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Development of Method to Map Potential Stream-Aquifer Connectivity: a case study in the Border Rivers Catchment

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Foreword

Integrated management of surface water and groundwater is critical in ensuring sustainability of the water resource and for meeting the objectives of the National Water Initiative. Water issues such as over-allocation, environmental flows and river salinity are all influenced by the connectivity between streams and aquifers. This means that groundwater-surface water interactions need to be assessed and incorporated into the management response to a range of water quantity and quality issues.

This report describes a new method for mapping the potential stream-aquifer connectivity in a catchment. An index model approach combines the available catchment-scale data sets such as watertable depth, geology, geomorphology and soil type to identify the level of connectivity along river reaches. The method allows a first-cut prioritisation of stream reaches enabling targeting of sites for further investigations and priority management.

The connectivity mapping approach was developed under the *Managing Connected Water Resources* project, a collaboration between Bureau of Rural Sciences (BRS), Australian Bureau of Agriculture and Resource Economics (ABARE), the Australian National University and State agencies. The project objective is to progress a more coordinated approach to the management of surface water and groundwater resources. The project has developed a comprehensive information package on connectivity issues at www.connectedwater.gov.au.

Dr Colin J. Grant

Executive Director

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May 2007

Executive Summary

Coordinated management of surface water and groundwater is critical in ensuring sustainability of water resources.

Recognition of the connectivity between surface water and groundwater resources and connected systems managed as a single resource is one of the key objectives of the National Water Initiative (NWI Clause 23x). Such an approach is called conjunctive water management.

A wide range of tools are available to assess the nature and degree of stream-aquifer connectivity.

A wide range of methods are available to assess the degree and nature of connectivity. The available methods varied in scale (temporal and spatial), cost and ease of use. The method chosen will depend on the purpose for which the measure is required. The most cost-effective strategies will usually involve a combination of coarse, broad scale mapping to identify sites where interaction is likely, followed by site-specific investigation to trace and quantify the flows.

Current methods to assess connectivity can be grouped into two categories - measurement or modelling.

The current knowledge on methods to determine the hydraulic connectivity between surface water and groundwater systems is developing. From the existing methods it would appear that there are two fundamental types to assess connectivity – measurement techniques and modelling techniques.

A new method has been developed to map potential stream-aquifer connectivity.

The Bureau of Rural Sciences (BRS) has developed a new method to map the potential hydraulic connection between groundwater and river systems and evaluated this mapping method in the Border Rivers catchment. An index based approach is used to combine catchment scale data sets such as depth to water table, geology, geomorphology and soil types.

The method provides sufficient information for a first-cut prioritisation of stream reaches identifying potential connected and disconnected systems, enabling targeting of sites for further investigations and management development. This is a precursor to methods such as hydrographic analysis or numerical modelling to derive an understanding of the direction and magnitude of seepage flux.

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Introduction

Groundwater and surface water are hydraulically connected in many catchments in Australia. These interactions can have significant implications for both water quantity and quality. The contribution of groundwater to the maintenance of river or stream ecosystems is increasingly being recognised as an important aspect of water allocation policy in Australia. Groundwater use across Australia has increased over the last decade and substantially within the last five years. This increase in groundwater use can affect streamflow and also impact on initiatives such as the Cap on surface water diversions and, indirectly on The Living Murray. While there are uncertainties with estimating the proportion of groundwater extraction in connected systems that should be accounted for as surface water, stream-flow depletion is projected to be 330 GL/yr in 20 years (MDBC, 2006).

Integrated management of surface water and groundwater is critical in ensuring sustainability of the water resource and will help meet the objectives of the National Water Initiative (NWI). One of the objectives of the NWI is to “recognise the connectivity between surface and groundwater resources and connected systems managed as a single resource” (NWI clause 23 x). Key actions in the NWI for connected water resources include: States and Territories to immediately establish common arrangements in the case of significantly inter-connected groundwater and surface water systems (NWI clause 79 i(c)); States and Territories to identify by end 2005 situations where close interaction between groundwater aquifers and stream flow exist and implement by 2008 systems to integrate the accounting of groundwater and surface water use (NWI clause 83). Although the recognition of connectivity issues has been acknowledged in the recent NWI, there is limited understanding on methods to determine the degree of connectivity across Australia.

Assessing groundwater-surface water interactions is often complex and difficult. There are many factors which influence groundwater-surface water interactions such as river bed characteristics, geology, geomorphology and climate. In general a number of methods have been used to ascertain the nature of connectivity across different catchments (see Baskaran et al 2005 and Brodie et al 2005). These methods include direct field measurements (either hydrologic or chemical), modelling or by expert knowledge. In most cases the limited number of data collection points results in a lack of detailed understanding of groundwater-surface water interactions in the field. Numerical modelling approaches on the other hand can provide a valuable tool for developing a framework by combining information obtained from the other field methods.

This report provides a comprehensive overview of the current knowledge on methods used to assess connectivity between surface water and groundwater systems in Australia. This report also presents a new methodology that has been developed for assessing the potential connection between groundwater and river systems and an evaluation of this method to better understand the nature of connectivity in the Border Rivers Catchment. The methodology is presented along with a discussion of the strengths and limitations of using such a method.

BRS has developed a desktop mapping method based on a connectivity index model, designed to be used as a catchment scale screening tool for identifying potential connection between surface water and groundwater resources. The tool builds upon work by Braaten and Gates (2002), which used depth to water table as the basis for distinguishing connected and disconnected systems. The mapping method incorporates additional data that is used to rate the hydraulic conductance of the geological material beneath the base of a river. The mapping method assumes that the hydraulic properties of geological material in contact and directly below a river is the primary factor controlling groundwater and surface water connectivity.

Current knowledge on methods used to assess connectivity: an overview

Traditionally, surface water and groundwater resources have been independently assessed. In taking an integrated approach, the characteristics of surface water features and groundwater systems in a catchment are both still investigated. The important addition is that the interactions between surface water features and the groundwater systems are also assessed and the assessment method depends on the availability of data and other resources.

Studies (Braaten and Gates 2002; REM 2002; SKM 2003) reported in Australia have applied a simple classification based on the primary connection between groundwater and surface water. In addition field assessments using environmental tracers based on water chemistry have been widely used as a method to assess the groundwater-surface water interactions in Australia.

Braaten and Gates (2002) assessed groundwater-river interactions for inland rivers in New South Wales by distinguishing between connected and disconnected systems, and whether a river reach was gaining, losing or variably gaining and losing. Hydraulic connection was assessed by comparing the differences in the elevation of the base of the river channel with the elevation of the groundwater level located within 1 km of the major rivers. In systems with multiple aquifers, water levels in the shallowest aquifers were used. Hydraulic connection was assumed to be present where river reaches overlayed groundwater levels less than 10m from the surface. The 10m threshold is an estimate of the difference in elevation between the floodplain, where groundwater levels are measured, and the base of the riverbed.

The results of Braaten and Gates (2002) showed that the groundwater and surface water systems are connected in the mid-sections of the major rivers in inland NSW where alluvial systems are well developed yet still narrow and constricted and groundwater depths are shallow. This method considers only depth to water table and distance from the river.

