Appendix 15-E. Nathan Dam groundwater model development

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Appendix 15E Nathan Dam groundwater model development

E.1 Model construct

E.1.1 Finite element modelling

Feflow, a finite element modelling code was used to construct the Nathan Dam Groundwater Model. Previous modelling work at the site was undertaken in the finite difference modelling code, Modflow. The key reasons for the finite element approach are outlined below:

- Finite element models enable the user to refine the mesh around specific areas of interest (e.g. Boggomoss Springs). This enables the creation of fine spatial detail around the springs whilst maintaining a coarse mesh elsewhere. This is ideal for minimising model run times whilst not compromising detail where it is required.
- The ability to specify nodal locations enables explicit representation of each individual spring within the model domain as its own model node (as opposed to lumping springs into a series of coarse grid cells)
- The Feflow package has proven to be numerically more stable in conditions where the watertable crosses through multiple geological layers, as is the case in this region.

E.1.2 Hydrogeological layering and parameterisation

The Nathan Dam Groundwater Model was constructed as a 5 layer, three-dimensional groundwater model. The layer structure follows the hydrogeological conceptualisation as described in (Section 15.1.3). A 3D block diagram of the model layer structure is presented in Figure 1. A description of how these layers were formed as well as isopach maps for the layers can also be found in Section 15.

The parameterisation for the model was based on the data presented in the hydrogeological conceptualisation with refinement during calibration. The final parameters are all within the bounds given within the literature. The final calibrated parameters are presented in Table 1. During calibration it was found that it was necessary to create a preferential pathway to allow upward vertical movement of water from the Precipice aquifer to the complex of springs north of Glebe Weir. This pathway is shown in Figure 2. It is likely that this pathway is linked to a fault line that runs approximately in-line with Cockatoo Creek but continues north of the Dawson River. It is likely that there will be other preferential pathways in the region. Due to a lack of data on such features however, they were not able to be incorporated into the model.

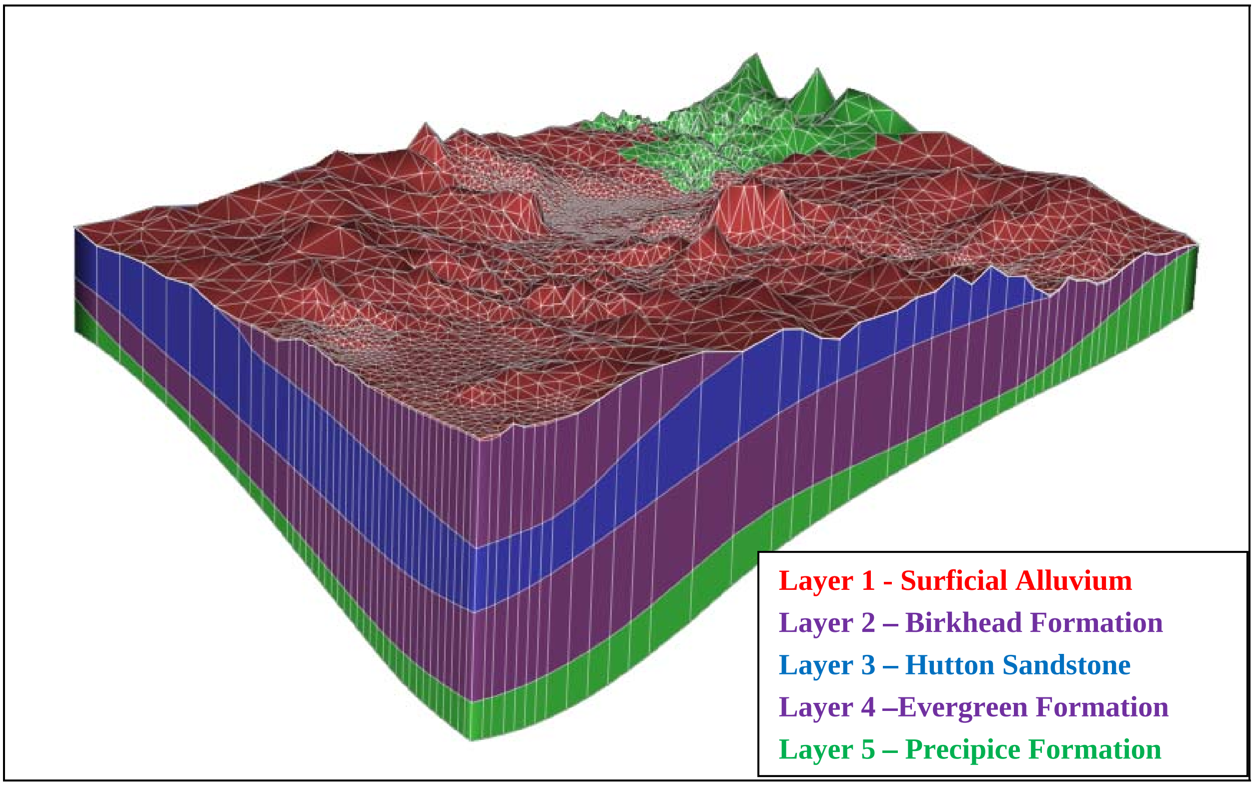

Figure 1 3D block diagram of the model layer structure

Table 1 Hydrogeological parameters used in the Nathan Dam Groundwater Model

Layer	Kh	Kv	Ss	Sy
1 – Alluvium	5	0.5	$5x10^{-6}$	0.1
2 – Birkhead Formation	0.01	$1x10^{-5}$	$5x10^{-6}$	0.1
3 – Hutton Sandstone	1	0.1	$5x10^{-6}$	0.1
4 – Evergreen Formation	0.01	$1x10^{-5}$	$5x10^{-6}$	0.1
5 – Precipice Sandstone	3	0.3	$5x10^{-6}$	0.1
Preferential Pathway	na	10	na	na

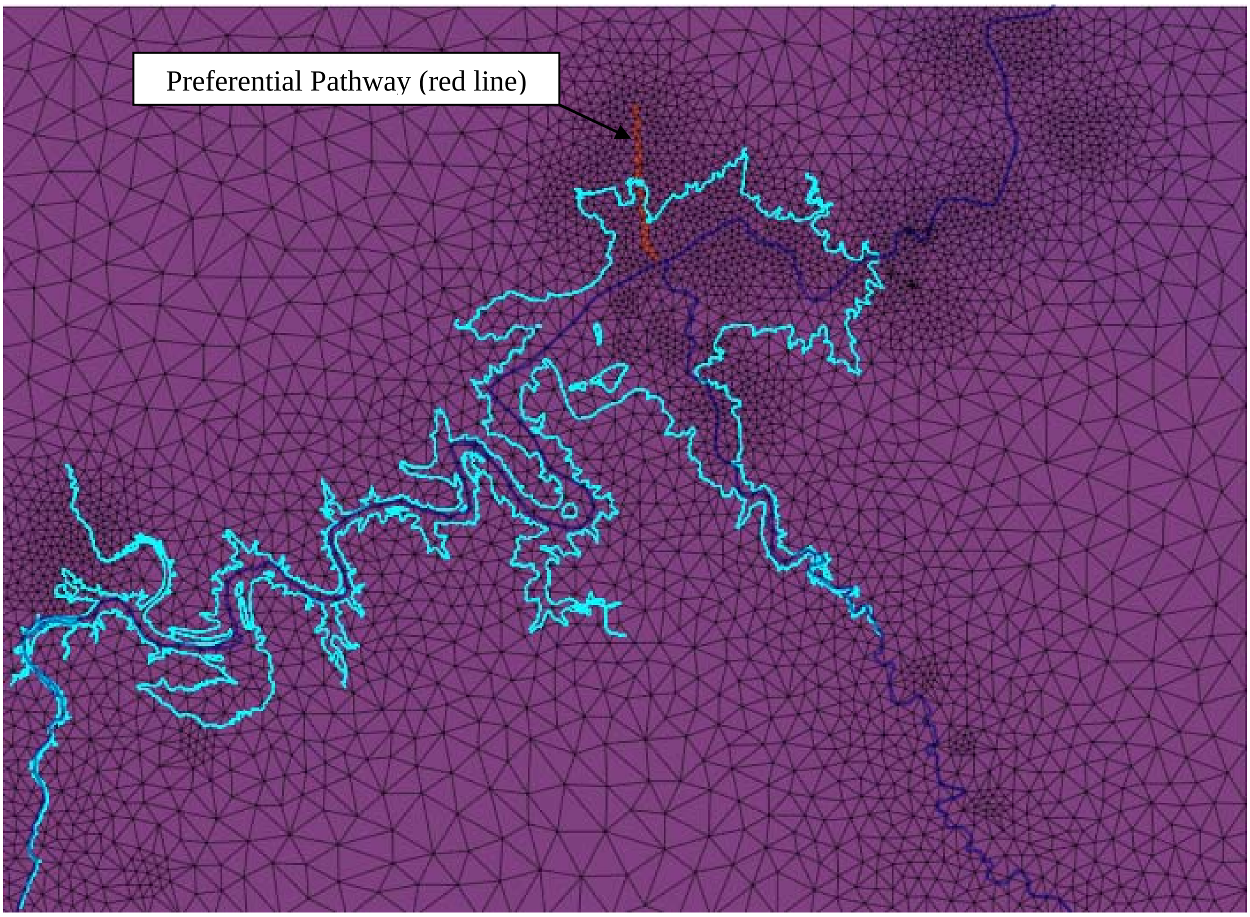

Figure 2 Location of a preferential pathway placed under the springs to the north of Glebe Weir.

