

Gwydir Catchment Groundwater Hydrographs

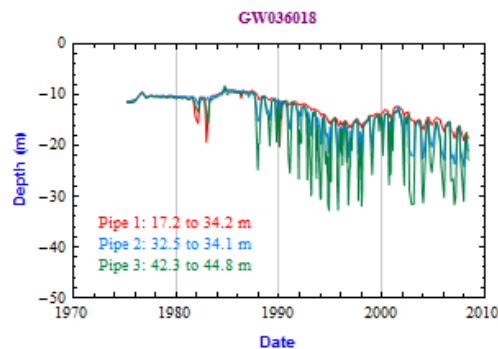
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Executive Summary

The hydrogeology of the Gwydir Catchment has been studied extensively in the past 40 years, but there are still many gaps in our understanding of the groundwater systems and river-aquifer interactions. These gaps in our knowledge limit our capacity to manage water resources throughout the catchment. This document captures our current understanding of the hydrogeology of the catchment and provides a multidimensional spatial analysis of the groundwater monitoring bore standing water level (SWL) data. Based on the findings, recommendations for further research are presented.

Abstraction of groundwater for the purposes of irrigating cotton and other crops started in the Gwydir Catchment in 1960s, and expanded until the turn of the last century. To monitor the impact of groundwater usage NSW state water management departments installed monitoring bores in relevant zones. The groundwater monitoring data are publicly available on the Pinneena Groundwater Works CD. This report presents all the hydrographs for the Gwydir Catchment, and examines the spatial and temporal trends displayed in these data. The primary goal of this report is to provide a graph of all the groundwater hydrographs in the catchment. A printout of the hydrographs for 48 groundwater work locations within the Gwydir Catchment is presented in the Appendix.

Through the implementation of water sharing plans there have been changes to groundwater allocations. At some locations there has been a reduction in the water allocated per share, with the aim of improving the long term viability of the groundwater resource for all users and the environment. The groundwater hydrographs provide a record of baseline conditions and can be used to assess the impact of variations in allocation and guide future management decisions.

Almost 40 years of groundwater hydrograph records enable long term groundwater level trends to be analysed throughout the alluvial regions of the catchment. Fluctuations in the groundwater level over long and short periods of time are analysed using traditional hydrograph plots and 3D plots to show the yearly and interdecadal impacts of groundwater extractions. The groundwater hydrograph data are interpreted in the context of existing geological knowledge, streamflow, rainfall and groundwater usage data.

Within the Gwydir Catchment a balance needs to be achieved in the way water is managed if urban centres and farms dependent on the water are to prosper, while maintaining important wetlands at the end of the catchment. The Gwydir River flows west from the head waters on the western side of the Great Dividing Range. Surface water flows in the Gwydir Catchment are now extensively regulated by dams, a series of weirs, bypass canals and irrigation channels that assist the diversion and abstraction of water for irrigation, industrial and domestic purposes. The major irrigation district is near Moree and east of the Gwydir Wetlands on the fertile soils of the floodplain. This floodplain overlies up to 100 m of valley-fill sediments which lie within the Gwydir River palaeovalley. It is the fresh groundwater within these sediments and immediately underlying rocks that is used for irrigation. The Gwydir Wetlands just west of the irrigation district are a large and diverse system of semi-permanent freshwater wetlands created by irregular flooding of the flat lands adjacent to the river and are an important ecological habitat.

This study identifies zones along the Gwydir River where aquifers within the sediments that fill the deep palaeovalley are locally hydraulically connected to the river, and zones where the deep aquifers are disconnected from the shallow aquifers and do not receive direct river recharge. The extent of the hydraulic connection between the alluvial aquifers and the immediate underlying

sedimentary rock aquifers is poorly understood. The largest zone of groundwater depletion is north of Moree. This zone requires further extensive hydrogeological and water chemistry investigations to better understand the recharge pathways. If the management goal is to reduce the decline in the groundwater level, then this region may require managed aquifer recharge.

There are 87 monitoring bores spread across 41 locations that have reliable groundwater level measurements for the years 1988 and 2008. Between these years 19 monitoring bores have rising water levels of between 0 and 3 m, 43 monitoring bores show a decline of between 0 to 3 m, and 25 monitoring bores have a decline of 3 to 10 m. These measurements indicate that over this period groundwater extractions have been in excess of recharge, particularly in the region north of Moree, where the largest declines were recorded at monitoring sites GW030460 and GW030461.

The preliminary 3D lithological model of the valley-filling sediments indicates that the Gwydir Catchment is not as uniform as previously interpreted and is in fact a complex heterogeneous arrangement of clays, sand and gravels reflecting the meandering paths of palaeorivers. Justification for 2 distinct formations, the Narrabri and Gunnedah Formations, is poor. At some locations there is good hydraulic connectivity via various sand and gravel units at all depths, while at others there are clay intervals that act as aquitards. Further work is required to develop a comprehensive interpretation of the depositional history of the catchment. The observation that there is no distinct boundary between the Narrabri and Gunnedah Formations in the Gwydir Catchment was also made by Barrett (2009). In this report it is shown that the aquifer system is better represented by a meandering fluvial river environment with various isolated and amalgamated palaeochannels throughout the unconsolidated valley-fill sequence.

Vertical sections and horizontal planes were taken through the 3D lithofacies model to identify ancient palaeochannels. Possible groundwater flow paths were identified from 80-110 meters above sea level (m.a.s.l.). The horizontal planes reveal that the ancient palaeochannels in the north drain to the south-west and the palaeochannels in the south drain to the north-west. The sand bodies that define the palaeochannels clearly highlight the meandering paths of the palaeorivers. Vertical cross sections identify possible sites of connection between surface and ground water as well as the vertical and horizontal continuity of aquifers. There is a high degree of vertical connectivity between aquifers in the Moree pumping district.

There is an ongoing debate about how water should be allocated and managed in the Gwydir Catchment. The graphs and maps presented in this report provide valuable information that can inform these discussions.

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1. Introduction

Understanding aquifer connectivity along with surface to sub-surface water interactions is vital for managing a groundwater resource effectively. The Gwydir Catchment represents 2% of the total area of the Murray-Darling Basin (MDB). This land is used for extensive dryland pasture and irrigated crops. Most of the irrigation water is used for cotton production.

Irrigation agriculture is a major economic activity in the region which relies heavily upon water extraction from river and aquifer storages. However, The Ramsar listed Gwydir Wetlands are located downstream of the Moree irrigation district. Therefore a delicate balance is required to support the irrigation industry while maintaining healthy wetlands.

The primary goal of this report is to provide a plot of all groundwater hydrographs in the Gwydir Catchment, and to interpret the hydrographs in the context of the hydrogeological setting, climatic data and historical groundwater usage. Plots of all the hydrograph data published on the NSW Government Groundwater Pinneena CD are presented in the Appendix. Finally the spatial and temporal trends observed in these hydrographs are discussed and recommendations for future projects made.

1.1 Gwydir Catchment

Within the Gwydir fan-plain water is conveyed by four main streams; the Gwydir River, the Mehi River, Moomin Creek and Carole Creek (Figure 1). In addition to within-channel flow it is normal for water to move over floodplains along watercourses such as the Gingham Watercourse and the Big Leather Watercourse. The watercourses are mostly a series of swamps or can be described as being wetlands without open water that connect occasional waterholes.

The distributary system of the Gwydir fan-plain is highly prone to flooding, except for isolated pockets of high ground. In most cases, floods spill along a particular floodway rather than inundating the entire fan-plain (Mahaffey, 1985). The total channel capacity of the Gwydir distributary system is insufficient to accommodate the peak within river bank flows of the Gwydir River upstream of Pallamallawa. The river profiles throughout the Gwydir Catchment are presented in Figure 2.

1.2 Land Use

The population of the Gwydir Catchment is approximately 26,500. Moree is the largest town with a population of 8,083 in 2006 (www.censusdata.abs.gov.au). The main industry in the region is agriculture, with irrigated cotton being the most financially significant sector (worth \$200 million per year) (DECCW, 2010). Lucerne and pasture are grown on the narrow alluvial floodplains of the upper Gwydir River and its tributaries, and broad acre crops are grown on the western plains. Irrigated crops were grown on 90,000 ha on the western plains of the region in the year 2000, of which cotton accounted for 85,000 ha (95%) of the irrigated area. The distribution of the irrigation farms is shown in Figure 3.

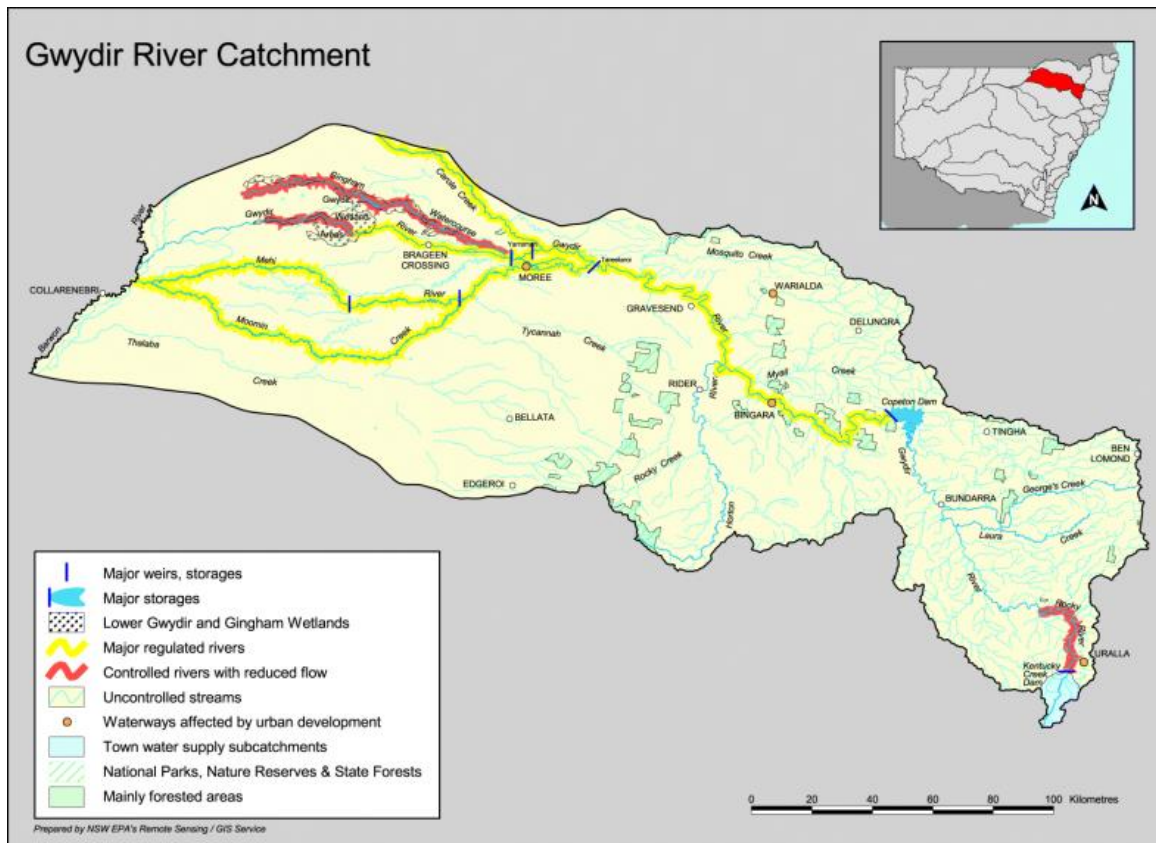


Figure 1: Gwydir Catchment boundary, major rivers and water storages (<http://www.environment.nsw.gov.au/ieo/Gwydir/map.htm>).

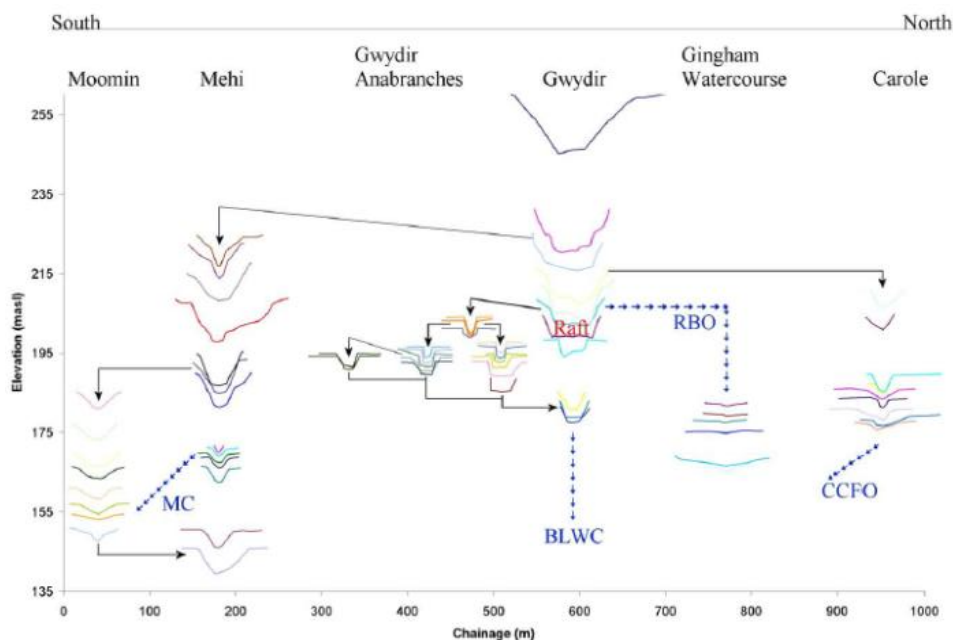


Figure 2: Cross-section form and elevations along the contemporary fluvial system of the Gwydir fanplain. Solid arrows represent flow distribution via effluences or confluences of channelised flow, whereas broken blue arrows represent flow distribution via predominately overland flow. MC: Mallowa Ck; BLWC: Big Leather Watercourse; RBO: Raft break-out; CCFO: Carole Ck flood-out. Horizontal locations of channel cross-sections have been adjusted arbitrarily. Plot colours have been selected arbitrarily to enable differentiation of closely spaced cross-sections (Pietsch, 2006).

