Review of Conceptual Basis for the Botany Aquifer Model

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August 28, 2006

1 Introduction

The Community Liason Committee (CLC) have requested an independent review of the conceptual basis of the Botany Groundwater Model - with particular emphasis on the boundary conditions. The task description is given:

> Prof Ian Acworth is to review the assumptions in the groundwater model and provide a paper commenting on how groundwater extraction for the cleanup project will impact on the Botany aquifer. Prof Acworth is also asked to provide comment on the adequacy of monitoring locations between the Secondary Containment Area (SCA) and Penrhyn Estuary.

The report produced by Alan Laase of A.D Laase Hydrologic Consulting was presented in November 2005 and titled "Refinement of the hydraulic model for the Orica extraction system, Botany NSW". This model is built upon earlier models designed by Associate Professor Noel Merrick.

The Botany Aquifer is essentially comprised of layers of wind blown sand that have accumulated over a weathered and eroded Tertiary surface formed from the Hawkesbury Sandstone. There is some evidence of alluvial infill in the base of valleys cut into this surface. The aquifer has a high hydraulic conductivity of approximately 20 m/day and represents a large source of water. The aquifer is essentially unconfined (open to the atmosphere) over large parts. Where the water table extends to the ground surface, wetlands are formed. These wetlands form important aquatic refuges in the aquifer and extended from the Bay to Centennial Park in the early 1880's. The middle section has been replaced by urban storm water drains between Alison Road and Gardeners Road. The storm water drain opens out into the top of the Botany Wetlands (Lachlan Lakes) in the suburb of Eastlakes. These wetlands now form part of the northern and western edges to the groundwater model.

Flow in a high hydraulic conductivity unconfined system such as the Botany Aquifer, is dominated by conditions at the boundary of the model. Inaccuracy in specifying the hydraulic head (depth to groundwater) or the volume of water flowing across the boundary, can have significant implications for the accuracy of the model predictions. For example, if the model conceptualization is that the Lakes provide a constant head of water and a constant source of water, then error in model predictions will occur if the Lakes begin to dry up under drought conditions. Inaccurate specification of boundary conditions leads to an inability to accurately predict the impact on the aquifer of the new abstraction by Orica associated with the groundwater clean up.

The internal part of the model is based upon all the available knowledge of the aquifer and represents the most detailed discretization of the lithology yet attempted. The Hawkesbury Sandstone basement is assumed to have very low hydraulic conductivity and to form the impermeable base to the aquifer. Built upon this basement layer are 5 separately defined layers. The extensive data base assembled by Orica as part of the ongoing clean up means that the discretization of the aquifer into 5 layers is well based in the area of the plant. Detailed data is not available to the same extent away from the plant and major assumptions are required to extend the 5-layer model to the boundaries.

In view of the importance of the specified boundary conditions to the model, it is unfortunate that little if any monitoring is undertaken to assess the accuracy of these conditions. This represents the greatest concern to the community.

In this report, a review of each boundary condition will be given and suggestions made for improved monitoring where necessary. The part of Alan Laase's report that this refers to is Section 4.2.1 on page 4-2. Before attention is turned to the detailed comment, some more general comments are in order.

1.1 General Comments concerning Parameter Distributions

It is not my intention to question the conditions associated with the internal boundaries used to represent the Springvale and Floodvale Drains. These areas are extensively monitored by the groundwater abstraction pumping, and any inaccuracy will be accounted for by modification of the pumping regimes at the various bores. However, the surface recharge estimates require some comment. The values given for each of the zones are exceptionally specific. 291 mm/y for residential zones overlying aeolian sediments, yet 1,054 mm/y is associated with cells in the parklands (Fig 5.2.2.1). Has there been any consideration of the sensitivity of these zones? What are the error bounds? It would seem that the figure for residential areas is very low, given the propensity for much roof runoff to be directed to soak aways in this region. It is noted that there are very significant differences between the design model (Merrick) and the calibrated model (Laase), yet no reason is provided, for example, as to why Merrick's estimate of Parkland recharge of 407 mm/y is replaced by Laase's value of 1,054 mm/y. Both figures are very specific, yet very different! Which, if either, is correct and what are the implications of choosing one or the other. Similar comments could be made concerning the other recharge estimates.

