Hydrogeological Conceptualisation of the Burdekin River Delta

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ABSTRACT

Major initiatives have been taken, and are proposed by Australian Government agencies to improve the efficiency of the water industry and to assist in achieving the ecologically sustainable use of the nation's water resources. The Queensland Department of Natural Resources (QDNR) is currently implementing a new system for allocating and managing water in Queensland. QDNR is developing a groundwater management model to study the behaviour of the groundwater system underlying the Burdekin River Delta area in north Queensland in order to evaluate water management strategies to ensure that irrigation in the Delta is sustainable. This model will be a predictive tool to study the effects of changes in land and water use on groundwater levels, and will include the spatial and temporal variation of hydrogeologic characteristics and hydrologic responses in the Delta aquifer system. Conceptualisation and characterisation of the aquifer system are fundamental steps in groundwater modelling and this has become an important process in simplifying the aquifer system so that field data can be easily transferred into the computer model.

The Burdekin River Delta aquifers comprise sedimentary deposits in excess of 100 metres thick overlying a predominantly granitic basement. The nature of sedimentation is very complex with sediments comprising a mixture of interbedded gravel, sand, silt, mud and clay. The sediments are rarely continuous laterally, with layers pinching out and grading with distance. Due to the complexity of sediment distribution, an understanding of the processes of delta formation is important in defining the distribution of the main aquifers and their properties.

Water use in the delta is predominantly for the irrigation of sugarcane as well as the supply of potable water to three towns. The dynamic behaviour of the groundwater system is a result of additions and abstractions of water from the aquifers. Water is sourced from a combination of groundwater extraction from these unconfined aquifers, direct pumping from the natural watercourses, and the distribution of open water through a network of distribution channels. Recharge to the unconfined system is complicated and involves recharge via diffuse infiltration from rainfall, irrigation return flow, natural watercourse leakage (vertical and lateral), artificial recharge facilities, and overbank flood flows. The artificial recharge scheme involves directly pumping water from the Burdekin River into a distribution network of natural and artificial channels that replenish the groundwater in areas of preferred recharge.

Water use efficiency measures and other management strategies will be developed using the model for a groundwater system which is the one of the largest of its type in Australia. This paper outlines the conceptual model development for the Burdekin Delta and the quantification of the hydrologic components operating on the delta, particularly the various recharge mechanisms. This incorporates an integrated approach of applying geologic principles and methodologies to the hydrogeologic framework in order to best represent the extent and nature of the unconfined aquifers and how their features control the nature and movement of groundwater within the delta.

INTRODUCTION

Numerical modelling of groundwater flow provides resource managers with tools to better understand the various hydrological processes in a groundwater system. Groundwater resource management in Queensland is implemented on a regional scale, so groundwater models are increasingly used to consider the full range of complex interacting hydrological processes operating on a groundwater system. One such model is currently being developed to study the behaviour of the groundwater system in the Lower Burdekin to evaluate water management strategies that ensure that irrigation in the Delta is sustainable. This model will be a predictive tool to study the effects of changes in land and water use on groundwater levels, and will include the spatial and temporal variations of hydrogeologic characteristics and hydrologic responses in the aquifer system.

Qualitative conceptualisation and quantitative characterisation are the fundamental steps of groundwater flow system modelling (Kolm *et al.*, 1996). This is an iterative process that starts with the development of a preliminary assessment of the groundwater system based on general hydrogeologic principles and is continuously refined during the numerical model development stage. The reliability of a numerical model for groundwater resource management depends upon how the processes controlling water movement into, through, and out of the groundwater system are characterised. Therefore, a quantitative analysis of the resource requires an integrated method of geologic interpretation, deterministic procedure, and effective discretisation (schematisation) before a mathematical function can be applied. The level of detail engaged in conceptualisation depends largely on the project objectives, quality of output required, and available data.