E.1.3 Grid refinement

The use of a finite element modelling approach allowed the creation of a mesh with fine detail around the springs, moderate detail along the Dawson River and Cockatoo Creek and a coarse mesh elsewhere. A plan view map of the final mesh geometry is given in **Figure 3**. Nodal spacing's (or element lengths) are in the following ranges:

- Boggomoss Springs – 100 to 300 m (finer where individual springs are particularly close together)
- Dawson River & Cockatoo Creek – 500 m (coarsening away from river)
- Elsewhere – 1 to 2 km

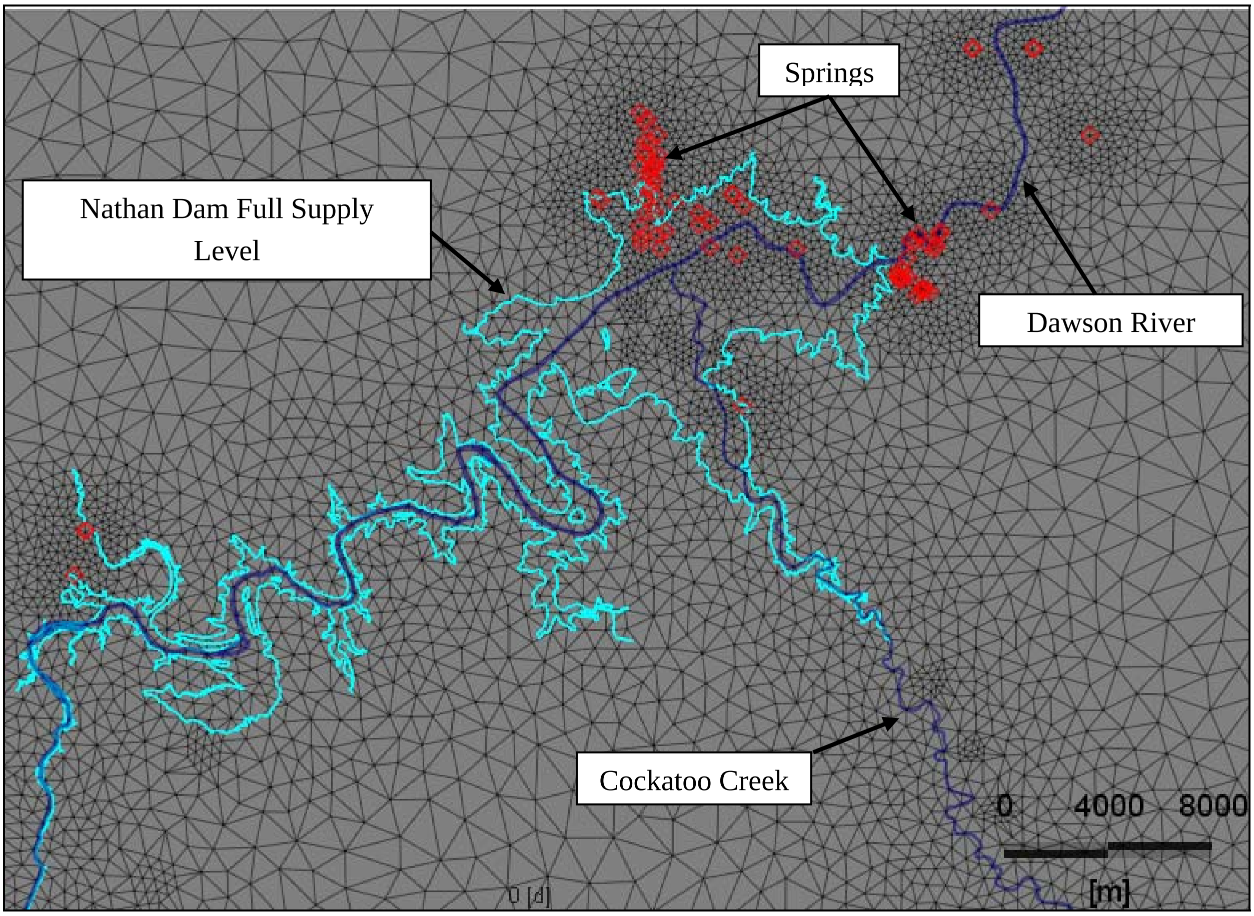

Figure 3 Mesh geometry in the Nathan Dam Groundwater Model

E.1.4 Model boundaries

Based on the hydrogeological conceptualisation (refer **Section 15.1.3**), the general flow direction in the Precipice Sandstone was from the outcropping area in the north-east toward the south-west corner near Taroom. However this is complicated by both mounding and drawdown in various parts of the model domain. Due to the complex flow paths it was impossible to define any one set flow direction and therefore constant head boundary conditions were placed around the entire perimeter of the model in each layer. The hydraulic heads were set as per the inferred heads from the conceptualisation. Given that the key areas of interest are a significant distance in from the model boundaries this was thought to be a reasonable approach.

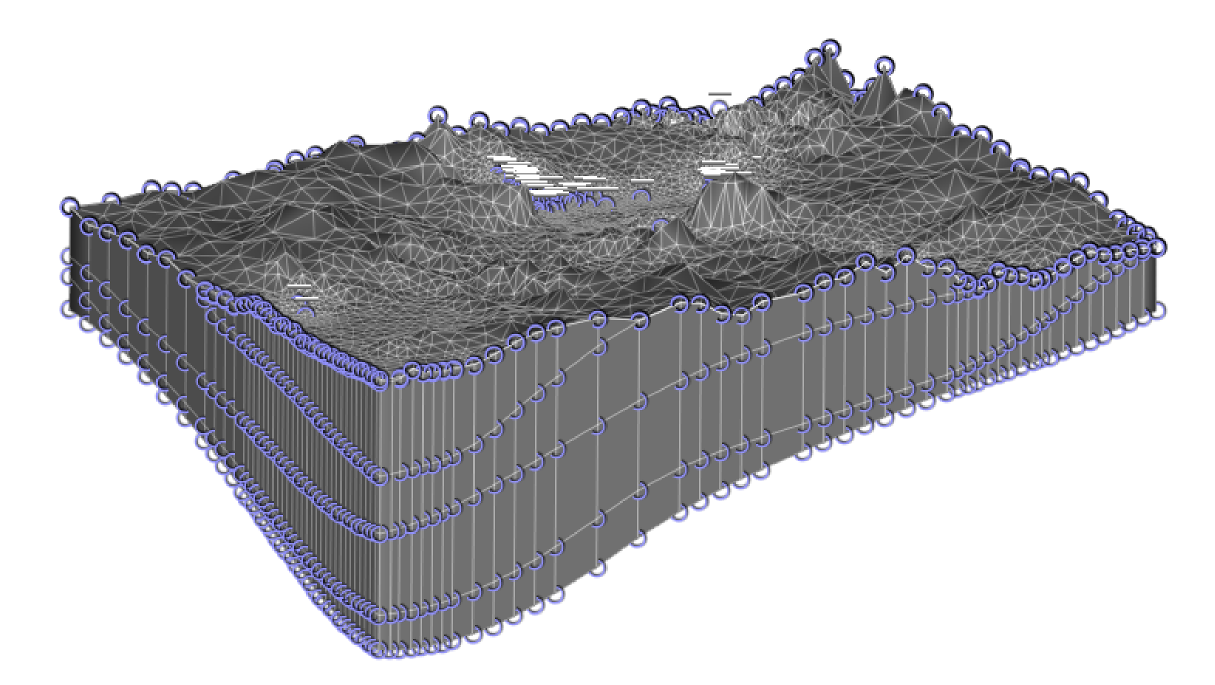

Figure 4 Hydraulic-head boundary conditions (represented by the blue circles)

E.1.5 Rivers and drainage lines

Rivers and drainage lines were set along major watercourses in the model domain using Feflow “Fluid-transfer boundary conditions”. Transfer boundaries allow the user to set both a hydraulic head and also a transfer rate which can be used to replicate the impact of bed sediments impeding fluxes between rivers and the groundwater system. A map of all fluid-transfer boundaries set in the model is provided in Figure 5.

In the calibration model the Dawson River was set as a time-varying boundary condition based on recorded flow and level gauging. The time series for the available gauges is shown in Figure 6 and further detail of the gauges used is provided in Table 2. As Figure 6 shows, the head and tail water levels from Glebe Weir are set as constant levels throughout the model run. This was set partly because there were no gauging records for the calibration period, but more so because the available record showed that the weir maintains relatively static water levels which are only broken on large flood events. Based on the water level held behind Glebe Weir the extent of the pondage was defined and river levels held static within this area (refer Figure 7).

