

Upper Lachlan Groundwater Model Calibration Report

A report to the Australian Government from the
CSIRO Murray-Darling Basin Sustainable Yields Project

Murray-Darling Basin Sustainable Yields Project acknowledgments

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Preface

This is a report to the Australian Government from CSIRO. It is an output of the Murray-Darling Basin Sustainable Yields Project which assessed current and potential future water availability in 18 regions across the Murray-Darling Basin (MDB) considering climate change and other risks to water resources. The project was commissioned following the Murray-Darling Basin Water Summit convened by the then Prime Minister of Australia in November 2006 to report progressively during the latter half of 2007. The reports for each of the 18 regions and for the entire MDB are supported by a series of technical reports detailing the modelling and assessment methods used in the project. This report is one of the supporting technical reports of the project. Project reports can be accessed at <http://www.csiro.au/mdbsy>.

Project findings are expected to inform the establishment of a new sustainable diversion limit for surface and groundwater in the MDB – one of the responsibilities of a new Murray-Darling Basin Authority in formulating a new Murray-Darling Basin Plan, as required under the Commonwealth Water Act 2007. These reforms are a component of the Australian Government's new national water plan 'Water for our Future'. Amongst other objectives, the national water plan seeks to (i) address over-allocation in the MDB, helping to put it back on a sustainable track, significantly improving the health of rivers and wetlands of the MDB and bringing substantial benefits to irrigators and the community; and (ii) facilitate the modernisation of Australian irrigation, helping to put it on a more sustainable footing against the background of declining water resources.

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1 Key messages

- Although groundwater extractions of about 60 GL/year appear to be sustainable in the long term (111 years of model duration) the aquifer does not reach a stable equilibrium in which inflows balance outflows over this period. As a result the groundwater levels continue to fall while extractions remain at this level.
- An analysis of all available recharge sources indicates that dynamic equilibrium with stable groundwater levels would be attained at an extraction rate of about 50 GL/year.
- Prolonged extraction of groundwater at about 60 GL/year will lead to a loss of river flow (due to increase in losses to groundwater and reduced baseflow) of up to 17 GL/year.
- The influence of future climate change may reduce or increase the total recharge to the aquifer by up to about 15% of historical levels.

2 Introduction

The primary objectives of the Murray-Darling Basin Sustainable Yields Project are to evaluate the available water resources of the Murray-Darling Basin (MDB) and to determine how the resource will be affected by future climate change. Groundwater forms an integral part of the water resources of the MDB and as such investigations have been carried out to quantify the accessible and usable groundwater resources. While there are a number of methods that can be used to quantify groundwater resources, appropriately calibrated numerical models provide the most accurate estimates of extractable groundwater volumes. Unfortunately the size of the project area precludes the development of a single, whole-of-basin groundwater model of sufficient detail to represent all of the features of importance for this project. Accordingly it is necessary to consider a number of individual groundwater models that cover specific areas of interest within the MDB. Obtaining reliable groundwater models for the principal aquifers in the MDB was therefore a priority for the project. A number of existing groundwater models were made available by the state jurisdictions for the project and these were used wherever possible. Within the time and resource constraints of the project, additional new models were developed in areas of significant groundwater extraction.

To assist in selecting areas to develop new groundwater models a groundwater management unit (GMU) based ranking system was applied (CSIRO, 2007). This system relies on a ranking index that is based on:

- normalised current (2004/05) groundwater extraction
- the fraction of groundwater allocation that is currently extracted (2004/05)
- the fraction of sustainable yield currently extracted (2004/05)
- a potential growth index
- an index of the predicted future impact of groundwater extraction on surface water flows.

The resultant ranking system assisted in deciding which GMU based models should be developed. The Upper Lachlan Alluvium GMU includes approximately 4.3% of the annual groundwater extraction from the MDB and is ranked as the seventh most important GMU in the MDB. Accordingly a new groundwater model was developed for the Upper Lachlan Alluvium.

A hydrogeological conceptualisation of the Upper Lachlan Valley was developed from information provided by the New South Wales Department of Water and Energy and from published information (NSW Water Resources Commission, 1986; Ross, 1982; Dept. Water Resources, 1994; DIPNR, 2004; DNR, 2007) and from unpublished data provided by the Department of Water and Energy. This information included digital terrain models, bore logs, recorded streamflow and climate data, and recorded groundwater extraction data. A three-dimensional finite difference groundwater flow model was formulated to represent the important features of the conceptualisation. The model was calibrated by matching predicted aquifer behaviour to measured groundwater hydrographs over the period 1998 to 2006.

This report describes the development and calibration of the model and its subsequent use to investigate the impacts of future groundwater extraction with special consideration given to the future impacts arising from various modelled climatic conditions.

3 Model description

The extent of the Upper Lachlan groundwater model is shown in Figure 3-1. Figure 3-2 shows the local groundwater management zones 1, 2, 3 and 5. The model area was chosen to cover these management zones. Other groundwater management zones in the Upper Lachlan area do not form part of the groundwater model.

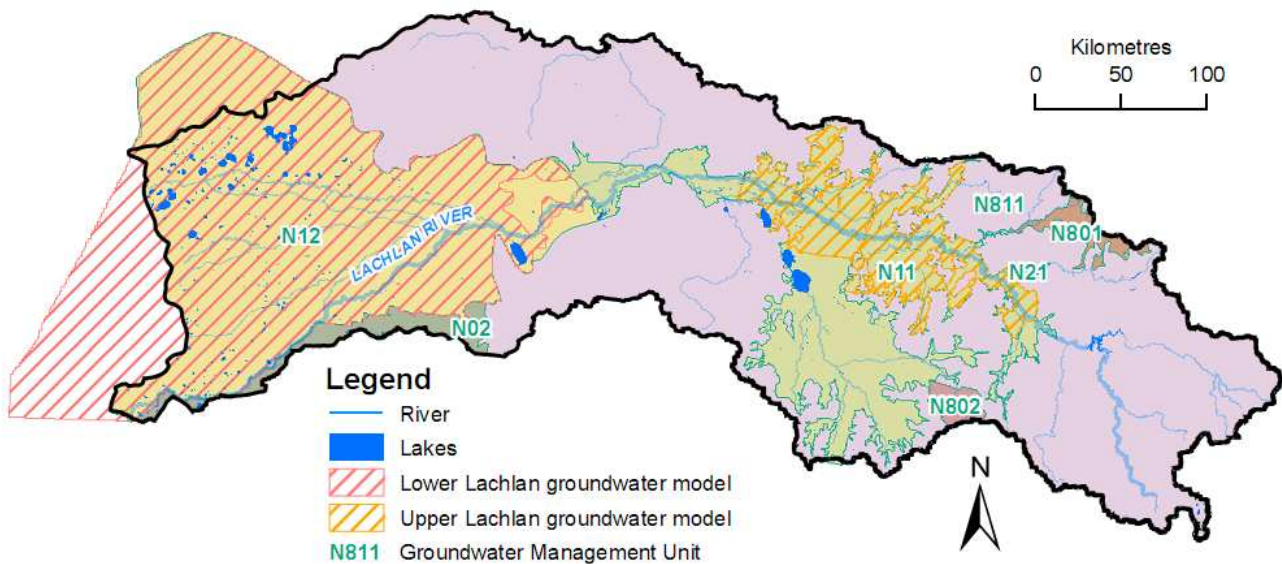


Figure 3-1. Lachlan catchment showing the location of the Upper Lachlan groundwater model

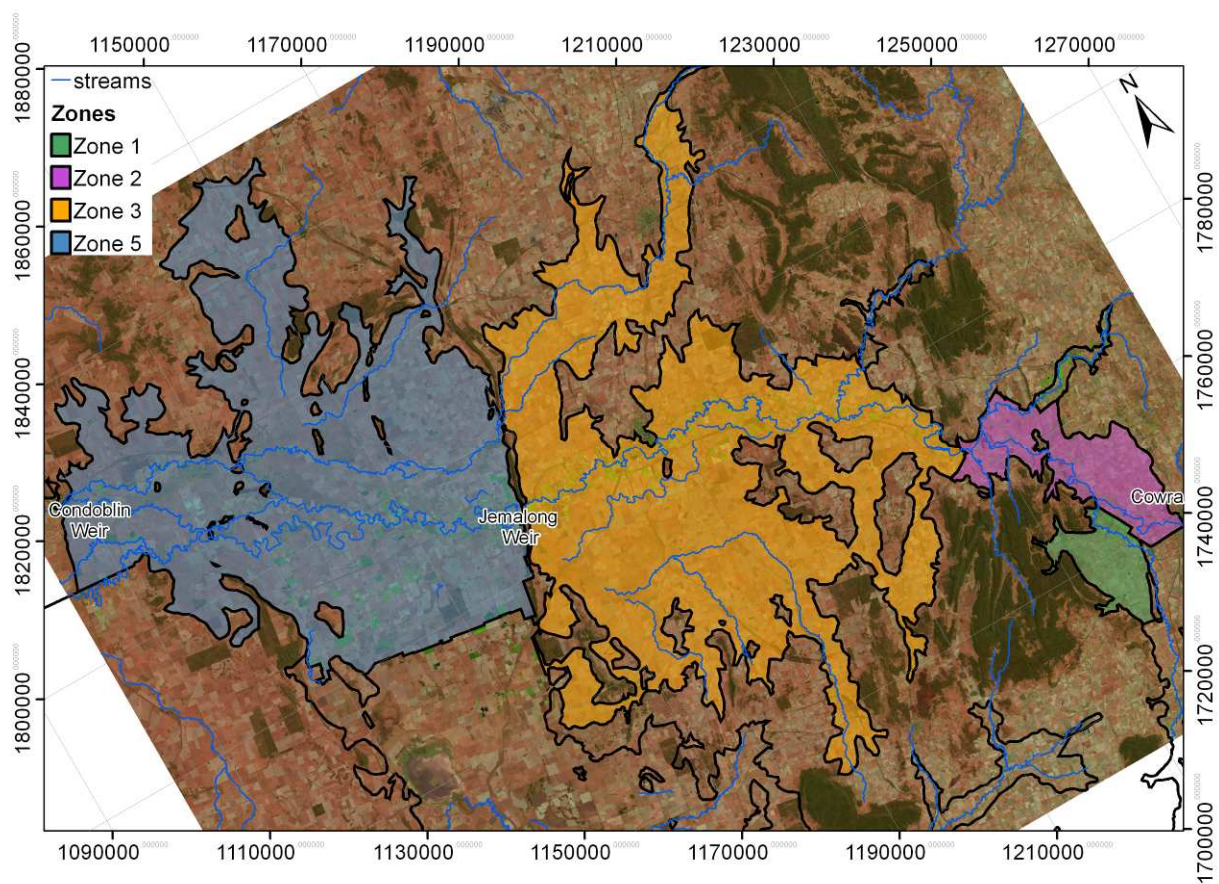


Figure 3-2. Upper Lachlan model extent and ground water management zones

3.1 Conceptualisation

The conceptual model for the Upper Lachlan model is two layered. The Lachlan Formation consists of highly conductive gravels and sands in a palaeochannel at the base of the alluvial sediments that forms a relatively narrow aquifer near the centre of the current river valley. The Lachlan Formation lies under the less conductive Cowra Formation, which fills the rest of the MDB. Due to the higher permeability of the Lachlan Formation, the majority of pumping bores extract water from this unit where it is present. A schematic of the conceptual hydrogeological model is shown in Figure 3-3.