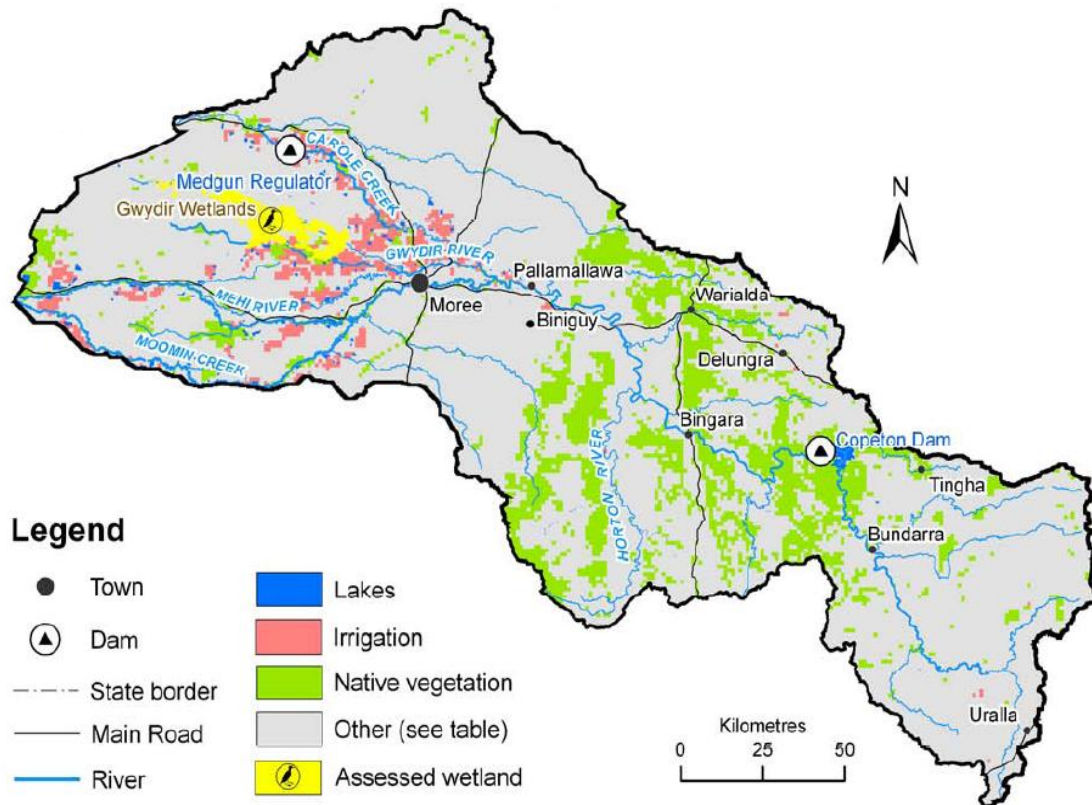


Figure 3: The distribution of the irrigation district, wetlands and native vegetation in the Gwydir Catchment (CSIRO, 2007).

1.3 Climate

The Gwydir Catchment has an east-west climatic gradient, with annual rainfall averaging 800 mm in the eastern mountain headwaters, falling to 500 mm in the far west of the catchment (CSIRO, 2007). Annual evaporation potential ranges from less than 1,250 mm in the east, to 1,750 mm in the west (Pietsch, 2006). The western portion of the Gwydir Catchment has a semi-arid climate with over 60% of the annual rainfall falling between November and March.

Figures 4 and 5 show the annual rainfall at Pallamallawa and Tingha from 1913-2009 and 1910-2009 respectively. At Pallamallawa the yearly mean and median rainfalls are 614.6 mm and 623 mm respectively. For Tingha the yearly mean and median rainfall are 802 mm and 780 mm, respectively.

Long term trends in rainfall were highlighted by plotting the cumulative rainfall departure (CRD) curves for the Pallamallawa and Tingha rainfall data (Figures 6 and 7). A CRD graph is constructed by determining the mean rainfall using the complete record, finding the residual from the mean for each year (subtracting the mean value from the total yearly rainfall), and then accumulating the residual (Webber and Stewart, 2004). Negative (downward) slopes indicate periods of below average precipitation and positive (upward) slopes indicate periods of above average precipitation.

In Figures 6 and 7 the negative slope from 1910 until the late 1940s indicates a drier than average climate in the first 1/2 of last century. Since midway through last century the region has been in a predominantly wet phase, with only minor periods of drought.

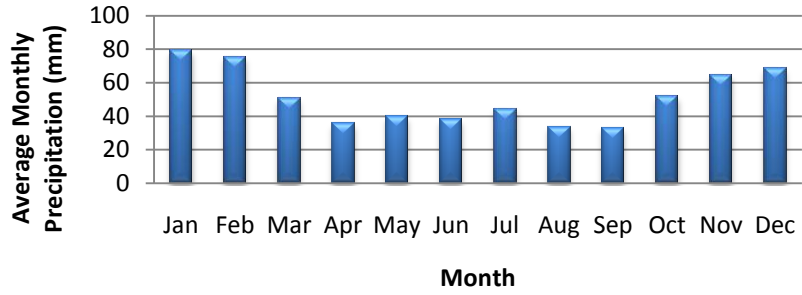


Figure 4: Average monthly precipitation at Pallamallawa (1913 to 2009).

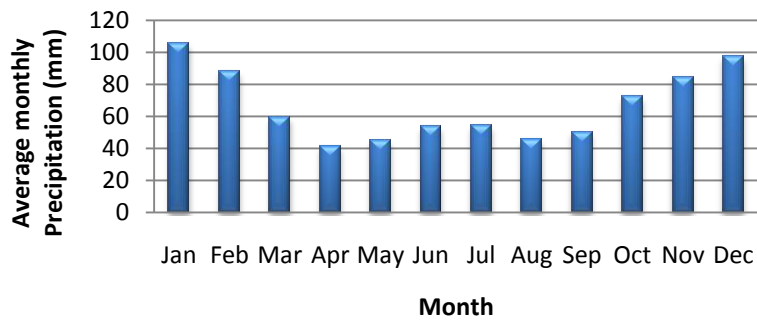


Figure 5: Average monthly precipitation at Tingha (1910-2000).

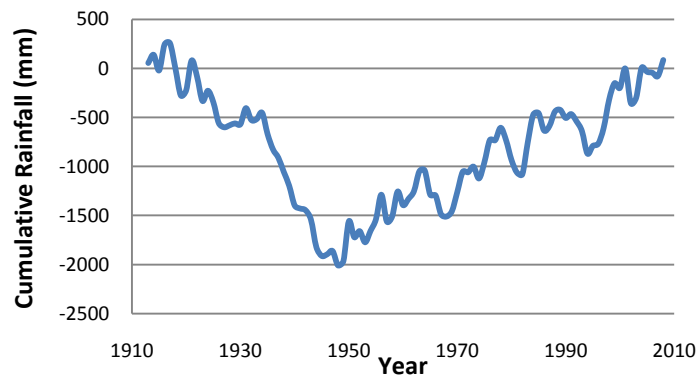


Figure 6: Cumulative rainfall departure at Pallamallawa.

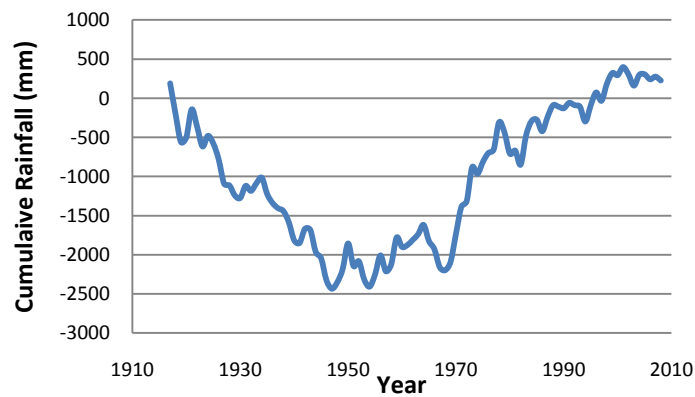


Figure 7: Cumulative rainfall departure at Tingha.

1.4 Surface Water

1.4.1 COPETON DAM AND WEIRS

Copeton Dam, which is located in the east of the catchment on the western side of the Great Dividing Range (Figure 3), has a water holding capacity of 1,360,000 ML (almost three times the size of Sydney Harbour when full). It was completed in 1976, and since this time it has had a large impact on the movement of water within the catchment. Copeton Dam regulates 55 percent of the total inflow into the Gwydir River (Keyte, 1994); the majority of the rest flows down the unregulated Horton River. Government-built weirs at Tareelaro, Boolooroo, Tyreel and Combadello in the 1970s and 1980s directed water down the southern part of the river system where there was a defined channel. After the dam was established 86,000 ha of irrigation licences were granted equating to 530,000 ML per year were issued (Keyte, 1994), exceeding the natural median annual flow (520,000 ML). Irrigation farming, mostly for cotton, expanded rapidly from 1976 until 1991. Figure 8 shows a time series of reservoir volume in storage (GL). It can be observed that the volume of water in storage follows an inter-decadal cycle between full and near empty. Copeton Dam stores rainfall and associated runoff throughout the year, resulting in reduced winter flows and peak summer flows downstream of the dam (Figure 9). The peak releases are associated with the water orders for irrigating cotton and other crops. Since 2003, due to the lack of water flowing into the dam (Figure 8), the water release rate has been reduced, indicated by the reduction in the gradient of the rate of release in Figure 9.

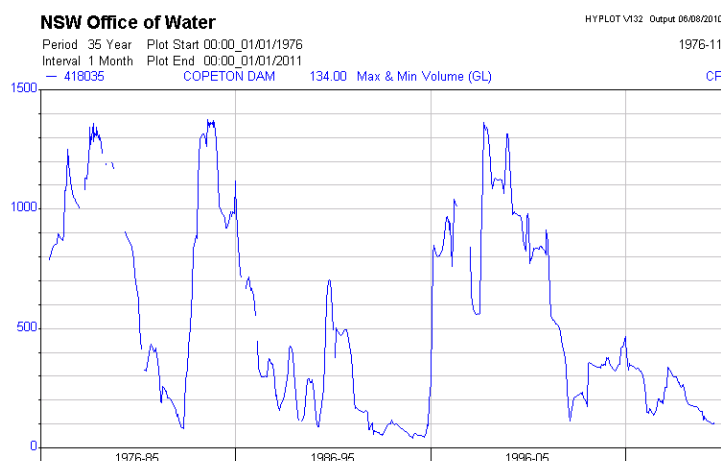


Figure 8: Copeton Dam giganlitres (GL) in storage (Data from NSW Office of Water, http://waterinfo.nsw.gov.au/water.shtml?ppbm=STORAGE_SITE&da&3&dakm_url, 06/Aug/2010).

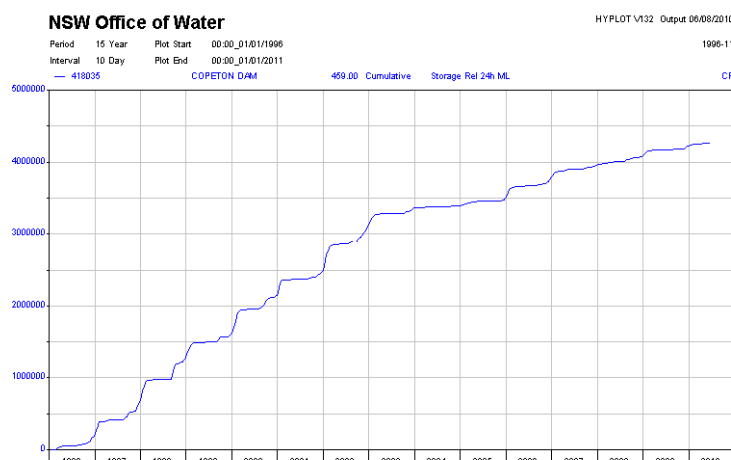


Figure 9: Copeton Dam accumulated 24 hour water release volumes since 1996 (units megalitres), http://waterinfo.nsw.gov.au/water.shtml?ppbm=STORAGE_SITE&da&3&dakm_url, Accessed 06/Aug/2010).

1.4.2 MAJOR RIVERS

Groundwater level measurements in bores within the Gwydir Catchment are most affected by the Gwydir River, which flows through the irrigation district near Moree, and by flood events. The Gwydir River flows out of the foothills of the Great Dividing Range approximately 7 km south east of Pallamallawa. From there it runs by Pallamallawa, then north of Moree extending approximately 90 km from the embouchure before losing definition in the vicinity of the Wandoona Waterhole. The average flow of the Gwydir River as it enters the fan is approximately $800 \times 10^6 \text{ m}^3$ ($\sim 25 \text{ m}^3 \text{ s}^{-1}$) (median: $520 \times 10^6 \text{ m}^3$ per year), however variation is high with annual discharges ranging from zero to over four times the average annual discharge (Pietsch, 2006).

Monthly hydrological stream flow data were obtained from the NSW Office of Water (Pinneena 9.3 Continuous Monitoring DVD). Several gauging stations were analysed within the Gwydir Catchment tributaries to gain an understanding of the water balance. Just downstream of Copeton Dam before the main flow enters into the Gwydir River valley, the Horton River merges with the Gwydir River upstream of the Gravesend monitoring station. Horton and Pinegrove monitoring stations are located just before the flows merge above Gravesend. In Figure 10 it can be seen that the flow at Gravesend is approximately the addition of flow measurements at Horton and Pinegrove.