The purpose of this modelling study is to develop a calibrated transient groundwater management model that will assist how future land use practices impact upon groundwater levels in the Burdekin River Delta. As such, the groundwater management model is being developed by linking the groundwater flow model based on MODFLOW (MacDonald & Harbaugh, 1988), with a SPLASH model (Arunakumaren, 1997) that simulates soil-water processes and their effect on hydrology.

GEOGRAPHIC SETTING

The Burdekin River Delta in north Queensland has an area of about 850km^2 and comprises one of the largest unconfined groundwater systems of its type in Australia. It is located approximately 90 km southeast of Townsville and contains the townships of Ayr, Home Hill and Brandon (figure 1). Land use throughout the delta is dominated by sugarcane crops with other minor horticultural crops (citrus, tropical fruits and vegetables). The suitability of the deltaic soils for cultivation, the tropical climate, and groundwater availability have allowed the sugarcane industry to expand rapidly for over one hundred years. Two autonomous bodies – the North Burdekin Water Board (NBWB) and South Burdekin Water Board (SBWB), control the water resources within the delta area. Their main objectives are to implement and manage the provision of surface water to farms through the distribution network, manage artificial recharge facilities, and assist farmers with other water-related issues. Since the completion of the Burdekin Falls Dam in 1987, there has been a notable increase in the number of farms relying on open water from distribution channels. Therefore, the role of the Water Boards has progressively evolved from management of a groundwater-dominated resource, to a more conjunctive use operation. Due to the expansion of farming land and recent concerns regarding the quality and supply of groundwater to the farms, an initiative has been taken by the Water Boards and QDNR to develop a groundwater management model that will simulate the behaviour of groundwater movement through the delta's aquifers (Arunakumaren *et al.*, 2000). This model will allow for an evaluation of water management strategies to ensure that irrigation use in the Delta is sustainable. To augment this investigation, a research initiative (Bristow *et al.*, 2000) has also been established between various research organizations to provide a holistic assessment of the delta's crop, land, and water use requirements.

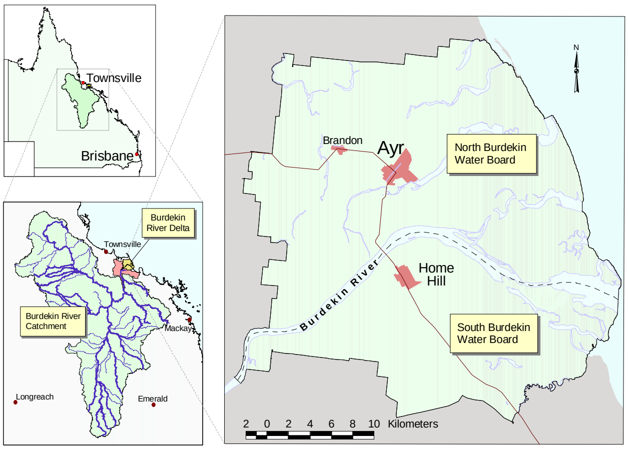

Figure 1. The geographic setting of the Burdekin River Delta

SURFACE CHARACTERISATION

Characterising the surface features of the delta provides information that controls the input of water to the groundwater system through natural and artificial processes. This includes the topography, surface water distribution and extent, history of land and water use, type of anthropogenic activity, vegetation analysis, climate analysis, soil type, and geomorphology. Each of these components affects the mechanisms of recharge and consumptive water use practices.

The topography of the delta is gently undulating to flat with the natural slope dipping towards the coast. Coastal floodplains, mud flats, levee banks, and coastal sand dunes dominate the delta plain, with occasional bedrock outcrops around the south and southwest. A digital elevation model (DEM) of the delta was constructed using existing 1:25000 topographic mapping data to produce a final coverage as the top of aquifer. In an unconfined aquifer, the topographic surface is important for defining drainage cells where the water table comes close to or intersects the surface (particularly near the discharge areas). Surface water in the delta comprises the main river channel, a few distributaries and a network of artificial diversion channels and recharge facilities (channels and pits). The channel network was implemented to divert water from the Burdekin River to a range of farms to complement their groundwater supply, and to help reduce the risk of seawater intrusion and dropping water tables.