Aside from the main surface water features of Dawson River and Cockatoo Creek, drainage lines were set at a number of sites across the model. In all cases drainage lines were set 0.5 meters below the natural surface elevation to allow for the natural incision of drainage lines in the landscape that is not picked up in coarse digital elevation models. All drainage lines were constrained such that water can only discharge to them and they cannot act as recharge features (the constraints are indicated by the white lines in Figure 5).

Transfer rates for the model were set as follows:

- Dawson River & Cockatoo Creek = 1 (-/day) indicating typically good connection with the aquifer
- Drainage Lines = 1000 (-/day) the high value allowing complete discharge where necessary

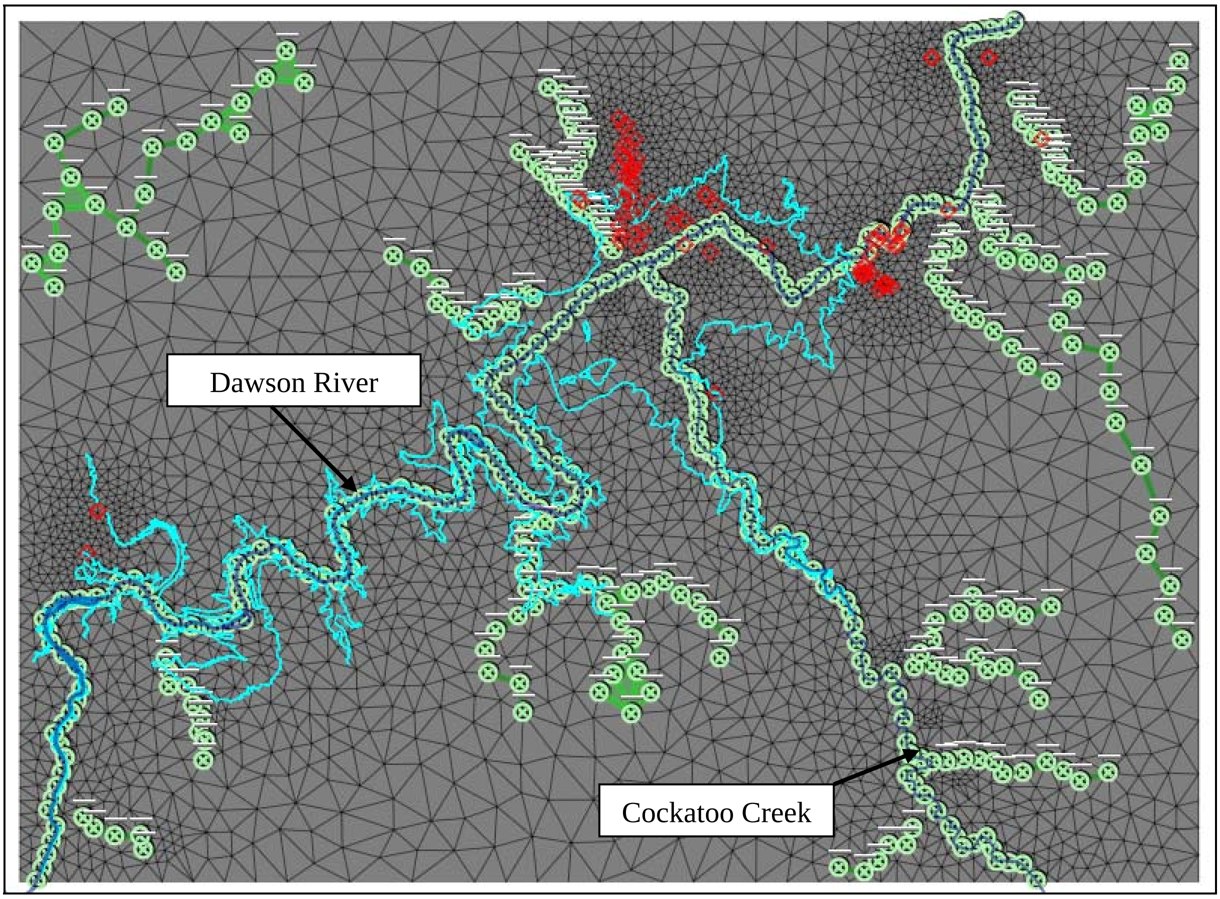

Figure 5 Rivers and drainage lines set in the Nathan Dam Groundwater Model

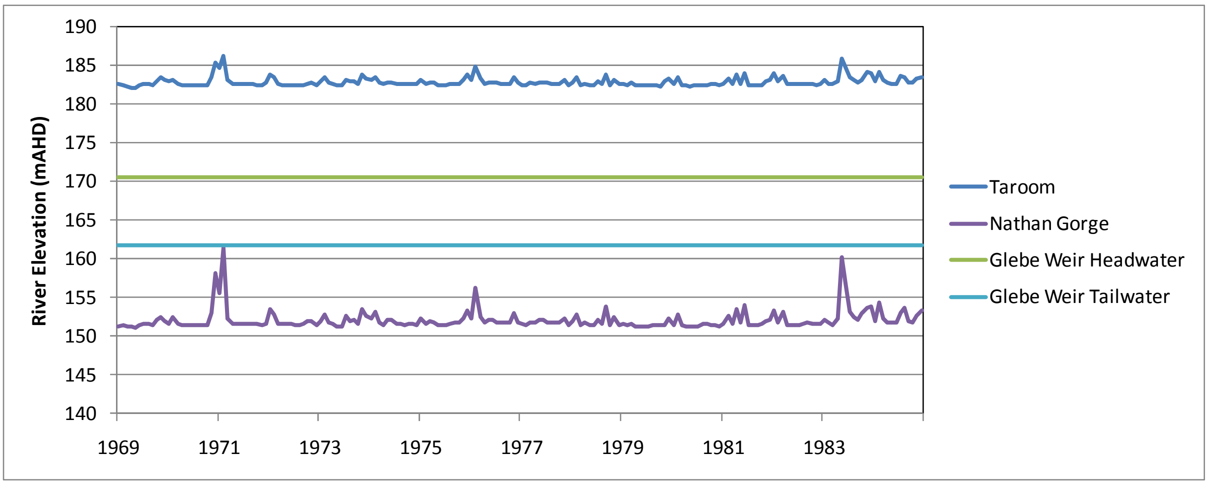

Figure 6 River levels set at key gauging points within the model domain

Table 2 River gauges within the model domain

Gauge	Gauge No.	Easting	Northing	Long Term Average Level
Dawson River @ Taroom	130302	177676	7161491	182.85
Glebe Weir Headwater	130338A	201683	7180202	170.54
Glebe Weir Tailwater	130345A	201683	7180202	161.84
Dawson River @ Nathan Gorge	1303020A	214834	7183842	152.10

