Influence Of Different Evidence-Based Models On Hydrogeological Parameters: An Example From The Burdekin Delta, Queensland

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EXTENDED ABSTRACT

The properties of hydrogeological units depend on their formative processes and history. A good understanding of how hydrogeological units are formed is essential to accurately characterise their geometry and properties. Accurate characterization is necessary for the robust models needed for applications such as groundwater extraction, waste water disposal, management of salt water intrusion, and salinity control. Such characterization is possible only through multidisciplinary approaches using geological, geophysical, and hydrological data. Inaccurate characterization and understanding of these parameters will lead to flawed conceptual models. Numerical models based on flawed conceptual understanding will fail to adequately describe the response of the hydrogeological units and therefore seriously impinge on the integrity of management decisions that might be based on them.

The lower Burdekin region of north Queensland is an area of intensive, high value agriculture and accurate characterisation of the subsurface is an essential part of effective water management. The lower Burdekin has been interpreted in many different ways, including as a wave, wave and tide, tide, or river-dominated delta. This paper summarises recent preliminary studies by the authors under the auspices of the Cooperative Research Centre for Landscape, Environments, and Mineral Exploration into the geophysical and sedimentological characterization of the lower Burdekin. Our studies have led to us to conclude that the system is actually a fan-delta.

This new interpretation has arisen out of consideration of the whole system, rather than component parts. Data used in the study include down whole electrical logs (resistivity and natural gamma) of 73 bore holes, detailed geological analysis of materials in two recent bore holes, review of the existing geological data on holes logged geophysically, and geomorphic analysis of a high resolution DEM of the lower Burdekin.

Evidence in favour of a fan-delta interpretation of the lower Burdekin include:

- The seaward sloping nature of the depositional surface typical of fan-deltas rather than the sea level progradation found in deltas.

- The bipartite nature of the land surface with headward entrenchment of the Burdekin River in the upper part of the system resulting in the formation of a residual upper plain and an active distributary depositional system on the lower plain.

- The predominance of terrestrial sediments within the succession typical of fans and the absence of marine incursions more characteristic of deltas.

- The fan-like predominance of poorly sorted gravelly sands in both channel and over bank environments in contrast to the well differentiated channel sand and inter channel mud sediments found in typical deltas.

- The combination of the previously noted textural immaturity with compositional immaturity with sediments being predominantly arkosic representing a fan-like the very proximal depositional pattern.

Reinterpreting the coastal sediments of the Burdekin region as the result of a fan system rather than delta deposition has major implications for how hydrogeological responses have to be modeled. Deltas and fan deltas have very different sedimentary architectures with significant implications for hydrogeological properties and their prediction. In particular fan-deltas have less well differentiated facies, are coarser grained and drastically different trends in hydrogeologic properties to deltas. Aquifers are typically unconfined to semi-confined, in contrast to the confined aquifers common in more conventional delta settings.

1. INTRODUCTION

Mathematical modeling of groundwater flow is an essential part of predicting hydrogeological response to both natural and artificial water gains and losses to and from aquifers. Accurate models are therefore vital to efficient, sustainable groundwater management. Essential to accurate modeling are accurate constraints on the aquifer parameters such as porosity and permeability, water chemistry, and the aquifer architecture.

2. THE IMPORTANCE OF PARAMETERISATION

The physical and chemical properties of hydogeological units depend on their formative processes and history. These control such parameters as grain size, porosity, permeability, and reactivity with groundwater. A good understanding of how hydrogeological units are formed is essential to achieve the accurate characterization of their geometry and properties necessary to the produce the robust models needed for a range of applications such as groundwater extraction, waste water disposal, management of salt water intrusion, and salinity control. Such characterization is possible only through multidisciplinary approaches using geological, geochemical, geophysical, and hydrological data. Inaccurate characterization and understanding of these parameters will lead to flawed conceptual models. Numerical models based on flawed conceptual understanding will fail to adequately describe the response of the hydrogeological units and therefore seriously impinge on integrity of management decisions that might be based on them. Such an approach has been used by the Cooperative Research Centre for Landscape, Environment, and Mineral Exploration (CRC LEME) in a range of environmental geoscience applications associated with salinity and groundwater management at different locations around Australia.