Since sugarcane farming is the dominant industry within the Burdekin River Delta, a large component of assessing the water budget for the region involves understanding the main irrigation practices used and how the efficiency of the watering schedule contributes to the overall recharge of surface water to the system. The watering of sugarcane within the delta is almost wholly applied by flood (furrow) irrigation, where water is fed by gravity through long drills adjacent to the plant. To assist in effectively wetting an entire block, the topsoil layer is usually laser-levelled and any tailwater at the base of the paddock is either drained away or recycled. An assessment of improved farming practices has led to an understanding of improved water use efficiency, which can improve the accuracy of the model simulation.

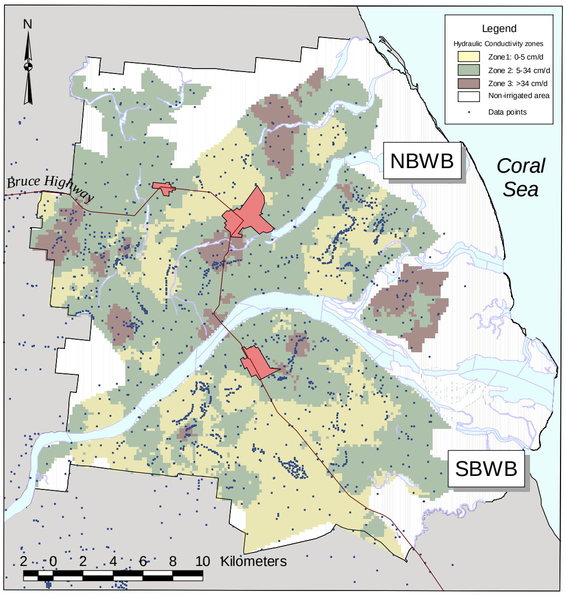

Figure 2: Three reclassified soil hydraulic conductivity (K_{sat}) zones for the Burdekin River Delta. Data is based from sediment textural classifications.

To assist with the assessment of recharge properties throughout the delta, an approach was developed to provide a preliminary concept of the lateral distribution of hydraulic conductivity of the delta soils. Any available textural classifications from existing strata logs were tabulated and compiled, and hydraulic conductivity (K_{sat}) values assigned to different class intervals. The top one metre of sediment was analysed and an effective K_{sat} value applied as a first approximation of soil hydraulic conductivity. These were then plotted, contoured, and reclassified into three zones that were used as input data for the model. Figure 2 illustrates the estimated distribution of soil hydraulic conductivity for irrigated soils throughout the delta.

GEOLOGIC CHARACTERISATION

The sediments of the delta have been deposited by the Burdekin River and its distributaries to depths in excess of 100 metres near the coastline. Commonly, these sediments comprise a combination of clean permeable channel sands and low permeability clay layers and lenses that grade into and interfinger with each other. Sedimentation has occurred from both terrestrial and marine deposition. The extent of this deposition has been controlled by the relative position of the coastal boundary over geological time. Alluvial sands and floodplain silts dominate terrestrial deposition, which accumulate as the main channel systems reduce in flow energy. Marine deposition is dominated by mangrove / tidal muds and estuarine clays. Over time, these sediments continued to aggrade with respect to the changes in sea level (base level of erosion).

The relationship between the terrestrial and marine sediments is complex, and an interpretation of their significance to the hydrogeology of the delta can only be inferred from the available borehole data. Figure 3 shows two schematic cross-sections developed from strata-log information across the delta. Evidence from these sections reveals a distinct lack in lateral continuity of any one layer. All clays and sands are typically discontinuous over short distances, making correlations of sedimentary units and interpretations of aquifer extents difficult to define. It is apparent that the channels that deposit clean sandy units are also responsible for some degree of down-cutting during their developmental stages. This localised eroding action can breach underlying clay layers, effectively reducing their ability to impede vertical groundwater flow.