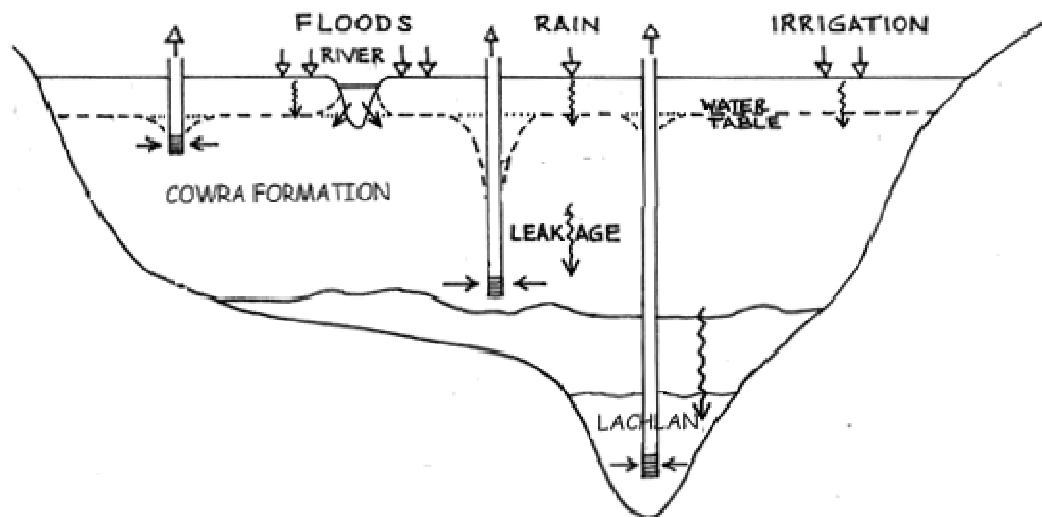


Figure 3-3. Conceptual model of the Upper Lachlan aquifers

3.2 Model construction

3.2.1 Model construction

The groundwater model domain and grid structure are shown in Figure 3-4 and Figure 3-5. The model extends from the Cowra river gauge upstream to the river gauge at Condobolin Weir downstream to the west. The numerical model grid consists of square cells that are 500 m by 500 m across the bulk of the model area, with a refined grid of 250 m by 250 m at Jemalong Weir. The smaller cell size at Jemalong Weir is needed to adequately represent groundwater movement in this region as there is only a narrow gap in a bedrock ridge through which all laterally moving groundwater must travel. The model includes three layers that represent the following stratigraphic units:

1. Upper Cowra Formation
2. Lower Cowra Formation
3. Lachlan Formation (deep lead aquifer).

There is no hydrogeological distinction between the Upper and Lower Cowra formation layers included in the model. The division of the Cowra Formation was included in order to avoid over estimating aquifer storage potential within this formation. MODFLOW assumes that all of the model's top layer will act as an unconfined aquifer that has storage characteristics defined by the specified specific yield term. In reality the Cowra Formation consists of shoestring sands with intervening silts and clays and it is unrealistic to assume that the full thickness of this unit acts in the manner of an unconfined aquifer. The Upper Cowra Formation was therefore included in the model with an arbitrary thickness of approximately 10 m near the centre of the valley. The base of the model and the boundary between the Cowra and Lachlan formation layers included in the model have been contoured from stratigraphy interpreted from bore logs of bores drilled in the region and from mapped outcrops. The Lachlan Formation was assumed to have limited extent, and to follow an ancient path of the Lachlan River. The extent of the Lachlan Formation was provided by New South Wales Department of Energy and Water (M. O'Rourke, pers. comm.)

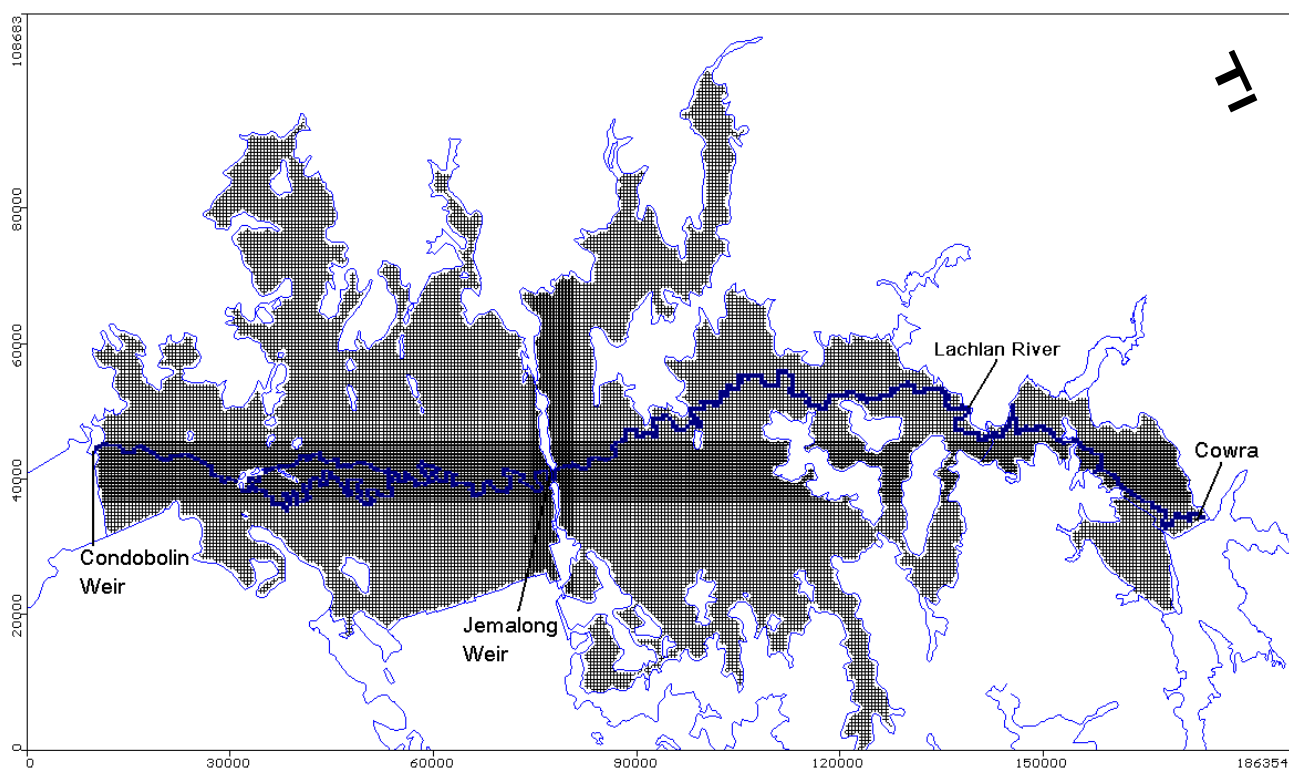


Figure 3-4. Numerical model grid – Cowra Formation

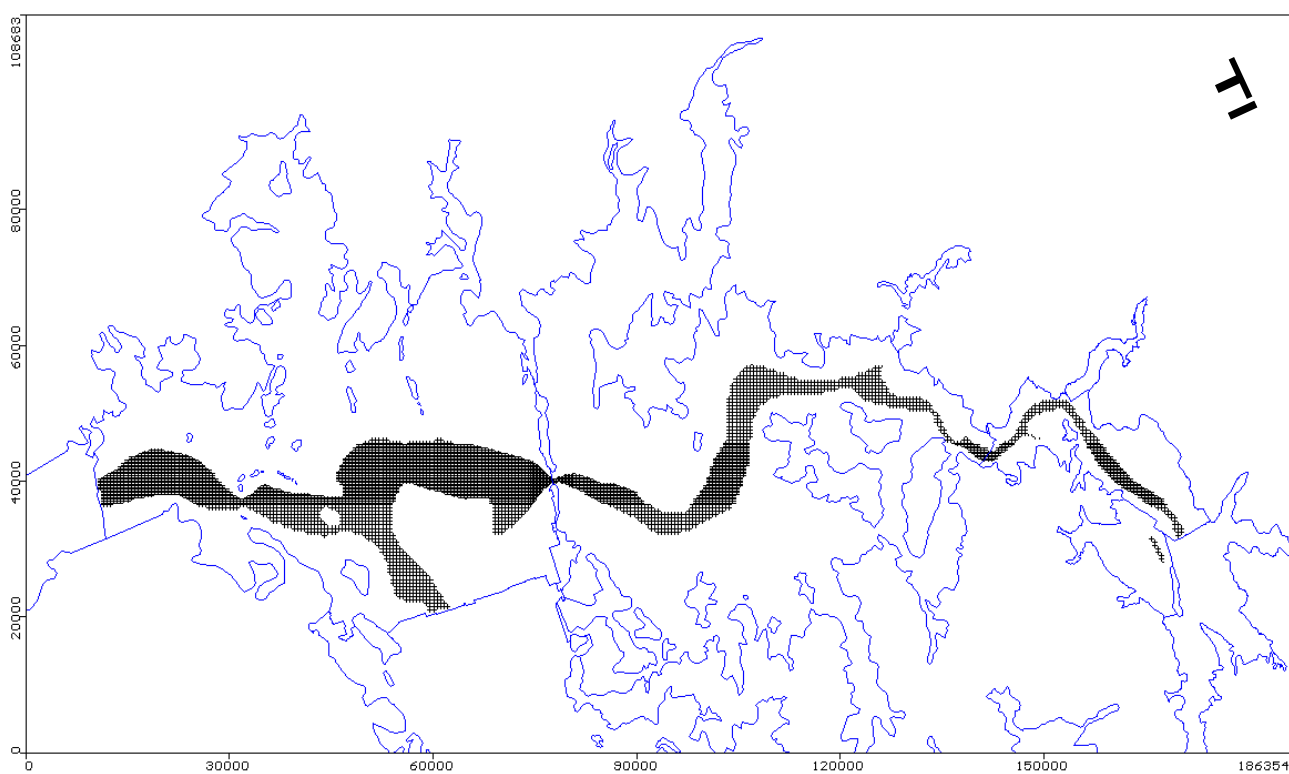


Figure 3-5. Numerical model grid – Lachlan Formation

3.2.2 Boundary conditions

In general the lateral model extents are defined as no flow boundaries. Flow is permitted across small segments of the model boundaries that have been assigned as general head boundaries as shown in Figure 3-6. General head boundary conditions allow water to enter or leave the model from or to surrounding aquifers according to prevailing groundwater gradients and as moderated by specified flow resistance terms. The Lachlan River is included as a line of MODFLOW river cells that also allow for water to enter or leave the model (shown in Figure 3-6). The river boundary condition is applied only in the top model layer, while the general head boundary cells are in all three model layers.

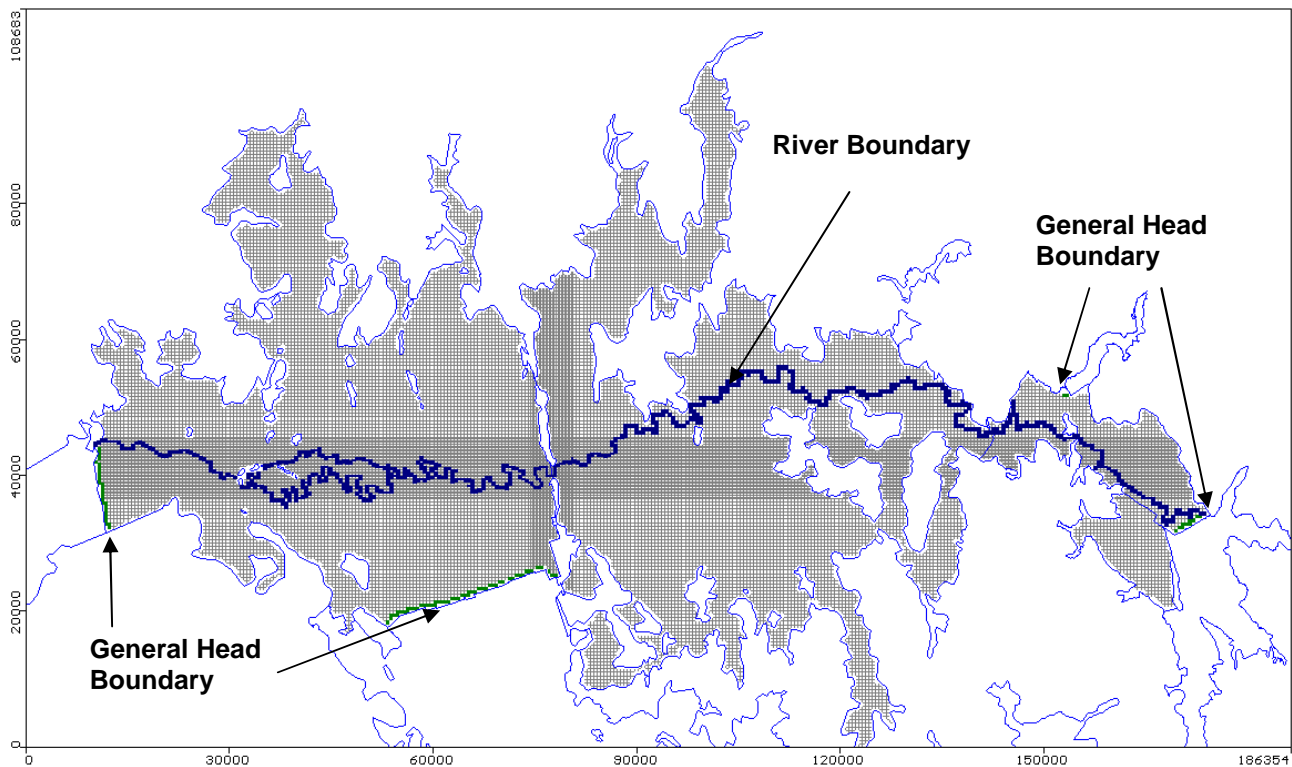


Figure 3-6. General head boundaries

3.2.3 Recharge

Recharge and evapotranspiration fluxes were applied to the model in a manner that was intended to replicate the combined impacts of rainfall recharge, irrigation accessions to groundwater and evapotranspiration from the watertable. Recharge fluxes were zoned in accordance with irrigation regions as identified in satellite imagery (Figure 3-8) and groundwater management zones (Figure 3-7). Figure 3-9 shows the interpreted recharge zones included in the model. Within the 'rainfall infiltration' areas, 1% of rainfall was applied as groundwater recharge. In the 'hills runoff' areas, 2% was applied. In the irrigated areas, 1% of monthly rainfall was used, except during summer months, when an additional 12.3 mm/year of irrigation-derived recharge flux is applied. This has the effect of adding a relatively small surcharge to rainfall-derived recharge during the irrigation season to account for irrigation accessions to groundwater.