REM (2002) proposed a simple qualitative classification building on that of Braaten and Gates (2002) for conjunctive water use management in the Murray-Darling Basin. The classification distinguishes between systems that are hydraulically connected and those where the water table is separated from the river. The system further classifies the linkages into gaining, losing or variably gaining/losing stream as well as defining the likelihood of impacts of one resource on the water quality or quantity of the other (Table 1).

Table 1: Classification system based on key groundwater and surface water interaction processes (after REM, 2002)

Hydraulic connection	**Stream-aquifer interaction process**	**Potential impacts on surface water resources by groundwater extraction**	**Potential impacts on surface water quality by poor groundwater quality**	**Potential impacts on groundwater by changes in surface water quantity or quality**
Connected	Gaining stream	High	High	Low
Connected	Losing stream	Medium	No impact	High
Connected (may also be variably connected-disconnected)	Variable gaining/losing stream	Medium to high	Low	Medium to High
Disconnected	Losing stream	No impact	No impact	High

The classification system outlined in Table 1 can be used to prioritise areas and issues where further study is required. For gaining river reaches, impacts of groundwater pumping on surface water resources can be significant. Also, groundwater inflow to gaining streams can cause a reduction in quality of the surface waters due to high groundwater salinities or contaminants such as nitrate, metals and other compounds. In these connected river reaches surface water quality management will be of priority. For losing river reaches, impacts of river leakage on the quantity and quality of the underlying groundwater system will be a priority.

The REM (2002) classification system indicated that the connected streams are those shorter, less mature streams commonly found in the upper-to-middle reaches but also some lower reaches of the major streams in the Murray-Darling Basin. Disconnected reaches appeared to be restricted to the more mature, middle-to-lower parts of the larger streams.

SKM (2003) proposed a rating system approach described in Table 2 to classify connection between river reaches and groundwater management units (GMU) within the Murray-Darling Basin, partially based on seepage flux. The three main categories are losing, gaining and seasonal streams based on the direction of water movement. Within each of these categories there are subcategories described by high, medium and low rates of flux. The classification was used in the subjective mapping of the major stream reaches in the Basin using datasets such as the aquifer lithology close to the river, depth to the water table and additional datasets from State agencies.

Table 2: Groundwater/surface water interaction categories based on seepage flux (adopted from SKM 2003)

Main category	Sub-category	Rate of flux in/out of stream
Losing	High	> 1000 m^3/day/km
	Medium	> 10 m^3/day/km & < 1000 m^3/day/km
	Low	< 10 m^3/day/km
Seasonal	Naturally occurring or induced by pumping	All
Gaining	Low	< 10 m^3/day/km
	Medium	> 10 m^3/day/km & < 1000 m^3/day/km
	High	> 1000 m^3/day/km

Recently REM (2006) reviewed methods used to determine the hydraulic connectivity between surface water and groundwater systems in the Murray Darling Basin. From the report it would appear that there are two fundamental types to assess connectivity – measurement techniques and modelling techniques. Measurement technique includes approaches that use hydrologic datasets to assess connection (such as hydrograph analysis, or hydraulic gradient mapping) or tracer techniques that involve field measurement for physicochemical parameters (such as major ion chemistry, environmental tracers such as deuterium, oxygen-18 and radon or basic parameters such as temperature). Modelling techniques involve analysis of the water balance, either by simple means or via complex numerical simulations. The report also indicated that there is no explicit definition for connectivity consistently used across the Basin.

In addition to methods described above, there is a wide range of field tools available to assess the nature and degree of the interaction between surface water and groundwater systems. Box 1 summarises the main categories of these assessment tools, with additional details provided in Brodie et al. (2006).

Box 1 Summary of tools for assessing connectivity

- *Field Observations*, where an initial reconnaissance can highlight hotspots where groundwater is interacting with surface water features.
- *Seepage Measurement*, the direct measurement of water flow at the surface water-groundwater interface using seepage meters and similar devices.
- *Ecological Indicators*, mapping of specific vegetation communities or biota indicating groundwater discharge to surface water features.
- *Hydrogeological Mapping*, to define the geological or geomorphological features such as faults, facies changes or river morphology that can control groundwater flow, and to provide the general hydrogeological setting.
- *Geophysical Survey*, the use of geophysical and remote sensing technologies such as airborne electromagnetics (AEM), radiometrics, seismic waves, electrical charge, or satellite imagery to map catchment properties.
- *Hydrographic Analysis*, the use of techniques such as recession analysis or baseflow separation to analyse the monitoring record of water levels or flows.
- *Hydrometric Analysis*, based on Darcy's Law and investigating the hydraulic gradient between aquifer and surface water feature and the hydraulic conductivity of the intervening aquifer material.
- *Hydrochemical Studies*, the interpretation of the chemical constituents of water such as isotopes, radon or chlorofluorocarbon (CFC) involving the application of environmental isotopes.
- *Temperature Studies*, the use of time series monitoring of temperature in both the surface water and groundwater systems.
- *Artificial Tracers*, the monitoring of the movement of an introduced tracer such as fluorescent dye.
- *Water Budgets*, such as river reach water balances where the water inputs and outputs are estimated.

Although the NWI recognises the need to manage interconnected groundwater-surface water resources as a single resource, our current knowledge of methods used to determine connectivity in Australia is limited. A screening tool that enables the decision makers to quickly assess areas of hydraulic connection between river and groundwater systems is therefore needed for the facilitation of integrated water resource management.

Development of method to map connectivity

A method has been developed to map the potential hydraulic connection between groundwater and surface water systems in a catchment, taking into account hydrological and hydrogeological factors. The methodology provides sufficient information for a first-cut prioritisation of stream reaches identifying potential connected and disconnected systems, enabling targeting of further investigations and management development. This methodology focuses on the conductance of the geological material to derive an indicator for the potential for water movement. This is a precursor to methods such as hydrographic analysis or numerical modelling to derive an understanding of the direction and magnitude of seepage flux.

Description of methodology

Stream-aquifer connectivity potential in a catchment can be determined by means of a rating index approach. Hydrological and hydrogeological factors mapped at the catchment scale can be combined to obtain a final rating. The four data inputs needed for this method are:

(i.) Depth to water table
(ii.) Stream bed sediments
(iii.) Geology
(iv.) Geomorphology

One of the prime considerations is the conductance of the geological material that interfaces with the stream bed and the aquifer itself. This also includes the material of the stream bed and banks. For example, it is assumed that connectivity will be high where stream bed sediments consist of gravel and the aquifer consists of alluvial sands/gravel. Alternatively, the connectivity will be low where there is an intervening layer of clay of significant thickness.

A numerical rating and ranking system was devised for the four data inputs mentioned above. The system contains the three components of ranges, ratings and weights. Firstly the dataset representing each input is reclassified into simplified data range. Each data range is assigned a rating based on the connectivity index model (Box 2).

The rating represents the relative influence of the input data on connectivity. The weights determine the relative importance of each input data set within the connectivity index model. Each input data set is assigned a relative weight between 2 and 5; a weight of 2 is the least significant and a weight of 5 is the most significant. As shown in Box 2, the connectivity index model assumes that stream bed characteristics and aquifer material data have the greatest influence on stream-aquifer connectivity. Sensitivity analysis has been undertaken to determine the appropriate weightings. The following is the data input, rating and additive connectivity index model (Box 2).

