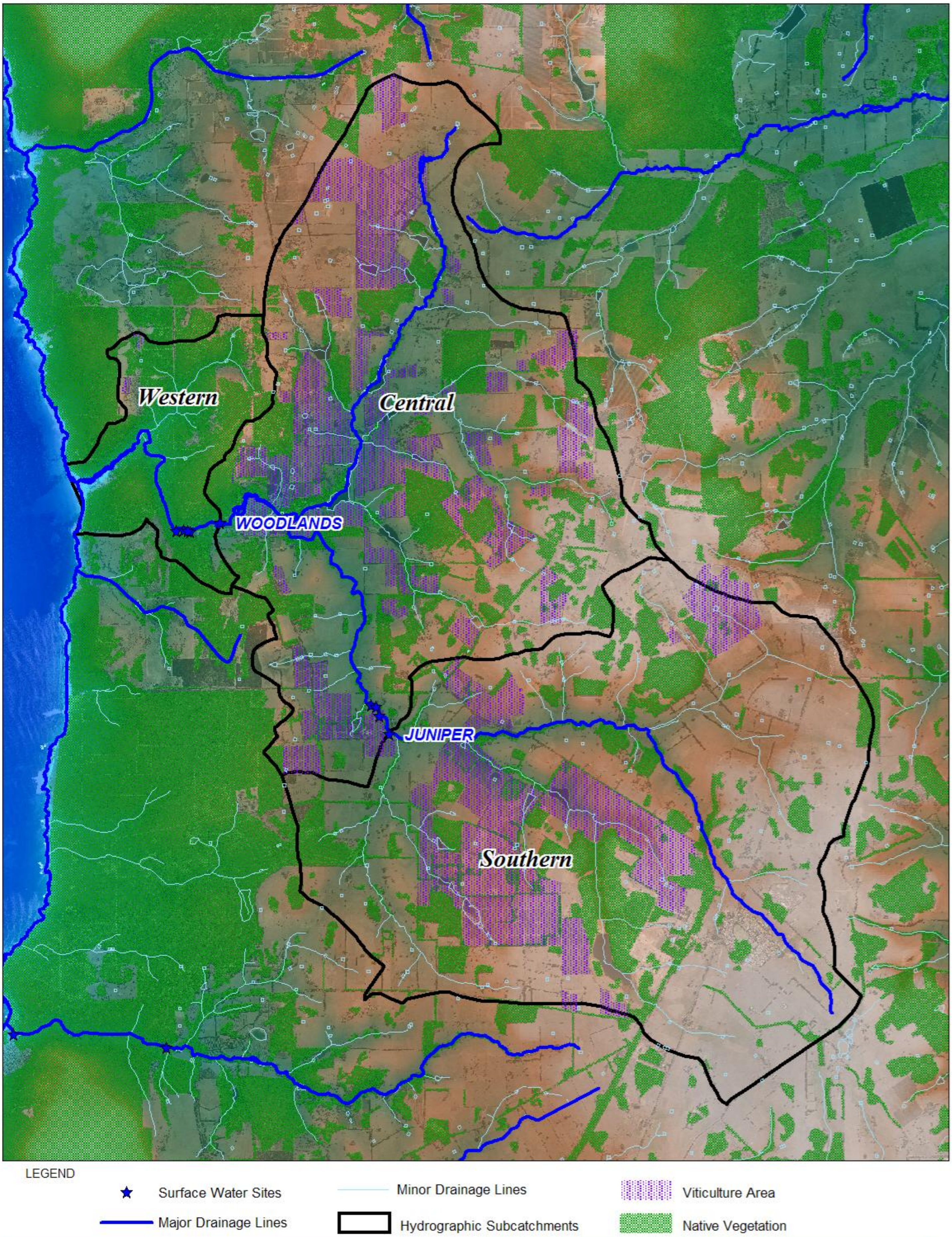
Job Number	6124253
Revision	A
Date	01/10/2009

Figure 3

G:\Dir\JobNo\WorkspaceName.WOR

239 Adelaide Terrace Perth WA 6004 Australia T 61 8 6222 8222 F 61 8 6222 8555 E permail@ghd.com.au W www.ghd.com.au

Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by: GIS Operator



Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid of Australia, Zone XX

CLIENTS PEOPLE PERFORMANCE

Client Name: National Program for Sustainable Irrigation
Project Name: Groundwater and Surface Water Interactions