The nature of sedimentation within the delta is similar to that observed in the Burdekin River Irrigation Area (BRIA) to the immediate west. However, the Burdekin delta has been formed more recently than the coastal plain of the BRIA (Hopley, 1970), so a much smaller extent of semi-confining surficial clays exist over the main aquifers. In many parts of the delta, overlying clays are completely absent exposing the main aquifers to direct infiltration from the surface.

Stratigraphically, there are two identifiable horizons that can be linked to known geological events. These two horizons can be described as the glacial Pleistocene event and the interglacial Holocene event (Chappell, 1987). The glacial Pleistocene event represents a stage when relative sea level was at a low and the soils of the delta were exposed to become oxidised and semi-consolidated. In the borehole stratalogs, this is represented by a change from grey and brown soft loose clays and sands to much tighter red-brown to grey clays and sands. The interglacial Holocene event is slightly more distinguishable in the delta sediments by the presence of dark-coloured mangrove muds that are sometimes underlain by blue estuarine clays. This horizon represents a stage when sea level was at a relative high and the shoreline was dominated by mangrove habitats. As sea level dropped, the coastline extended seawards with the position of the mangroves shifting accordingly. This resulted in the formation of a seaward layer of thick dark organic muds with minor shell fragments. As older muds became exposed by the regressing sea, they were sometimes eroded by surface channels down-cutting through them. This is evident in some bores where sandy channel sands exist close to and at similar depths to thick mangrove mud sequences.

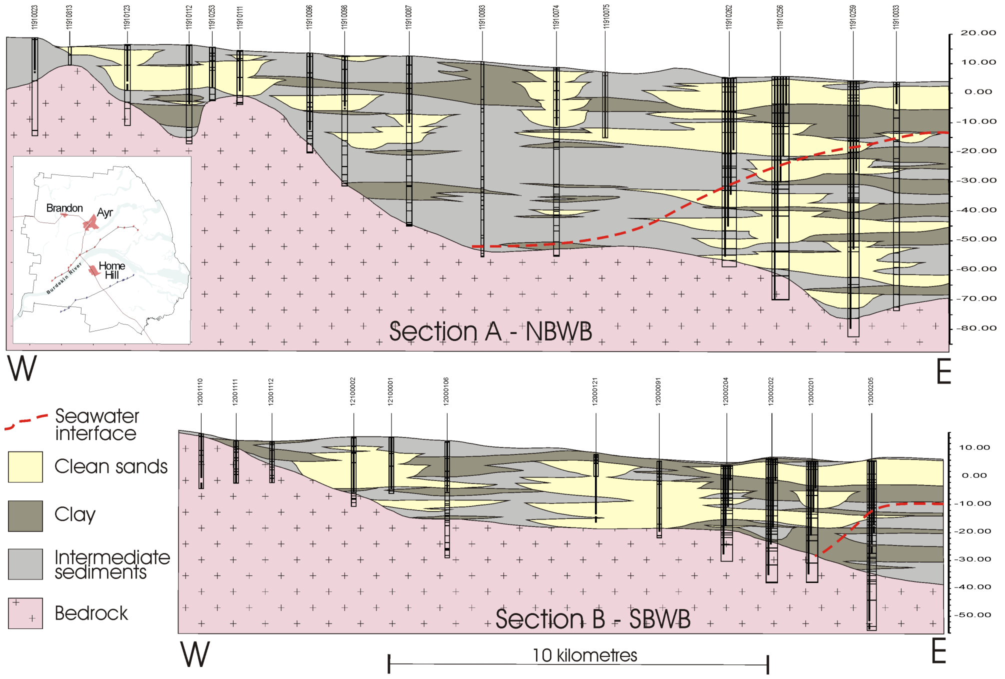

Figure 3: Schematic geological cross-sections of the Burdekin River Delta for the North and South Burdekin Water Boards, showing distribution of sediments and approximate position of the seawater interface (5000µS/cm boundary).