Box 2 Input data, rating and Connectivity Index Model

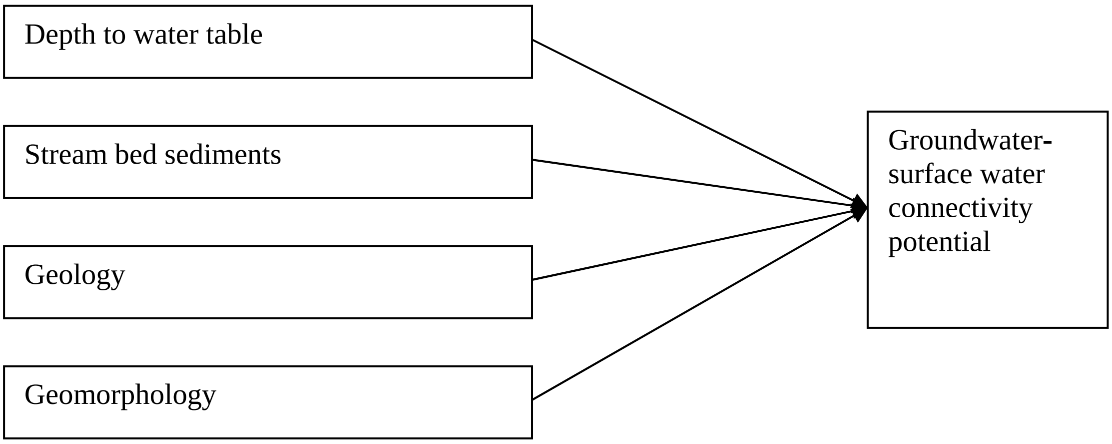
Data input	Range	Rating
Depth to water table (m)	<10m	5
	10-20m	3
	>20m	0.5
Stream bed sediments	sand/gravel	5
	sandy loam/silt loam	3
	silt/clay loam	-1
	clay	-4
Geomorphology	Erosional environments	5
	Depositional environments (floodplain)	1
	Hill tops	0
Geology	gravel/sand	5
	clay/sand	3
	clay	-4

Weighting

Connectivity index model = Potential for stream-aquifer connectivity
= (3 x depth to water table) + (5 x stream bed sediments)
+ (5 x geology) + (2 x geomorphology)

Figure 1 outlines a flow chart for this process. The calculated index identifies the stream reaches that will have potential for groundwater-surface water connectivity. The higher the connectivity index, the greater the potential for stream-aquifer connectivity. The rigour in the index model has been achieved without making it a data-hungry model and sacrificing its practicality. The potential connectivity ratings for different river reaches provided by this model can be compared with actual field measurements.

Figure 1: Flow chart showing structural component of the connectivity index model



Selection of input data sets

The topography, geology, hydrology and hydrogeology of the catchment are important factors that need to be combined in a ranking index for potential stream-aquifer connectivity. The number of input data sets used depends on the characteristics that are rated and the intended use of the ranking system. In general, the more the input data sets, the higher chance for better relative evaluation of connectivity. With a larger number of data sets, a judgemental error in rating one input data usually does not greatly affect the overall relative rating. Another important consideration is the scale and coverage of the input data.

Criteria for numerical rating

After the input data are selected, their values are then converted to a numerical rating. Although there are several ways of assigning a numerical rating to geological and hydrogeological factors, the potential range of values and the relative influence of each individual parameter need to be considered. The final rating numbers are then combined to derive a connectivity index. The higher the index, the greater the potential for stream-aquifer connectivity.

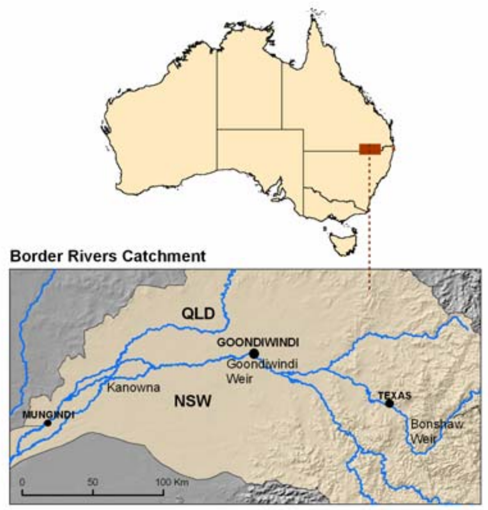
Application of index model to spatial mapping of potential connectivity in the Border Rivers catchment

The index method was implemented in a GIS environment using ESRI ArcGIS 9.0 to enable the creation of a map showing connectivity potential within the Border Rivers catchment. Potential connectivity was mapped spatially by combining four raster datasets into one representing water table depth, stream sediments, aquifer material and geomorphology. Map algebra was used to derive a raster dataset containing a single numerical conductivity index along the river reach of the catchment. The map algebra equation is formulated from the connectivity index model (Box 2) based on weighting individual data parameters and combining the results into a single index value. The higher the index value, the greater the potential for groundwater-surface water connectivity. The index value output from the map algebra equation for each grid cell in the raster was categorised into low, medium and high connectivity potential classes based on the output classification classes in the connectivity model. These categories were then mapped using a standardised legend to spatially represent the estimated potential connectivity along the river reaches.

Study area

The Border Rivers catchment lies in the Murray-Darling Basin, and spans across Queensland and New South Wales (Figure 2). The catchment covers almost 50,000 km^2 and is divided almost evenly between the two States. The focus of this study was on the alluvial aquifers of the catchment where existing State owned boreholes are located. The two major rivers in the Border Rivers catchment, the Dumaresq River and the MacIntyre River, define the border between the two States.

Figure 2: Location of Border Rivers Catchment study area



In the Border Rivers catchment there is a high degree of connectivity between surface water features such as streams, wetlands and drains and their underlying groundwater systems. It has been shown that the Dumaresq River and the shallow aquifers are intimately related and interact in a variety of physiographic and climatic conditions (Tennakoon, 2002). Any groundwater extraction in the upstream of Goondiwindi will ultimately affect the flow in the river downstream and consequently existing irrigation use from surface water supplies.

Spatial data inputs

The following four catchment scale datasets for the Border Rivers catchment were combined to derive a connectivity index values.

(i) Depth to water table: The depth to groundwater measurements from existing NSW and Qld State water agency borehole monitoring were interpolated into a grided surface (250m cell size) of the depth to the water table. The resulting watertable depth raster was then reclassified into three broad categories according to the weighted value in the connectivity index model. Shallow water tables (<10m) were assumed to reflect higher connectivity with streams when compared with deeper water tables (>20m).

The potential for connectivity categories derived from the depth to water table are highly dependant on stream bed material hydraulic conductivity. For instance, it would be possible to have a water table < 10m below the stream bed where there is a low potential for connectivity where the underlying material posses a low hydraulic conductivity. The stream bed characteristics, geology and geomorphology data set have been incorporated into connectivity index model to derive a qualitative estimate of hydraulic conductivity of the stream bed material as well as material adjacent to the river. Three datasets are required as no one data set gives a definitive estimate of hydraulic conductivity. However when these three datasets are combined with depth to water table, a good qualitative estimate of potential hydraulic connection can be obtained.