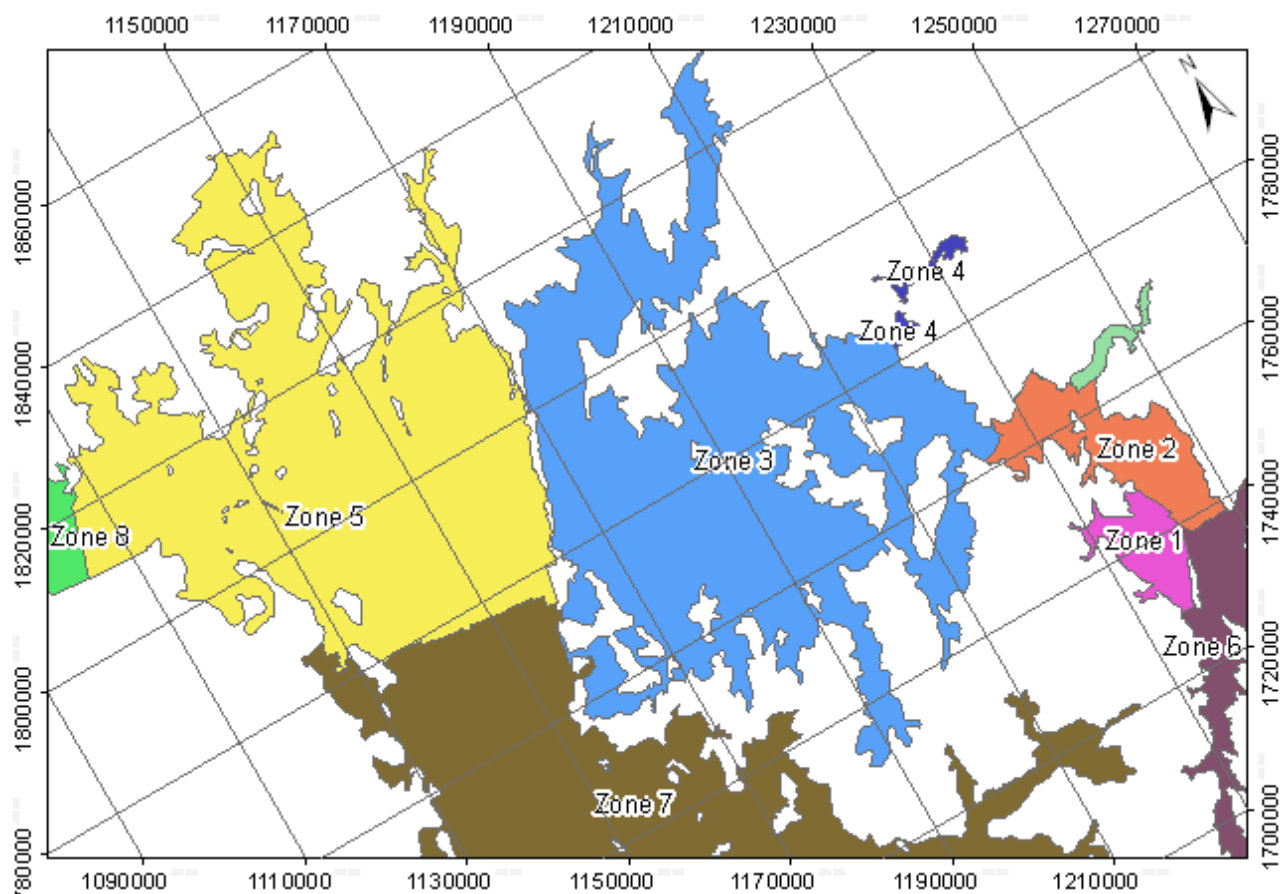


Figure 3-7. Groundwater management zones

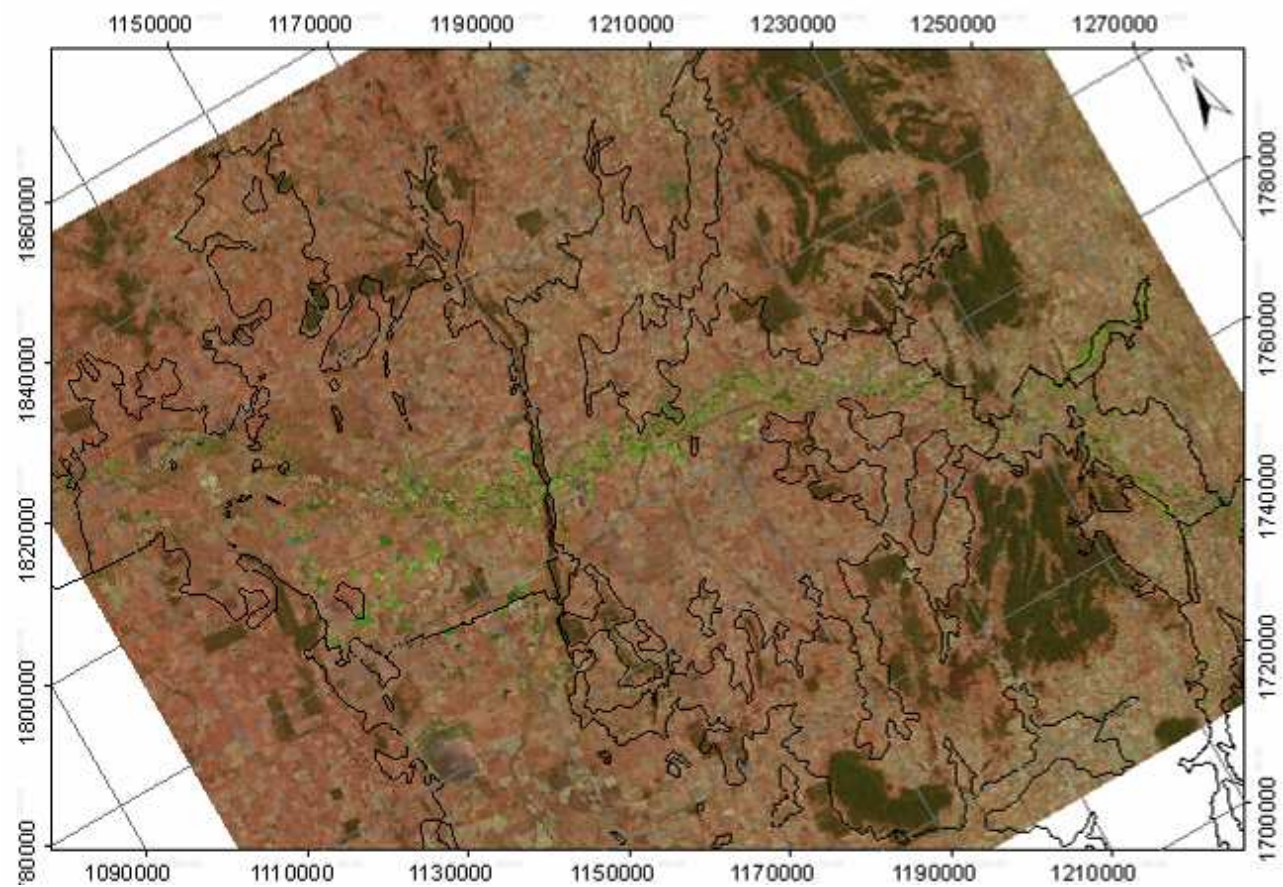


Figure 3-8. Landsat image from 2000 showing areas of irrigation

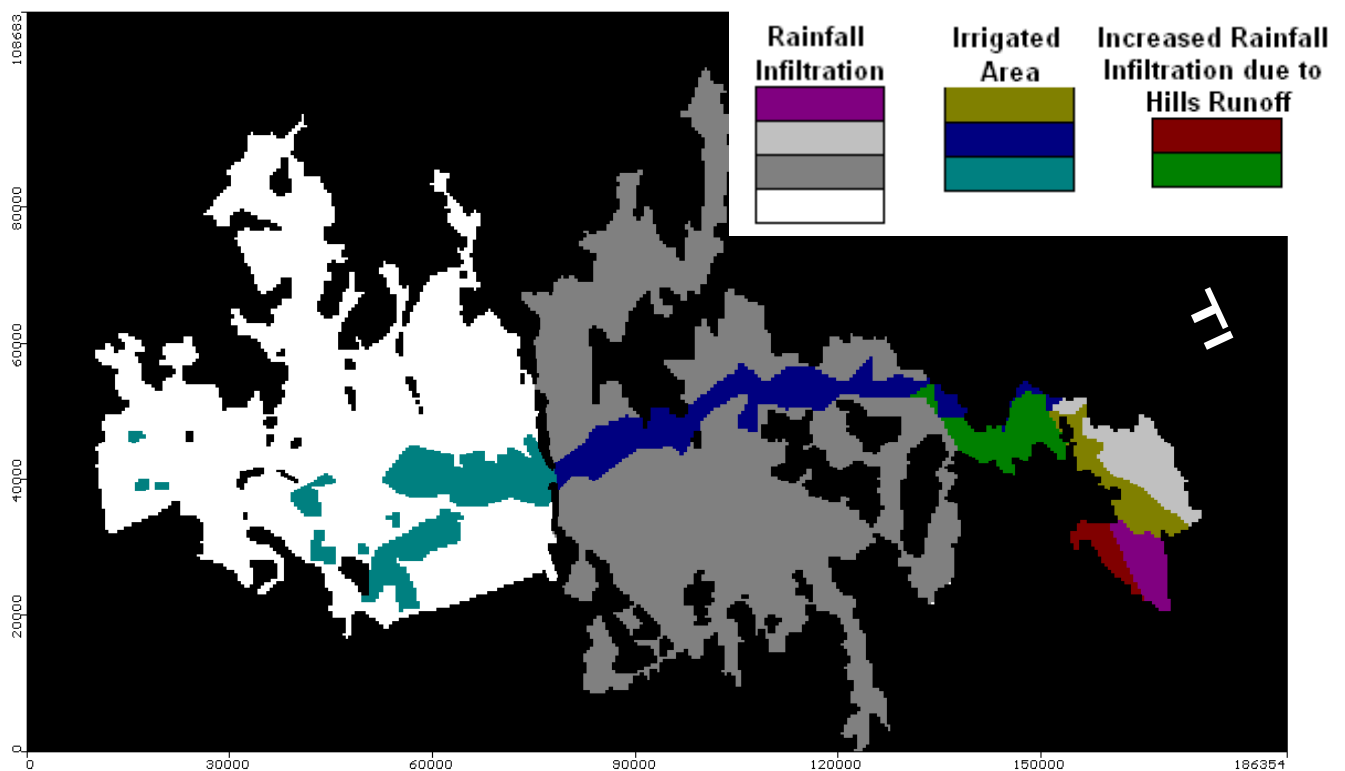


Figure 3-9. Recharge zones

3.2.4 Evapotranspiration

The model includes a single evapotranspiration zone that assumes a maximum groundwater evapotranspiration rate of 50% of average monthly recorded pan evaporation with a 2 m extinction depth.

3.2.5 Hydraulic properties

Figure 3-10 and Figure 3-11 show the hydraulic conductivities used in the model. It can be seen that conductivities are much higher in the Lower Lachlan aquifer than in the Upper Cowra Formation.

Specific storage (confined storage parameter) was set at $5 \times 10^{-6} \text{ m}^{-1}$ for all layers, and the specific yield or unconfined storage coefficient was set at 10%. The specific yield values are only activated when the watertable resides within the given model cell. When the watertable is predicted to be above a model cell it automatically assumes a confined storage (specific storage) value as the storage coefficient.