HYDROGEOLOGIC CHARACTERISATION

From assessment of the cross-sections shown in figure 3, it is evident that there is limited lateral continuity of any single sedimentary layer across the extent of the delta. On smaller-scales, it is possible to examine log correlations and interpret sedimentary layers, however the lateral discontinuity of these layers makes the definition of distinguishable aquifer units unfeasible. Small clay lenses are most prevalent in the near-shore areas where marine mud incursions are interfingered with land-derived sandy units. These sand layers often contain some terrestrial clays and silts deposited from processes such as flooding. Therefore, the high complexity of sedimentation and the inconsistent distribution of extensive layers do not allow for the total delta-wide groundwater system to be simulated with multiple aquifers. McMahon & Cox (1998) have used a hydrochemical approach to help distinguish aquifer layers at a local scale, however this application cannot be applied to a regional system due to the complexity of sedimentation patterns. A single-layer approach to modelling the Burdekin delta aquifers allows all minor variations to be incorporated into a single hydrostratigraphic unit.

The groundwater system within the Burdekin River Delta aquifers is generally considered to be unconfined, due to the presence of sandy to loamy soils and the discontinuous extent of underlying clay layers. On a broad scale, these clay layers cannot be incorporated into the model, as there is strong hydraulic continuity between channel sands on a regional scale. Recharge to the aquifer occurs via a range of mechanisms; including rainfall infiltration, channel seepage, percolation through artificial recharge facilities, overbank flood flows, and irrigation return flows.

A series of nested boreholes have been installed at various localities throughout the delta, which are used to monitor and analyse variations in water levels and chemistry at various depths throughout the delta profile. Hydrographs of these bores show that variations in water levels at shallow depths resemble deep bore trends very closely. The fluctuations in these trends can also be correlated with variations in rainfall, indicating that recharge to the water table through the unsaturated zone is rapid, and that there is a significant degree of hydraulic connection between bores screened at various depths. Therefore, different aquifers cannot be distinguished based on their hydrographical response.

GROUNDWATER SYSTEM CHARACTERISATION

The determination of the temporal variation and spatial distribution of groundwater recharge and discharge is fundamentally important in the characterisation of a groundwater system. From the measured groundwater levels, monthly time variant water table contours were derived for the period 1981 to 1997 to develop a reliable assessment of the Delta's temporal groundwater storage behaviour.

There are no metered use records available for groundwater pumping in the Delta, so historical groundwater pumping rates were estimated using SPLASH - a one-dimensional model in which all calculations are performed on a unit area basis with depth below ground surface being the single dimension. A SPLASH model simulation was performed on a daily time-step using rainfall, pan evaporation, crop coefficient and rooting depth for different stages of crop growth together with rules for transfer of moisture amongst the various moisture stores. The Delta area was divided into three irrigation use zones, based on the root-zone soil characteristics shown in figure 2. The average irrigation use in those three zones were assigned 15, 20 and 30 ML/ha respectively as a first assumption. From this data, the simulated annual historical pumping between 1981 and 1997 varied between 440,000 and 830,000 ML/year; and the simulated annual groundwater recharge from rainfall, irrigation return flow and floods in the same period varied between 330,000 and 650,000 ML/year. A time-variant water balance analysis (recharge – discharge = change of storage) was carried out in order to obtain an order-of-magnitude estimation of the unquantifiable hydrologic stresses operating in the groundwater system.

In SPLASH, the effect of crop growth is represented by a crop coefficient that reduces potential evapotranspiration below the maximum determined by the climatic conditions. Crop coefficients for sugar cane development were obtained from BSES at Brandon on a weekly basis over a one-year period. Historical annual sugar cane yield in the Delta area was obtained from the Water Boards for the period from 1981 to 1997, and the SPLASH evapotranspiration parameters were adjusted such that SPLASH simulated annual evapotranspiration matched the crop water required for the historical yield. An understanding on the Burdekin Delta irrigation scheduling was obtained from a preliminary Land and Water Use Survey and the SPLASH irrigation efficiency parameters for the three irrigation zones were calibrated. A sensitivity analysis of irrigation on cane showed that irrigation application rates above 18ML/ha contribute marginally to the cane yield.