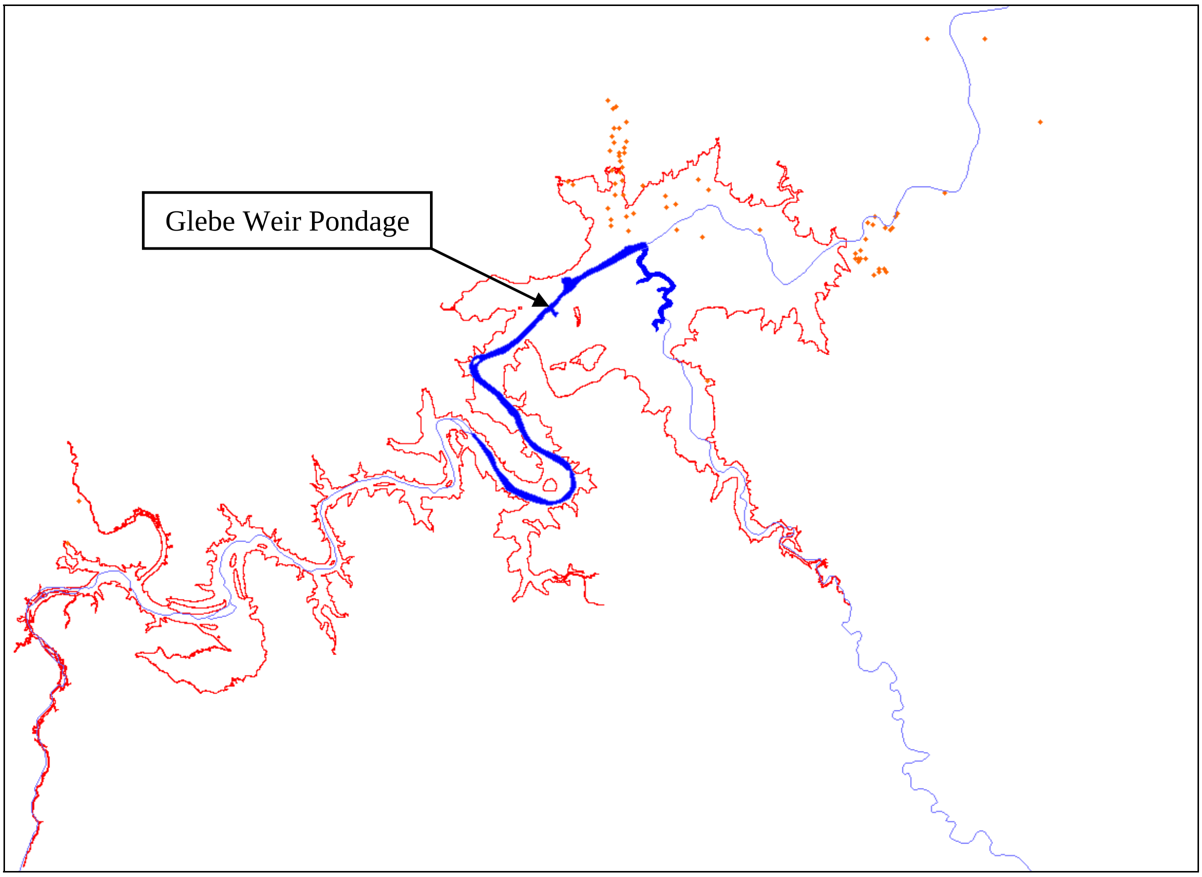

Figure 7 Simplified map showing the extent of the pondage behind Glebe Weir

E.1.6 Boggomoss springs

Each individual spring site is represented discretely by a single Feflow node with a constrained constant head boundary condition. The constant head is set at 0.5 meters below the natural surface elevation and then constrained such that water can only discharge to a spring (i.e. the springs cannot act as a recharge source). This representation mimics the conceptualisation for the springs for when the watertable rises closer to the surface the spring discharge will increase. However, if the depth to water is greater than 0.5 meters it is assumed that no discharge will occur other than through transpiration from deep rooted vegetation.

The controls on the various spring complexes are discussed in the hydrogeological conceptualisation (Section 15.1.3). In summary, it was inferred that the north south trending line of springs consisting of the "Boggomoss" and "Dawson River 5" spring complexes (Figure 8) is thought to be fault controlled and fed by artesian pressures from the Precipice Formation pushing water up through a preferential pathway and creating elevated watertables along that line. Therefore it is inferred that these springs are not as susceptible to short term fluctuations associated with climate or other localised influences on the watertable. Elsewhere, such as the "Dawson River 3 & 4" complexes, the springs are inferred to be linked to local flow systems and are therefore strongly influenced by climatic conditions and the local movement of the watertable.

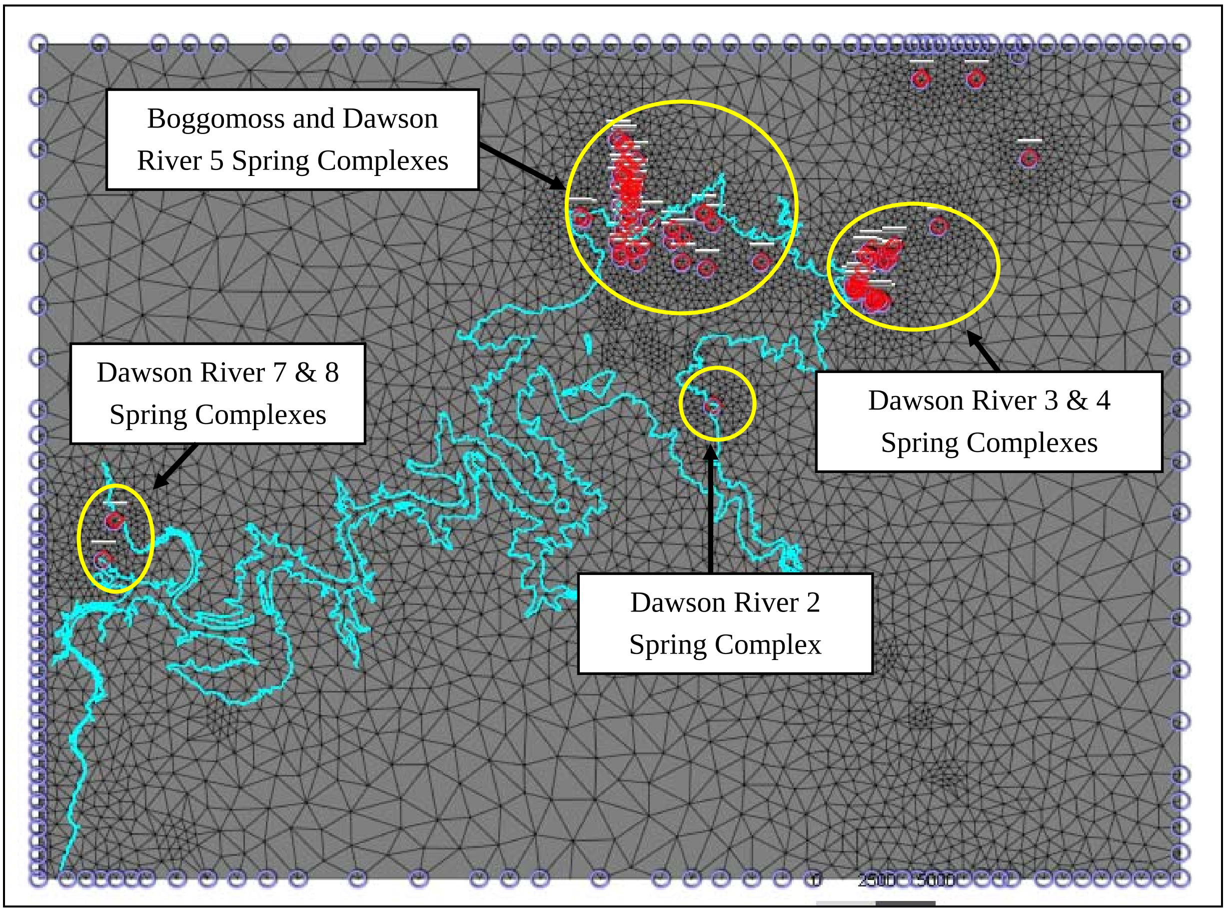

Figure 8 Boggomoss Springs in the model domain (indicated by red diamonds)

E.1.7 Recharge & evapotranspiration

Recharge to the groundwater system was applied through the Feflow “In/Outflow on Top” functionality.

Unfortunately traditional evapotranspiration (ET) functions that estimate ET as a function of the depth to water proved to be unavailable due to what is assumed to be a bug in the new Feflow 6.0 code. Herein, when ET was estimated in this manner a small number of nodes in the model continually removed water regardless of the depth to water, thus creating a series of unexplainable irregular drawdown cones.

An alternative modelling approach was adopted that reduces the recharge to account for potential for evapotranspiration fluxes. The approach estimates the recharge to the groundwater system as a function of rainfall, pan evaporation and landuse. Recharge was assumed to occur when rainfall exceeded ¼ of pan evaporation (higher fractions of pan evaporation were tested but this only allowed recharge to occur on rare large rainfall events). Recharge was then calculated as 4% of rainfall minus ¼ of pan evaporation for dryland and irrigation (plus 0.1mm/day for irrigation accessions where applicable). In the area where the outcropping precipice occurs it was necessary to increase recharge to 100% of rainfall minus ¼ of pan evaporation. While this recharge estimate is unreasonably high it was found to be necessary to compensate for the fact that there is a large recharge area immediately outside of the model boundary in which large amounts of water are recharging the outcropping Precipice Sandstone. Without the high recharge rates it was found to be impossible to replicate the inferred watertable elevation from the conceptualisation report.

The adoption of a simplified approach to evapotranspiration is not expected to have a significant impact on the modelling outcomes as the principal impacts of dam construction and operation relate to the transmission of pressures within the confined aquifer where evapotranspiration has little or no effect.

A map of the simplified landuse classifications utilised in the model is provided in **Figure 9**.