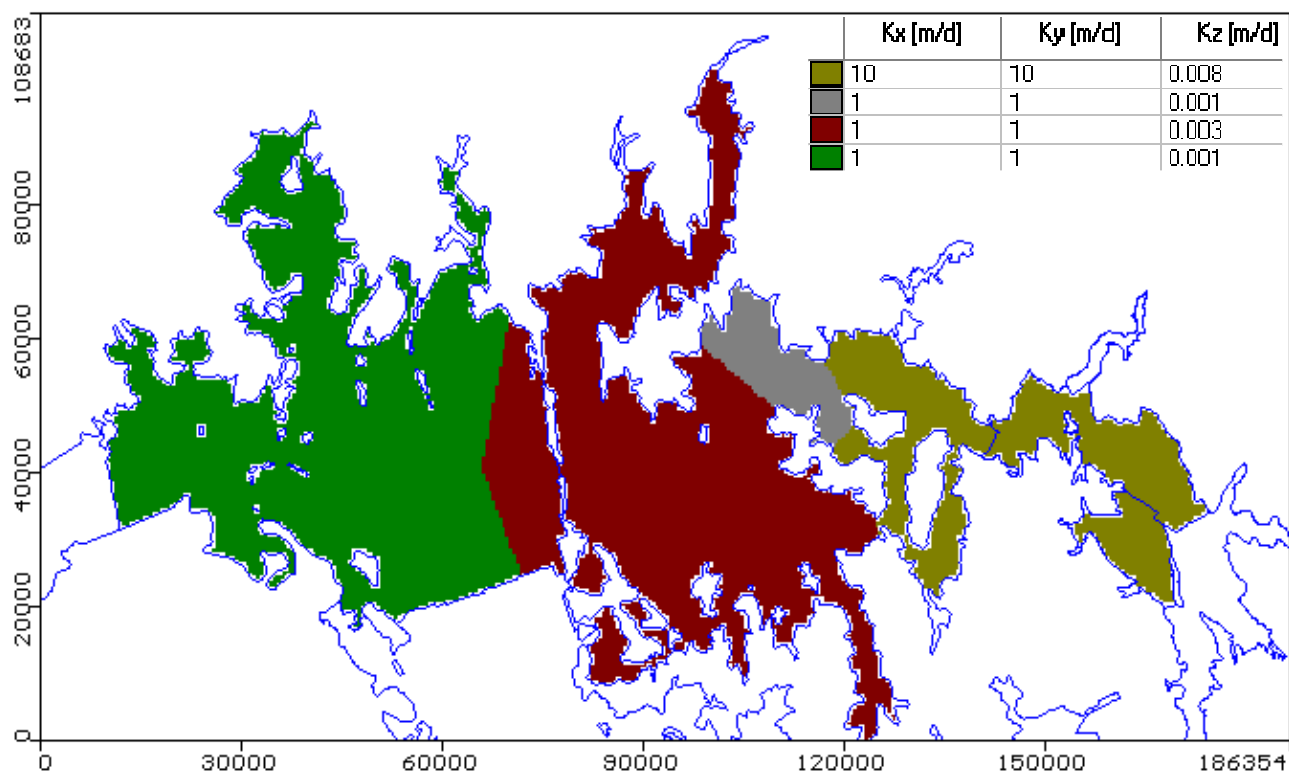


Figure 3-10. Hydraulic conductivity in the Cowra Formation (layers 1 and 2)

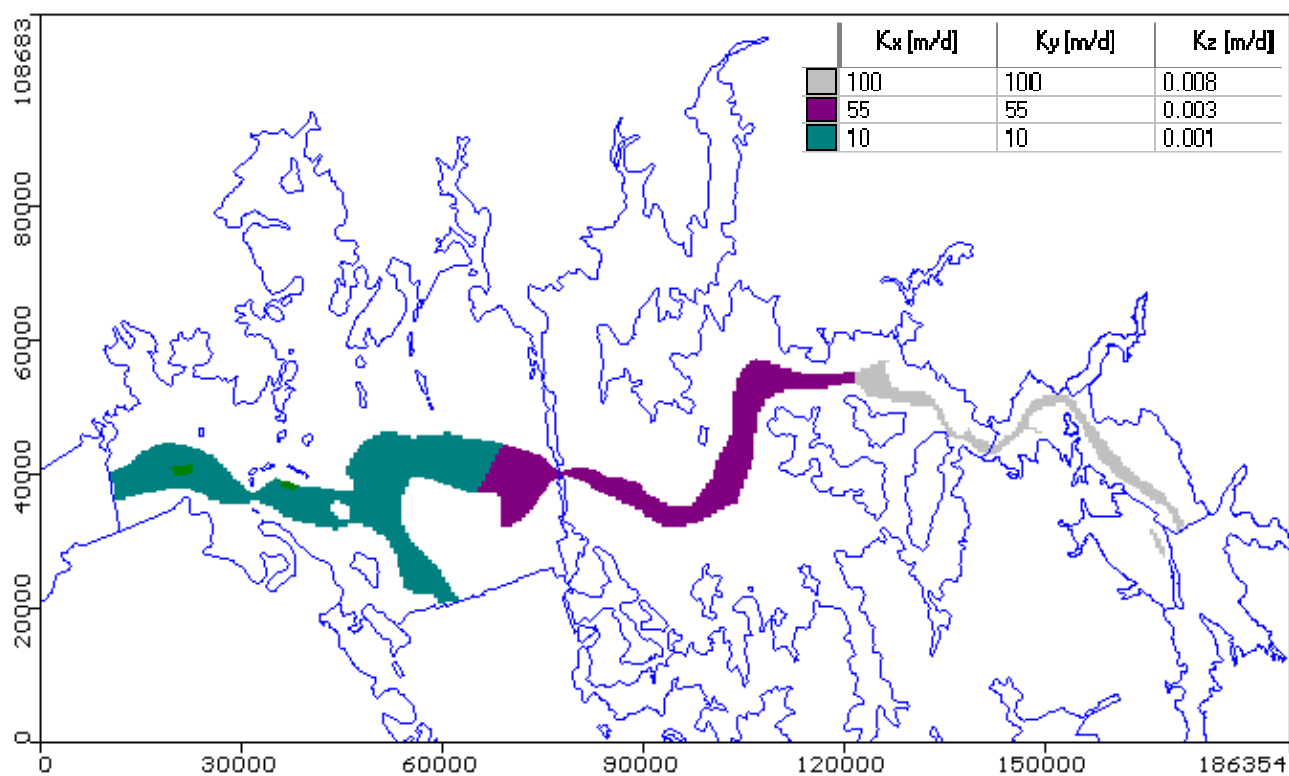


Figure 3-11. Hydraulic conductivity in the Lachlan Formation (Layer 3)

3.2.6 Pumping bores

Large-scale groundwater extraction for irrigation commenced in the late 1990s and continues today (Figure 4-2). The locations of the extraction bores are presented in Figure 3-12. Model calibration was based on metered water extractions from these bores. Subsequent predictive scenarios used the same set of groundwater extraction bores with volumes extracted being determined to match the conditions defined by the scenario being run.

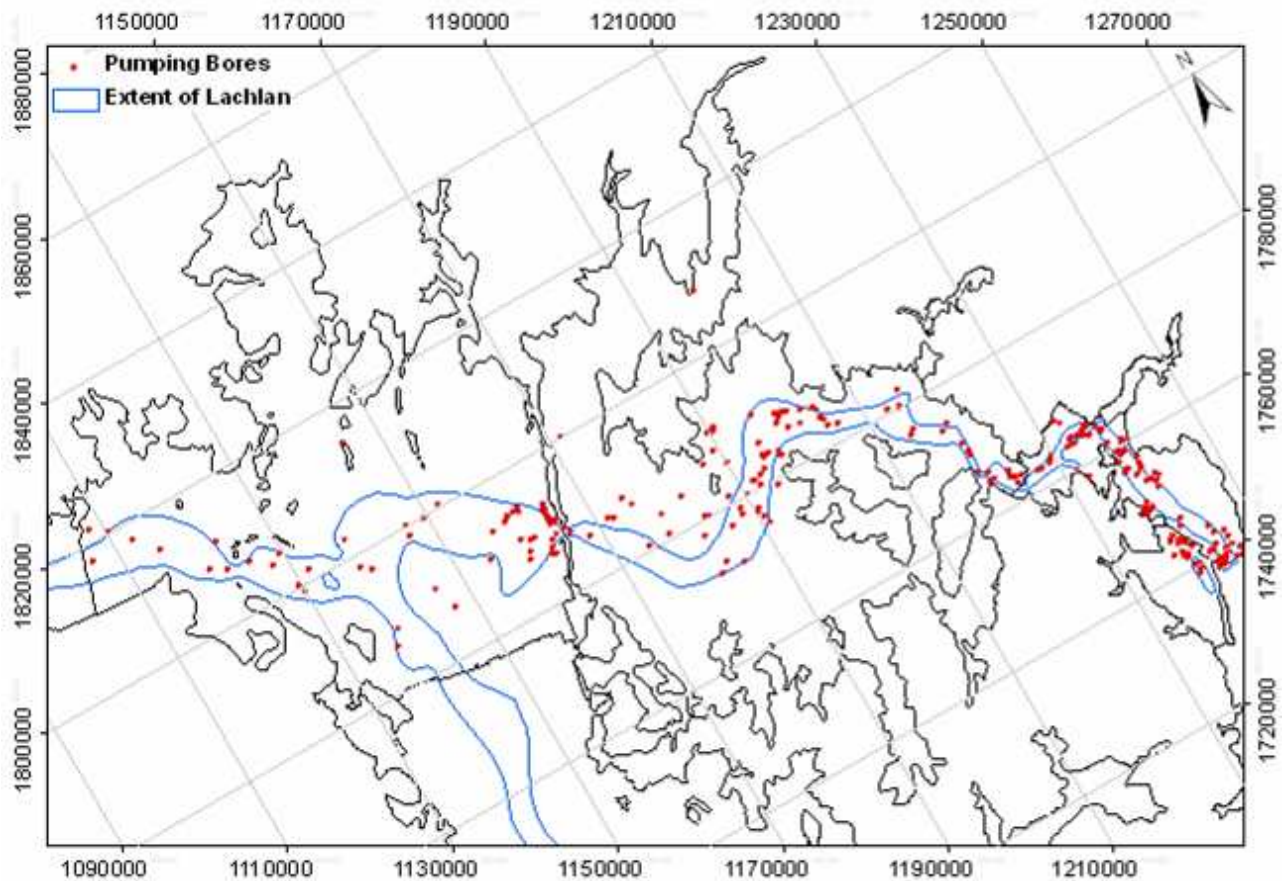


Figure 3-12. Extraction bores included in the model

4 Model calibration

4.1 Calibration method

The model was calibrated by matching predicted groundwater levels against measured hydrographs in a selection of observation bores located within the model domain. Many of these observation bores had multiple screens with recorded groundwater heads in both the Lachlan and Cowra formations. The locations of the observation bores used for calibration are shown in Figure 4-1.

The calibration model was run over the period 1998 to 2006 with monthly stress periods. The calibration period was chosen to include the onset and rapid increase in groundwater extraction that has been recorded in the area. The groundwater extractions included in the calibration model are shown as combined annual extraction volumes in Figure 4-2, and the locations of the extraction bores are presented in Figure 3-12.

Through a trial-and-error method the storage and hydraulic conductivity values were adjusted until the model was able to recreate measured hydrographs to an acceptable level of accuracy. The final calibrated properties are discussed in Section 3.2.5.