(ii) Stream/river bank hydraulic characteristics: The National Land and Water Resources Audit (NLWRA) soil saturated hydraulic conductivity (permeability) of the Layer 2 grided (1.1km cell size) national dataset (1999) has been used as a surrogate for stream bank hydraulic characteristics. The soil textural information gives an indication of groundwater recharge adjacent to the river. For example, the presence of highly permeable sandy soils could indicate a high potential for connection between the river and groundwater. The data sets were categorised into five permeability classes of very low; low; moderate; high and very high based on hydraulic conductivity values. The permeability classes were then reclassified into a weighted value based on values from the connectivity index model. Finally the raster dataset were resampled to 250m cell size for the catchment using the bilinear re-sampling technique.

(iii) Geology: Lithology units from the existing geological mapping and/or drillers logs can be used to identify the type of geological material intersected by river reaches. This information can be used to determine the hydraulic conductivity of the sediment and bedrock beneath and adjacent to river reaches. Data derived from existing geological maps such as the Australia wide 1:250 000 geological map series is useful for estimating relative hydraulic conductivity in upland erosional areas of the Border Rivers catchment, where rivers have cut into the underlying rock formations. However, in flat low lying depositional areas, intersected by river reaches, the geology is commonly mapped as undifferentiated alluvium. Such areas can contain sediments ranging from clay to coarse gravel or conglomerates, making hydraulic conductivity estimates difficult. Therefore lithological logs sourced from borehole databases maintained by NSW and Qld State water agencies have been used as an alternate dataset for differentiating sediment types.

The mean hydraulic conductivity for particular sediment type and their rating are presented in Table 3. It has been assumed that sediments greater than 10m below the base of a river or stream do not influence streambed/aquifer connectivity. Using this assumption, only the top 15m of the available lithological logs was used for estimate relative hydraulic conductivities. The figure of 15m was chosen to accommodate the difference in elevation between the base of the river and top of the logged boreholes. The lithological log were assessed and the bore hole given a rating based on the weighted average of the mean hydraulic conductivity of each type of geological material and its thickness. The output from this process is a point data layer of relative scores relating to the hydraulic conductivity of the aquifer material.

Table 3: Aquifer sediment types and relative rating based on hydraulic conductivities

Ratings	**Rock/sediment type**	**Mean hydraulic conductivity (m/s)**
8	Gravel	$10^{-1.5}$
7	Clean sand	10^{-4}
7	Permeable basalt	10^{-4}
7	Karst Limestone	$10^{-3.6}$
6	Fractured Igneous and Metamorphic rock	10^{-6}
6	Silt	10^{-6}
5	Loam	10^{-7}
4	Limestone and Dolomite	$10^{-7.5}$
4	Sandstone	10^{-8}
3	Clay	$10^{-10.5}$
2	Shale	10^{-11}
1	Unfractured Igneous and Metamorphic rock	10^{-12}

(iv) Geomorphology: The Multi-resolution Valley Bottom Flatness Index (MrVBF; Gallant and Dowling, 2003) was used to interpret landscape geomorphology. The MrVBF index allows for the delineation of erosional and depositional environments based on an algorithm applied to a Digital Elevation Model (DEM) at multiple scales. MrVBF has been used to broadly characterise past fluvial environments within the study area. Characterising the fluvial environments gives an indication of depositional processes and thus the dominant sediment type. Within the study area MrVBF has been used to distinguish between the upstream narrow alluvial valley and the broad low relief flood plain. Narrow alluvial valleys that are either erosional or high energy depositional environments and `high rainfall and shallow groundwater are assumed to have high connection with streams and are thus assigned higher values compared with lower values assigned to wide, arid alluvial plains with deep groundwater levels.

Discussion of results

Geomorphology

The erosional environment classification derived from the MrVBF is shown in Figure 3. The boundary between erosional and depostional sedimentary environments intersects the river approximately 5 km downstream from the Keetah bridge. Keetah bridge has been previously recognised as the boundary between the highland alleviated valley to the east and the alluvial fan area to the west (Williams et al.1987). This indicates that within the study area Mr VBF gives a reasonable approximation of the boundary between erosional and depositional environments. The results of the landscape geomorphology indicate that the area upstream of Keetah is characterised by a narrow, incised alluvial valley that are either erosional or high energy depositional environments on both the Qld and NSW sides of the Dumaresq River (Figure 3). However, in the area downstream of Keetah the alluvial deposits become more extensive, characteristic of an alluvial plain.

Stream bed characteristics

The stream/river bank hydraulic characteristics are shown in Figure 4. Soils intersected by the Dumaresq River exhibit a sandy loam and sand/gravel deposits (high hydraulic conductivity) in the area upstream of the Glenarbon gauging station. The area of high conductivity in the upstream of the junction between the MacIntyre and Dumaresq Rivers corresponds to a point at which the river is in close proximity to highly conductive Cainozoic residual and aeolian sand deposits. This also occurs in vicinity of Boggabilla. In the MacIntyre River valley the river bed is composed of dark or grey clay deposits with poor infiltration capacity (low hydraulic conductivity).

Depth to water table

The depth to water table based on measurements of exiting State monitoring bores during 2004 field investigations are presented in Figure 5. In general the depth to water table in the area upstream of Keetah is shallow (<10m) and most bores are located within 1-2 km of the river. The boundary between groundwater depths of <10m and 10-20m shows a correlation with the boundary between depositional environments derived from the MrVBF dataset. In the area downstream of Keetah the water table is relatively deep (10-20m) with the exception of bores near the Goondiwindi weir. The aquifer in the area downstream of Keetah reportedly has poor yields that are related to the high clay content. The area downstream of Goondiwindi 2 gauging station exhibits a shallow groundwater table thought to be associated with a groundwater mound associated with the Goondiwindi weir.