3. CONTRASTING ARCHITECTURE OF FANS & DELTAS

The terms “delta” and “fan deltas” (Nemec 1990, Nemec and Steele 1988) are applied to classes of distributary depositional complexes formed where rivers discharge into a body of water. They have very different internal architectures and considerable variation within each class. These differences have significant implications for a range of hydrogeological properties within each depositional complex.

3.1. Hydrogeologic units

In deltas these are typically well differentiated, with channels sands contrasting strongly with over bank silts and muds in the inter-channel areas. In fans the units tend to be much less differentiated with poorly sorted muddy sands and gravels predominating.

3.2. Longitudinal variability

This is comparatively low in deltas. As the deltas prograde basinward at or close to base level, they deposit longitudinally continuous bodies of distributary channel sands and inter-distributary silts. These units vary little longitudinally with respect to hydrogeological properties. Fans slope towards their terminus along their entire lengths, this is accompanied by major decreases in grain size and associated changes in sorting. Hydrogeological parameters can thus vary by as much as 15 orders of magnitude (Neton *et al.* 1992) along the length of the fan with resulting strong directional anisotropy.

3.3. Lateral variability

Deltas show well developed and abrupt systematic lateral changes across boundaries between distributary and interdistributary facies. Because sorting within these units is high, variability within them is comparatively low. Lateral variations in fans is very different. Channel and inter-channel units are poorly differentiated and much more internally variable, reading to hydraulic properties changing by 12 orders of magnitude over short distances (Neton *et al.* 1992).

3.4. Vertical variability

Deltas typically show high and well-developed vertical variability with a classic progradational sequence from prodelta muds to delta slope silts to delta top sands and silts. The delta sands are encased within finer grained facies. In fans there variation between units may be as great or greater, but because of the heterogeneity of fans there will be less systematic relationship. Depending on the tectonic and base-level setting, fans may show an overall upward fining or upward coarsening trend.

3.5. Aquifer properties

Deltas contain a combination of unconfined surface aquifers with confined aquifers at depth in buried channels sands. Because fans have such strong local variation in hydraulic properties but less systematic variation, except longitudinally, aquifers in fans are more likely to be unconfined overall, with local confining layers leading to smaller scale semi-confinement.

4. THE BURDEKIN DELTA

The Burdekin Delta of northern Queensland (Figure 1) provides a good example where high quality characterization and validation of aquifer properties and architecture is essential for accurate modeling and good management. The area is a major Australian irrigation area with more than 35,000 ha of irrigated sugarcane and other crops. Natural flows along the river have been extensively modified by dams and there has been extensive groundwater extraction, resulting in s high risk of intrusion of marine waters. The system overlies major groundwater supplies, is close to environmentally sensitive wetlands, waterways, and estuaries, and discharges into the lagoon of the Great Barrier Reef (LBI 2004). Water management practices have evolved over the last few decades in response to local needs, including riverbed sand dams, extraction of river water to distribution channels, and artificial replenishment of the groundwater systems.

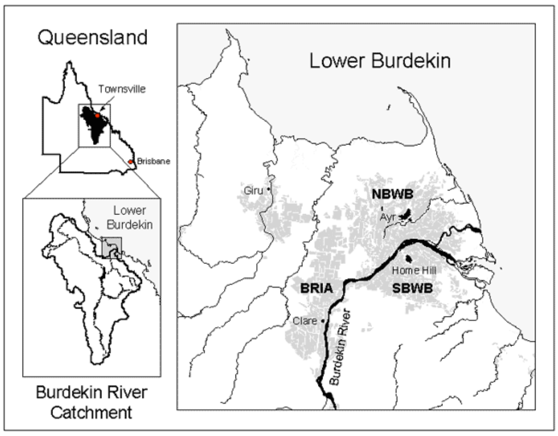

Figure 1. Location of the Burdekin region.