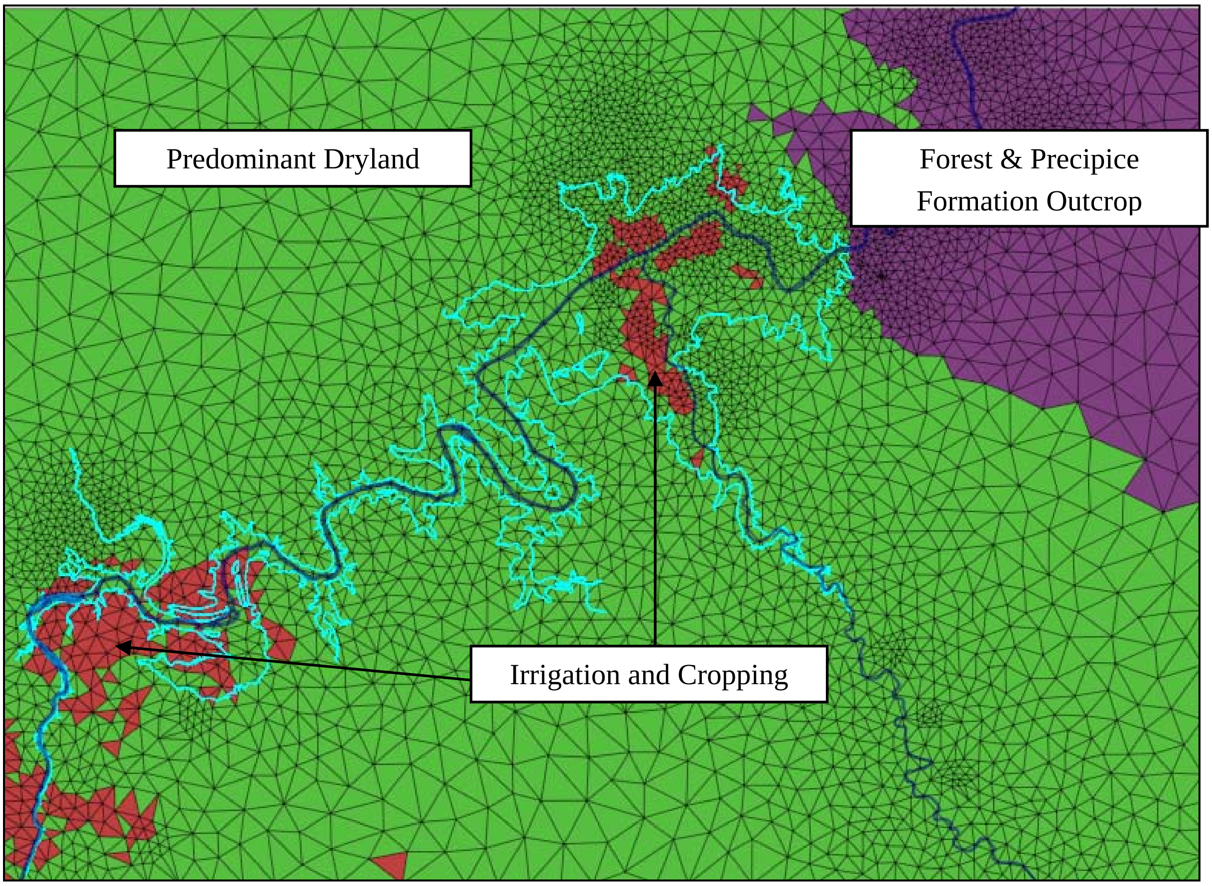

Figure 9 Simplified landuse classifications

E.1.8 Groundwater extraction wells

Groundwater extractions were set in the model using data from the DERM Groundwater Entitlement System. With the exception of the Taroom town water supply, extraction volumes are typically low with the majority of bores being for stock and domestic purposes. Maps of all the extraction wells are provided in Figure 10 and Figure 11.

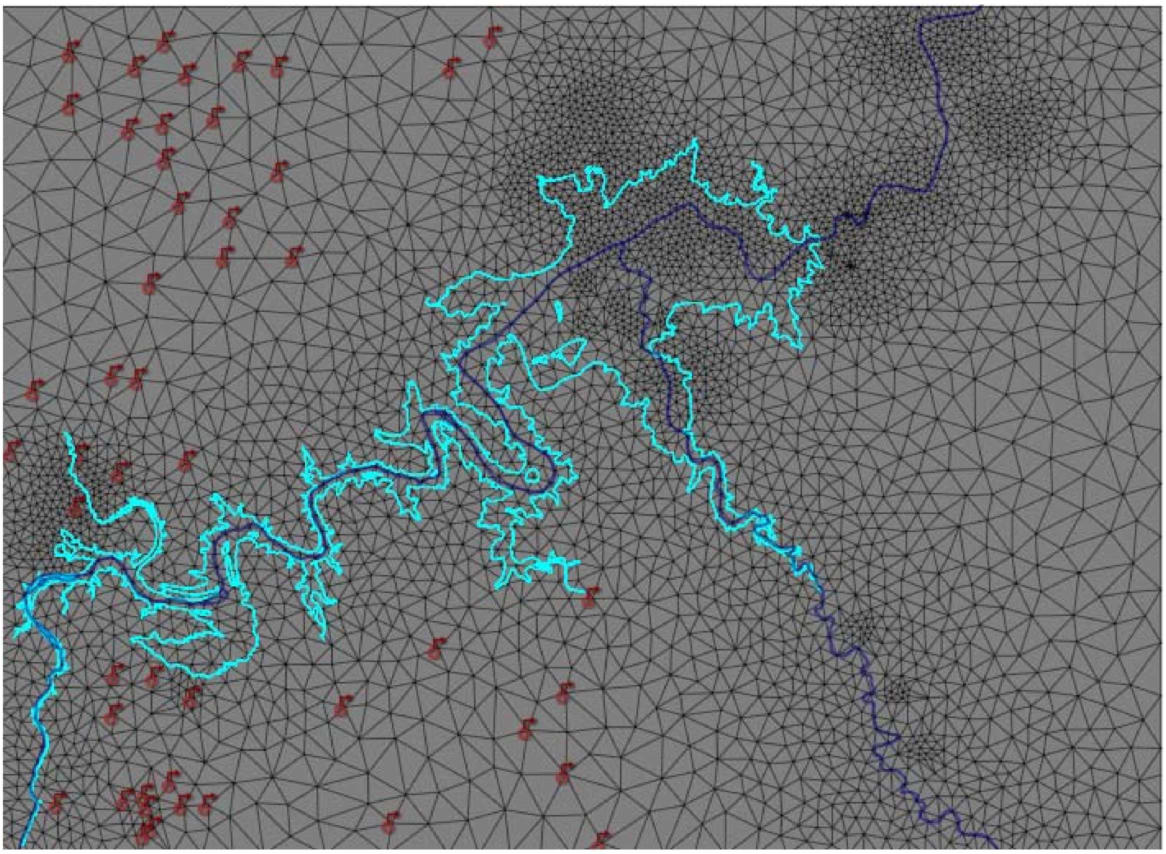

Figure 10 Groundwater extraction wells in the Birkhead and Hutton Formations

Note: Many bores have multiple licences therefore the number of actual bores is less than the number of licences.

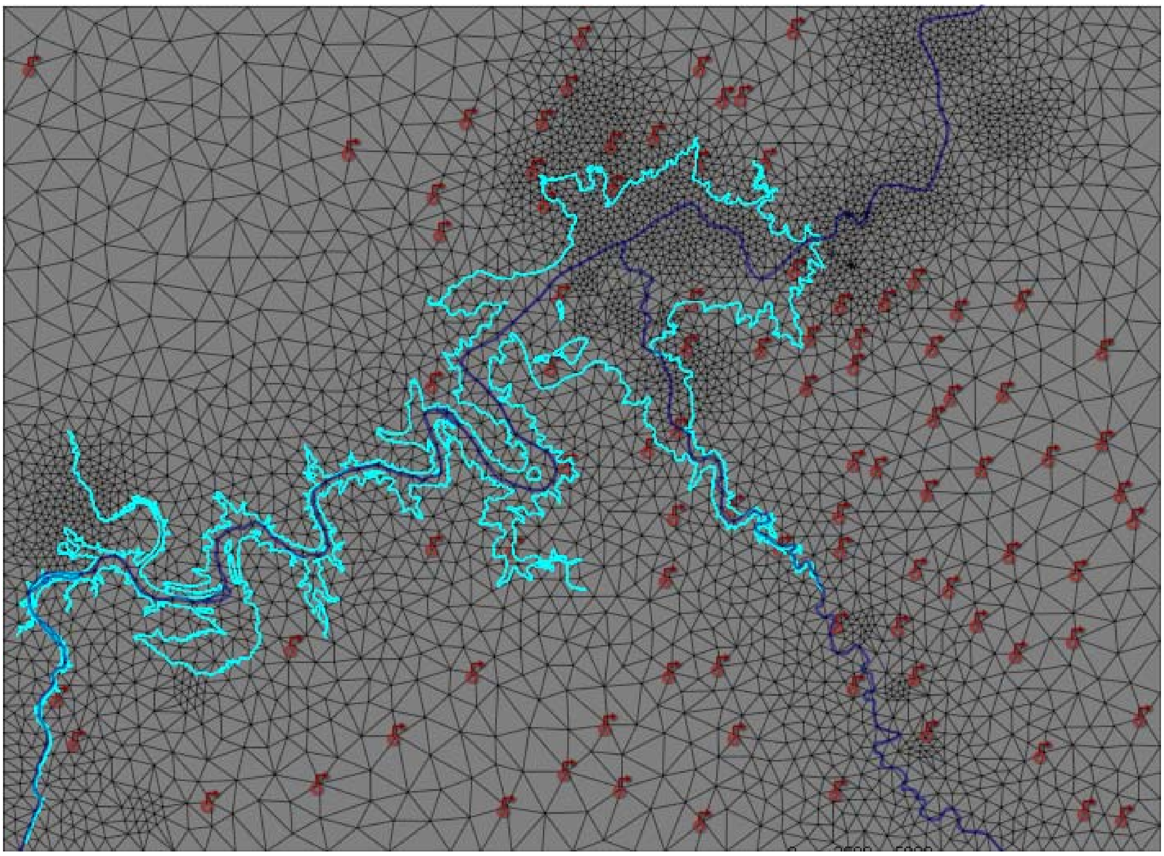

Figure 11 Groundwater extraction wells in the Evergreen and Precipice Formation

Note: Many bores have multiple licences therefore the number of actual bores is less than the number of licences.