Job Number	6124253
Revision	A
Date	01/10/2009

Hydrographic catchments and
native vegetation on DEM

Figure 3

G:\Dir\JobNo\WorkspaceName.WOR

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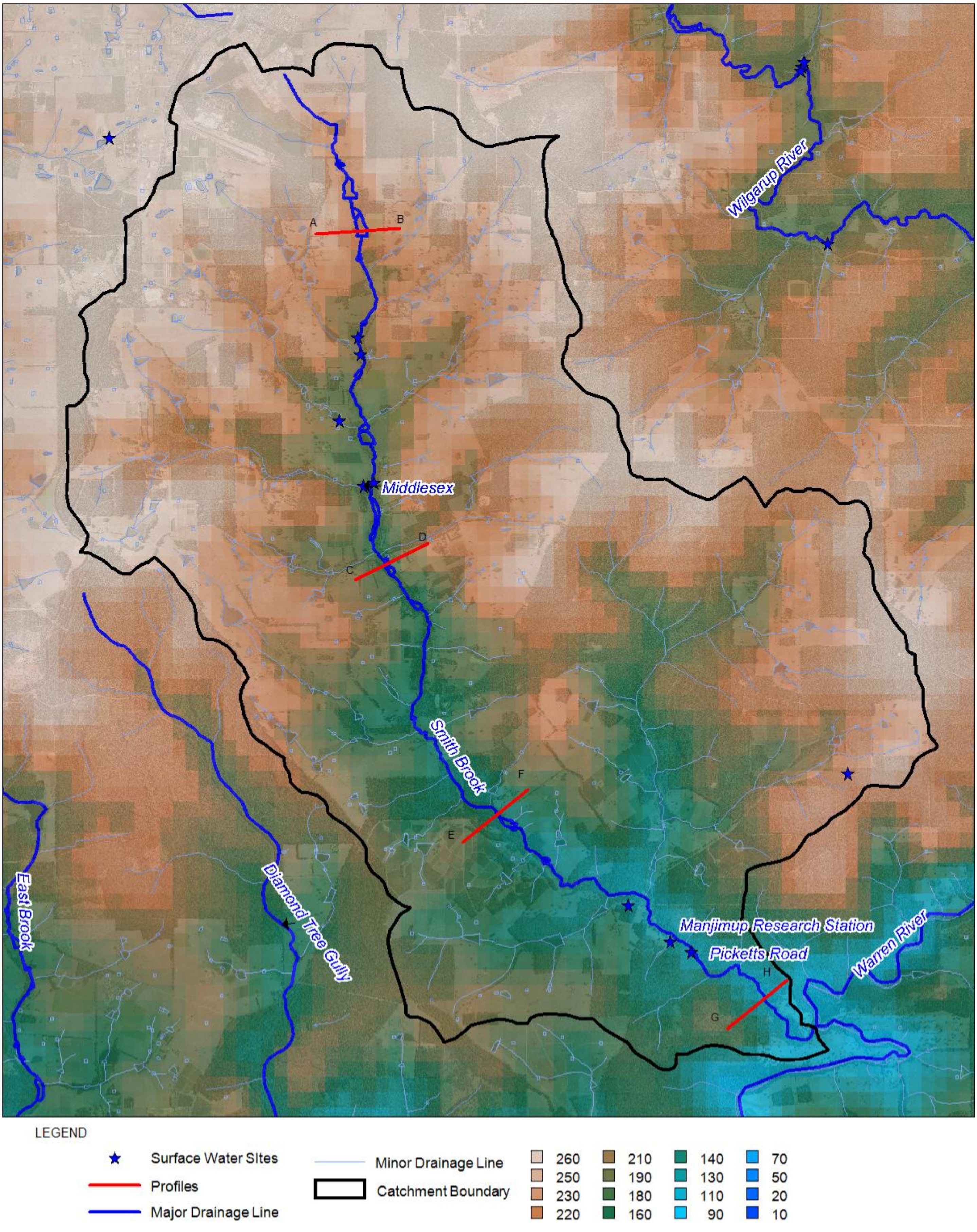
Appendix B