As streams diverge and then converge along the length of the catchment, flows are recorded at various gauging stations (Figure 11). These stations are used to quantify the surface water outflow for the irrigated region. The Gwydir River diverges into several different watercourses close to Moree. It predominately diverges to the continuing Gwydir River and the Mehi River, with lesser amounts flowing into Carole Creek which spills over into the Black Leather Watercourse. The flows into these watercourses are unmonitored. Pallamallawa is gauged just upstream of Moree, from there the flow is monitored at the Mehi River at Moree and Gwydir River at Yarraman.

Figure 12 shows the annual outflow discharge of the Gwydir (recorded at Millewa) and Mehi (recorded at Bronte) rivers. The Mehi generally accounts for most of the recorded outflow from the Gwydir Catchment to the Barwon River. However, a significant proportion of the flow spills out to the Gwydir Wetlands and the Black Leather Watercourse and is not accounted for in this graph. The annual discharge of the Gwydir and Mehi River are just a small proportion compared to the inflow recorded at Gravesend Figure 13.

1.5 Gwydir Catchment Hydrogeology

The Gwydir Catchment is divided into two broad areas – the hilly highland country to the east and a broad flat alluvial plain to the west. The primary groundwater resources are located in the alluvial aquifers associated with the main rivers and prior channels of the western flood plain. The alluvial sediments that fill the palaeovalleys have historically been divided into two main sedimentary formations: the Narrabri Formation (an unconfined aquifer) which overlies the Gunnedah Formation (a semi-confined aquifer) (Milne-Home et al., 2007). Groundwater for irrigation is usually extracted from sands and gravels within the Gunnedah Formation. Results from this study show that both the lithofacies and hydrofacies cannot be accurately represented by two formations. This interpretation will be justified using the 3D lithological model presented below.

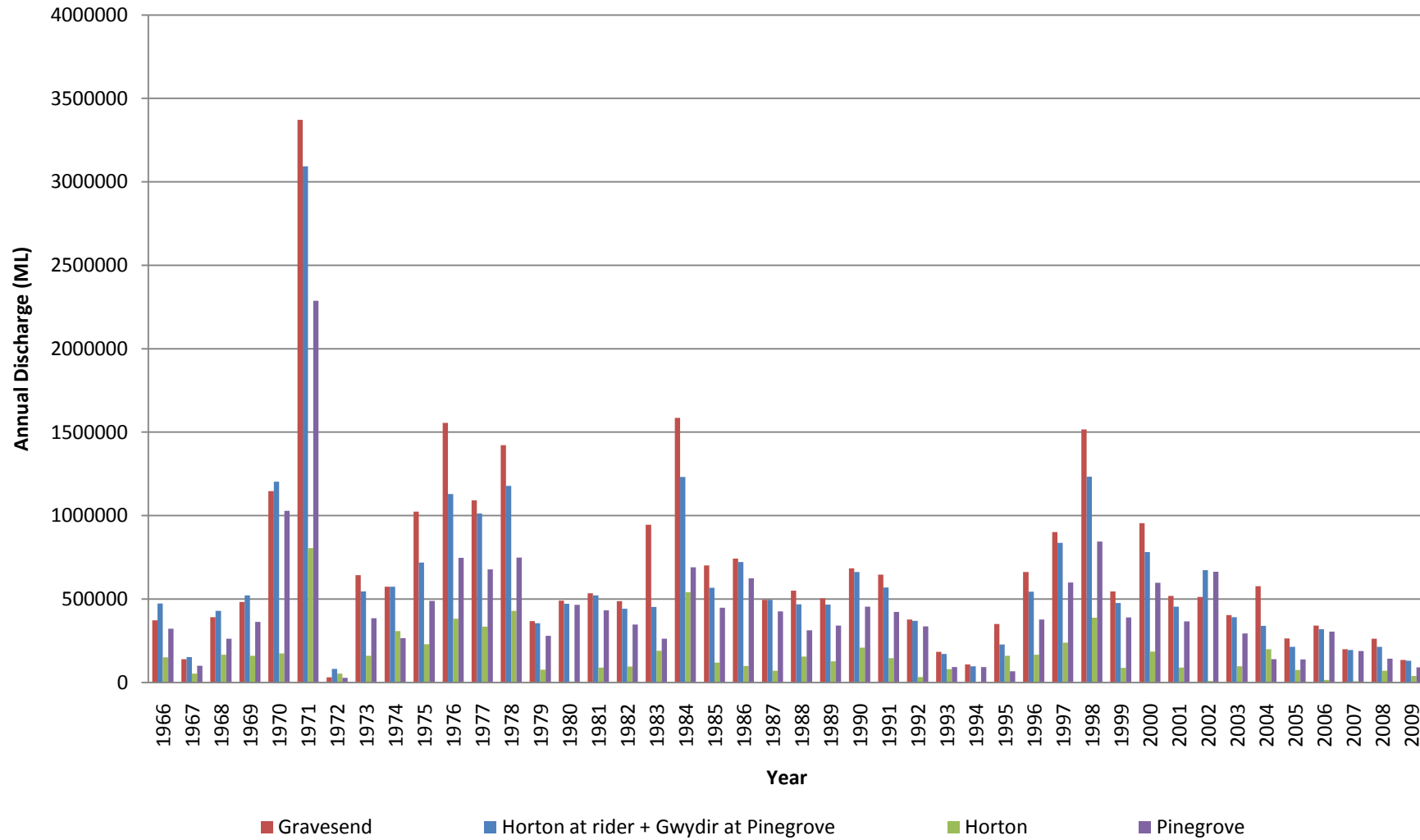


Figure 10: Gravesend annual discharge, compared to Horton and Pinegrove flows.

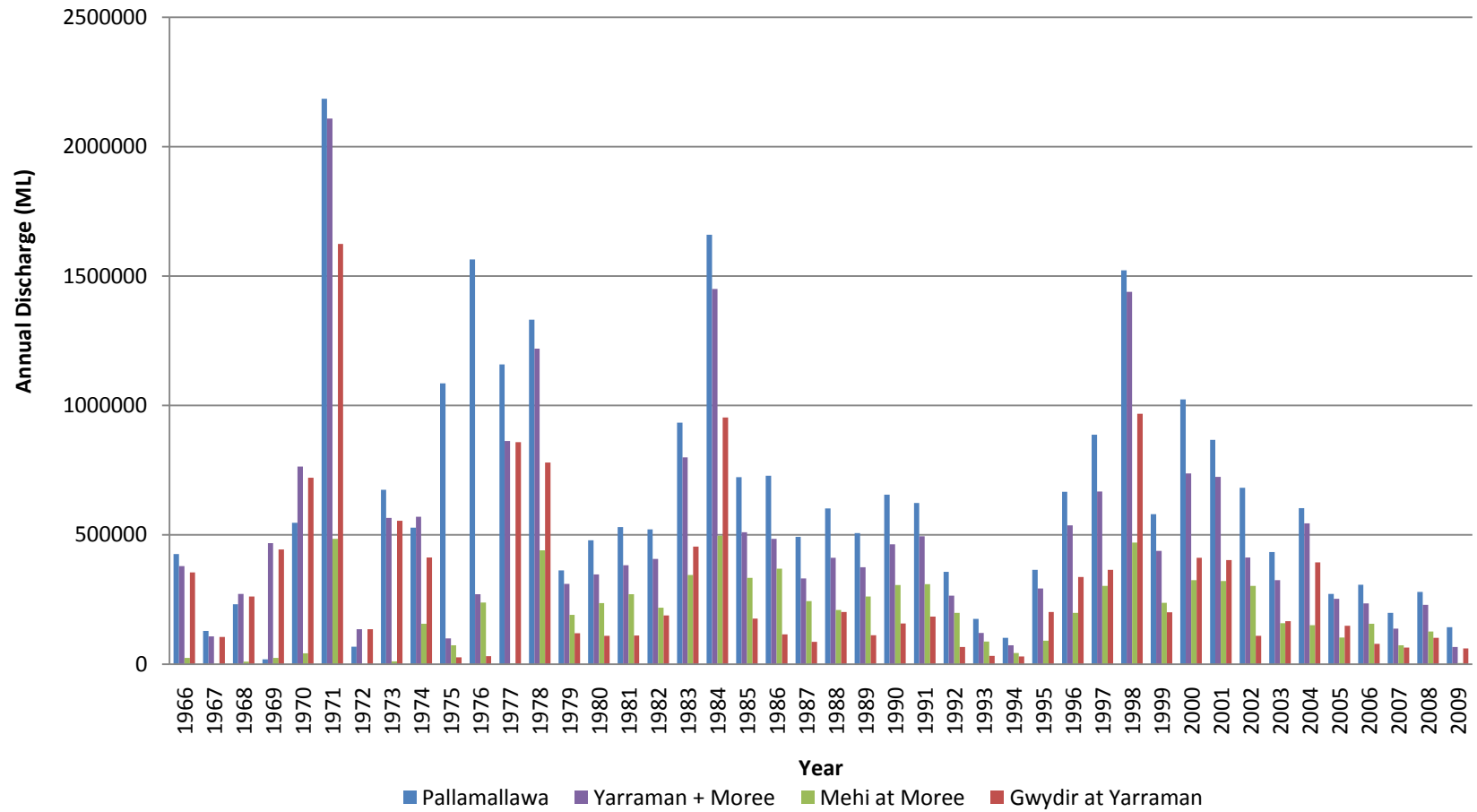


Figure 11: Annual discharge Gwydir diverging to Gwydir and Mehi Rivers.

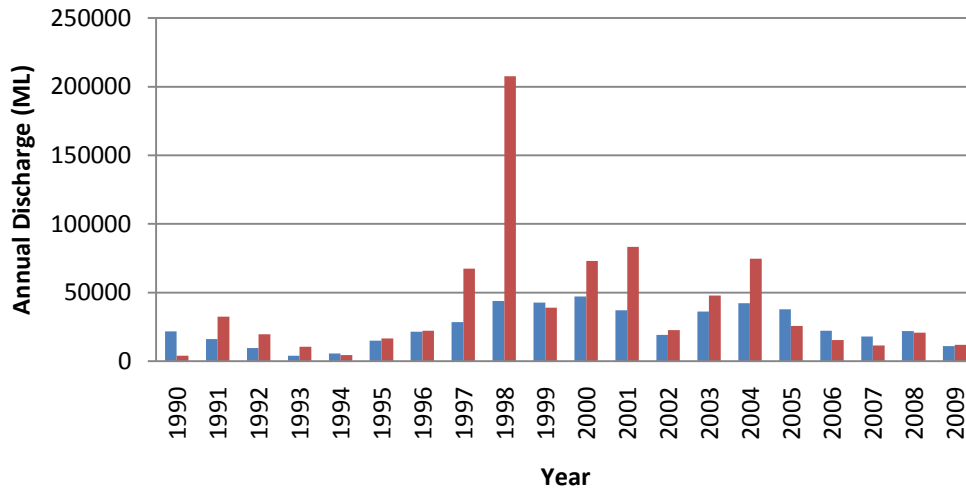


Figure 12: River discharges at Millewa (Gwydir, red) and Bronte (Mehi, blue).

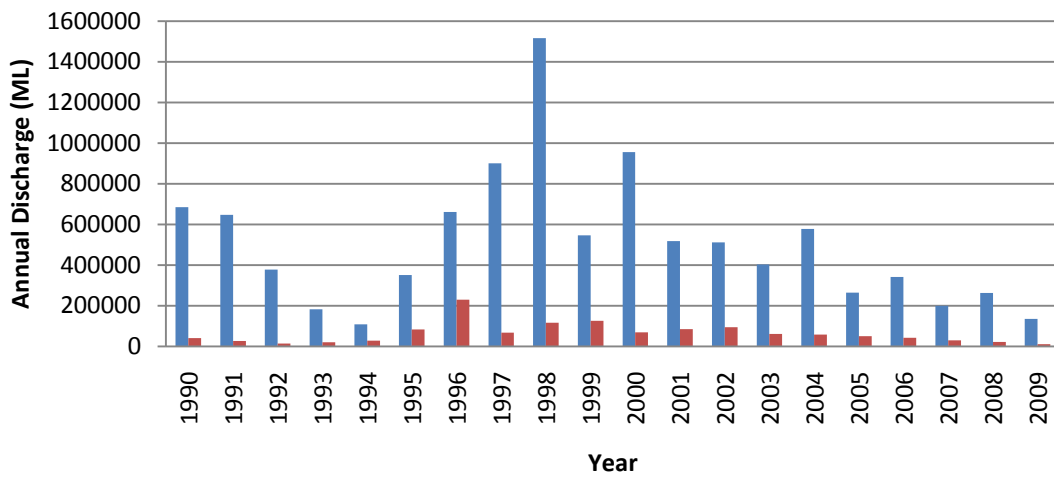


Figure 13: Annual discharge: Gwydir River inflow (blue) vs. Gwydir and Mehi River outflow (red).

The Gwydir River drains an area of considerable geological diversity. The eastern highland regions of the Nandewar and New England Ranges are dominated by fractured igneous and sedimentary rocks. Groundwater salinities in the fractured rock aquifers range from 1,200 to 3,600 mg/L total dissolved salts with yields of 1 to 2 L/s (CSIRO, 2007).

The central portion of the catchment is underlain by consolidated sandstones, shales and mudstone that form the multilayered aquifers of the Great Artesian Basin (GAB). A large area of Jurassic Sandstone, an extension of the Pilliga Sandstone, extends to the north of the Gwydir River. Cretaceous and Jurassic confining layers of the Surat Basin form the basement rock for the Gwydir fan-plain. An early-Cenozoic palaeovalley cuts into the basement rock. This palaeovalley runs to the north of Moree before swinging southwards to eventually join the Namoi palaeovalley. The alluvium of the Gwydir fan-plain has been accumulating since the mid Miocene (Martin, 1980), with a complex three-dimensional array of inter-bedded gravels, sands, silts and clays. The measured depth to the eroded bedrock surface increases from east to west, to a maximum depth in the order of 100 m. Throughout most of the catchment the unconsolidated sediments have a thickness of 40-60 m.