E.2 Model calibration results

E.2.1 Calibration methodology

The model calibration period was selected as a 15 year period running from 1969 to 1984. This was originally selected due the available observation bore data. However, after the model was constructed and calibration commenced it was quickly realised that there were obvious errors in the observation bore measurements that made them unsuitable for use during calibration. Consequently the calibration turned its focus to calibrating against the inferred potentiometry (as per the conceptualisation) and the estimated spring flow volumes provided by DERM (Springs of Queensland - Distribution and Assessment (Version 5.0)).

E.2.2 Spring flows

Note: For the purpose of extracting model outputs it was not feasible to decouple some of the spring complexes. Therefore the springs were grouped into four main clusters as per ***Table 3****.*

Given that there are no measured flows, just estimates, the aim of the calibration against spring flows was firstly to get the flows in the appropriate order of magnitude and then secondly to generate a time series that fitted with the conceptualisation for the implied controls of the springs. In both respects a good calibration was achieved.

Table 3 compares the estimated flow rates with the average modelled flows for each of the spring complexes. The spring complex on Cockatoo Creek and also the ones near Taroom proved to be difficult to match given they were very small flow rates. However given that most of the springs are effectively located on the Full Supply Level boundary of the dam it was inferred that there was less importance placed on these.

The spring complex in Nathan Gorge resulted in a very accurate calibration and was found to be strongly influenced by recharge on the outcropping area of the Precipice Sandstone. The spring complexes north of Glebe Weir remained a focus during calibration as these proved to rely on the model's ability to create artesian pressures in the Precipice Formation and 'push' water up through a preferential pathway to the springs. This process proved successful, although the final flow rates indicated an underestimate by the model. However, given it is still in the appropriate order of magnitude it was considered acceptable.

Importantly the time series plot of flows for the spring complexes north of Glebe Weir fitted well with the conceptual model. Figure 12 shows how the spring flows remained relatively constant with time through the calibration period. This suggests that even during times of low rainfall, the spring flows are maintained by the upward pressures from the Precipice Formation.

The time series plot for the spring complexes in Nathan Gorge display a different trend (Figure 13). Here, the springs are clearly linked to rainfall and this fits with the conceptualisation of the springs being controlled by local flow systems.

The time series plots from the spring complexes near Taroom and Cockatoo Creek show similar patterns that are heavily linked to rainfall and local flow systems (Figure 14, Figure 15).

Table 3 Calibration against estimated spring flows

Spring Complex	Model Group Name	Estimated Flow (kL/day)	Average Modelled flow (kL/day)
DawsonRiver2	Cockatoo Ck	31	2
DawsonRiver3		883	
DawsonRiver4		45	
Combined	*Nathan Gorge*	*929*	881
Boggomoss		3040	
DawsonRiver5		2906	
Combined	*Glebe Weir*	*5946*	*3135*
DawsonRiver7		1	
DawsonRiver8		31	
Combined	*Taroom*	*32*	*148*