Smith Brook Catchment



1 0 1 2
Kilometers

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid of Australia, Zone XX

N

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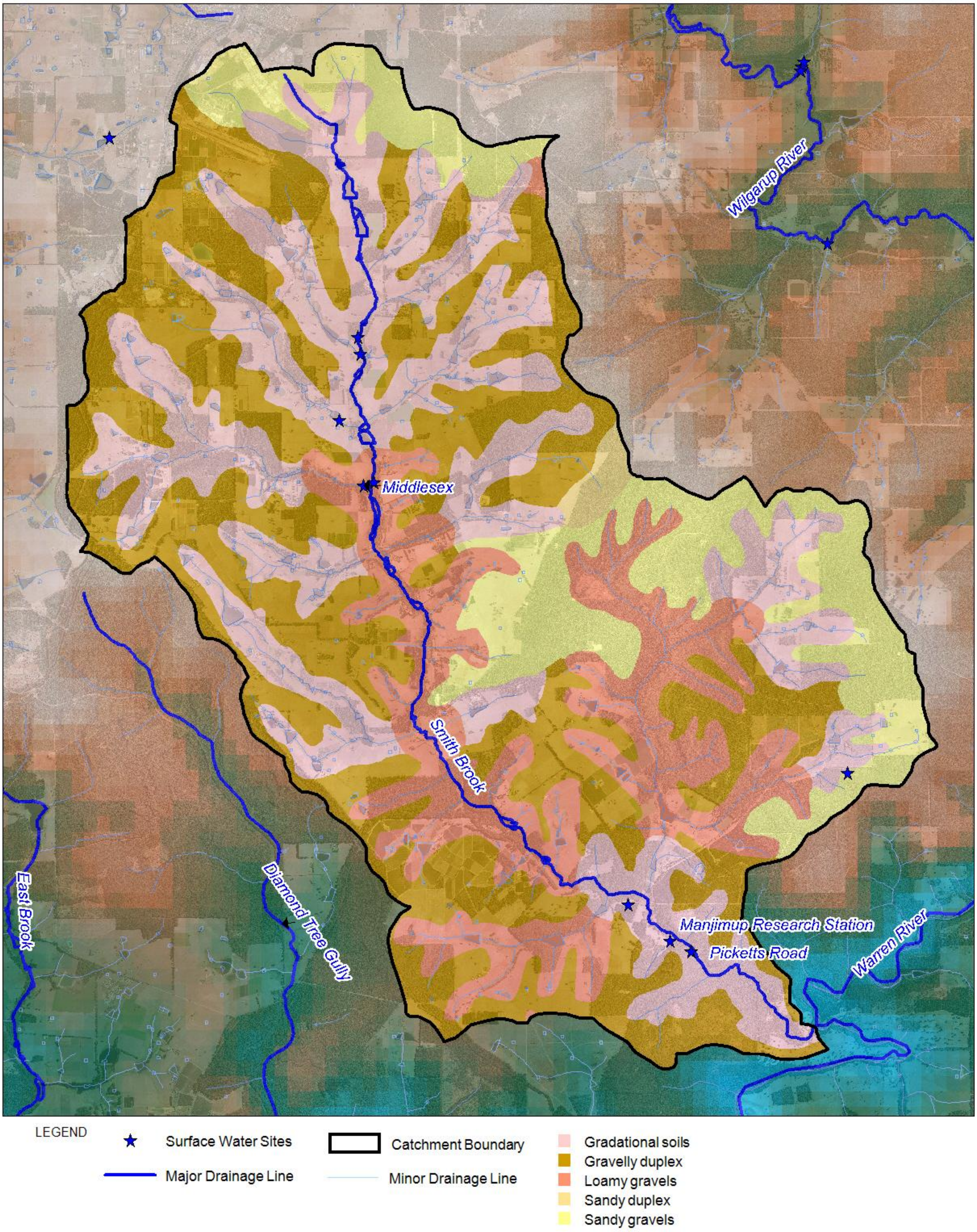
CLIENTS PEOPLE PERFORMANCE

Client Name - National Program for Sustainable Irrigation
Project Name - Surface and Groundwater Interactions

Job Number	61/24253
Revision	A
Date	15 12 2009

Smith Brook DEM

Figure 1



1 0 1 2
Kilometers
Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid of Australia, Zone XX

N

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CLIENTS PEOPLE PERFORMANCE

Client Name - National Program for Sustainable Irrigation
Project Name - Surface and Groundwater Interactions