All streams in the western parts of the region on the alluvial plain meander across the top of the Narrabri Formation. At the eastern margin of the plain the rivers are in direct hydraulic contact with the water table. The dominant proportion of usable low salinity groundwater resources in the

Gwydir Catchment is constrained to the Lower Gwydir Alluvium Groundwater Management Unit (GMU), which lies at the eastern end of the broad alluvial floodplain where the Gwydir River emerges from the slightly higher relief country of the eastern valley. Groundwater within the Lower Gwydir Alluvium GMU is largely extracted from the deeper gravel and sand units of the Gunnedah Formation.

1.5.1 PREVIOUS STRATIGRAPHIC INTERPRETATIONS USING CROSS SECTIONS AND LITHOLOGICAL LOGS.

Due to the complex nature of the sedimentary system in the Gwydir Catchment, lithological logs and cross sections are necessary to interpret the groundwater responses observed in the system, as they identify the lateral and vertical extent of the aquifers. Five cross sections, along the sections lines shown in Figure 14, were constructed by the Department of Water and Energy (Barrett, 2009) and have been used to aid the interpretation of the stratigraphy. Only one lithological section is presented here (Figure 15). Shown in this lithological section are 14 lithological bore logs and historical water levels. A deterministic correlation has been drawn on the lithological section in an attempt to delineate the Gunnedah and Narrabri Formations. This layer-cake depositional style has commonly been imposed on the interpretation of lithological logs throughout the Murray-Darling Basin. This deterministic style of interpretation is A in Figure 16. We believe that a depositional conceptual model (B in Figure 16) is a better representation of the unconsolidated sedimentary sequence for the Gwydir Catchment. The Lower Gwydir Alluvium GMU sediments are a complex system of alternating clays, sands and gravels. Good hydraulic connectivity between the sand and gravel units is limited to local areas; however the number of connections is such that there is hydraulic connectivity throughout most of the catchment, both vertically and horizontally. This will be discussed further in Subsection 3.4.

1.5.3 PALYNOLOGY DATA

Martin (1980) has undertaken the only known palynological study in the region, using the bores summarised in Table 1. Bedrock in the few bores examined was dated as Early Cretaceous. At lower depths in the alluvial sediments there was little preservation of the pollens needed for dating. Palynological data are limited because the climate at the time the sands and gravels were deposited was not conducive to the preservation of the pollens. The sediments from 5 to 40 metres below the ground surface were deposited in the Pleistocene.

Table 1: Gwydir Catchment Palynological Zones.

Bore	Depth from (m)	Depth to (m)	Palynological Zone or Age
36158	49.5	53	Early Cretaceous
36111	5.6	7.6	Pleistocene
Combadello 1	7.6	7.6	Possible Pleistocene
36017	38.1	39.6	Pleistocene
	78.2	80	Early Cretaceous
14837	56.1	61	Dictyotosporites speciosus Zone
36049	35.5	35.5	D. speciosus Zone
Mehi 1	35.8	35.8	Mid-Tertiary
	39.1	39.1	Early Cretaceous
30389	48	48	D. speciosus Zone
30390	34.5	34.5	Early Cretaceous

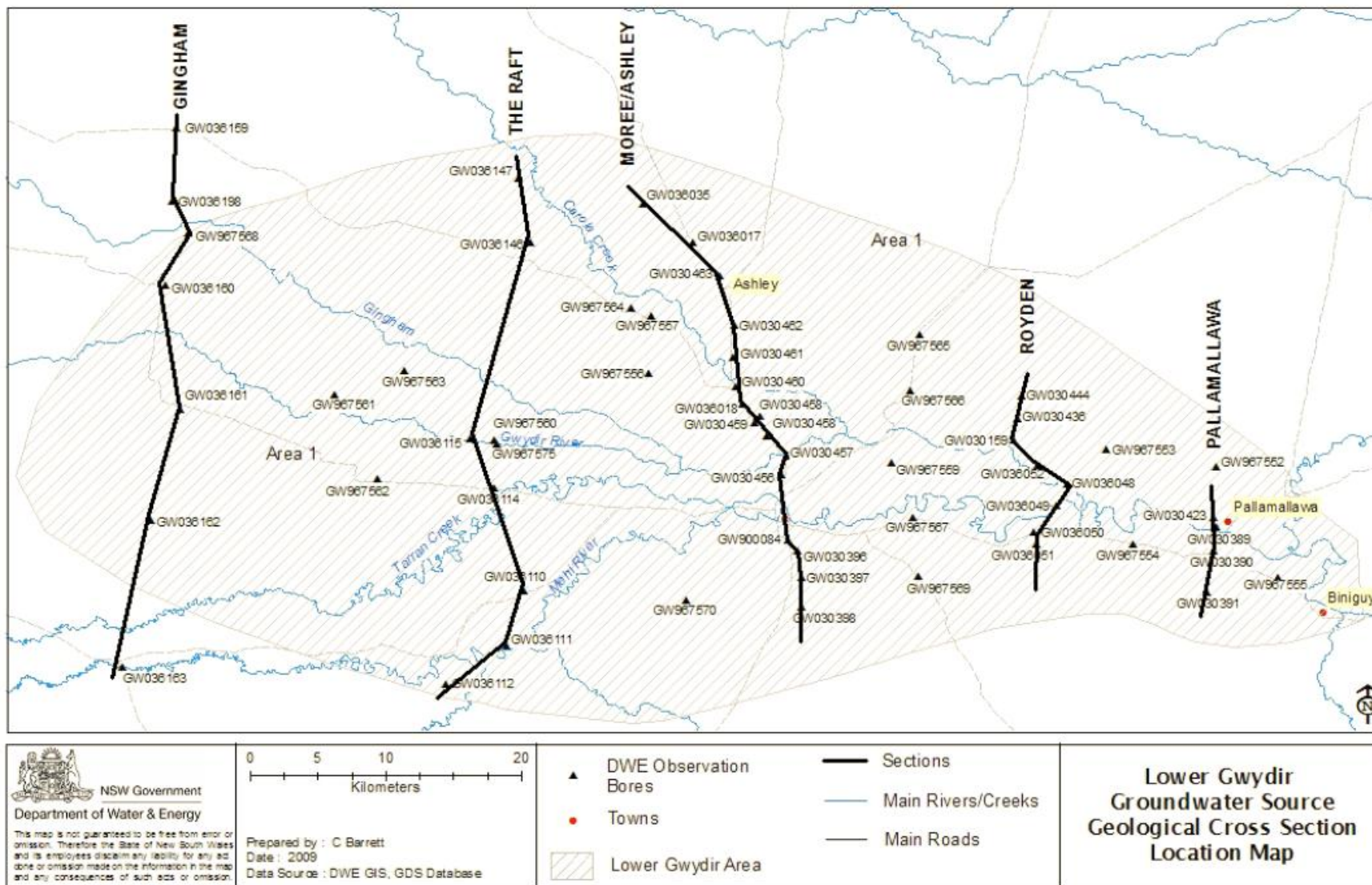


Figure 14: Cross section map Lower Gwydir (Barrett, 2009).

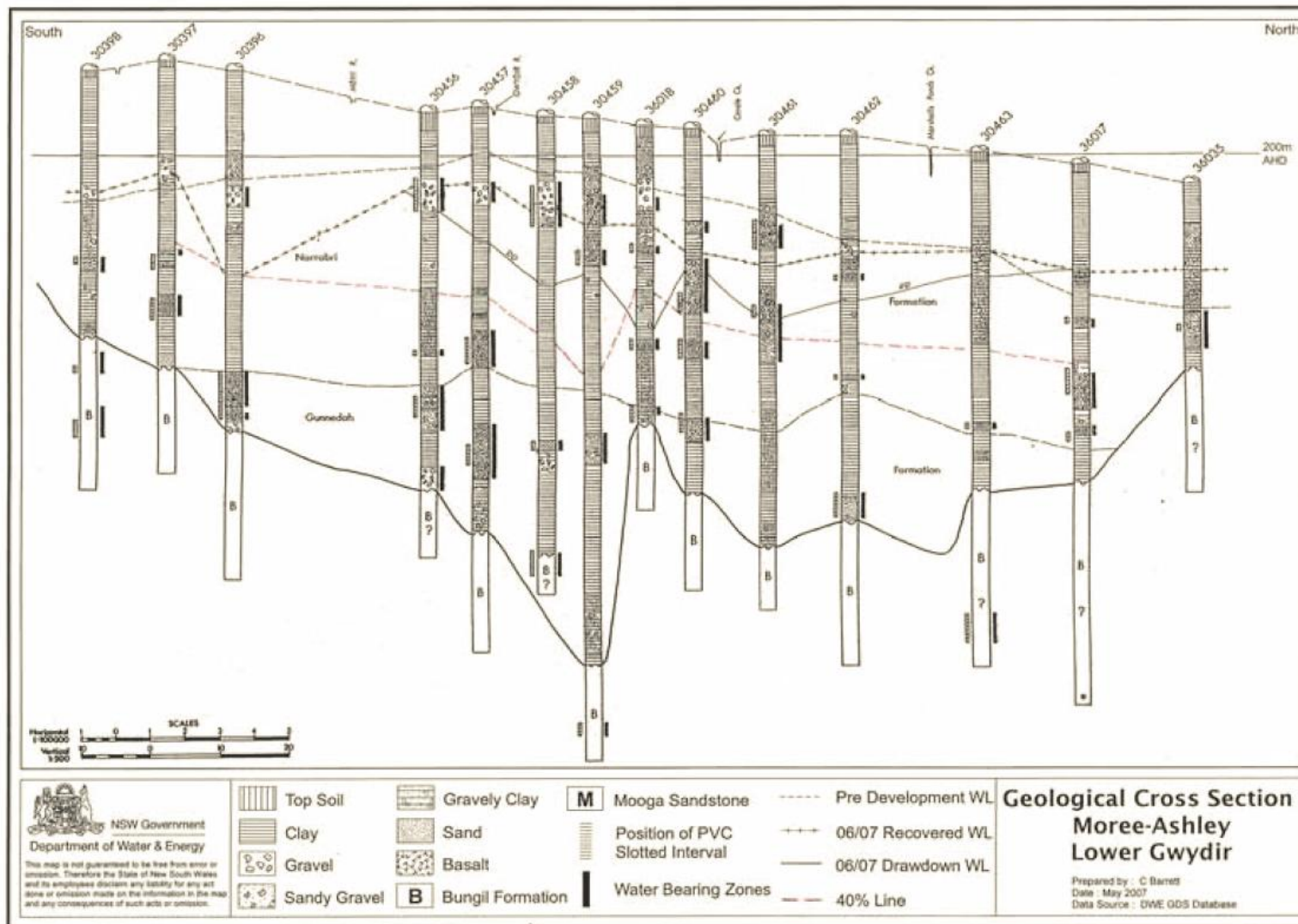


Figure 15: Moree/Ashley geological cross section (Barrett, 2009).

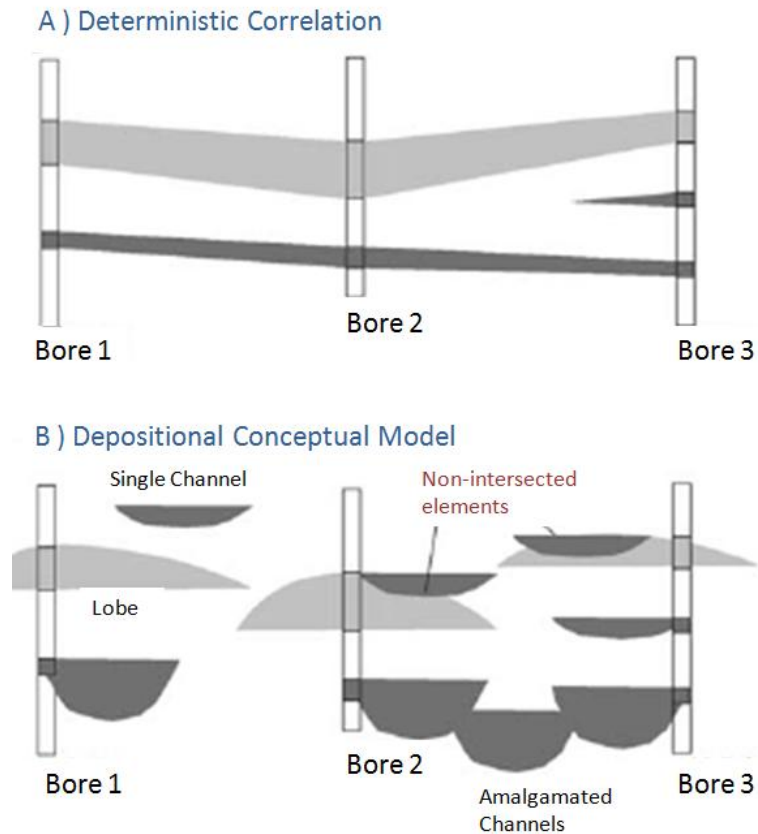


Figure 16: A comparison of facies distributions obtained by a deterministic reconstruction method (A), and a depositional conceptual model (B). The deterministic reconstruction is based mainly on bore data (hard data). The depositional conceptual model is constructed using geostatistical and object modelling techniques (modified from Falivene et al., 2007).