Geology material

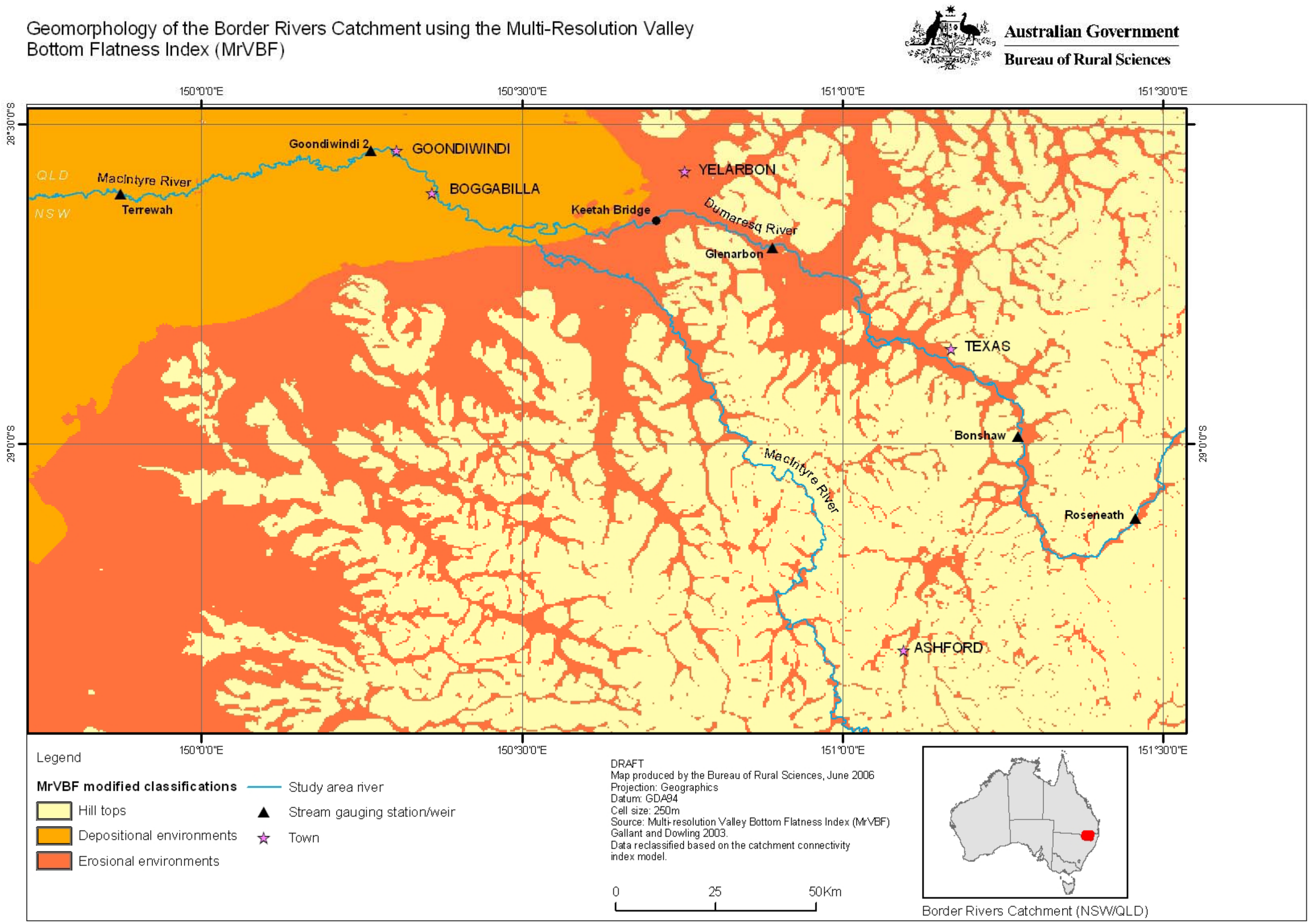
The classification of geological material shown in Figure 6 shows that the area downstream of the junction between the MacIntyre and Dumaesq Rivers is dominanted by a mixture of sand and clay. The area between the river junction and approximately 5km upstream of Keetah bridge is dominated by sand and gravel which is likely to be due to the close proximity of Cainozoic residual and aeolian sand deposits that may have intermixed with alluvial deposits associated the river. The area of clay and clay/sand centred upon the monitoring bore (41630009), located near Glenarbon weir, coincides with widening of the alluvial valley and a confluence of a creek feeding into the Dumaresq River. This suggests a change from an erosional to a depositonal sedimentary environment in this area.

Potential stream-aquifer connectivity in the Border Rivers Catchment

The results of the assessment of potential stream-aquifer connectivity in the Border Rivers catchment are mapped in Figure 7. The results indicate that the alluvial systems in the area upstream of Glenarbon are more developed but still narrow valley and constricted by bedrock. The narrow alluvial valley had relatively high rainfall produce shallow water tables and strong connection between river and aquifer. From Glenarbon to Boggabilla, the potential for connection ranges from low to high. The areas of high connection are associated with the sand deposits near the river. In the new mapping method the presence of clay and clay/sand centred upon the monitoring bore (41630009) located near Glenarbon weir has been detected. The presence of clay in the 0-9m depth restricts infiltration and categorised as a weakly connection in the river reach at Glenarbon. The area downstream of Boggabilla is generally categorised as a low potential for connection. In some areas medium potential for connection also exists.

Earlier studies (Tennakoon 2002; Chen 2003) indicate that the entire area upstream of Keetah is categorised as hydraulically connected system. However, the BRS mapping method showed some variation.

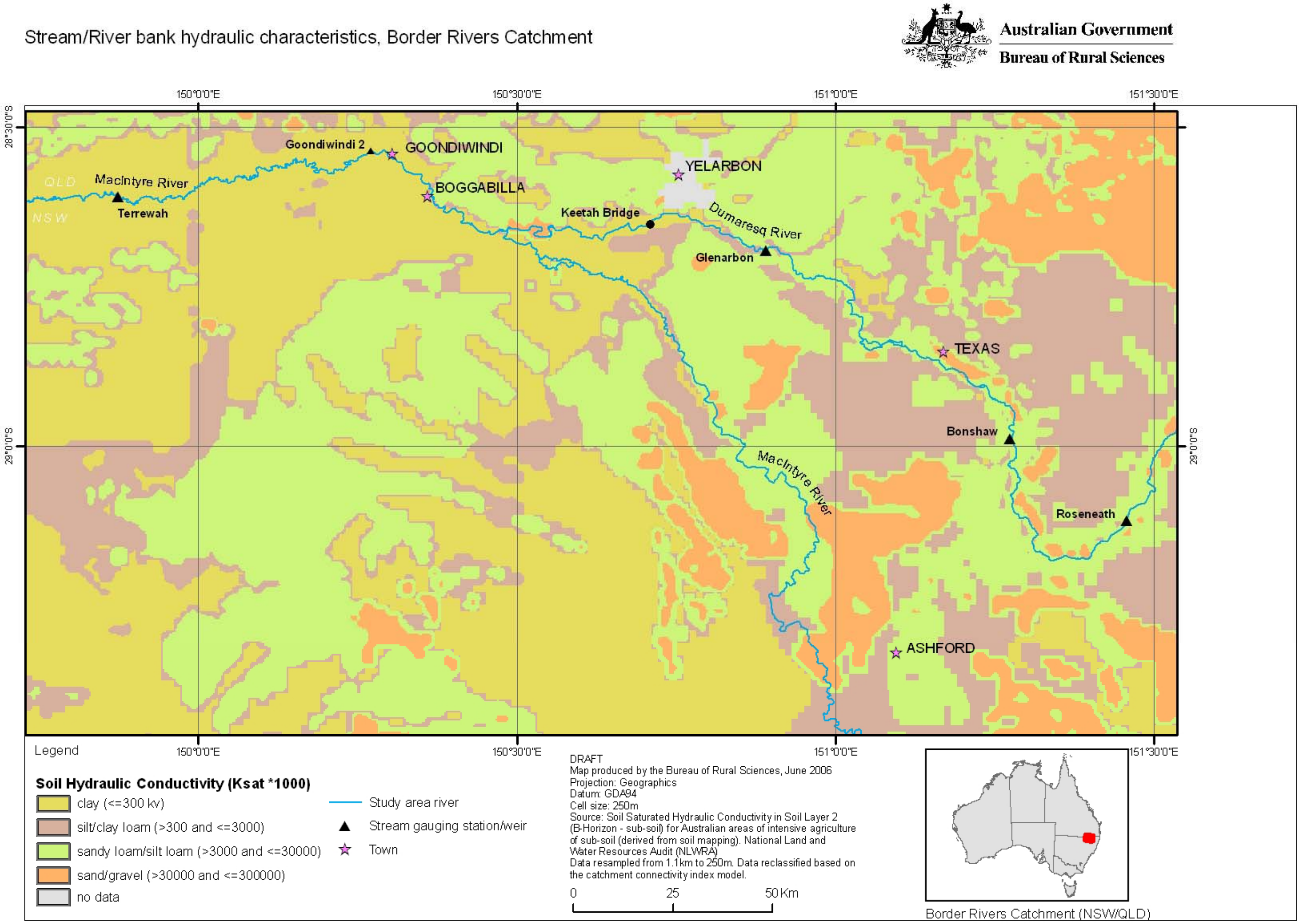
Figure 3: Geomorphology of the Border Rivers Catchment using the Multi-Resolution Valley Bottom Flatness Index (MrVBF)