Job Number	61/24253
Revision	A
Date	15 12 2009

Smith Brook Catchment and Soils Distribution

Figure 2

G:\Dir\JobNo\WorkspaceName.WOR

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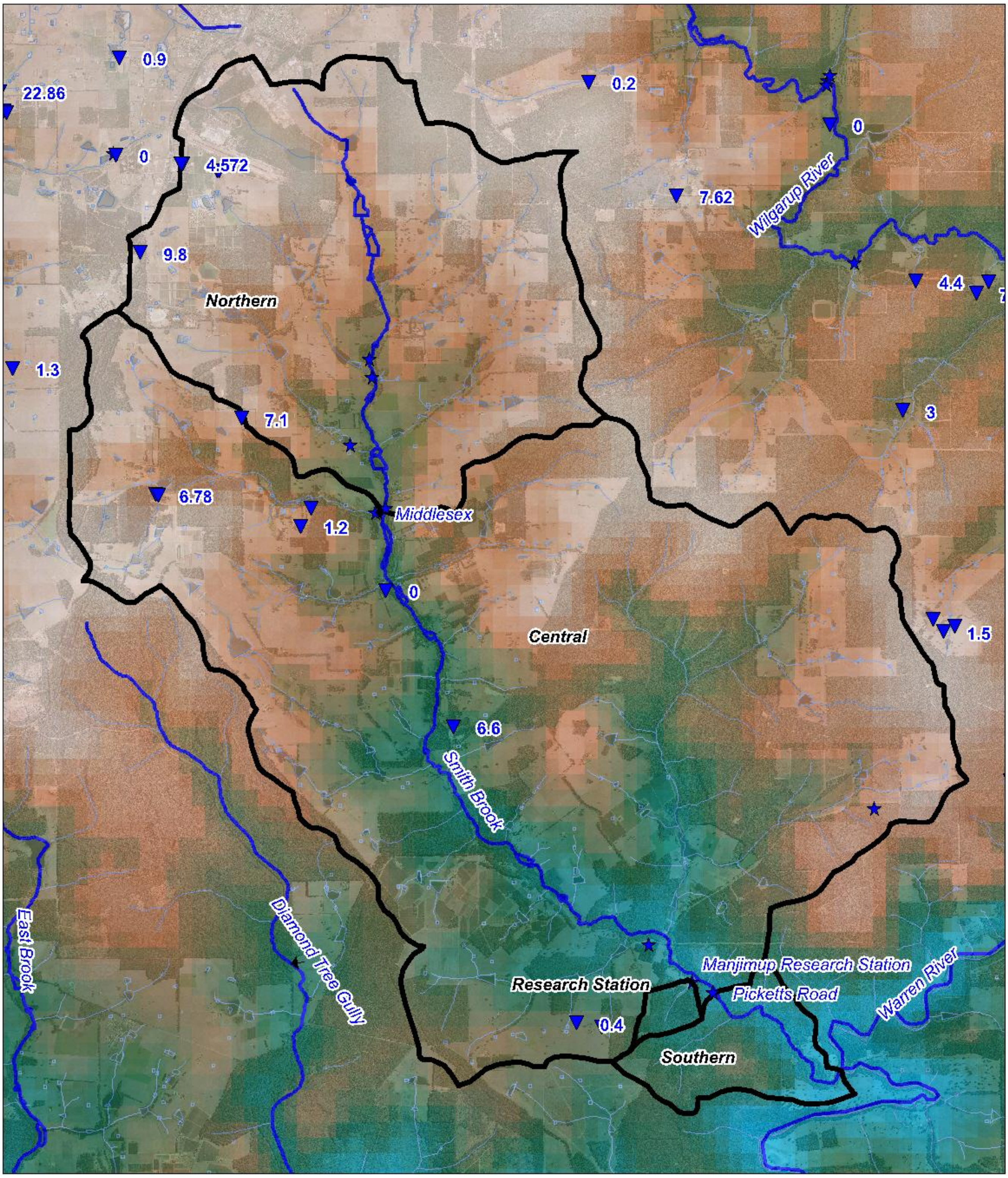
Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by: GIS Operator



Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid of Australia, Zone XX

CLIENTS PEOPLE PERFORMANCE

Client Name - National Program for Sustainable Irrigation

Project Name - Surface and Groundwater Interactions

Job Number	XX-12345
Revision	A
Date	DD MMM YYYY

Smith Brook Groundwater

Figure 3

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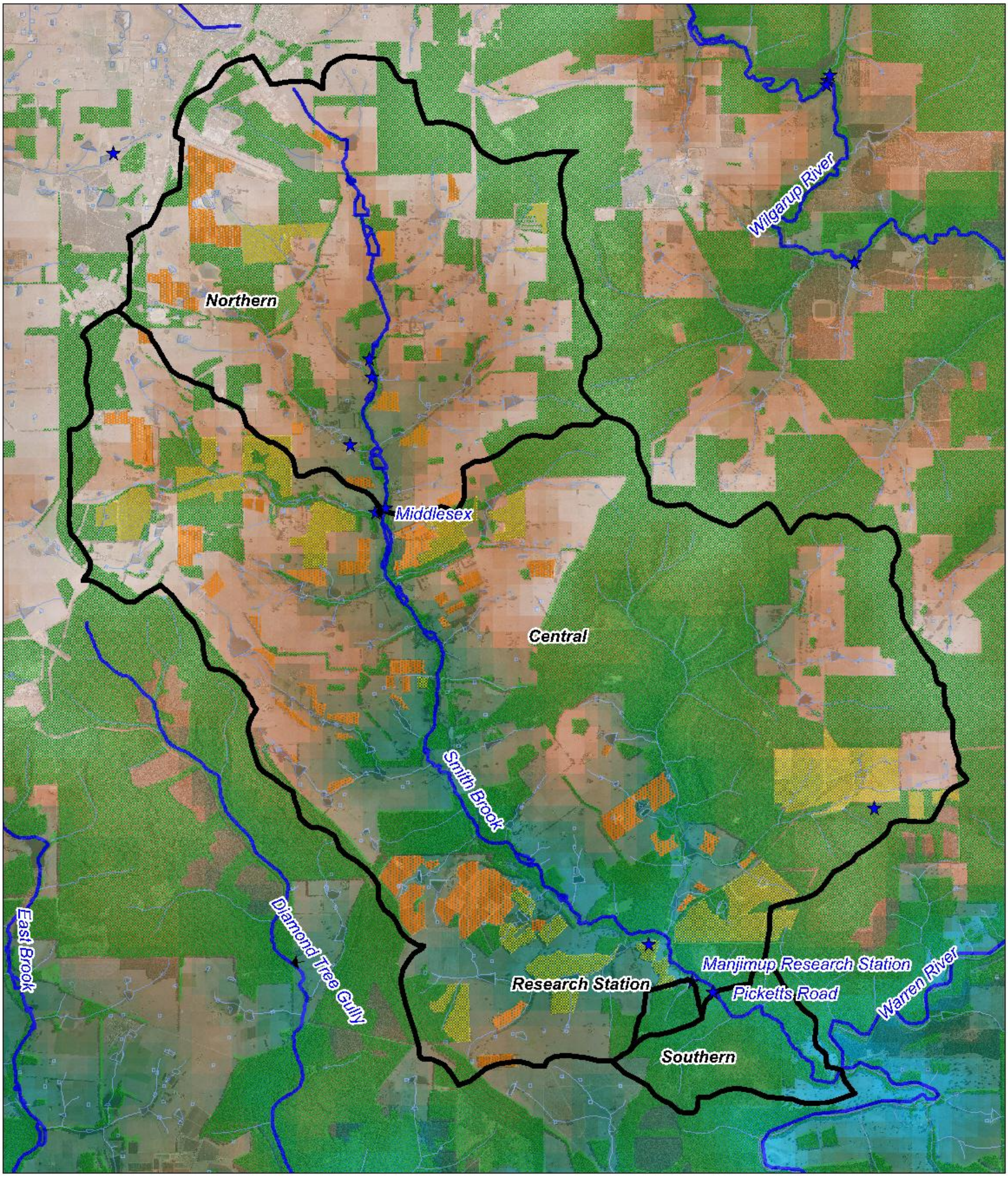

LEGEND

★	Surface Water Sites	▭	Hydrographic Subcatchment	🟩	Native Vegetation
—	Major Drainage Lines	🟨	Agroforestry	🟧	Active Agriculture
—	Minor Drainage Lines				

1 0 1 2
Kilometers
Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid of Australia, Zone XX

N

CLIENTS PEOPLE PERFORMANCE

Client Name - National Program for Sustainable Irrigation
Project Name - Surface and Groundwater Interactions

Smith Brook Landuse

Job Number XX-12345
Revision A
Date DD MMM YYYY

Figure 3

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National Program for Sustainable Irrigation
Product code: NPSI510
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