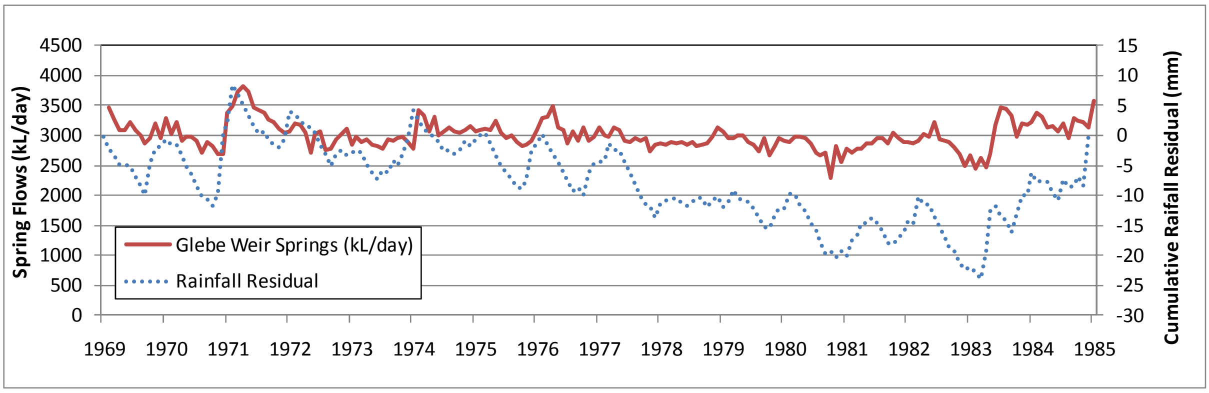

Figure 12 Spring flows from the spring complexes north of Glebe weir

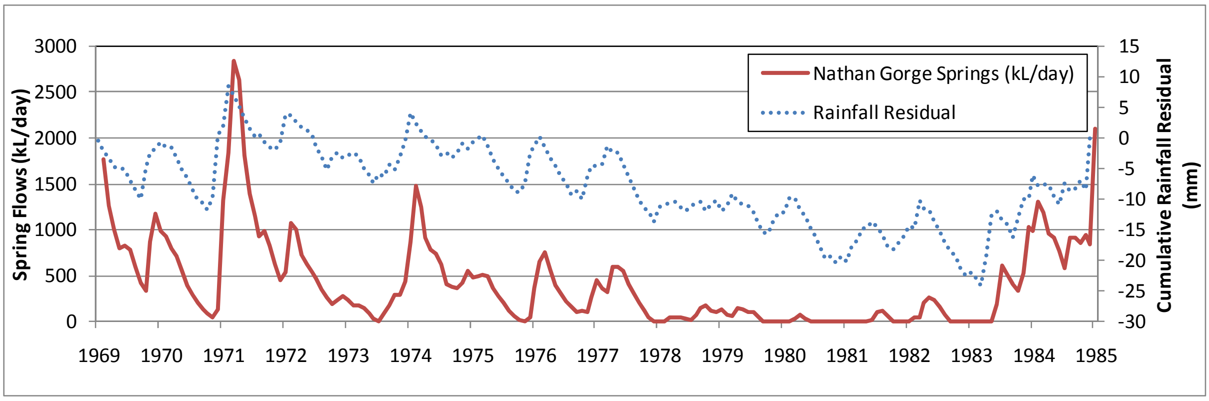

Figure 13 Spring flows from the spring complexes in Nathan Gorge

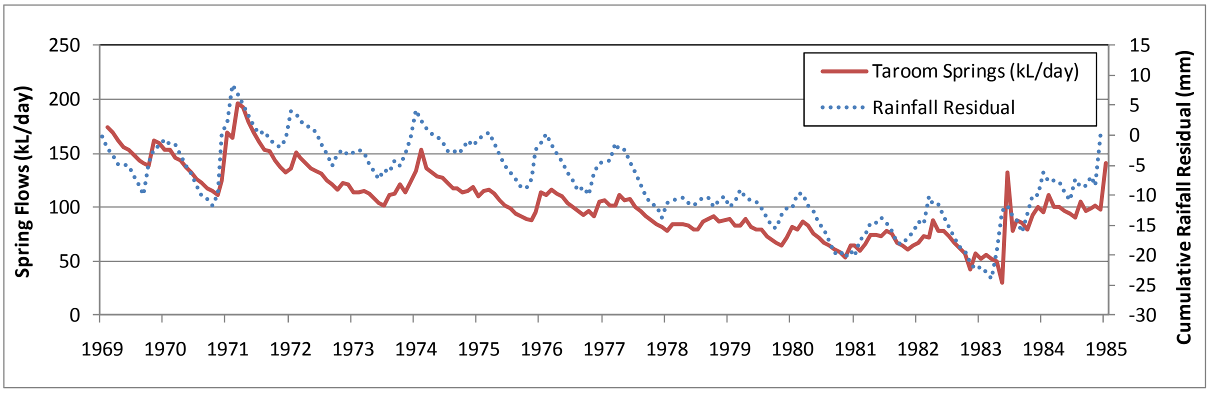

Figure 14 Spring flows from the spring complexes near Taroom

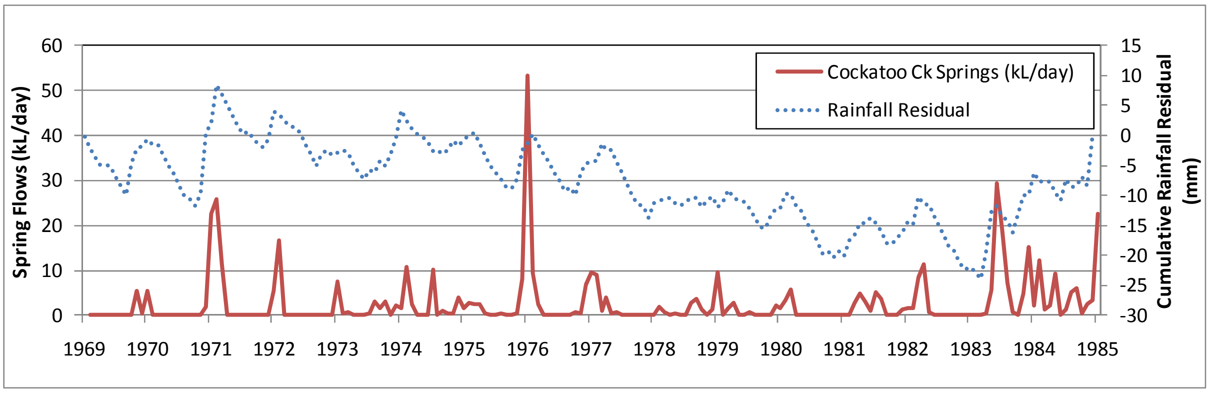

Figure 15 Spring flows from the spring complex on Cockatoo Creek

E.2.3 Potentiometry

Calibrated potentiometric surface maps are presented in Figure 15-21 and Figure 15-22 in Appendix H.

E.2.4 Mass balance

The calibrated model indicates that the key processes acting in the model domain are recharge and groundwater discharge to rivers and drainage lines (Figure 16). Given the large model area, spring flows only represent a very minor part of the overall water balance.

In total there is a large throughflow through the model domain. However, the net fluxes across the model boundary are relatively small, indicating that through the calibration period fluxes in through model boundaries approximately equalled fluxes out through model boundaries. There was also a small decrease in watertable elevation over the model domain and this is shown as water coming in from storage.

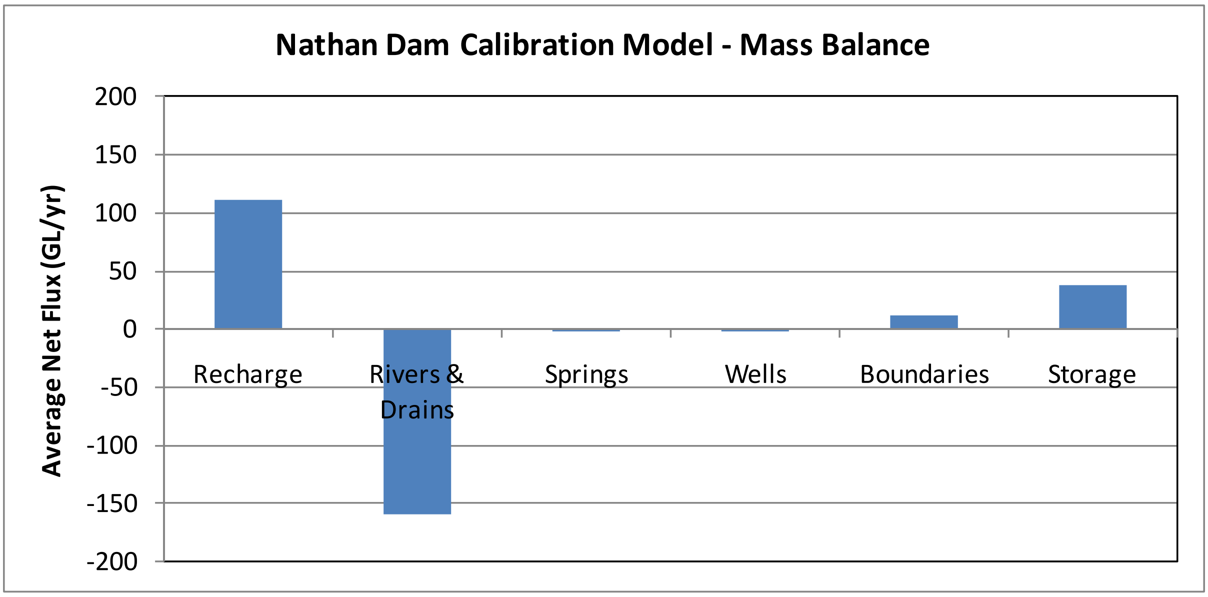

Figure 16 Average Net fluxes in the Nathan Dam Calibration Model (negative values indicate a net discharge)

E.3 Scenario model setup

E.3.1 Methodology

Four scenario models were compiled in order to assess the potential impacts of the Dam construction and operation. The four scenarios were as follows:

- Base Case – No dam
- Scenario 1 – With the dam at full supply level for the duration of the model run
- Scenario 2 – With the dam at median supply level for the duration of the model run
- Scenario 3 – Simulating the dewatering during the construction phase of the dam wall

Each scenario (except Scenario 3) was run as a repeat of 1900 to 2008 historical conditions, consistent with Hydrological modelling "Extended simulation Period" scenario. Specific details relating to the setup of each of the scenarios are discussed below.

Unless otherwise specified it can be assumed that model setup and inputs are as per the calibration model previously described in this report.

E.3.2 Base case scenario

The base case scenario was used to compare the results of the other scenarios and therefore assess the impact of the dam.

The only change from the calibration model was the conversion of the time-varying river levels on the Dawson River to constant levels as per the long-term average (refer to Table 2 previously presented).

Climate inputs were derived from the hydrological modelling "extended simulation period" scenario. Groundwater extractions were maintained at current levels (as per the calibration model). No changes to model parameters were required.

E.3.3 Scenarios 1 & 2 – full supply level and median supply level

The full supply level scenario can be considered a maximum impact scenario where the dam is maintained at full supply (183.5 mAHD) for an extended period. In order to model the influence of the reservoir, constant head boundaries were placed on all nodes on layer 1 within the inundated area when the dam is at full supply (Figure 17).

The Median supply level scenario was modelled in exactly the same way as the full supply level scenario. The median supply level is 181.7 mAHD as per the hydrological modelling "extended simulation period" scenario.

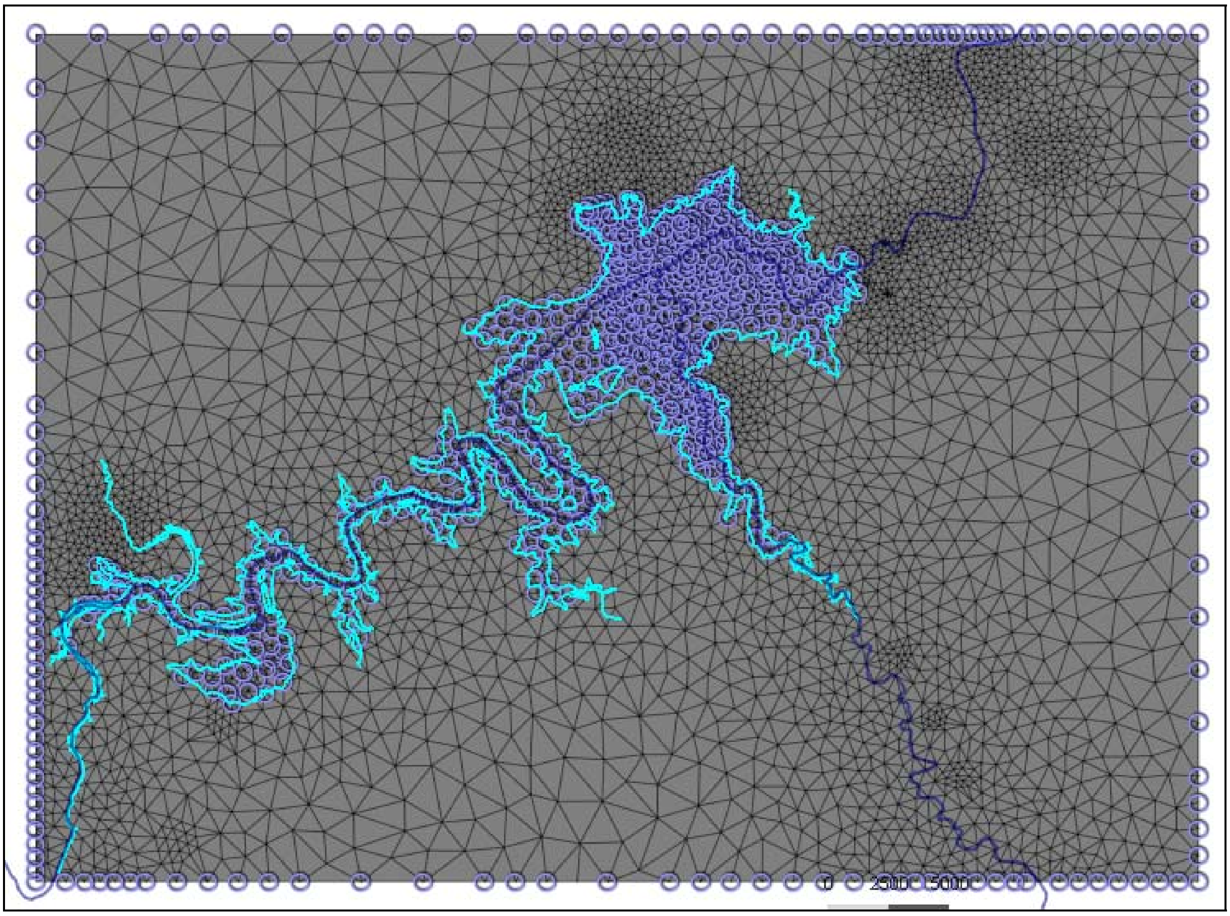

Figure 17 Constant head boundaries representing Nathan Dam at full supply level

E.3.4 Scenario 3 – dewatering

In scenario three the model was refined to enable the assessment of the likely impacts of dewatering during the construction phase of the dam. Based on discussions with Sunwater it was understood that dewatering was to occur for approximately a 50 day period during the installation of the chimney filter at the downstream toe of the dam wall. Dewatering was to occur to a depth of 3m below the base of the chimney filter (3m below the base of the river bed alluvium). This equated to an elevation of 142 mAHD, approximately 19m below the normal river elevation. It was expected that dewatering would be achieved through the use of 4 or 5 bores placed near the chimney filter.