2 Water Allocation

2.1 Historic Allocation

In 1983 the first volumetric groundwater allocation policy for the Lower Gwydir GMU was introduced. Under this policy the existing unrestricted area based licences were converted to an annual volumetric entitlement (Barrett, 2009). A moratorium on new groundwater entitlements was imposed on 18th November 1993 followed by an embargo of new entitlement and new bores in December 1993 for the whole of the Lower Gwydir Catchment downstream of Gravesend. Since then there have been no new groundwater licences issued other than for the replacement of bores within the property allocations (Kalaitzis, 1999). The volumetric groundwater allocation policy was replaced by the Lower Gwydir Groundwater Source Water Sharing Plan in October 2006 (http://www.water.nsw.gov.au/Water-management/Water-sharing-plans/plans_comenced/default.aspx).

2.2 Usage Data

Usage data for the Gwydir Catchment from 1994-2008 are summarised in Figure 17. The future usage target of 32,300 ML is displayed as a red line. Groundwater usage in 10 out of the 15 years shown has exceeded this target.

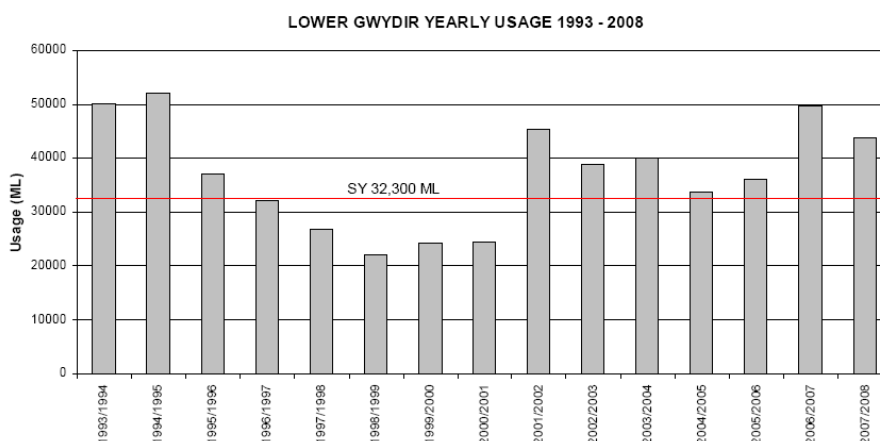


Figure 17: Lower Gwydir groundwater usage since 1993-94 (Barrett, 2009).

2.2 Current Water Sharing Plan

The current water sharing plan commenced on October 1st 2006 in response to the *Water Management Act 2000*. The Lower Gwydir groundwater source includes all the groundwater contained within the alluvial sediments associated with the Gwydir and Mehi Rivers and their tributaries west of Biniguy. Bores into the Great Artesian Basin (GAB) are tapping into what has been defined as a different water source; which is not reviewed in this report. The extent to which GAB water flows into the base of the alluvial sediments is poorly understood, but modelling indicates it cannot be a major contribution (CSIRO, 2007). The estimated average annual groundwater recharge for the Lower Gwydir GMU unit is 38,000 ML. The 2016 goal is to limit extractions to eighty-five per cent for irrigation purposes. The remaining 15 per cent, 5,700 ML, is reserved as ‘planned environmental water’.

2.4 Murray-Darling Basin Draft Plan

The Murray-Darling Basin Authority (MDBA) is the statutory agency that manages, in conjunction with the Basin states, the Murray-Darling Basin’s water resource in the national interest. It is responsible for preparing and overseeing the Basin Plan. The Water Act 2007 and the Basin Plan seek to address the over-extraction of water to restore and maintain the Basin’s key environmental assets and key ecosystem functions. To determine sustainable diversion limits (SDLs), the Authority undertook an assessment of the environmental assets and key ecosystem functions across the Murray-Darling Basin. The Authority is required to establish new long term average SDLs for surface and ground water. SDLs represent the long term average amount of water which can be used for consumptive purposes after meeting the environmental water needs that have been identified. In the guide to the Murray-Darling Basin Draft Plan, SDLs are presented as a range of scenarios for discussion. The current draft plan proposes no change to the 2016 groundwater usage goal of 32,300 ML/y (Table 2) (MDBA, 2010). However, the plan proposes a reduction from 20-27% in surface water diversions. These figures are currently being discussed in public forums.

Table 2: Proposed SDLs from the Murray-Darling Basin Draft Plan.

	Gwydir Surface Water (ML/y)	Lower Gwydir Alluvium Groundwater (ML/y)
Current Diversion Limit	451,000	32,300
SDL Proposal	From 361,000 to 330,000 GL/Y	32,300
Reduction	From 89,000 (20%) to 121,000 ML/y (27%)	Nil

3. Method and Results

One of the aims of this report is to infer aquifer characteristics based on 3D responses observed in bore hydrographs and the 3D lithological model. Work presented in this section describes the method used to interpret the bore hydrographs and construct the 3D lithological model.

3.1 Groundwater and Lithology Database

This report uses historic groundwater information from the PINNEENA groundwater works CD (2009 v3.1, <http://waterinfo.nsw.gov.au/pineena/gw.shtml>, 2/Aug/2010), published by the NSW Government. A subset of the information from the CD was extracted for all bores within the Gwydir Catchment boundary and collated in a Microsoft (MS) Access Database.

The Gwydir database includes:

- The location of types of bores (stock, domestic, irrigation etc.);
- Driller logs;
- Purpose and use for each bore; and
- The water bearing zones.

Since the 1960s various NSW state government departments have installed groundwater monitoring bores throughout the Gwydir Catchment. There are 48 monitoring sites with good groundwater hydrograph data sets. At each bore, between one and three pipes have been installed and set at different depths depending on the occurrence of high yielding water bearing sediments. Generally the first pipe monitors the shallow aquifer while the other pipes when present, are used to monitor intermediate and deep aquifers. The hydrographs for all monitoring sites in the Gwydir are presented in the Appendix.

Bores that had suspected errors (sudden jumps in water levels, zero reading) were removed from the 3D analysis of the hydrograph data. Groundwater hydrograph sets with minor errors (spikes in years not analysed) were used. It is expected that such an extensive database would have errors, given that the data have been collected over several decades, were manually measured, manually entered into the database, and transferred between various databases. Data are sufficient for examining the major spatial and temporal trends recorded in the groundwater monitoring standing water level (SWL). The SWL is measured from the top of the casing to the top of the water within the pipe. The terms groundwater head and groundwater level are used when the SWL is converted to a height above the Australian height datum, in metres above sea level (m.a.s.l.).

When a bore is drilled in NSW the driller logs are recorded and added to the NSW government records. The driller log descriptions are highly variable and of mixed quality. For the purpose of constructing a 3D lithological model the driller logs were placed into three classes: clay, sand and gravel.

3.2 Data Processing using *Crystallize Mathematica* Scripts

Mathematica (<http://www.wolfram.com/>, 2/Aug/2010) is a computational software program used in scientific, engineering and mathematical fields and other areas of technical computing. A collection of scripts and notebooks called *Crystallize* (Kelly et al., 2010) was used to interact with the MS Access Database, automatically plot the groundwater hydrographs, generate 3D bubble charts to map spatial and temporal trends in the hydrograph data, and to construct the 3D geological model. At each groundwater monitoring location there can be one or more holes. In each hole there can be one or more monitoring pipes, and in each pipe there can be one or more slotted intervals. On the hydrograph plots the highest and lowest levels reported were used to indicate the total length of the

aquifer for which the head was being measured. For some bores the slotted interval information was not on the Pinneena CD or the information was possibly entered incorrectly. For such cases the information was not added to the hydrograph plots. In the 3D bubble charts below the data were graphed at the midpoint of the upper and lower slotted intervals. Comprehensive details on the *Mathematica* scripts are given in Kelly et al. (2010).

3.3 Bore Hydrographs

Variability in the SWL was examined both spatially and temporally over two time periods. Connectivity throughout the aquifer systems and the impact of pumping were examined by looking at the extent of SWL fluctuation recorded in a year (Figure 18). The long term trends were examined by determining the relative difference in the recovered SWL between 1988 and 2008 (Figure 19). The relative difference is determined using the recovered SWL reading for the year, which is taken to be the SWL measurement recorded just prior to the start of the irrigation season. This is typically recorded in June or July.

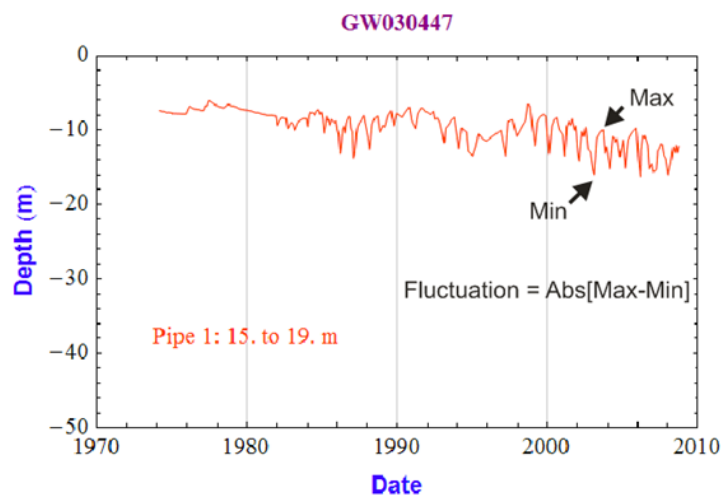


Figure 18: Method for determining the standing water level fluctuation for a year.

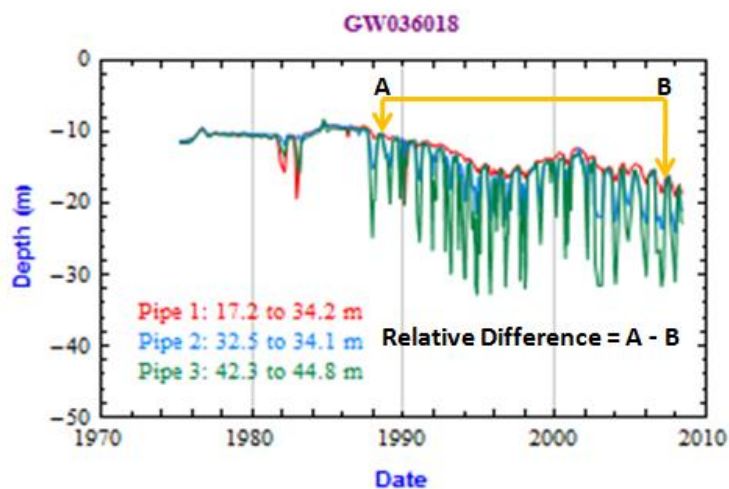


Figure 19: Method for determining the relative difference in the recovered standing water level recorded in the monitoring bore.

3.3.1 SHORT TERM HEAD FLUCTUATION ANALYSIS

Fluctuations in the SWL were analysed over a time span of one year in order to understand how the aquifer system responds to seasonal pumping stress. The year 2002 was selected for analysis because this was a year when most sites were measured, there were no floods, the yearly rainfall was low (261.6 mm of rainfall recorded at the Pallamallawa weather station, Figure 20) and groundwater usage was reasonably high (Figure 17). The maximum difference in the SWL within one year for each groundwater monitoring pipe was plotted in 3D at the midpoint of the slotted interval(s) (Figure 21).

As the aquifer is stressed due to groundwater extraction the groundwater head is reduced near the point of extraction. The longer a pump runs the larger the affected zone. Monitoring bores (pipes) near a groundwater bore pump detect this change in groundwater head, which is reflected as changes in the SWL recorded in the monitoring bores. The groundwater head surrounding a pump decreases laterally and vertically. If there is a layer that impedes the flow of water and pressure transfer between the pump at depth and the ground surface (for example a clay layer), then the groundwater head will only change at depth. However, if the system is hydraulically connected at all levels of the saturated sedimentary sequence, pumping will result in a groundwater head change at all depths as the pressure transfer will be distributed throughout all depths of the saturated sedimentary sequence.

Where there are nested sets of hydrographs, the impact of pumping is observable at all depths (Figures 21 and 22), although the fluctuation in the near surface measurement points is minimal compared to that at the depths near the pump. The near surface impacts are usually a dampened response to the pumping at depth, which can be rapid (GW030159 and GW036115, Figure 22) or it can be a slow leakage response (GW030457, GW030458, Figure 22).

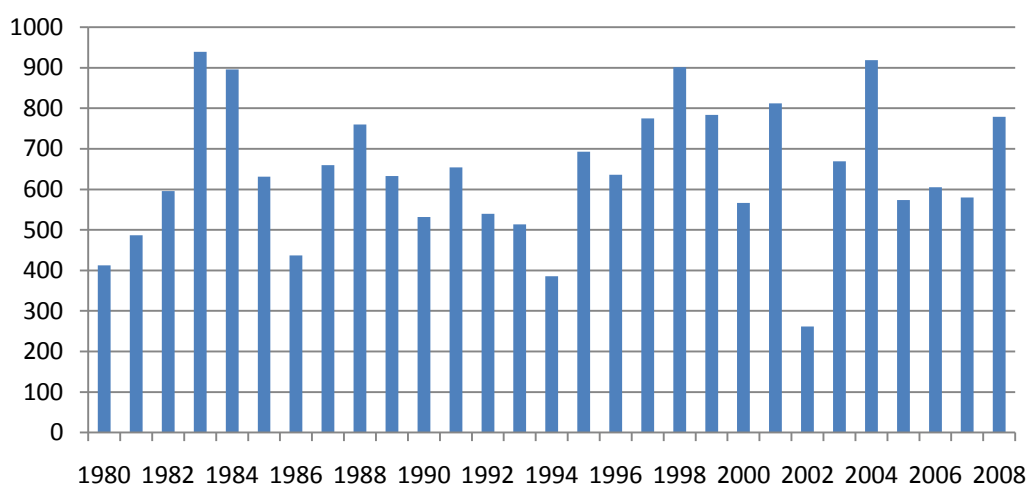


Figure 20: Annual rainfall at Pallamallawa 1980-2009.