Sophistocated parameter estimation techniques have been used to estimate the hydraulic conductivity throughout the 5 layers of the model. Figures 5.2.1.1, 5.2.1.3, 5.2.1.5, and 5.2.1.7 provide the final aerial distributions. The result of this approach has been to delineate many areas of very high (>40 m/day) hydraulic conductivity. What is more, these zones are strongly influenced by the location of the pilot points used. Is this reasonable? The vertical distribution of these layers with depth is not provided in the report so it is difficult to comment further. It is noted that any error in these estimates within the contaminated zone will be accounted for by modification to the abstraction regime. Errors away from the abstraction zones will not be picked up without further monitoring.

An approximate overlay of the model area to a google image is provided in Fig. 1.

1.2 Flux Estimates

The design model (Merrick) and the revised model (Laase) were both constructed using best available information. An unfortunate error in the assigned boundary conditions to the east caused a significant over-estimation in model throughput in the design model. However, it is worth comparing the differences in the predicted fluxes between these two models and realising that both represent different conceptualisations of the groundwater system that have been arrived at after extensive work. Both are accurate model solutions arrived at using the latest optimisation techniques. The variability in fluxes is the result of significant uncertainty concerning the boundary conditions. The comparison between the two model conceptualisations is shown in Table 1. Note that the unit of mega litre per day is chosen as this is a useful comparison for the Botany aquifer. A mega litre per day (ML/d) is the equivalent to 11.57 L/s, or the typical yield of a large abstraction bore in the aquifer. The SCA are proposing to develop groundwater resources from the fractured Hawkesbury Sandstone aquifer of 50 ML/d to supplement Sydney water supply.

The lack of closure of the water balance in each model is the result of small fluexs (eg. evapotranspiration loss) not accounted for in the major groupings shown in Table 1.

Figure 1: Google Earth image showing approximate model boundaries

Table 1: Comparison of design and updated model-predicted fluxes (Table 5.4-2 from Laase).

Groundwater Inflows	Design Model ML/d	Revised Model ML/d	Change Δ
Northeast Inflow Zone	8.625	2.580	6.045
Southeast Inflow Zone	9.810	0.034	9.776
Northern Constant Head Zone	0.567	1.313	-746
Aeolian/Residential Zone - recharge	3.676	5.085	-1.409
Lacustrian/Industrial Zone - recharge	2.188	1.073	1.115
Aaeolian/Residential Parkland Zone - recharge	3.789	6.278	-2.489
Lacustrian Parkland Zone - recharge	None	0.528	-0.528
Inflow from the Lachlan Lakes	2.085	1.078	1.007
Outflow to Botany Bay	8.114	3.640	4.474
Production Bores	15.000	8.474	6.526
Springvale Drain Outflow	3.888	1.735	2.153
Floodvale Drain	2.533	1.714	0.819
Balance of Inflows less Outflows	1.205	2.406	

Note: Table 5.4-2 in Laase shows the design model abstraction as 8.474. This can not be correct as the plant has been designed for 15 ML/d. For this reason, a value of 15 ML/d is shown in this Table.

1.3 External Model Boundaries

The boundaries can be grouped together as:

- Sandstone Hills to the east
- Northern throughflow zone between Daceyville (Astrolabe Park) and Kingsford
- Lachlan Lakes
- Foreshore Road

The sandstone hills to the east respresent the least concern. Flow into the aquifer from these areas is not considered significant as most drainage occurs eastward to the coast or into the stormwater channel adjacent to Walsh Road and draining through Heffron Park along Bunnerong Road to Port Botany. It is noted that the final calibrated model assigns an input of 2.58 ML/d from the northern part of this area (Kingsford an Maroubra) and only 0.034 ML/d from the southern part (Hillsdale and Matraville). The inaccuracy in the Southeast inflow zone (9.8 ML/d to 0.034 ML/d) was the major reason for the plant over design. However, it is important to realise that there are a number of other major differences - as shown in Table 1.

1.4 Northern Throughflow Zone

This zone has been modelled as a constant head boundary with 15 m assigned to the top of the Lachlan Lakes system and then increasing linearly to 19 m to the eastern edge of the model. This is an important boundary as it determines the throughflow from the upper part of the aquifer. Observations by the author have shown that the average head in Pond 5 adjacent to Astrolabe Park is 14.2 m. Heads to the east are less during dry periods and water moves eastward from the Lakes into the aquifer. The calibrated model results indicate that 1.3 Ml/d cross this boundary. As there are at least 2 bores operated by UNSW capable of each pumping 1 Ml/d, at this boundary, this figure seems rather low.