Geomorphology of the Border Rivers Catchment using the Multi-Resolution Valley Bottom Flatness Index (MrVBF)

DRAFT
Map produced by the Bureau of Rural Sciences, June 2006
Projection: Geographics
Datum: GDA94
Cell size: 250m
Source: Multi-resolution Valley Bottom Flatness Index (MrVBF) Gallant and Dowling 2003.
Data reclassified based on the catchment connectivity index model.

Figure 4: Stream bed characteristics, Border Rivers Catchment



Stream/River bank hydraulic characteristics, Border Rivers Catchment

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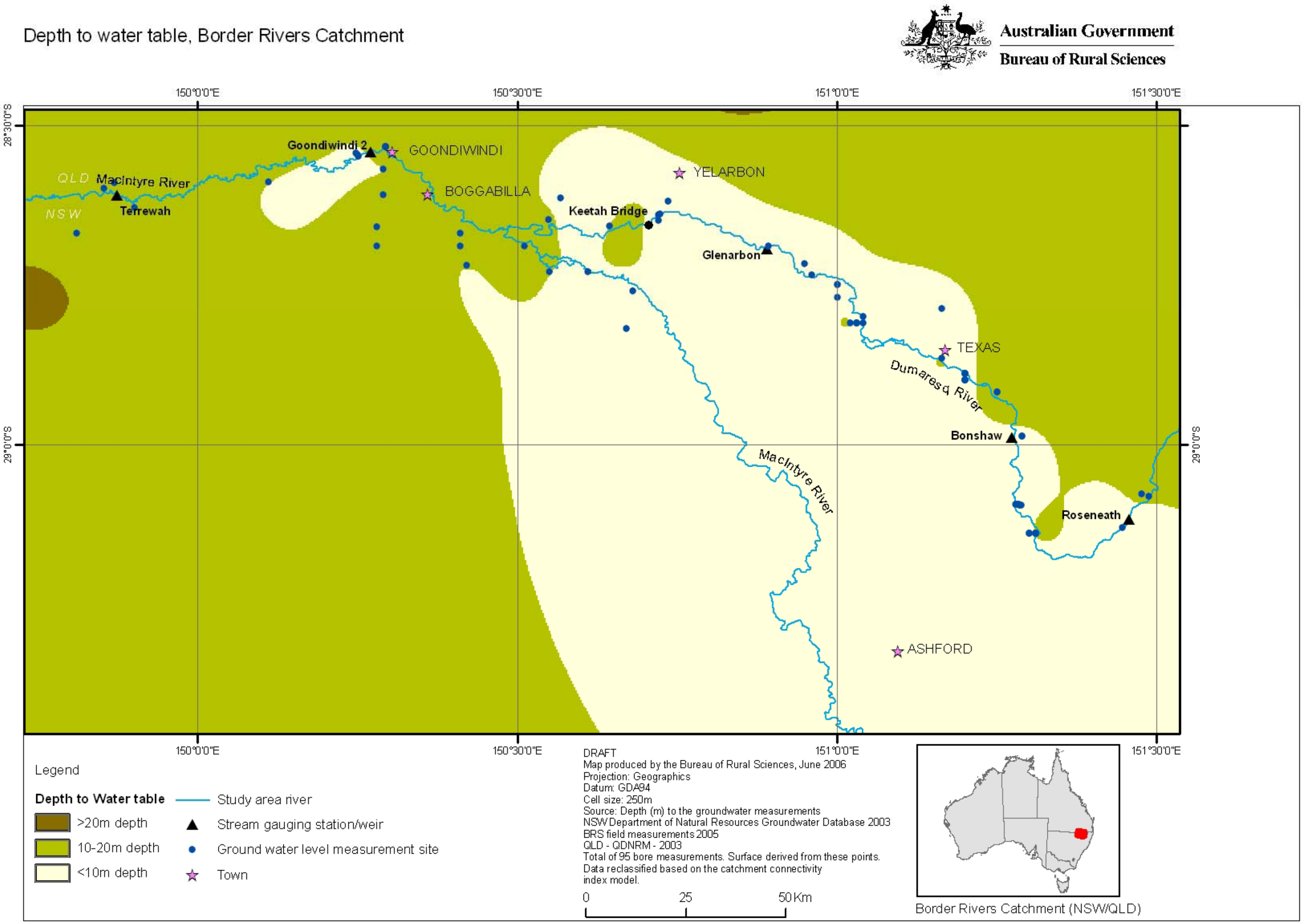
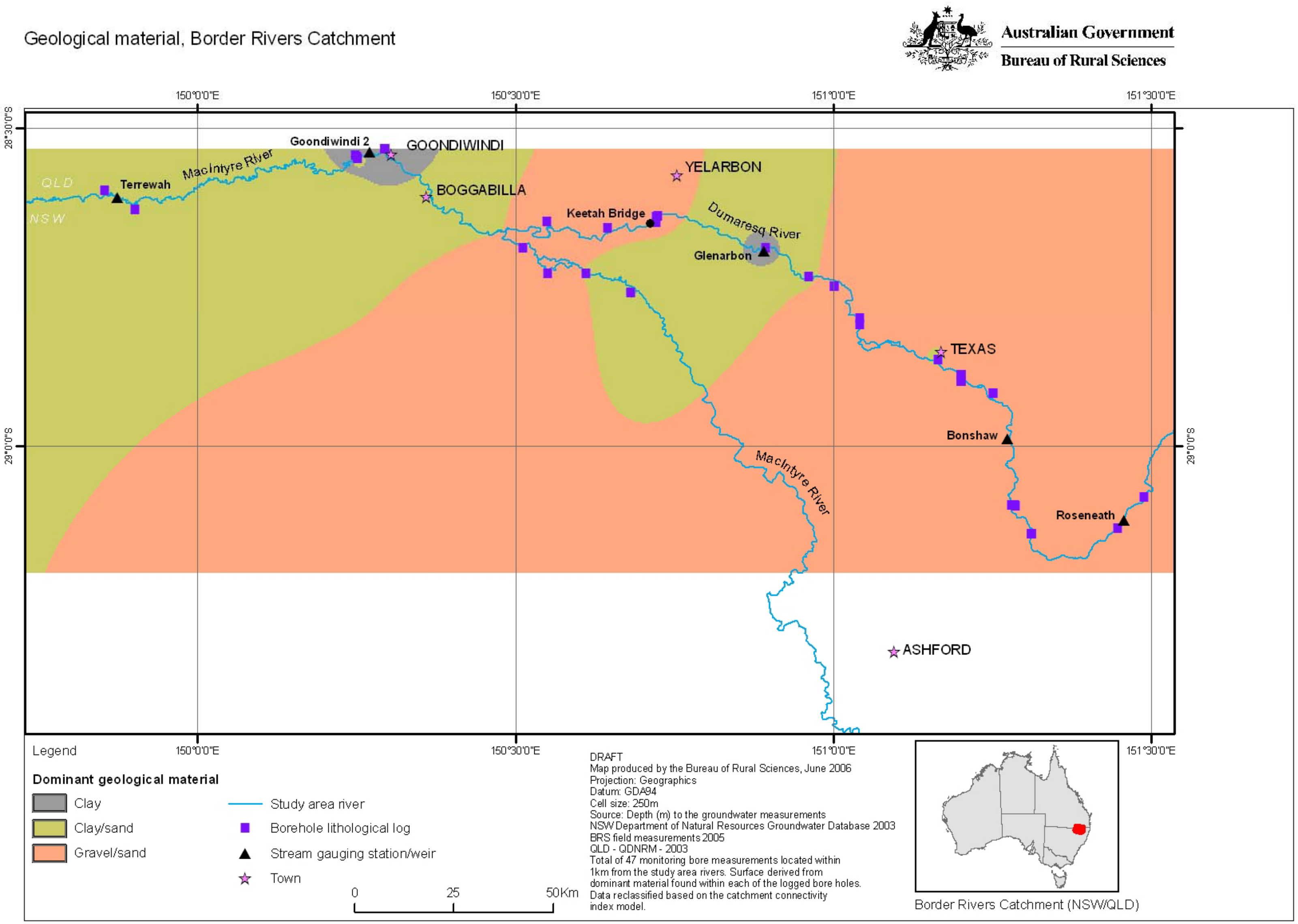
DRAFT
Map produced by the Bureau of Rural Sciences, June 2006
Projection: Geographics
Datum: GDA94
Cell size: 250m
Source: Soil Saturated Hydraulic Conductivity in Soil Layer 2 (B-Horizon - sub-soil) for Australian areas of intensive agriculture of sub-soil (derived from soil mapping). National Land and Water Resources Audit (NLWRA)
Data resampled from 1.1km to 250m. Data reclassified based on the catchment connectivity index model.