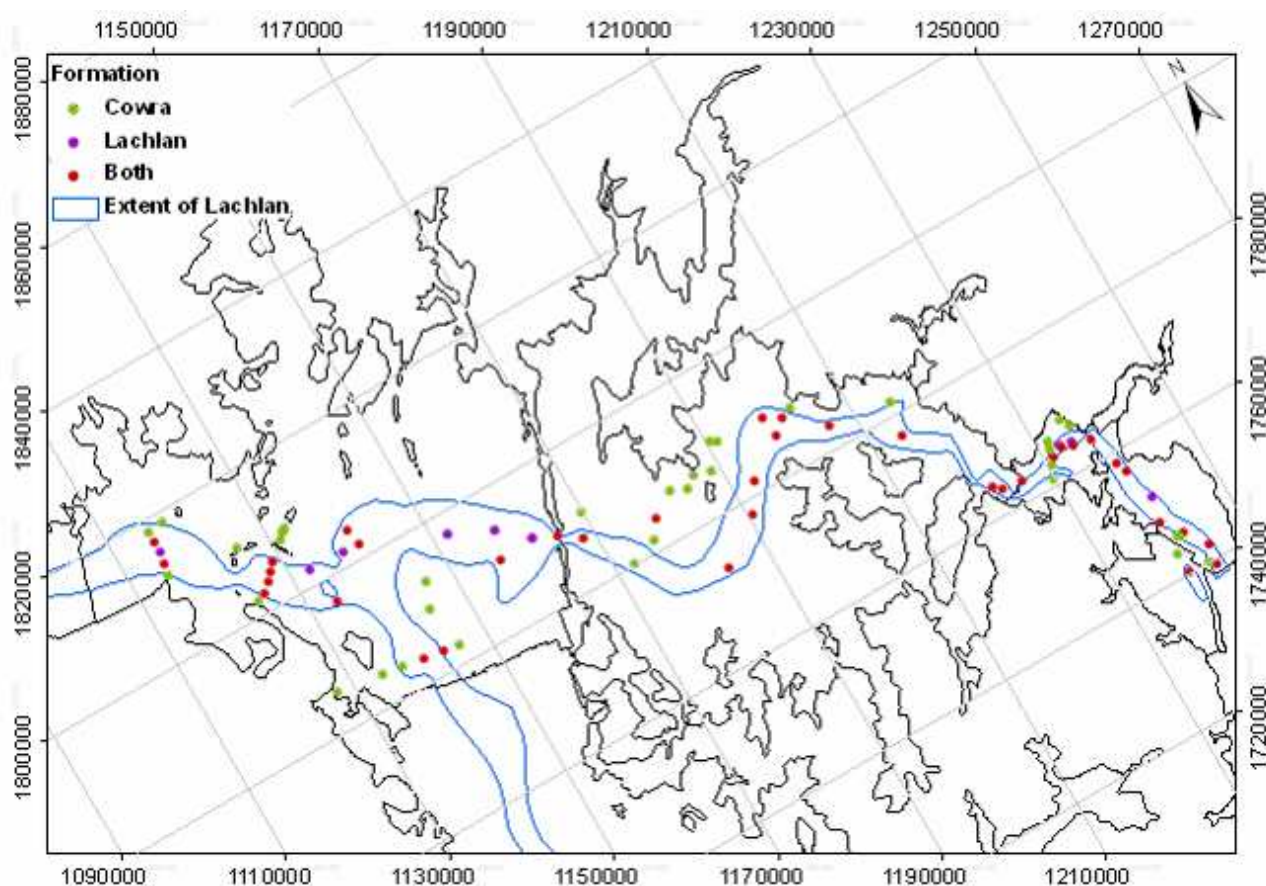


Figure 4-1. Calibration bores included in the model

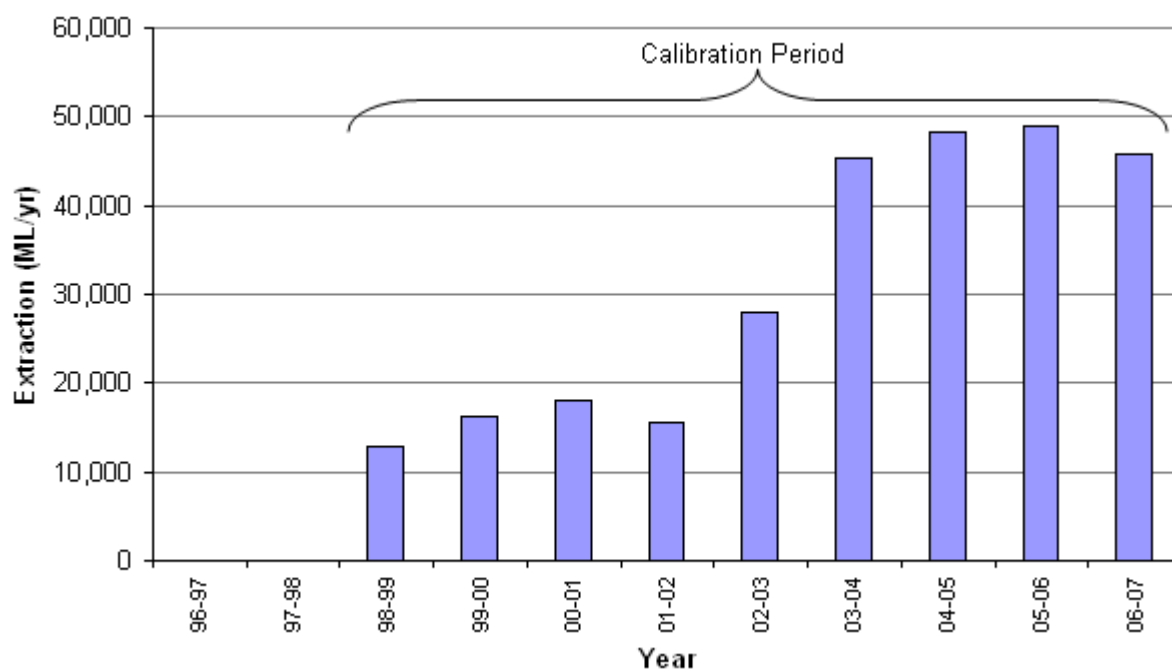


Figure 4-2. Volume of water extracted from aquifer system each year

4.1.1 Calibration statistics

The root mean squared (RMS) error for the calibrated model across all observation bores throughout the entire model period was 3.1%, and the correlation coefficient was 0.992 (Figure 4-3). This indicates a very strong correlation between predicted and expected head values.

When the RMS error is calculated on a time step by time step basis (Figure 4-4), it can be seen that the RMS grows in the last few time steps to 6%. This is because, although the model predicts general trends well, increased seasonal pumping at the end of the model creates groundwater fluctuations in adjacent bores that are hard to model exactly.

Figure 4-5 shows that the model residuals are centred on zero. This shows that the model residuals are not skewed and that the model does not consistently over or under estimate groundwater levels.

Two examples of calibrated bore hydrographs are shown as Figure 4-6 and Figure 4-7. In total, 78 observation bores were used to calibrate the model, many with screens at multiple depths. Observation bore GW030373 in Figure 4-6 has four screens, but only two predicted hydrograph traces. This is because the four screens were positioned within only two of the model layers. When two or more screens are positioned in the same model layer they have the same predicted hydrograph, even if they are at different depths within the layer. A full set of calibration hydrographs is included in Appendix A.