During construction the river is to be diverted through a constructed channel around the construction site between two coffer dams approximately 50 m upstream and downstream from either toe of the dam wall.

In order to simulate these changes it was firstly necessary to refine the model in the vicinity of the dam wall. This refinement is shown in Figure 18. The refinement allowed the accurate modelling of drawdown caused by the dewatering within a relatively small area near the chimney filter.

Five dewatering bores were placed in the model approximately in line with the location of the chimney filter. However, instead of assigning pumping rates constant head boundaries were assigned at an elevation of 142 mAHD, the level of drawdown required. This method was selected to ensure that the required drawdown was achieved and it also speeds up the analysis (i.e. it avoided the need to run multiple pumping scenarios until the appropriate drawdown was achieved). The river was also removed between the approximate location of the coffer dams to simulate the diversion of the river around the construction site.

The dewatering scenario was run for a period of 2 years. The first year was effectively run as a 'warm-up' period. At the end of the first year the dewatering commenced and continued for 50 days before being turned off again for the remainder of the second year.

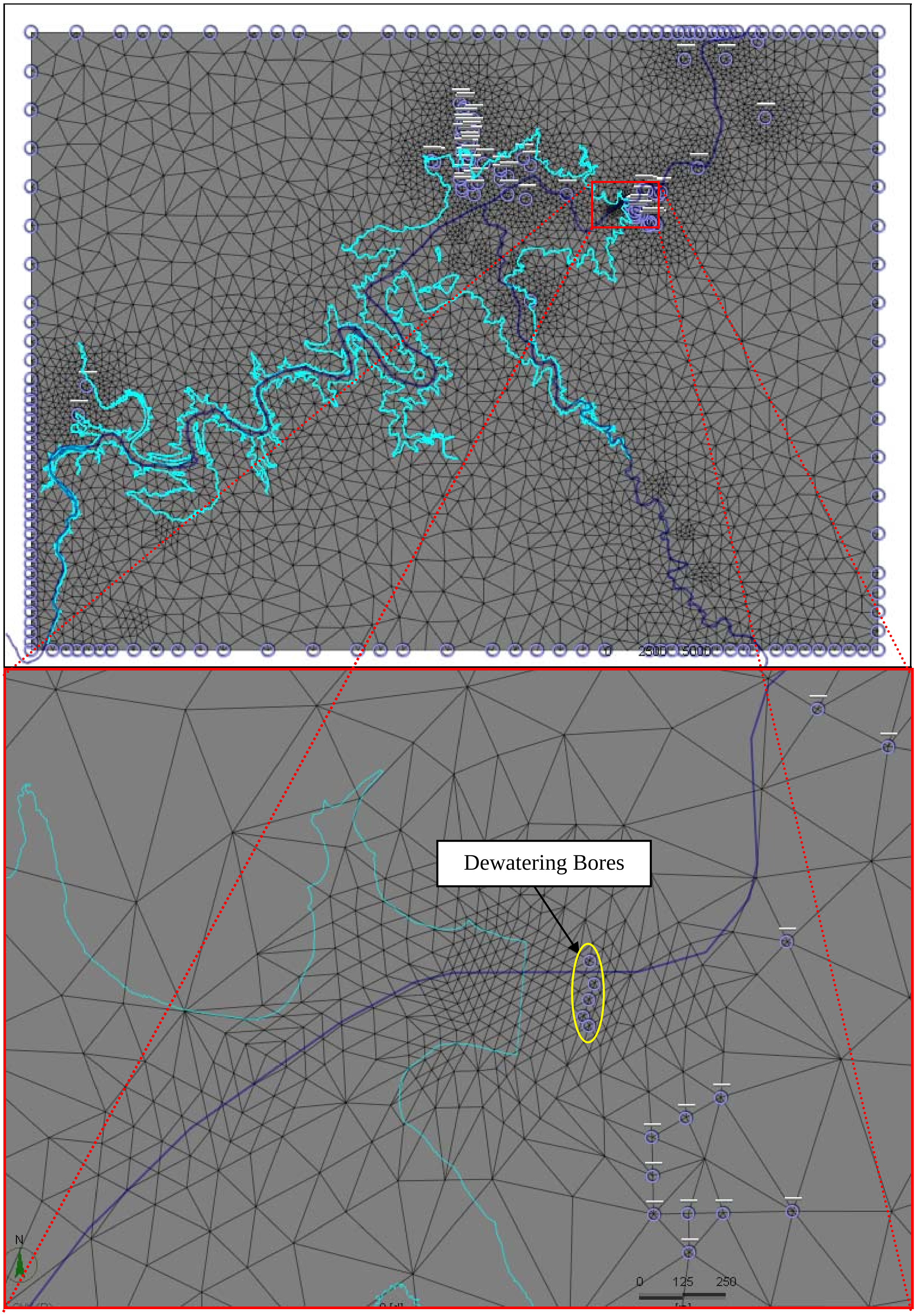

Figure 18 Refinement of the Feflow mesh for the dewatering scenario

E.4 Modelling assumptions

Numerical groundwater models include a number of assumptions inherent in the modelling codes that are used. These include assumptions on conservation of mass and the applicability of Darcy's Law to estimate groundwater fluxes between adjacent model nodes. In addition to these basic high level assumptions there are a number of additional assumptions that have been made in the development of this particular model. These include:

- It is assumed that licensed groundwater users extract groundwater at a constant rate throughout the year and that the annual extraction of groundwater is equivalent to the licensed take.
- It is assumed that the Dawson River is connected to groundwater in model layers 1 (Alluvium) and 2 (Birkhead Formation). In other words water can flow into or out of the model from or to Layer 1 or 2 and not directly to any other model layer.
- Apart from Dawson River and Cockatoo Creek all other minor tributaries and drainage lines act as groundwater drains and do not contribute to groundwater recharge.
- It is assumed that recharge from rainfall infiltration occurs only when rainfall rates exceed the 25% of the rate of mean annual pan evaporation.
- It is assumed that the springs discharge at a constant head equal to the elevation of the ground surface at the spring.

E.5 Model uncertainty

All groundwater models include a level of uncertainty and non-uniqueness. Uncertainty arises from the fact that all complexities and features of a groundwater domain cannot be truly represented in all of its fine detail by a mathematical model that subdivides the domain into discrete and interconnected elements. This problem arises from the fact that a groundwater resource cannot be seen and hence heterogeneities at a scale less than the drilled interval are unknown and cannot be mapped.

Model uncertainty can be reduced through an appropriate model calibration process in which the model is modified or refined in order to best match groundwater behaviour that has been observed in the past. The value of the calibration process and the degree to which it is able to reduce model uncertainty depends on the length of record of groundwater observation, the spatial density of observations and the different features of the system that have been observed and are replicated in the model.

Even after exhaustive calibration groundwater models are intrinsically uncertain for a number of reasons including:

- Errors included in the data on which the models are based (e.g. extraction rates, rainfall, observation data etc.),
- Errors in interpretations of data (e.g. interpretation of well logs and interpolation of surfaces between wells),
- Heterogeneity within the aquifer that is not represented in the model,
- Simplification of hydrogeological structures represented by the model,

- Disaggregation of physical properties to a grid that is often coarser than the structures that are represented (e.g. representation of rivers, pumping wells etc),
- Non-uniqueness of calibration
- Errors in calibration.

The Nathan Dam model described in this report has been calibrated against a measured and inferred potentiometric surface in the Precipice Sandstone and against measured spring flows. This represents a modest level of calibration and reflects the amount of data that is available for the site. The resultant groundwater model is still relatively uncertain however and as such, all model predictions should be considered as estimates that include inherent inaccuracies. The predicted model outcomes do however illustrate the general physical processes and the types of impacts that are likely to arise from the dam construction and operation and are considered appropriate for the purposes of this investigation.