Figure 5: Depth to water table, Border Rivers Catchment



DRAFT
Map produced by the Bureau of Rural Sciences, June 2006
Projection: Geographics
Datum: GDA94
Cell size: 250m
Source: Depth (m) to the groundwater measurements
NSW Department of Natural Resources Groundwater Database 2003
BRS field measurements 2005
QLD - QDNRM - 2003
Total of 95 bore measurements. Surface derived from these points.
Data reclassified based on the catchment connectivity index model.

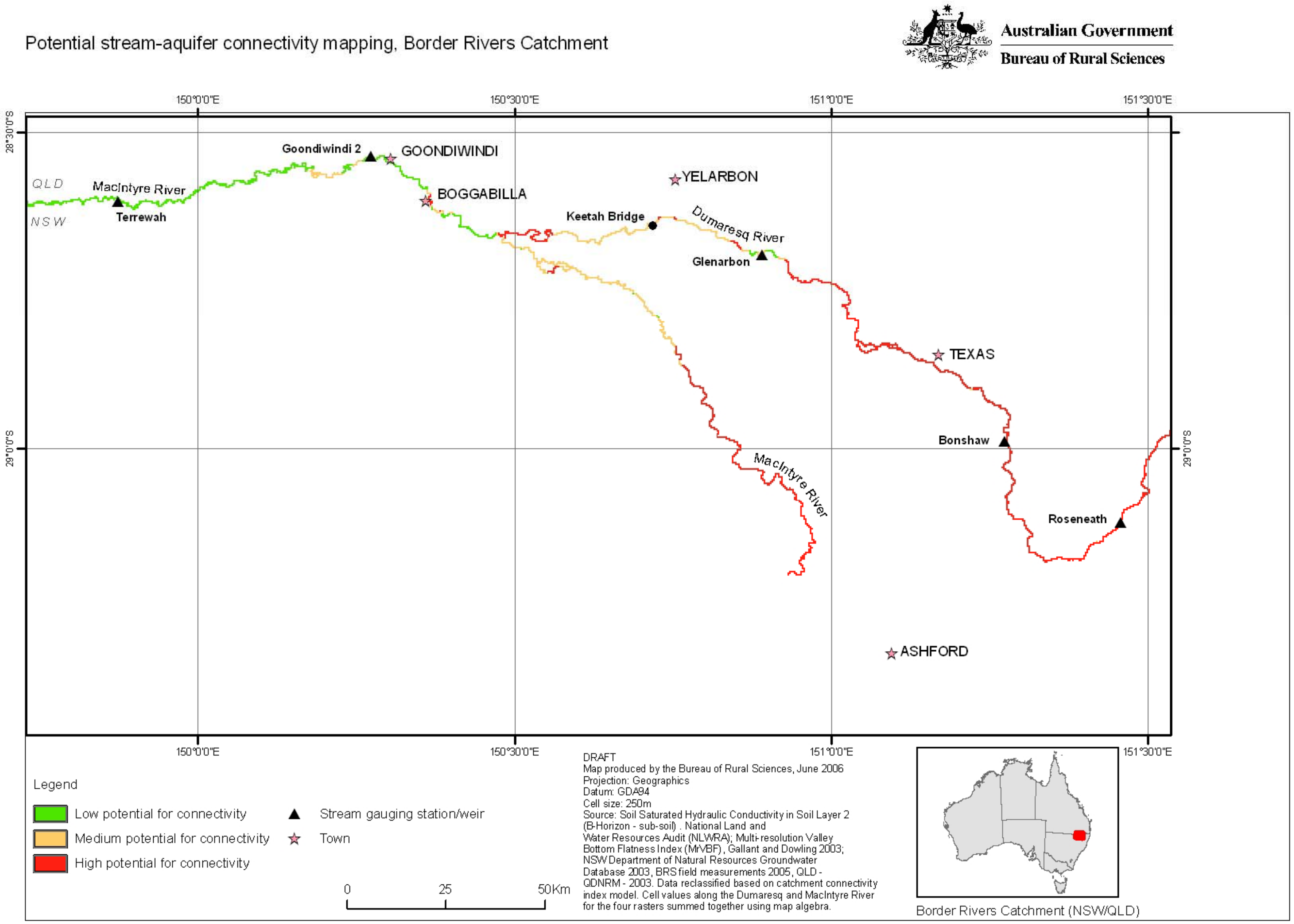
Figure 6: Distribution of geological material, Border Rivers Catchment



Geological material, Border Rivers Catchment

DRAFT
Map produced by the Bureau of Rural Sciences, June 2006
Projection: Geographics
Datum: GDA94
Cell size: 250m
Source: Depth (m) to the groundwater measurements
NSW Department of Natural Resources Groundwater Database 2003
BRS field measurements 2005
QLD - QDNRM - 2003
Total of 47 monitoring bore measurements located within 1km from the study area rivers. Surface derived from dominant material found within each of the logged bore holes. Data reclassified based on the catchment connectivity index model.