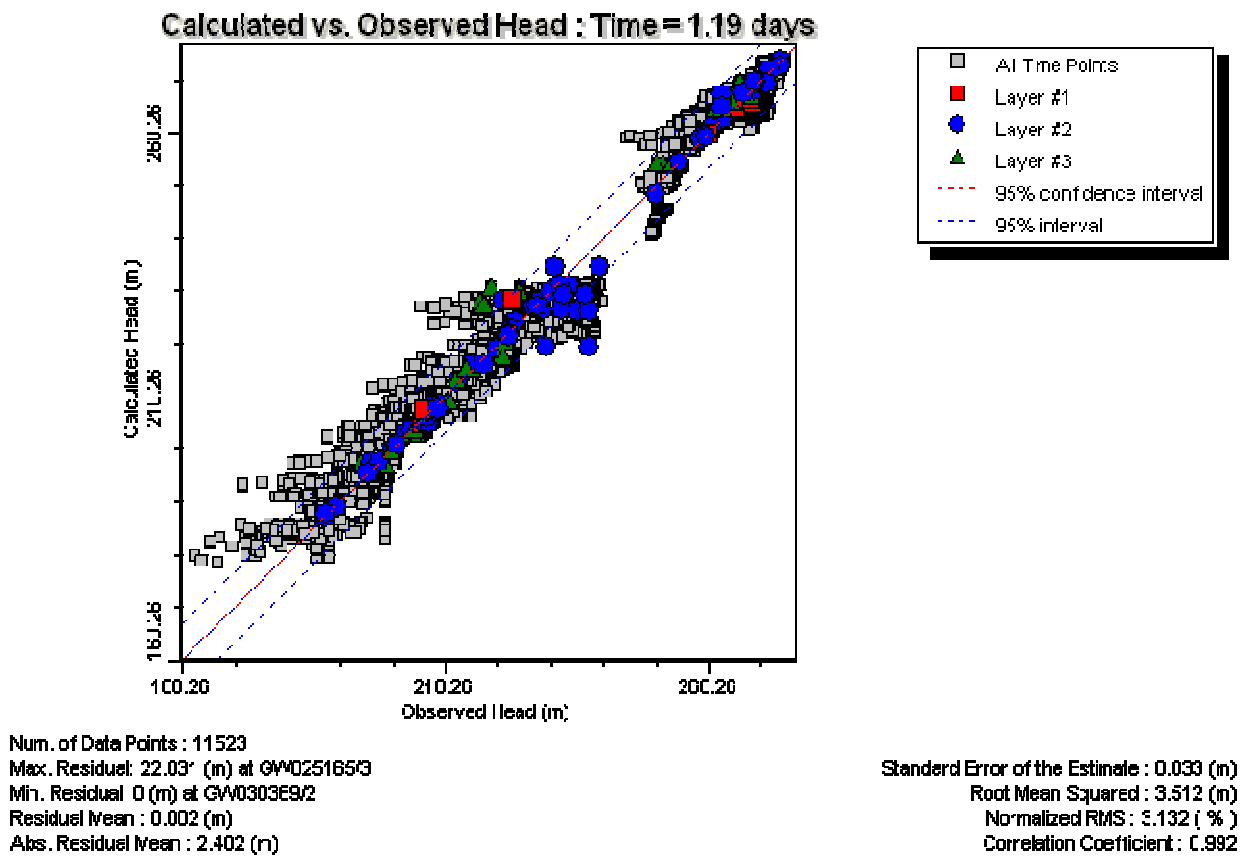


Figure 4-3. Observed versus calculated head normalised root mean squared error

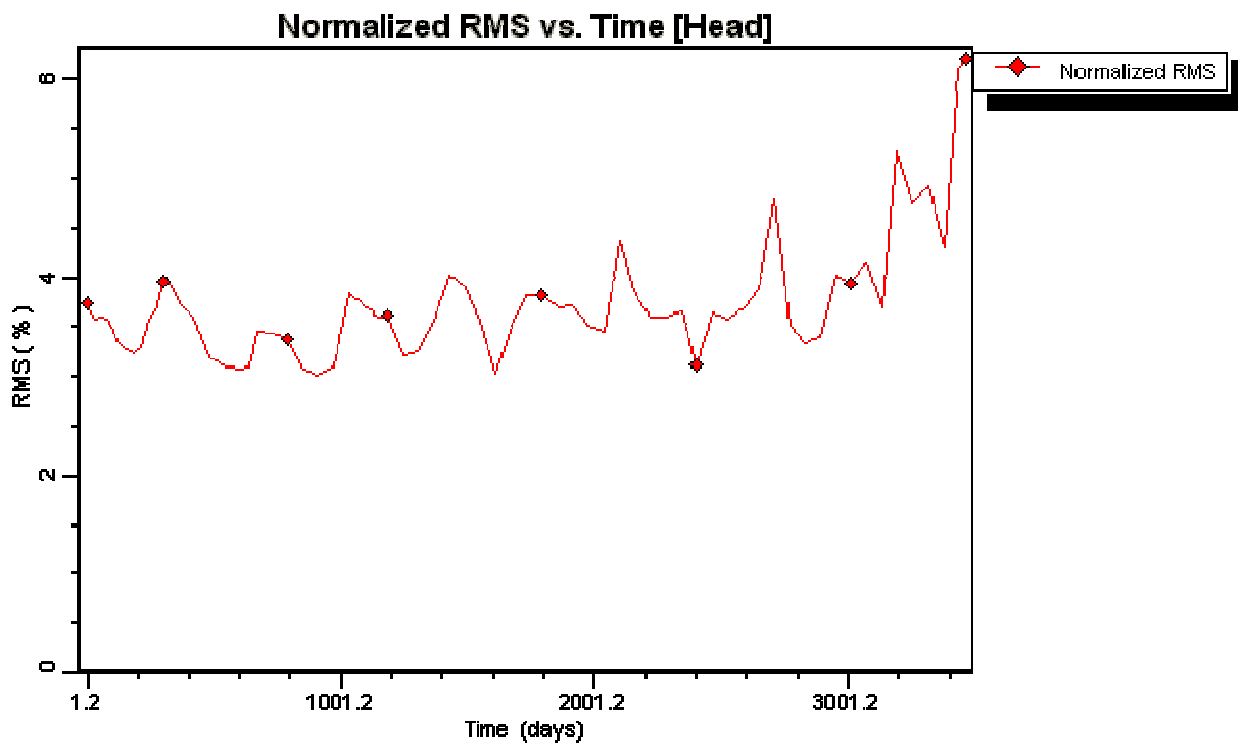


Figure 4-4. Normalised root mean squared error versus time

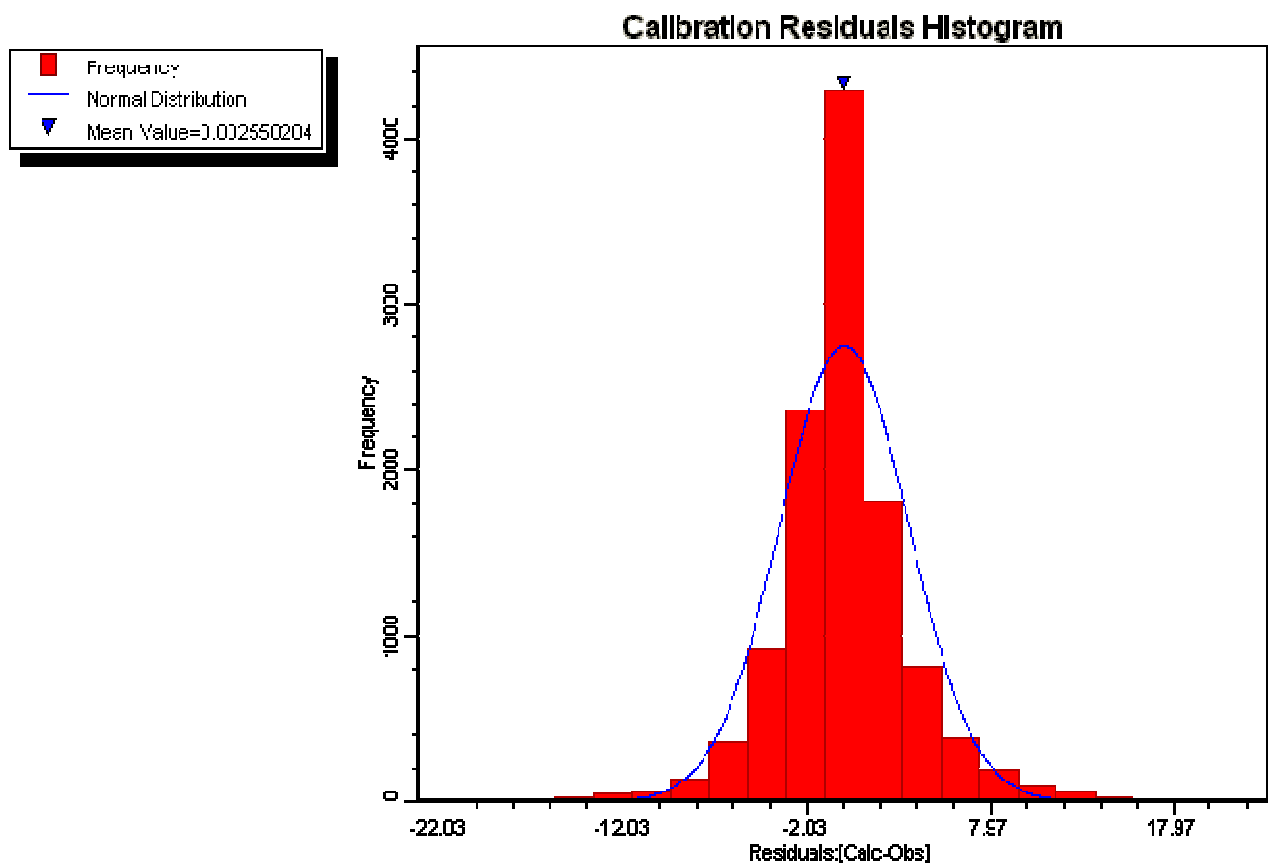


Figure 4-5. Residuals histogram

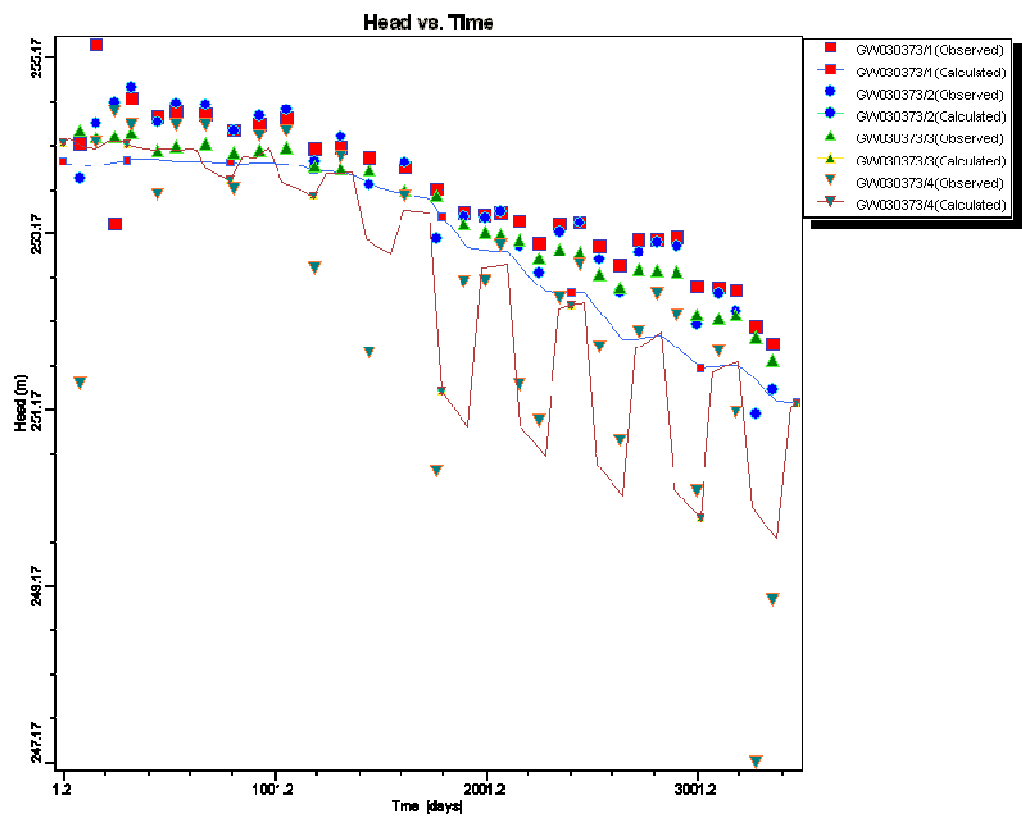


Figure 4-6. Example calibrated bore hydrographs plot 1

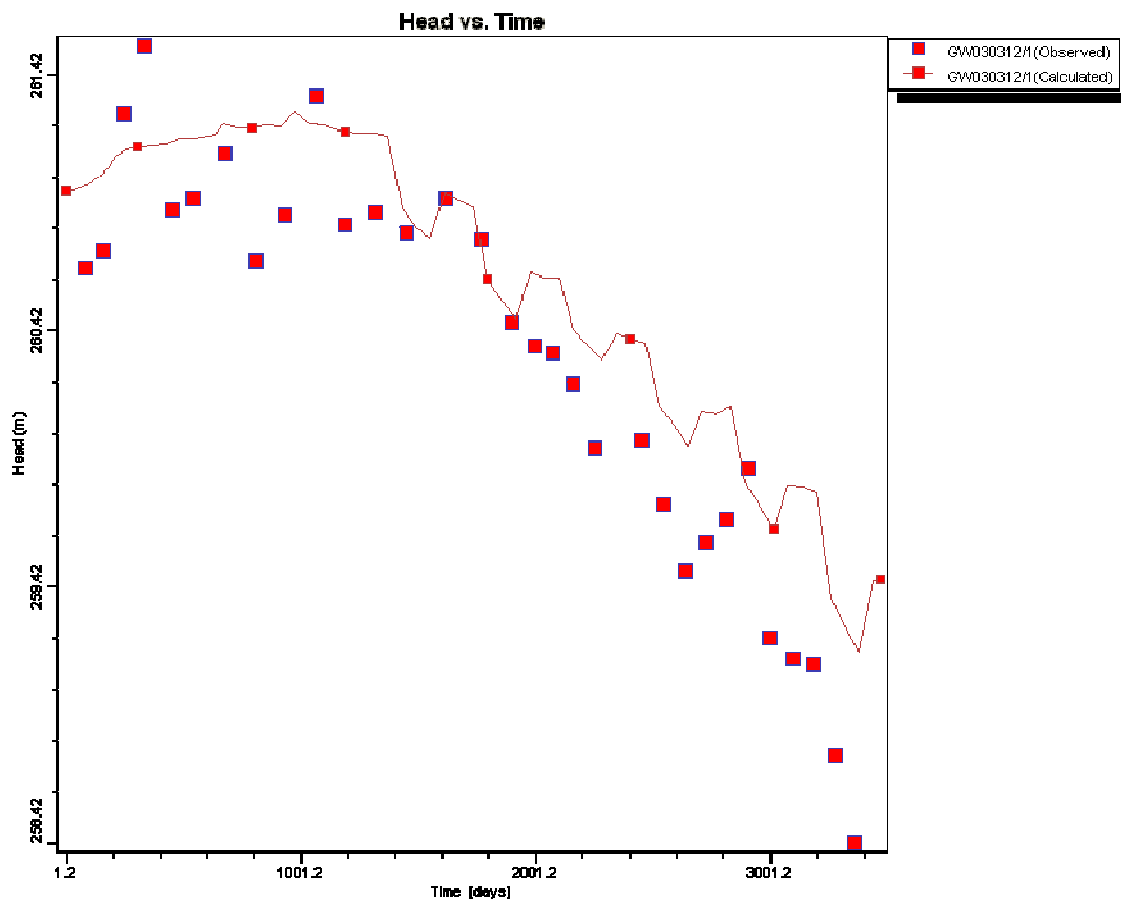


Figure 4-7. Example calibrated bore hydrographs plot 2

4.1.2 Mass balance

The mass balance for the calibrated model is presented graphically in Figure 4-8. Evapotranspiration is a major component of the groundwater discharge (OUT) occurring in the calibration model. Evapotranspiration has been defined, in accordance with MODFLOW input requirements, as having a maximum rate equal to about 50% of the mean monthly pan evaporation for the region and an extinction depth of 2 m. Water is extracted from the model at a rate determined from a linear interpolation ranging from the maximum rate (when the watertable is at the ground surface) to zero (when the watertable is 2 m below the surface). Evapotranspiration is therefore only active in those areas where the watertable is within 2 m of the ground surface.

Figure 4-9 shows the regions in the model where the depth to watertable is less than 2 m and hence evapotranspiration is active. The region is colour coded according to depth to watertable with the red being close to 2 m depth while the blue is where the watertable is close to the surface and evapotranspiration rates are close to the maximum rate. While most of the active evapotranspiration zones in the central and western parts of the model exhibit water levels marginally less than 2 m below the surface, that region highlighted around the river has watertables at or near the ground surface (top of model) and therefore has relatively high evapotranspiration fluxes. Evapotranspiration therefore appears to be concentrated on that region around the river upstream of Jemalong Weir. The apparent superposition of evapotranspiration fluxes on MODFLOW river cells can, in some cases, give rise to model artefacts in that there are competing, head-dependent boundary conditions acting on the same cells. River cells force water to enter or leave the model to maintain the specified river stage while evapotranspiration extracts water from the model in accordance with the watertable depth at the same cells. The net impact of the superposition is that predicted river losses and evapotranspiration fluxes can become artificially inflated. In order to avoid potential double accounting of losses to the river and evapotranspiration a number of results relating to model water balances are presented for the model with and without evapotranspiration fluxes from river boundary cells. This correction not only affects the evapotranspiration fluxes; it is also applied to the river leakage (river OUT) results.

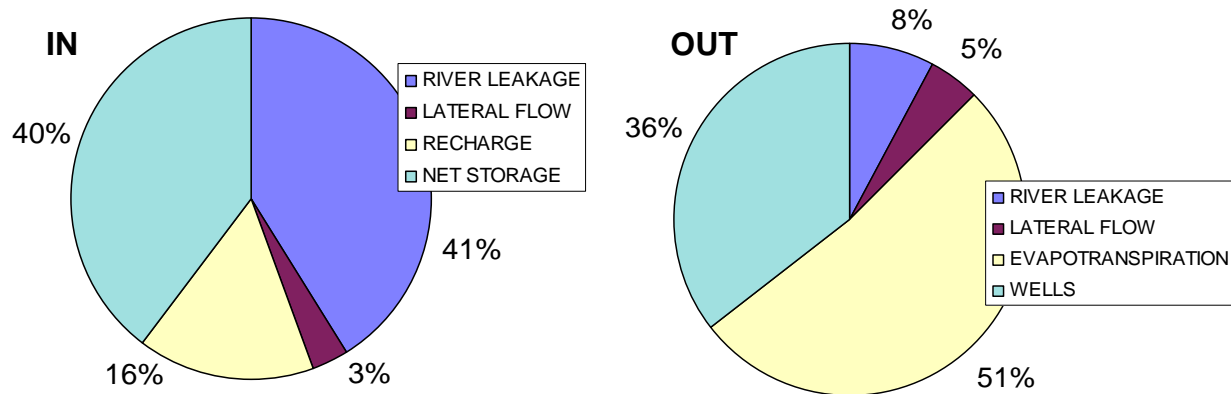


Figure 4-8. Mass balance for calibration model (total flow in = total flow out)