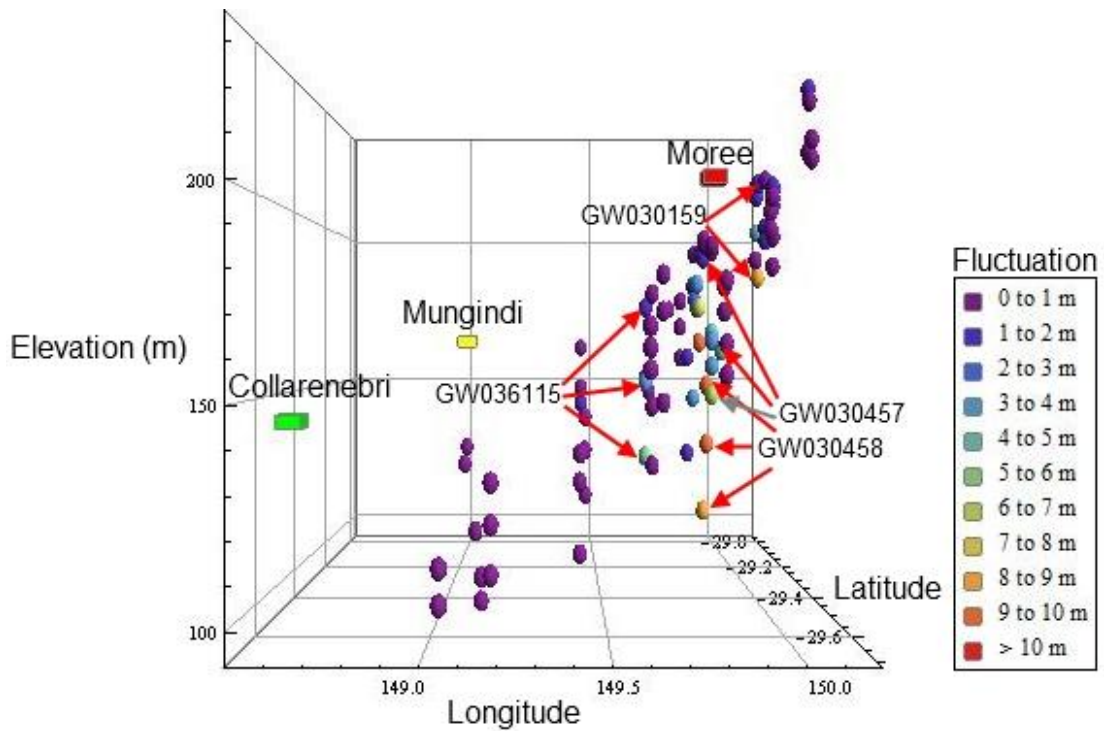


Figure 21: Gwydir groundwater level fluctuation 2002.

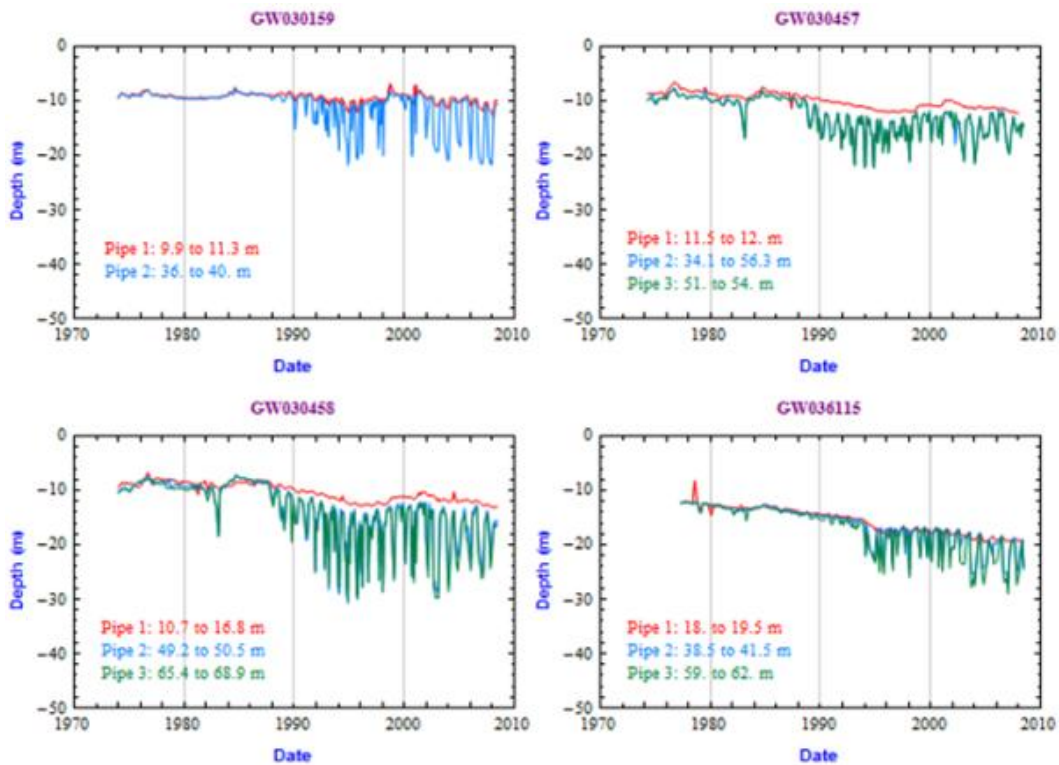


Figure 22: Nested monitoring locations displaying the impact of pumping at all levels of the aquifer. In all cases the shallow monitoring bore (red pipe) displays a dampened response to the seasonal drawdown observed in the monitoring bores closer to the groundwater pumps (blue and green pipes).

3.3.2 LONG-TERM TREND IN THE RECOVERED GROUNDWATER LEVEL

To analyse the long term impact of groundwater extraction the difference between the 1988 and 2008 recovered SWL were computed. This interval of time was selected to get a balance between the length of the record and coverage across the catchment. The recovered SWL is the level recorded throughout the year closest to the ground surface (excluding flood years) and usually occurs in June or July before the beginning of the pumping season, which runs from late August until February. Recovery of the groundwater level is important for the health and functioning of the aquifer. During the pumping season the groundwater level drops and if usage is in balance with recharge, the SWL recovers to the pre-development level over time. Sometimes this requires one or many flood recharge events. If the SWL falls over time this indicates that usage is in excess of recharge for that time period.

The relative difference in the SWL was determined for each location, tabulated in a histogram (Figure 23) and plotted in 3D at the midpoint of the slotted interval (Figures 24 and 25). The majority of the measurement points indicate a small decline of 0 to 3 m, and there has been a significant decline of 3 to 10 m at 25 measurement points. The spatial distribution of the locations where the SWL has declined by more than 3 m is indicated by the light blue through red spheres in the 3D bubble charts (Figures 24 and 25). The largest falls in the SWL are north of Moree (GW030460 pipes 1,2 & 3, declined 9.14 m, and GW03046 pipe 2 recorded a fall of 9.95 m).

Figure 27 shows 4 representative locations where the SWL has declined since 1988. The long term similarity in trends at all locations where there are nested monitoring bores indicates that there is no clearly defined aquitard in the Gwydir Catchment, and that the aquifer system is hydraulically connected throughout all depths.

At 19 measurement points there has been a rise in the SWL. It is not possible from the SWL measurement alone to determine if the rise in the SWL is due to a damaged pipe or due to changes in the surrounding water pressure. This can only be determined from a site inspection. Figure 26 shows four locations with monitoring intervals in the upper 30 m where the groundwater level is rising. This is possibly due to deep drainage beneath irrigated crops.

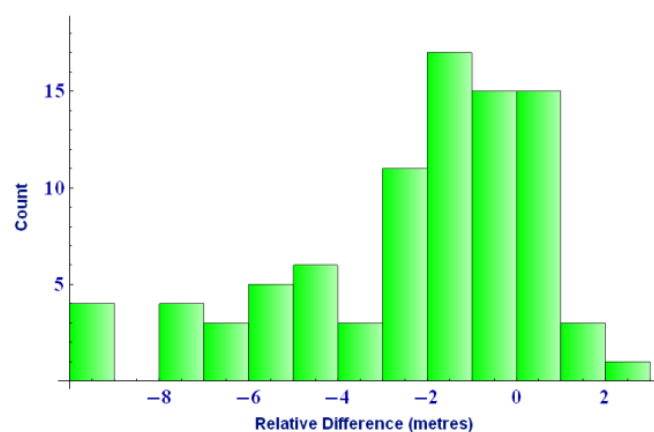


Figure 23: The relative difference in the standing water level between 1988 and 2008 for all monitoring bores in the Gwydir Catchment.

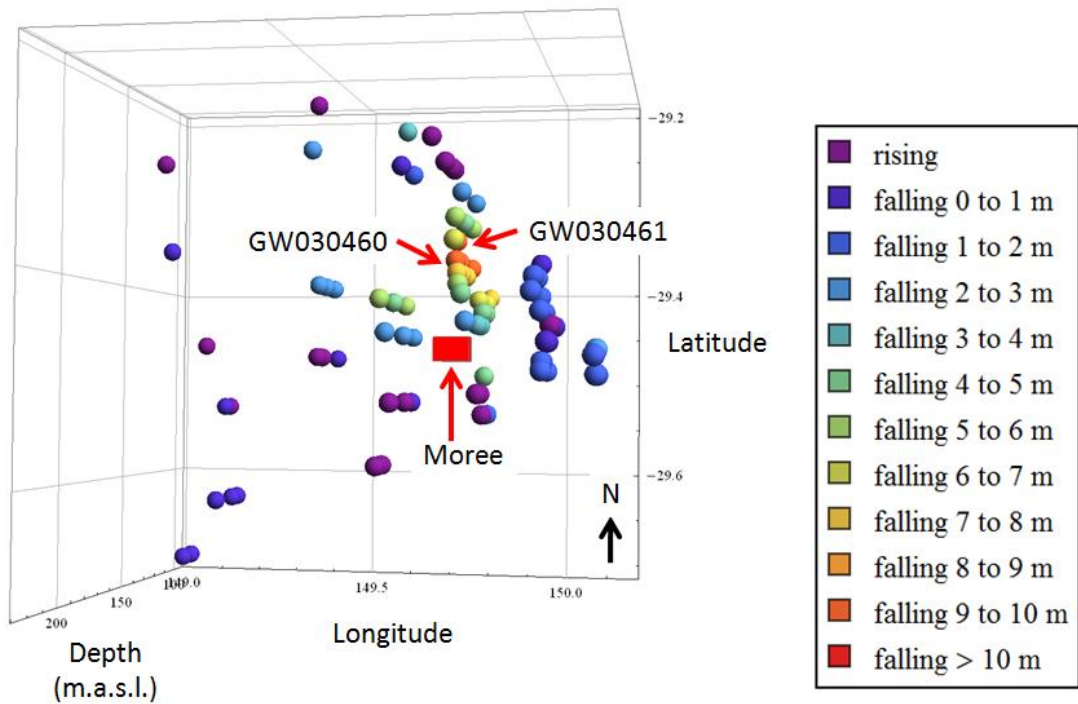


Figure 24: Gwydir Catchment long-term trend in the recovered standing water level recorded in the NSW groundwater monitoring bores between 1988 and 2008 (overhead view).

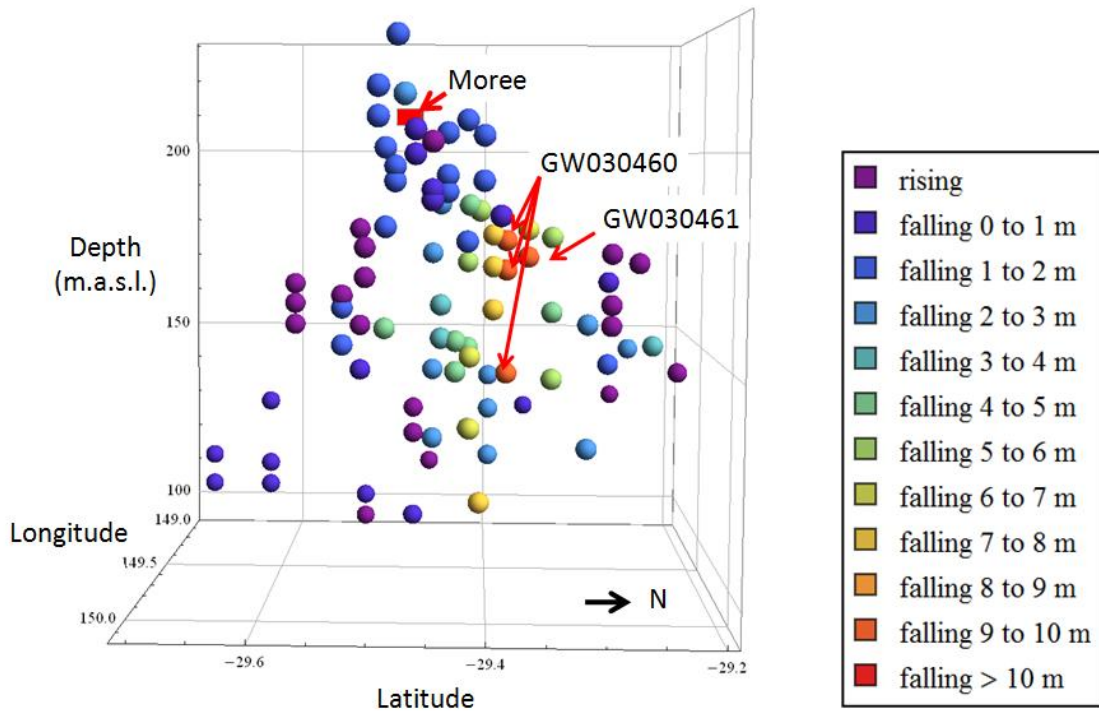


Figure 25: Gwydir Catchment long-term trend in the recovered standing water level recorded in the NSW groundwater monitoring bores between 1988 and 2008 (looking west).