Because of the importance of hydrogeology in water management in the Burdekin Delta, there has been a long history of subsurface investigations since the 1960's when such data began to be kept (Narayan *et al.* 2003, Bistrow *et al.* 2000, McMahon *et al.* 2000). These models all assume a basic deltaic sedimentary architecture. The Burdekin has been variously classed a wave (Galloway 1975), wave and tide (Coleman and Wright 1975), tide (Ryan *et al.* 2003), or river-dominated (Fielding *et al* in press) delta. However, research by the authors at LEME has led to us concluding that the system is actually a fan-delta (Clarke 2004), with a significantly different internal architecture.

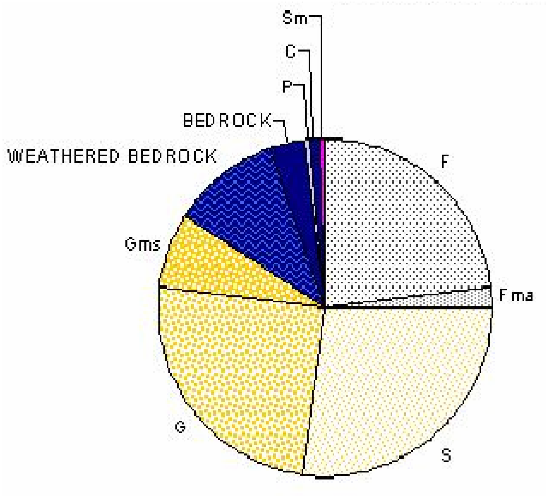

Figure 2. Proportions of different lithologies in 73 bores in the Burdekin Delta. F = undifferentiated fine-grained sediments, Fma = fine-grained marine sediments, G = well sorted gravel, Gms = poorly sorted and muddy gravels, S = sand. Facies classification after Miall (1985).

5. METHODS AND RESULTS

The sediments of the Burdekin delta, based on the analysis of lithologies intersected in 73 drill holes, are predominantly sand and gravel, with lesser amounts of fine-grained lithologies (Figure 2). Down hole natural gamma and conductivity logs were also acquired. These were sampled at a much higher resolution (10 cm) compared to the geological logging (1 m). The gamma logs provided detailed information on stacking sequences within the succession, while the conductivity log revealed correlated well with high clay zones, areas of salt water encroachment, and bedrock weathering.

6. DISCUSSION

A conceptual understanding of the lower Burdekin as a deltaic system will result in representation of the succession as consisting of stringer-like permeable sand and gravel bodies surrounded by impermeable fine-grained sediments (Figure 3). Although the "fine grained" sediments in this figure are predominantly muddy sands and gravels, this interpretation emphasizes the delta-like characteristics, with the implication that aquifers will be often vertically confined, laterally discontinuous and longitudinally continuous.

In contrast, conceptually modeling the Burdekin as a fan system (Figure 4) shows the delta as consisting of numerous lenses of gravelly sand with variable mud content. Locally the bodies are broken up by discontinuous fine-grained units. This interpretation, which is more constant with the gravel-rich nature of the sediments and the geomorphology, implies that the aquifers will be predominantly unconfined to semi-confined and both laterally and longitudinally continuous, although there will also be a strong decrease in grainsize downstream. The scale of these differences needs to be tested.