Table 1: Summary of water balance calculations for the Burdekin River Delta

Hydrologic Components	**Range of Estimated Values (1981 - 1995) – ML/yr**
Recharge from Rainfall and Floods	25,000 to 250,000
River Recharge	6,000 to 67,500
Artificial Recharge	~100,000
Irrigation Accessions to Groundwater	330,000 to 650,000
Total Aquifer Recharge	**~430,000 to 850,000**
Irrigation Use	480,000 to 980,000
Open Water Pumping	33,000 to 171,000
Groundwater Pumping	440,000 to 830,000
Burdekin River Leakage	0 to 16,250
Groundwater Discharge to Sea	1,500 to 9,000
Lateral Flow to BRIA	100 to 3,200
Total Aquifer Discharge	**440,000 to 845,000**
Groundwater Storage above MSL	154,000 to 670,000

From available artificial groundwater replenishment records from the water boards, it was estimated that average annual artificial groundwater recharge was around 100,000 ML/year. The Burdekin River leakage, lateral boundary flows at the western boundary (BRIA) and fresh water discharge to sea are the other hydrologic components operating in the Delta groundwater system. Table 1 shows the estimated values of hydrologic components for the period from 1981 to 1995.

A forward model run was carried out to check the model performance and to ensure that the conceptual model data had been transferred correctly into the numerical model. The delta groundwater storage behaviour simulated with the model (Figure 4) shows that the simulated storage before 1990 was above the observed storage, but below the observed storage after 1991. This may be due to inaccuracies in the estimated input hydrologic inputs (recharge & groundwater extraction) to the model. Initiatives have been taken to verify the accuracy of the model inputs, to fine-tune the simulation results.

MANAGEMENT SCENARIOS

After the successful model development, the impact of possible management scenarios will be investigated. The model will be run for a 50-year period (2000 –2050) with 1981 initial conditions. 1998 land use conditions and climatic conditions from 1930 to 1980 will be used to simulate the future irrigation use and groundwater recharge for a baseline case simulation. A range of hypothetical scenarios will be tested with the calibrated model, and the groundwater levels will be compared with the baseline case. All scenarios will involve a reduction and variation of groundwater pumping and artificial recharge, representing a continuation of present land use practices for the 50-year period from 2000 – 2050.

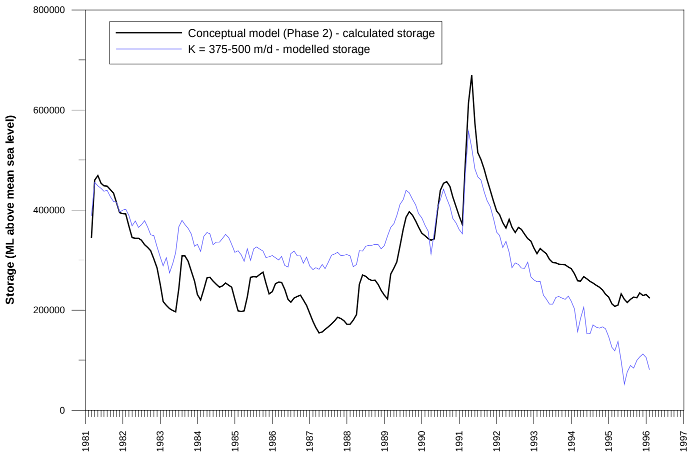

Figure 4: Comparison of calculated (observed) versus modelled groundwater storage (above MSL).

CONCLUSION

The hydrogeological conceptualisation of the Burdekin River Delta has been developed by identifying the main features affecting groundwater flow, and assessing the range of hydrologic stresses in the context of scientifically acceptable principles and methods. The interpretation phase is constrained by the available data, however by developing a range of assumptions and hypotheses and combining this with a calculated water budget, an initial estimate of the groundwater system can be quantitatively characterised. A forward model simulation of storage in the delta correlates remarkably well with calculated storage volumes, providing confidence in the characterisation of the resource. Some uncertainties have arisen due to the absence of reliable data, and these are being resolved as part of a new research initiative involving a number of organizations.

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