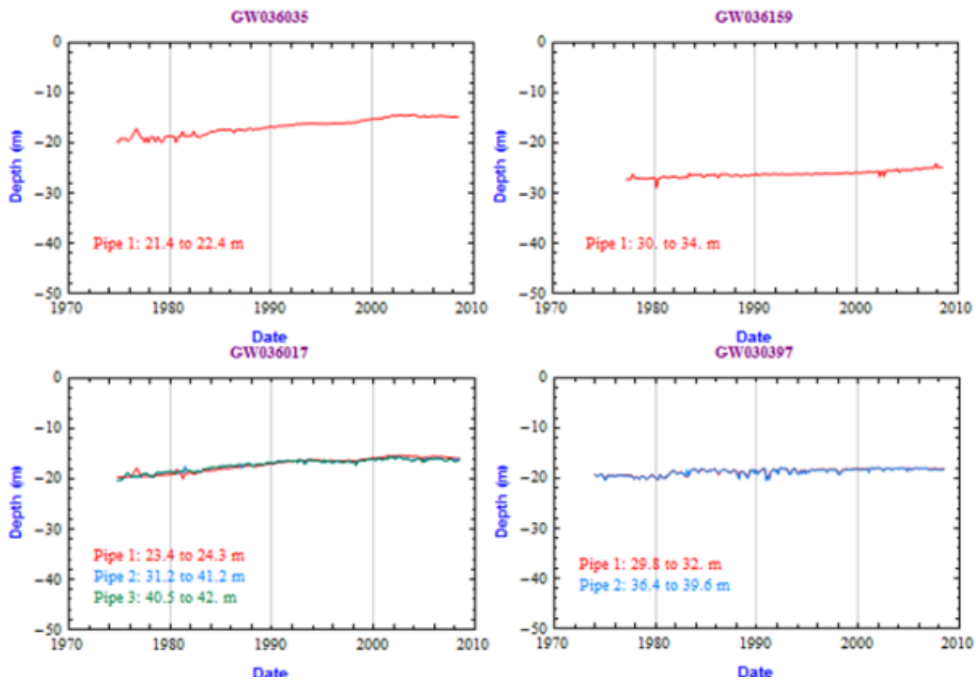


Figure 26: Rising SWLs in shallow aquifers. This is a potential indicator of irrigation deep drainage.

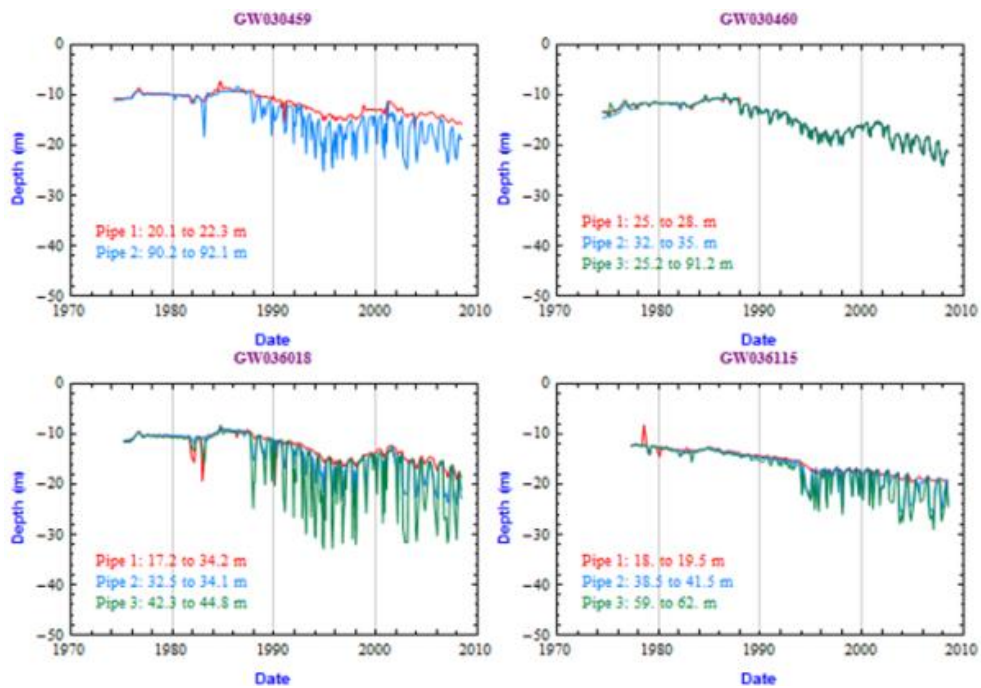


Figure 27: Four nested hydrograph sets that show a long term decline in the SWL.

3.3.3 FLOOD RECHARGE EVENTS

The most recent dramatic response in the groundwater hydrographs came from the 2001 flood. Details of the flood were recorded in local papers as follows:

“By 31st January Moree was all but cut in two by rising flood waters in what was described as the worst case of local flooding in living memory. Sandbagging and pumping operations continued following more than 260 mm of rain in the three days to 9 am on 1st February. The record for the highest rainfall in a 24 hour period in Moree – 95.6 mm was broken when the Met. Bureau recorded 112 mm”.

(EMA Disasters Database <http://www.ema.gov.au/ema/emadisasters.nsf>, Accessed 18/09/2010).

Figure 28 shows example hydrographs where there is a response to the 1998 and 2001 floods, observable as an upwards spike in the recorded SWL. It is interesting to note that there are other high rainfall years, such as 2008, where there is no observable recovery in the SWL. This suggests that groundwater recharge may only occur when there is sufficient wetting of the vadose zone and overburden pressure from the flood waters for there to be significant percolation of the water to depth.

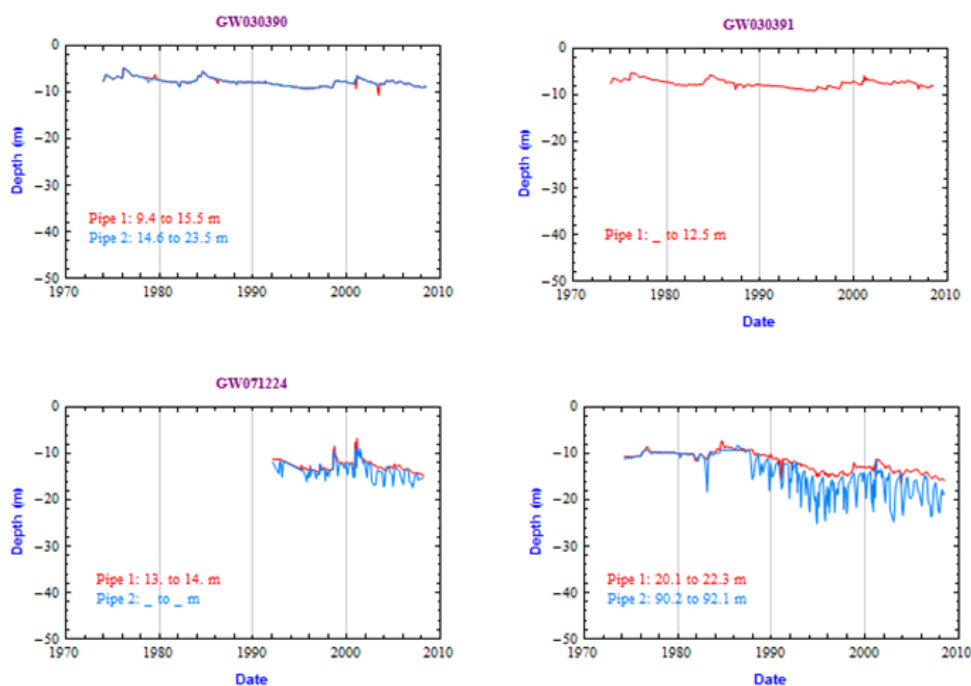


Figure 28: Example hydrographs that show flood response spikes to the 1998 and 2001 floods.

3.4 Three Dimensional Lithological Model of the Gwydir Catchment

A 3D lithological model was created to better understand the hydraulic connections in the Gwydir alluvium. In the past, two formations have been defined based on 2D cross sections: an upper unconfined aquifer, the Narrabri Formation, that is dominated by clay, with significant sand and gravel units, overlying a semi-confined sand and gravel rich aquifer, the Gunnedah Formation. Below a three dimensional lithofacies model is presented which allows a more detailed examination of the vertical and horizontal continuity of the sand and gravel units that are the major conduits through which the groundwater moves.

The model was constructed using the *Crystallize Mathematica* scripts developed by Kelly (2009), Kelly and Giambastiani (2009) and Kelly et al. (2010). The detailed steps used in constructing the 3D lithological model are given in Kelly (2009). In brief, the bedrock was taken as the first shale, sandstone or volcanic rock pick recorded in the driller logs. The unconsolidated sediments were classified into three classes: clay, sand and gravel. The driller logs were then interpolated using nearest neighbor gridding (Tartakovsky et al., 2007). The resulting 3D lithology model is shown in Figure 29. It is apparent from this plot that two distinct formations (the Narrabri and Gunnedah Formations) cannot be observed.

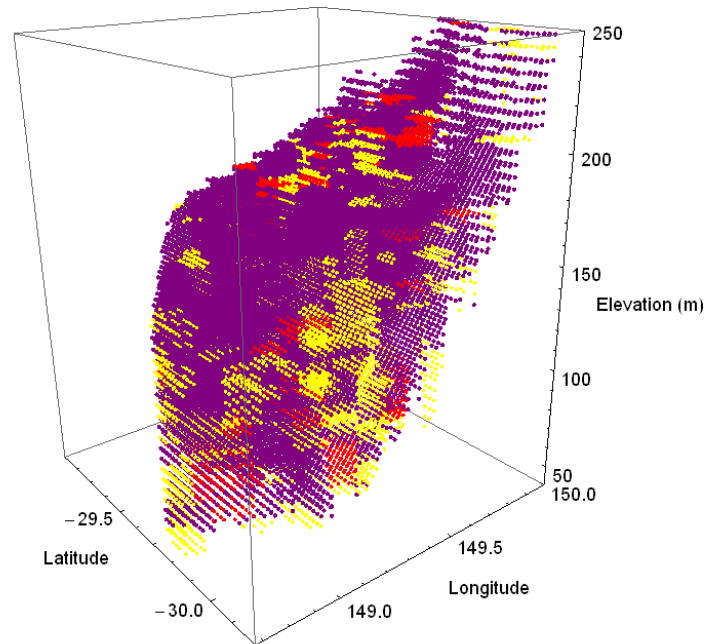


Figure 29: Gwydir 3D lithology model (clay purple; sand yellow; gravel red).

To further explore vertical connectivity within the alluvium, sand and gravel data were combined and extracted in 10 m thick slices from 80 to 170 m.a.s.l.. For each slice two views are presented: one side view looking east and one overhead view (Figure 30 parts a and b). In the images the sand/gravel units are displayed as orange points overlying the bedrock surface. The following observations are made for each slice:

170 to 160 m.a.s.l.: only two small patches of sand/gravel are present in the central northern and southern portions of the image. This indicates that clays are the dominant sediment at this depth.

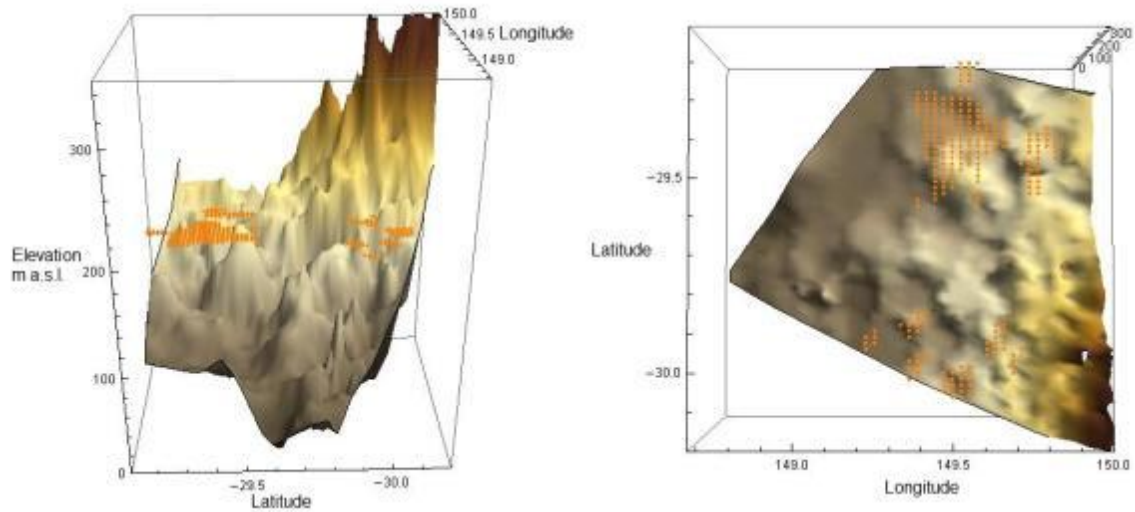
150 to 140 m.a.s.l.: there appears to be a possible connection from the 170-160 m sand/gravels to the central zone of the model. The sand/gravels of the north and south have broken up into smaller lenses.

130 to 120 m.a.s.l.: there is less horizontal connectivity between sand/gravels as the larger bodies are broken up into many smaller lenses.