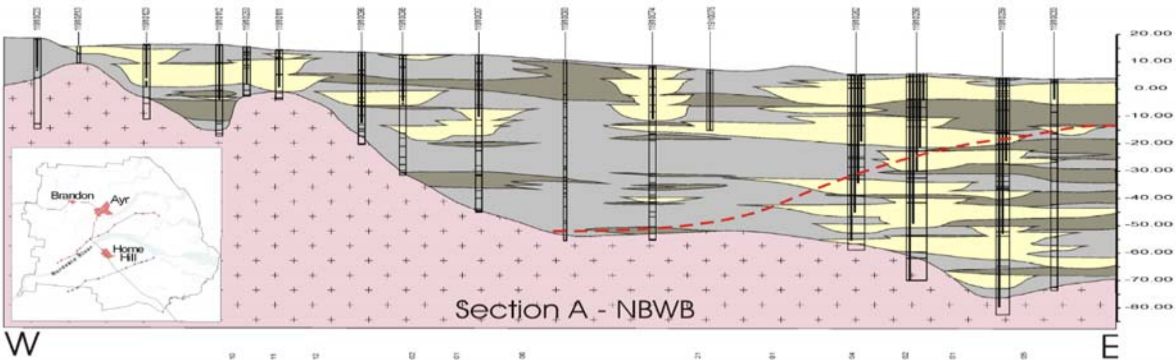

Figure 3. Typical cross section through the Burdekin region showing correlation of lithological units as expected in a classic deltaic system (after McMahon *et al.* 2000). Yellow = sands, light-grey = poorly sorted units, dark grey = muds, pink = bedrock.

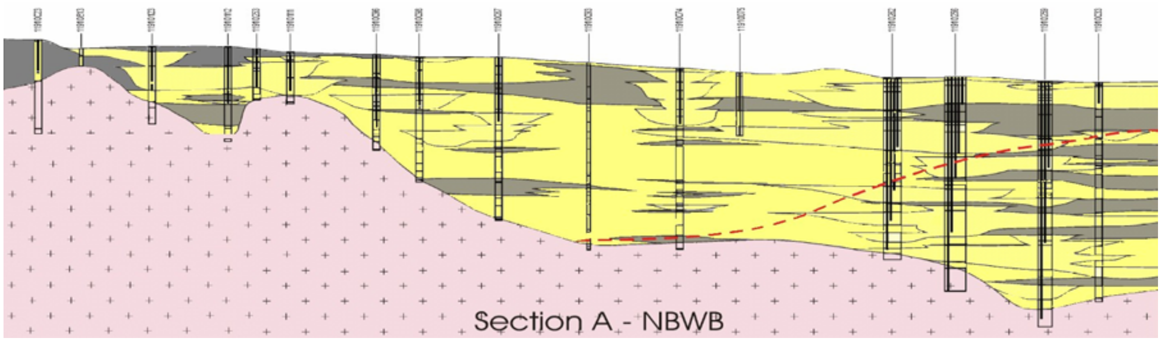

Figure 4. Reinterpretation as a fan delta of the same cross section as Figure 3, showing resulting high levels of connectivity between coarse-grained units. Yellow = sands and gravels, dark grey = muds, pink = bedrock

An additional problem for accurate modeling in the Burdekin is that of scale. For accurate predictive models of specific units their sub-surface distribution must be mapped with considerable accuracy. However, even the trunk stream of the Burkekin fan-delta is generally no more than 500 m wide. This is too small to be accurately mapped using existing drill holes in the area as the holes are typically several km apart. It is possible that major channels may be mapped using a range of electrical geophysical methods, provided that there is a significant difference in electrical properties between channel and non-channel facies. Our studies indicate that such contrasts exist, supporting the validity of early studies that mapped possible subsurface digitate distributaries controlling zones of salt water intrusion (Figure 5).

Another possible approach may be to use Markov chain analysis of both the vertical succession from drill holes and the horizontal distribution from surface maps to produce a descriptive model of the different units (Weissman and Fogg 1999,) Weissmann *et al.* 1999),. While unable to predict where a particular hydrogeological unit occurs, this approach may make it possible to produce a realistic overall descriptive model of the aquifer properties.

7. CONCLUSIONS

This new interpretation has arisen out of consideration of the whole system, rather than its component parts. Reinterpreting the coastal sediments of the lower Burdekin as a fan rather than a delta deposit has major implications for how hydrogeological responses have to be modeled for management of irrigation, artificial recharge, and salt water intrusion. These implications are beginning to be explored by CRC LEME and its partners.