The UNSW Water Research Laboratory has recently installed a nest of piezometers in the bedrock and overlying sands at David Phillips Field (Latitude -33.931855 Longitude 151.222782). These would provide valuable monitoring locations to control head variation in the sandstone, and in model layers 1 and 4? along this boundary. There is almost a complete lack of monitoring, and therefore water-level elevation targets in modelling, in this part of the aquifer. It is not clear why the Rowland Park piezometer installed a few years ago by the State Government was not used. It this piezometer is available, it should be monitored. If it has been lost, then a replacement nest should be installed. The installation of monitoring nests at the western side of Astrolabe Park and adjacent to the western side of Pond 5 are also recommended. Without this monitoring, the accuracy of the northern flux is impossible to verify. As this is the flux that eventually passes through the abstraction site, it is important to assess it correctly.

1.5 Lachlan Lakes

The Lakes provide a major boundary to the aquifer along the western side of the model. Flow from the Lakes to the groundwater system was downgraded from 2.08 Ml/d to 1.08 Ml/d by Laase. Laase has considered that the Lakes are a groundwater divide. The implication of this is that no water can flow beneath the Lakes from the area to the north. The lakes themselves are represented by a series of fixed heads that step down to the Bay. The design of this part of the model appears to be based on the SMEC work carried out in the early 90's. I have not been able to trace a copy of this report.

The assumption that the Lakes are a groundwater divide requires verification by monitoring. In drought conditions, when there is no longer tangible flow down through the Lakes system, it seems eminently possible that the cone of depression caused by pumping from the Orica bores may extend north beneath the

Lakes. In my opinion, this represents an equally valid conceptual model that requires testing. The Lakes are a groundwater dependent ecosystem and their health during drought conditions will be determined by surface water and groundwater exchanges in this part of the aquifer.

Monitoring bores are required along at least two transects across the Lakes to determine which conceptual model is correct. These bores should be completed as nested piezometers so that the various hydraulic head changes with depth on both sides of the Lakes can be determined. Suitable transect locations would be the intersection of Wentworth Avenue and Southern Cross Drive and between Dransfield Avenue and the Sydney - Botany Goods Railway.

Efforts should be made to monitor Lake discharge and relate this to hydraulic heads in the transects.

1.6 Foreshore Road

Conditions along Foreshore Road are complex and require close monitoring. The pumping scheme has been designed to halt any movement of contaminants from the Botany Aquifer to Botany Bay. The situation there is going to be significantly complicated by the proposed works for the Botany Port Expansion. The CLC have requested separate advice on the question of likely movement of salt water from the Bay to the Botany Aquifer as the result of groundwater abstraction along Foreshore Road. It is sufficient to state here that I do not believe that it is reasonable to attempt to control water levels in this zone when there is no available monitoring between the beach and Foreshore Road. There is a common misconception in the modelling work that the boundary condition between groundwater and ocean water at a sloping beach is 0 m AHD. This is not the case - based upon other investigations in this zone. A more appropriate level may be closer to the average high tide mark. This error may be partially compensated for by the fact that no account of the density difference between sea water and discharging groundwater has been made in the modelling so far.

The inaccuracy in the conceptual model used along Foreshore Road will be compounded by the hydrochemical implications of mixing of sea water and discharging groundwater. This will cause precipitation of iron compounds that will likely cause problems with the operation of pumps in this zone.

It remains highly unfortunate that the extraction bores along Foreshore Road were not placed to the north of the road rather than in the central reservation. If they had been placed to the north, then monitoring bores could have been drilled in the central reservation. We are now left with difficult access to the south of Foreshore Road, but these difficulties must be overcome if the important conditions between the Foreshore Road abstraction line and the coast are to be properly understood.

2 CONCLUSIONS

The groundwater modelling work undertaken to date represents sound and sophistocated analyses based upon the stated conceptual model of this part of the Botany Aquifer. However, too often, the basis of the conceptual model is uncertain due to a lack of information concerning conditions around the boundaries of the model. This is unfortunate and relatively easy to resolve. A program of investigation drilling is required to establish model boundary conditions. It is only when this is completed that the considerable variability in model prediction identified in Table 1 can be overcome and the model used to predict the impact on the groundwater resource (as requested in the CLC Task) of pumping from the contaminated site at Orica.