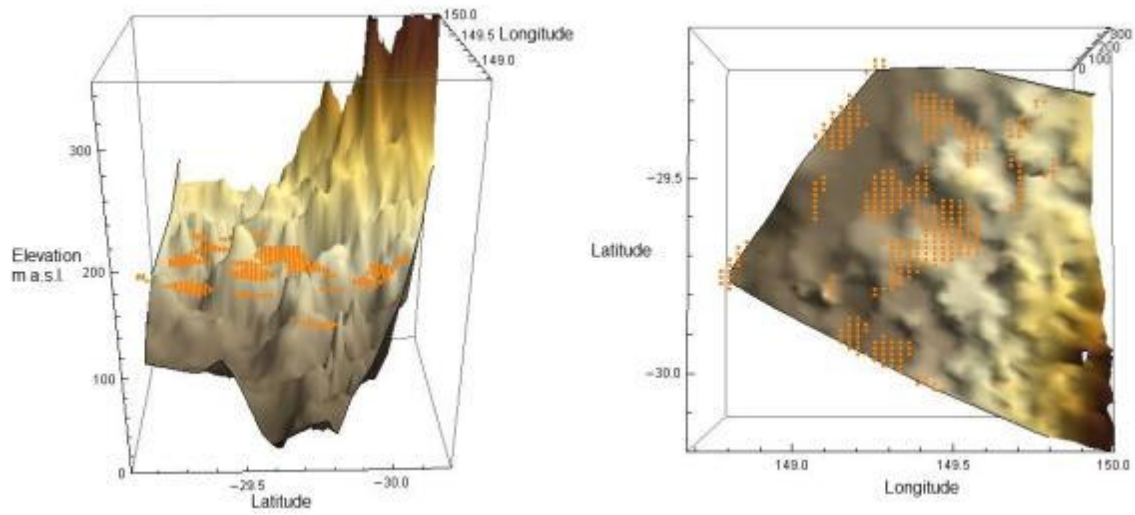
110 to 100 m.a.s.l.: there is a well connected north/south unit of sand throughout the central portion of the model. It is in this unit that many of the irrigation bores are located.

90-80 m.a.s.l.: the centrally located east-west ridge in the bedrock divides the sand units into two palaeochannels, which flowed in a westerly direction.

170-160 m.a.s.l.



150-140 m.a.s.l.



130-120 m.a.s.l.

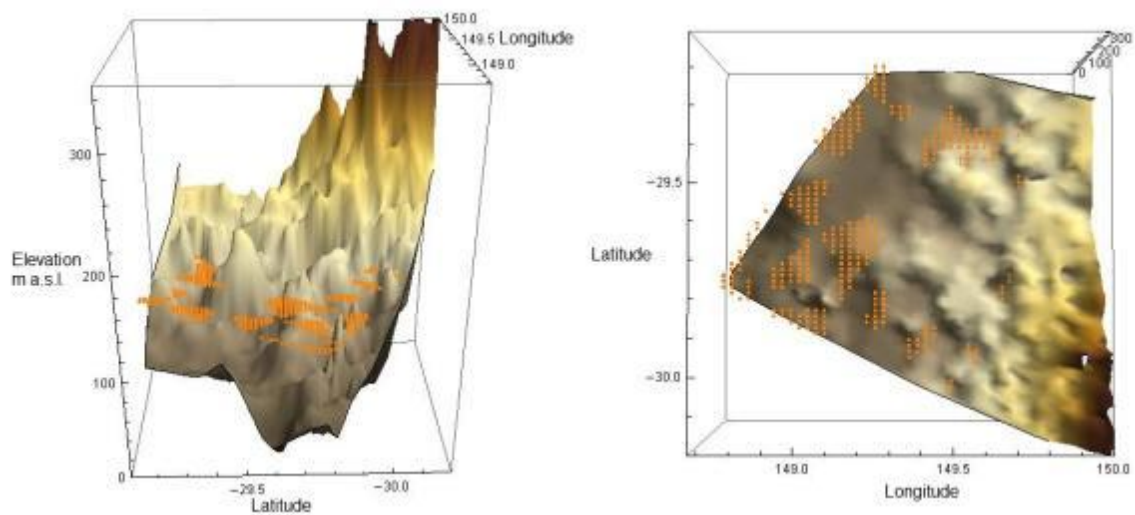
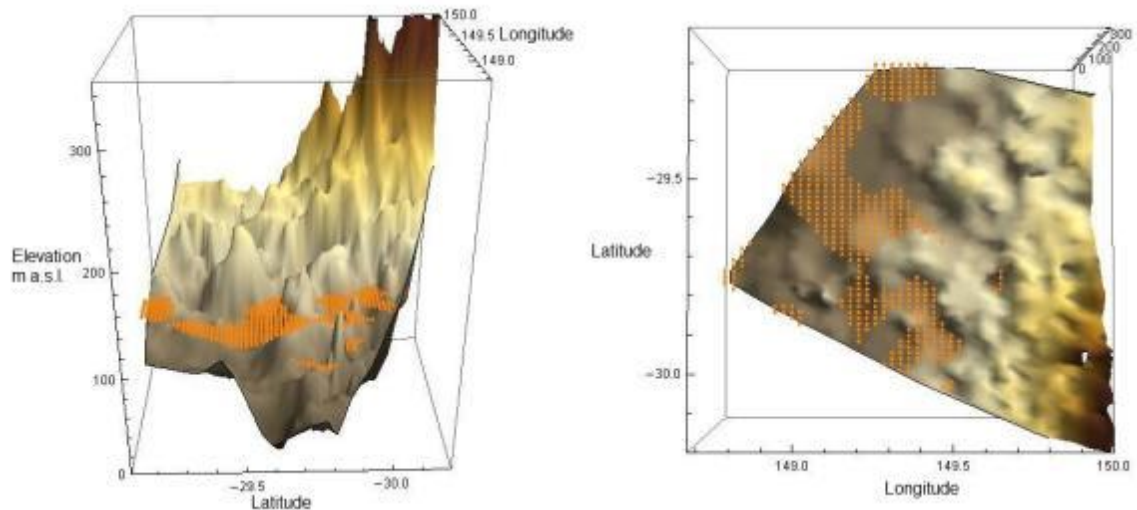


Figure 30, part a: Horizontals slices through the Gwydir 3D lithological model, showing the position of the sand and gravel units (orange dots) for 10 m slice intervals, overlying the bedrock surface.

110-100 m.a.s.l.



90-80 m.a.s.l.

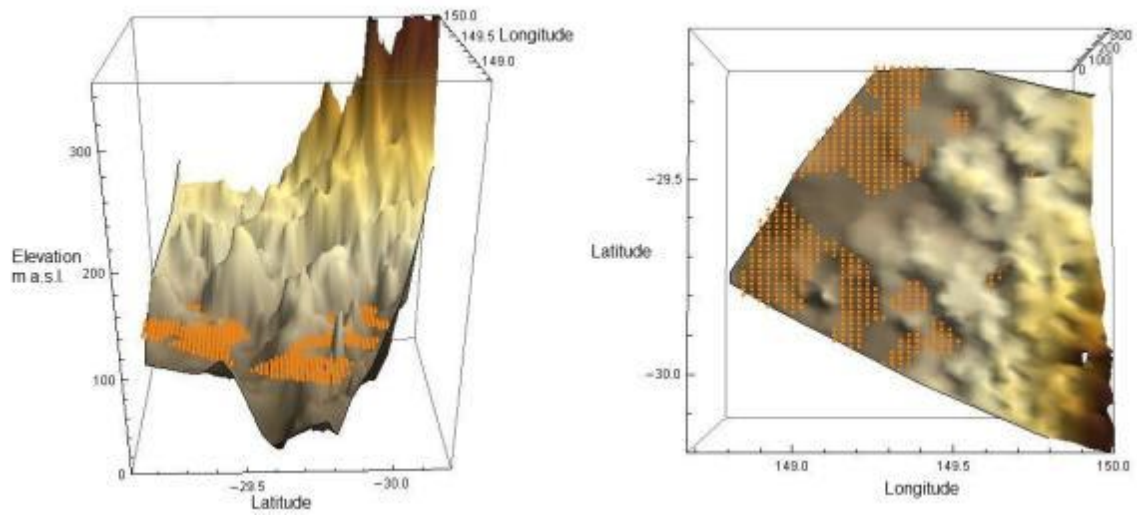


Figure 30, part b: Horizontals slices through the Gwydir 3D lithological model, showing the position of the sand and gravel units (orange dots) for 10 m slice intervals, overlying the bedrock surface.

5. Conclusions

From the groundwater hydrographs presented in this report the following conclusions can be made:

- Most bores in the Gwydir Catchment show a decline in the SWL since 1988. The largest decline in the SWL, almost 10 m, was recorded north of Moree at monitoring sites GW030460 and GW030461.
- Groundwater fluctuations due to pumping impacts are greatest in the Moree irrigation district with fluctuations in the SWL up to 15 m per year. This is observable at locations GW030159, GW030457, GW030458 and GW036115.
- The only pause to the continuing decline in groundwater level observed in most bores around Moree has been immediately after major floods. Representative bores that display partial recovery in the SWL are GW036112, GW036114, GW030457 and GW036018.
- At a regional scale there is a high degree of vertical connectivity between all depths of the aquifer system, particularly near Moree. However, at a local scale at some monitoring locations there are clay lenses that dampen the impact of pumping at depth in the shallow monitoring bores. Representative bores that display a dampened response to pumping at depth are GW030457, GW030462 and GW030458.
- Some shallow bores have rising SWL readings since the 1988. Representative monitoring bores include GW036035, GW036159, GW036017 and GW030397. This is possibly due to irrigation deep drainage, but could also be due to a damaged pipe.

A 3D lithological model was constructed to examine the spatial distribution of clays, sands and gravels that fill the Gwydir Catchment palaeovalley. The present stratigraphic interpretation of the valley-fill alluvial sediments needs revising. This study has shown that the catchment does not consist of two clearly observable formations. This is indicated at all locations where there are nested hydrographs, and driller lithological logs. The valley-fill sediments are dominated by sand and gravels at depth with increasing clay in the upper 30 m, but in general there are isolated and amalgamated palaeochannels at all depths that reflect the meandering pathways of the palaeorivers.

The Gwydir Catchment is included in the scope of the Murray-Darling Basin Plan, which when released may change the way surface and ground water are managed throughout the Murray-Darling Basin. The hydrographs and supporting interpretations presented in this report will hopefully inform the community discussion.

References

- Barrett, C. (2009) 'Lower Gwydir Groundwater Source: Groundwater Management Area 004 Groundwater Status Report 2008', NSW Department of Water and Energy, Sydney.
- CSIRO (2007) 'Water availability in the Gwydir. A Report to the Australian Government from the CSIRO Murray-Darling Basin sustainable Yields Project', CSIRO, Australia. 134pp.
- DECCW (2010) 'Draft Gwydir Wetlands Adaptive Environment Management Plan', Department of Environment, Climate Change and Water NSW.
- Falivene, O., Cabrera, L., Munoz, J.A., Arbues, P., Fernandez, O. & Saez, A. (2007), 'Statistical grid-based facies reconstruction and modelling for sedimentary bodies. Alluvial-palustrine and turbidic examples', *Geologica Acta*, vol 5, no. 3, pp. 199-230.
- Kalaitzis, P. (1999), 'Status Report for the Alluvial Groundwater Resources of the Lower Gwydir Valley NSW 1998/99. Groundwater Use and Water Level behaviour in the Lower Gwydir Valley NSW. Status Report Number 3.', NSW Department of Land and Water Conservation Department of Water Resources Sydney, NSW.
- Kelly, B.F.J. (2009) 'Catchment Scale 3D Geological Models from Sparse Data Sets', International Mathematica User Conference 2009.
- Kelly, B.F.J. & Giambastiani, B. (2009) 'Functional Programming for Constructing 3D Geological Models', The University of New South Wales. Connected Waters Initiative, Sydney, NSW, Australia.
- Kelly, B.F.J., Giambastiani, B., Andersen, M., McCallum, A., Greve, A. & Acworth, I. (2010), "'Development of a 3D Geological Mapping and Database Interface to Support Interconnected Groundwater and Surface Water Management", A report by the Connected Waters Initiative', UNSW and National Centre for Groundwater Research and Training for the Cotton Catchment Communities CRC and the National Water Commission, Raising the National Water Standards, Groundwater Project, Final Report, 310 pages.
- Keyte, P.A. (1994) 'Lower Gwydir Wetland plan of management – 1994 to 1997'.
- Mahaffey, K. (1985) 'The Watercourse Country. Moree and District Historical Society'.
- Martin, H.A. (1980), 'Stratigraphic palynology from shallow bores in the Namoi and Gwydir River Valleys, north-central New South Wales.', *Proceedings of the Royal Society of New South Wales*, pp. 113, 81-87.
- MDBA (2010), 'Summary of Gwydir Region From the Guide to the proposed Basin Plan', Murray Darling Basin Authority.
- Milne-Home, W., Merrick, N., Kelly, B., Dent, B. & Yates, D. (2007) 'Groundwater Knowledge and Gaps in the Border Rivers - Gwydir Catchment Management Area. Report 2.2.05 Nov 2007 UTS Border Rivers-Gwydir Report NCGM 2007/5', National Centre for Groundwater Management University of Technology.
- NSWG (2009) 'Historic data CD PINNEENA for groundwater works', New South Wales Government. Available from <http://waterinfo.nsw.gov.au/pinneena/gw.shtml> (Access verified 04/07/2010).
- Pietsch, T.J. (2006) 'Fluvial geomorphology and late quaternary geochronology of the Gwydir fan-plain, PhD report', School of Earth and Environmental Sciences, University of Wollongong, p. <http://ro.uow.edu.au/theses/492>.
- Tartakovsky, D.M., Wohlberg, B. & Guadagninni, A. (2007), 'Nearest-neighbor classification for facies delineation.', *Water Resources Research*, 43 DOI 10. 1029/2007/WR005968.
- Webber, K. & Stewart, M. (2004) 'A critical analysis of the cumulative rainfall departure concept. ', *Groundwater* , pp. 42(6/7), 935-938.

Appendix: Bore Hydrographs (1968-2008)