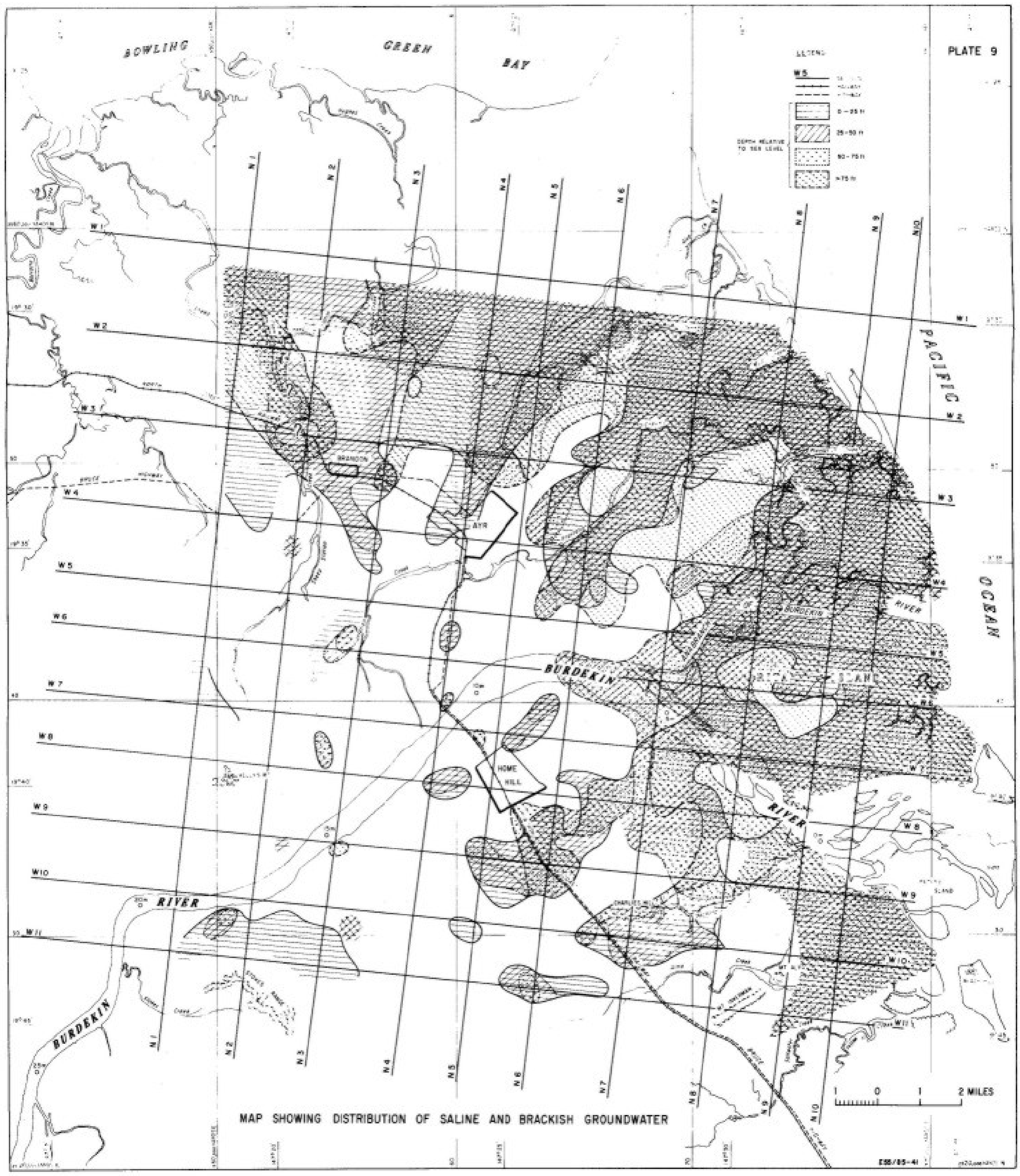

Figure 5. Radial distributary pattern in conductivity shown by intrusion of brackish water at different depths (after Wiebenga *et al.* 1975, plate 9).

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