Figure 7: Potential stream-aquifer connectivity in the Border Rivers Catchment



Potential stream-aquifer connectivity mapping, Border Rivers Catchment

DRAFT
Map produced by the Bureau of Rural Sciences, June 2006
Projection: Geographics
Datum: GDA94
Cell size: 250m
Source: Soil Saturated Hydraulic Conductivity in Soil Layer 2 (B-Horizon - sub-soil) . National Land and Water Resources Audit (NLWRA); Multi-resolution Valley Bottom Flatness Index (MrVBF) , Gallant and Dowling 2003; NSW Department of Natural Resources Groundwater Database 2003, BRS field measurements 2005, QLD - QDNRM - 2003. Data reclassified based on catchment connectivity index model. Cell values along the Dumaresq and MacIntyre River for the four rasters summed together using map algebra.

Evaluation of mapping method results with field observation

In Table 4 an example of field assessment of hydraulic connection along various river reaches of the Border Rivers catchment is used to show the validation of the mapping method.

Table 4: Validation of connectivity mapping method in the Border Rivers catchment

River	**River reach**	**Hydraulic connection based on field assessment**	**Stream-aquifer interaction process based on field assessment**	**Potential connectivity based on new mapping method**[*]
Dumaresq River	Source to Roseneath	Connected	Gaining/losing stream	yes
	Roseneath to Bonshaw weir	Connected	Losing stream	yes
	Bonshaw weir to Goondiwindi	Connected	Losing stream	no
MacIntyre River	Goondiwindi to Terrewah	Weakly connected	Losing stream	yes
	Terrewah to Kanowna	Weakly connected	Losing stream	yes
	Kanowna to Mungindi	Weakly connected	Losing stream	ND

[*] ND – not determined

The earlier field assessment shows that the entire area upstream of Keetah in the Border Rivers catchment is generally categorised as a hydraulically connected system. However, the new mapping method shows a potential hydraulic connection ranging from low to high. From Glenarbon to Keetah, some pockets of low and medium potential for connection have been detected. The area of low potential connection around Glenarbon is due to a change in the geological material. This area was previously regarded as highly connected due existence to a relatively shallow water table. The presence of clay in the 0-9m depth restricts infiltration resulting in a low potential connection in this area.

Overall the hydraulic connection results obtained in the area downstream of Goondiwindi through both the field assessments and the mapping method agree well. The majority of the river reaches of the MacIntyre River, downstream of Keetah (Goondiwindi to Mungindi) are classified as weakly connected system which corresponds to a low potential connection derived from the mapping method.

Strengths and weaknesses of the connectivity mapping method

The strengths and weakness of the new mapping methodology to assess stream-aquifer connectivity are briefly described below.

- The methodology will provide information on the tools to assess connectivity for the NWI Baseline Assessment, NWI Performance Indicators and NWI Water Accounting projects.
- This methodology will provide sufficient information for a first-cut prioritisation of stream reaches to identify potential connected and disconnected systems, for regional, State and National policy makers to assist with integrated resource and environmental management.
- The new mapping methodology is a rating index model based on simplifications of processes and does not require modelling skills needed to run a simulation model.
- The method takes into account both hydrological and hydrogeological factors such as depth to water table, stream bed characteristics, geology and geomorphology, which are important data sets but often ignored.
- In general the majority of input data needed to run this potential connectivity index model is readily accessible through existing national datasets.
- The limited validation of this methodology suggests that the results are consistent with field observations. However, this method has not yet been comprehensively tested for other catchments.

Conclusions

Better understanding of the interactions between groundwater and surface water is critical for effective management of connected water resources. Assessing groundwater-surface water interactions is often complex and difficult. However, there are a range of methods available to assess the nature and degree of connectivity. The methods outlined in this report will need to be selectively applied in the investigations of groundwater-surface water interaction processes, in order to develop suitable management options for connected water resources.

A new mapping method has been developed to assess the potential hydraulic connection between groundwater and river systems and also evaluated this method in the Border Rivers catchment. The mapping method combines depth to water table measurements with data summarising the hydraulic properties of the geological material in contact with, and adjacent to a river. The new mapping method builds on existing techniques that use only depth to water as an indication of potential connection. Depth to water table information relies, in most cases, upon sparsely located monitoring bores measurements. These point measurements are interpolated over distances of many kilometres to derive a large scale depth to water table surface. This results in a relatively poor resolution dataset that will not identify changes in connection at a smaller scale.

The mapping method detects areas along a river where changes in the geological material have a direct impact on the potential for connection between surface water and groundwater. Such areas would otherwise not be identified using depth to water table data alone. However, when the other catchment data sets such as geology, river bed characteristics and geomorphology are combined with depth to water table, a good qualitative estimate of potential hydraulic connection can be obtained.

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References

Braaten, R and Gates, G, 2002. Groundwater-surface water interaction in inland New South Wales: a scoping study. Water Science and Technology. 48(7): 215-224.

SKM 2003. Projections of groundwater extraction rates and implications for future demand and competition for surface water. Murray Darling Basin Commission Publication 04/03. Sinclair Knight Merz.

Baskaran, S, Ransley, T and Brodie, RS, 2005. Tools for assessing groundwater- surface water interactions: a case study in the Border Rivers catchment, Murray-Darling Basin. Bureau of Rural Sciences, Canberra.

Brodie, RS, Baskaran, S and Hostetler, S, 2005. Tools for assessing groundwater-surface water interactions: a case study in the Lower Richmond catchment, NSW. Bureau of Rural Sciences, Canberra.

Brodie, R., Baskaran, S, Tottenham, R., Ransley, T., Hostetler, S. and Baker, P. 2006. A framework for managing connected groundwater-surface water resources in Australia. Bureau of Rural Sciences, Canberra (unpublished report).

Chen, D. 2003. Dumaresq River Groundwater Model: Border Rivers model development, calibration and use. Department of Natural Resources and Mines. Brisbane, Australia. P 170.

Gallant, JC. and Dowling, TI. 2003. A multi-resolution index of valley bottom flatness for mapping depositional areas. Water Resources Research, Volume 39, Issue 12. 1347.

MDBC, 2006. The shared water resources of the Murray-Darling Basin. MDBC Publication 21/06. Murray Darling Basin Commission, Canberra.

REM 2002. Watermark: Sustainable groundwater use within irrigated regions. Project 2: Conjunctive resource management, milestone 2 final report. Prepared for the Murray Darling Basin Commission, Australia.

REM 2006. Evaluation of the connectivity between surface water and groundwater in the Murray-Darling Basin. Prepared for the Murray Darling Basin Commission, Australia.

Tennakoon, T. 2002. Status report for the groundwater resources of Border Rivers alluvial aquifers. Department of Land and Water Conservation, NSW, Barwon Region.

Williams, RM., Ross, J., Hillier, J. and Thompson, P., 1987. A Review of the Groundwater Resources of the Dumaresq-MacIntyre Border Rivers System, Report by Border Rivers Groundwater Sub-Committee, Dumaresq-Barwon Border Rivers Commission.