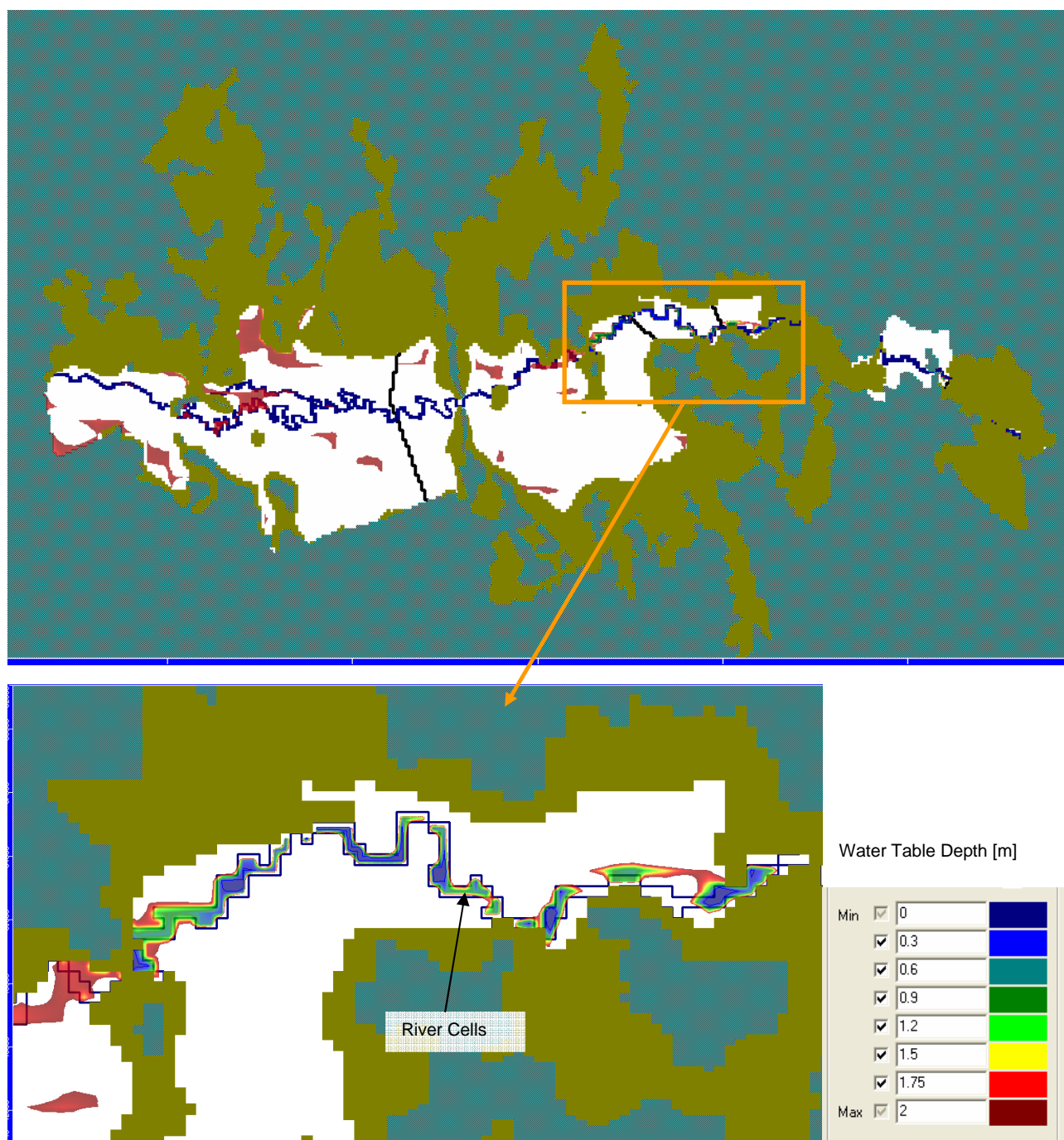


Figure 4-9. Region of active evapotranspiration at the end of calibration model

5 Predictive scenario method

The following predictive scenarios were run:

- **Scenario A** – Groundwater extraction levels are set at the proposed extraction limit for the aquifer (approximately 65,000 ML/year) and climatic stresses including rainfall recharge and flooding inundation were obtained from recorded climatic and river flow data over the period 1895 to 2006. River stage is obtained from an interpolation of stage heights obtained from the IQQM river model run over the same time frame with the same assumed climatic conditions. River stage time series for all river boundary cells are calculated using the IQQM model predicted stages at key nodes (refer to Figure 5-1 and Table 5-2 for locations of key river nodes included in the model).
- **Scenario B** – This scenario is defined as current levels of groundwater extraction with climatic stresses (rainfall and evaporation) based on the last ten years of measured climate. However since the last ten years of climate in the Lachlan Catchment has been wetter than the long-term average, this scenario was not run for the Upper Lachlan Model.
- **Scenario C** – This scenario includes the same assumptions and input data as Scenario A except that the assumed climatic stresses (rainfall recharge) are derived from climate models that assume varying levels of greenhouse gas emissions. Dry, medium and wet climate scenarios are defined for Scenario C and hence there are three different groundwater models for this scenario. River stage and recharge are calculated separately for these models given the climatic and river flow modelling results. Recharge fluxes are obtained by applying a scaling factor to the recharge fluxes included in Scenario A. The scaling factors have been obtained from recharge modelling and are shown in Table 5-1.

Table 5-1. Recharge scaling factors

Scenario	Scenario ID	Recharge scaling factor
Cdry, Ddry	CPH_10, DPH_10	0.66
Cmid, Dmid	CPM_50, DPM_50	0.98
Cwet, Dwet	CPH_90, DPH_90	1.21

- **Scenario D** – This scenario includes the same assumptions and input data as Scenario C except that the assumed groundwater extraction is at the long-term average extraction limit for the aquifer. In the Upper Lachlan this is assumed to be as high as 120 GL/year. Scenario D also includes assumptions of changes in land use, river diversions and groundwater extraction in areas upstream of the groundwater model. Dry, medium and wet climate scenarios are defined for Scenario D using the same climatic assumptions as those used in Scenario C. River stage and recharge are calculated separately for these models given the climatic and river flow modelling results.

The scenarios were run for 111 years of ‘warm-up’ followed by a further 111 years for the actual scenario. The warm-up model run is intended to establish quasi-steady state or dynamic equilibrium conditions prior to the start of the scenario run. The warm-up models include initial conditions defined by the without-development steady state model and the heads at the end of the warm-up model are used for the subsequent scenario runs.

In addition, a without-development scenario was run to generate data to determine the effect of pumping. Each of these scenarios is described below.

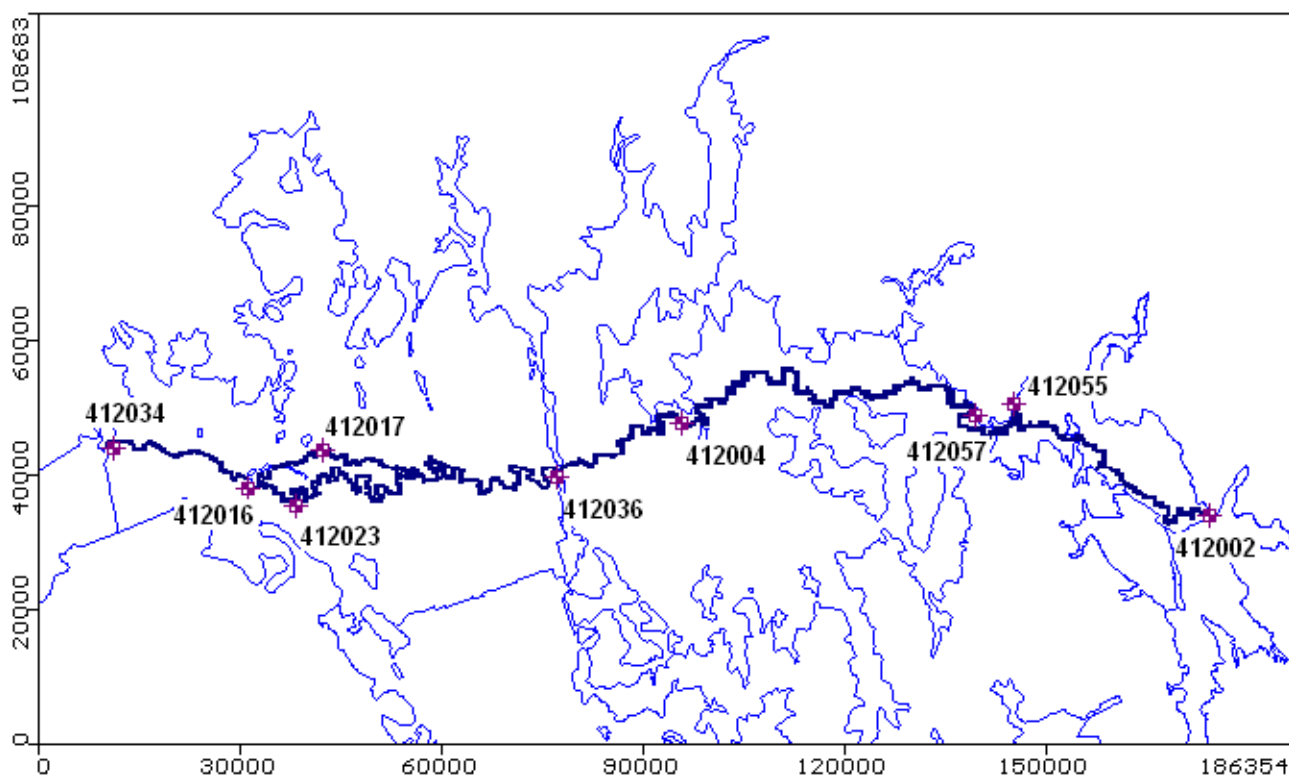


Figure 5-1. River gauge locations used to define MODFLOW river cells

Table 5-2. River gauges used to define MODFLOW zones

MODFLOW zone	Upstream gauge	Downstream gauge
2	412002	412055
3	412055	412057
4	412057	412004
5	412004	412036
6	412036	412017
7	412017	412016
8	412016	412034
10	412023	412016
11	412016	Outside IQQM

5.1 Results

5.1.1 Mass balances

The mass balance components under all scenarios are summarised in Table 5-3. As seen in this table the inputs to the mass balance under all scenarios consist of aerially distributed recharge associated with percolation of rainfall and irrigation, losses of water from rivers, and inflows from surrounding aquifers. The outflow includes groundwater discharge to rivers and evapotranspiration and the extraction of groundwater from wells. Lateral fluxes of groundwater out of the model domain are insignificant under all scenarios considered in this project.

Table 5-3 illustrates that although the model inputs specify an extraction rate of 120 GL/year for the three D scenarios, the model is only able to average 64 to 69 GL/year under these scenarios. This discrepancy is caused by the fact that drawdown induced by pumping leads to drying of cells in the Cowra Formation and to loss of groundwater production from these cells. The result suggests that with the current distribution of groundwater extraction wells the aquifer in the long term is unable to sustain levels of extraction that are greater than about 70 GL/year.

Table 5-3. Upper Lachlan groundwater modelled average annual water balance

Groundwater modelled average annual water balance	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	GL/y							
Recharge (gains)								
Rainfall/irrigation	18	none	13	18	21	13	18	21
River	44	none	43	43	44	48	48	49
Lateral flow	6	none	6	6	6	10	9	9
Total	69	none	63	67	71	70	75	79
Discharge (losses)								
Extraction	61	none	61	61	62	64	67	69
River	3	none	2	2	2	2	2	2
Lateral flow	0	none	0	0	0	0	0	0
Evapotranspiration	20		18	19	21	17	19	20
Total	84	none	81	82	85	83	88	91
Change in storage	15		18	15	14	13	13	12

5.1.2 Groundwater levels

Groundwater hydrographs were predicted for the Cowra and Lachlan formations at key locations in the model corresponding to existing monitoring bores. Reporting locations are presented in Figure 5-2. Predicted hydrographs under all scenarios are shown in Figure 5-3 to Figure 5-7. The hydrographs suggest that in much of the aquifer the groundwater levels are still falling and that dynamic equilibrium was not reached despite a 111-year warm-up period. Figure 5-8 and Figure 5-9 show the difference in groundwater head (drawdown) between the start and end of the Scenario A model for the Cowra and Lachlan formations respectively. It is clear that groundwater heads in the central part of the model have fallen over the duration of the model suggesting that the model did not reach dynamic equilibrium prior to the start of the scenario runs.

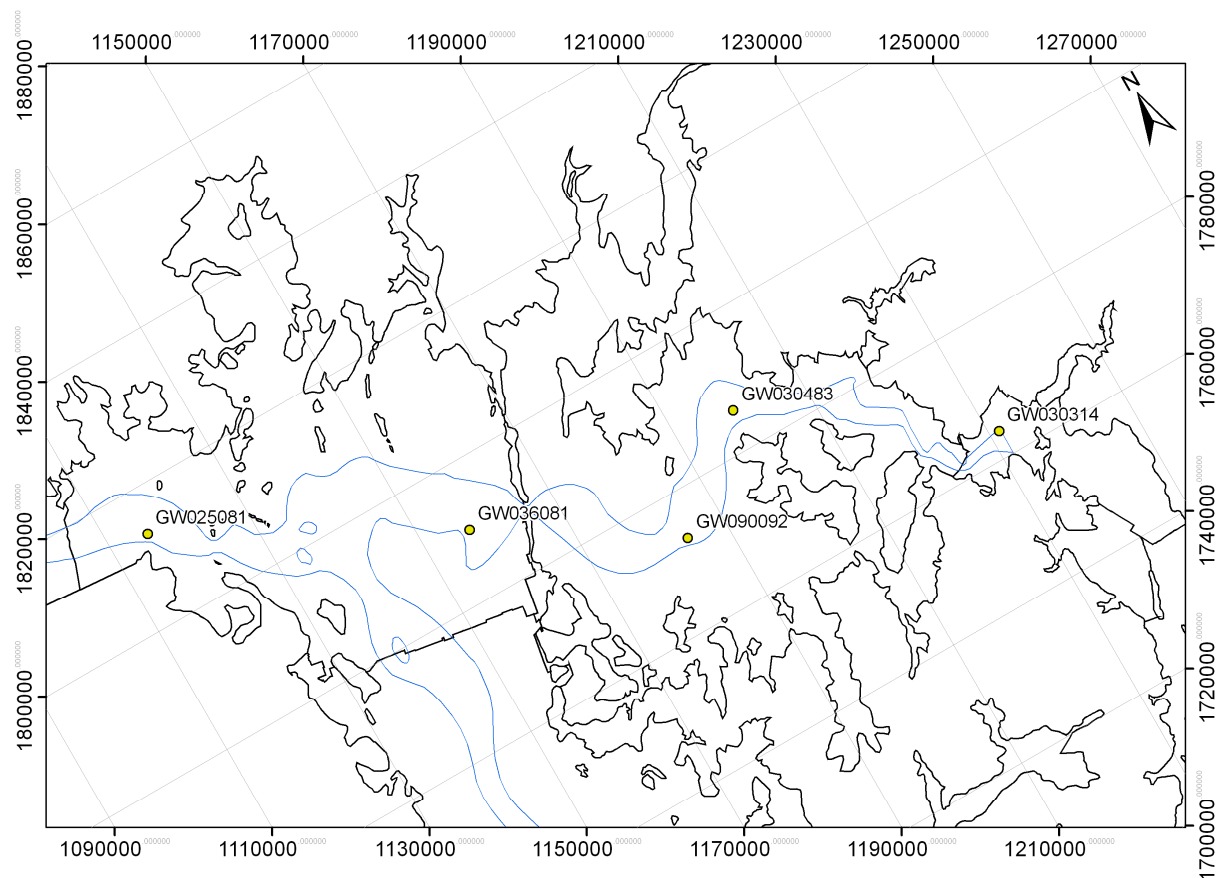


Figure 5-2. Locations of predicted hydrograph outputs

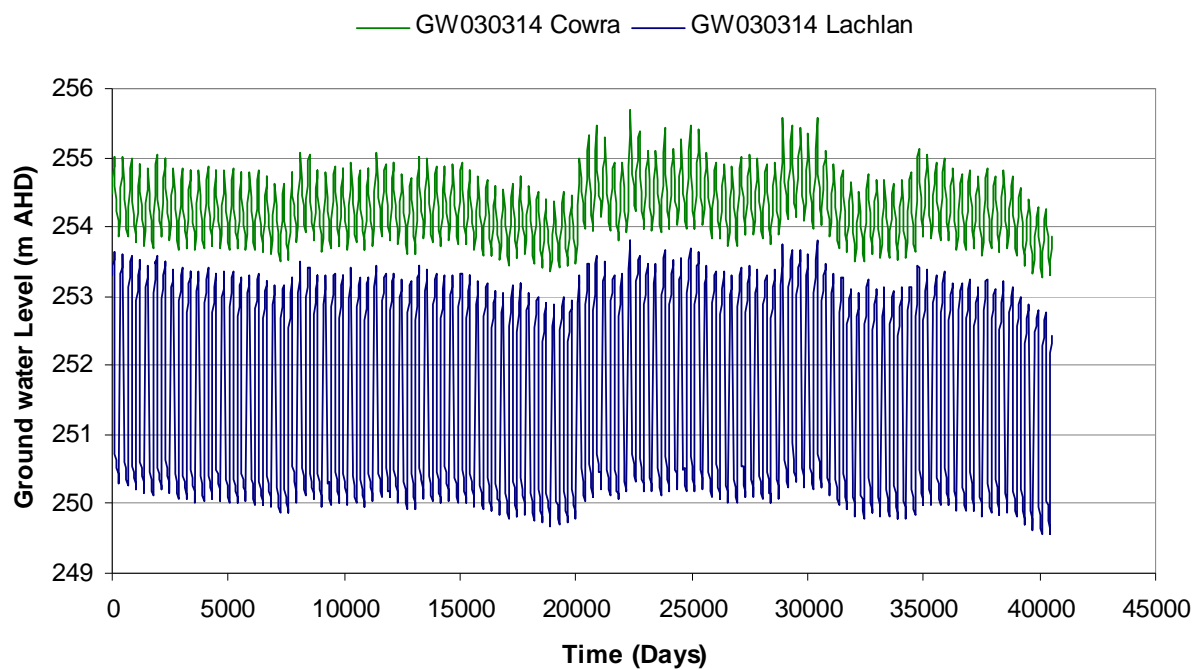


Figure 5-3. Calculated hydrograph for GW030314 under Scenario A

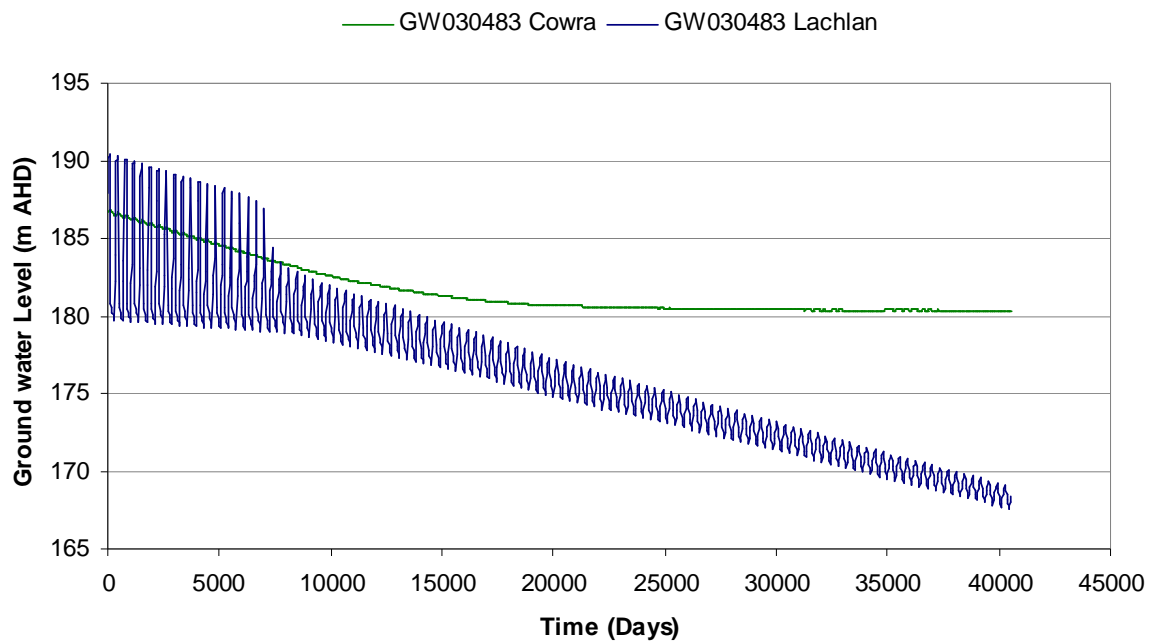


Figure 5-4. Calculated hydrograph for GW030483 under Scenario A

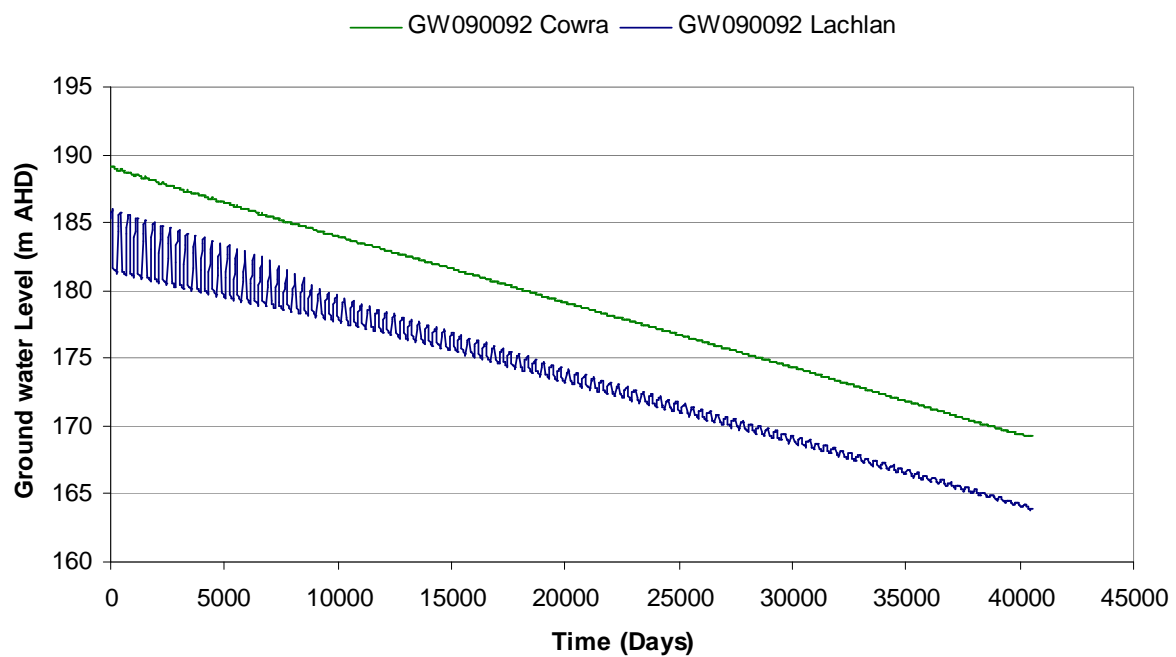


Figure 5-5. Calculated hydrograph for GW090092 under Scenario A

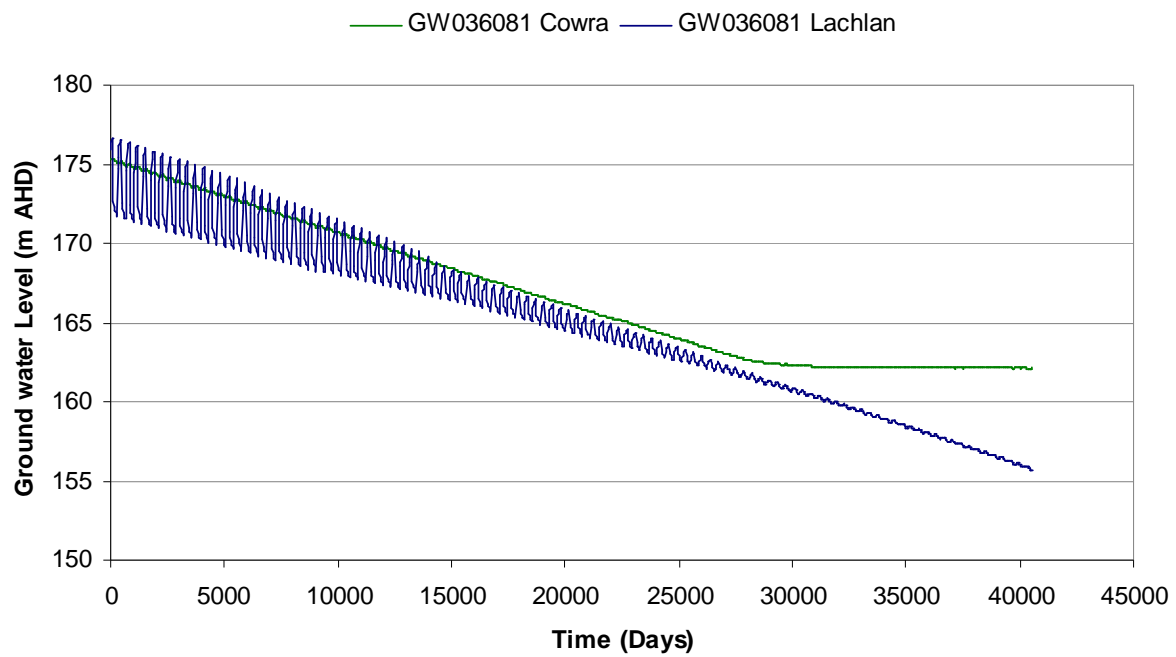


Figure 5-6. Calculated hydrograph for GW036081 under Scenario A

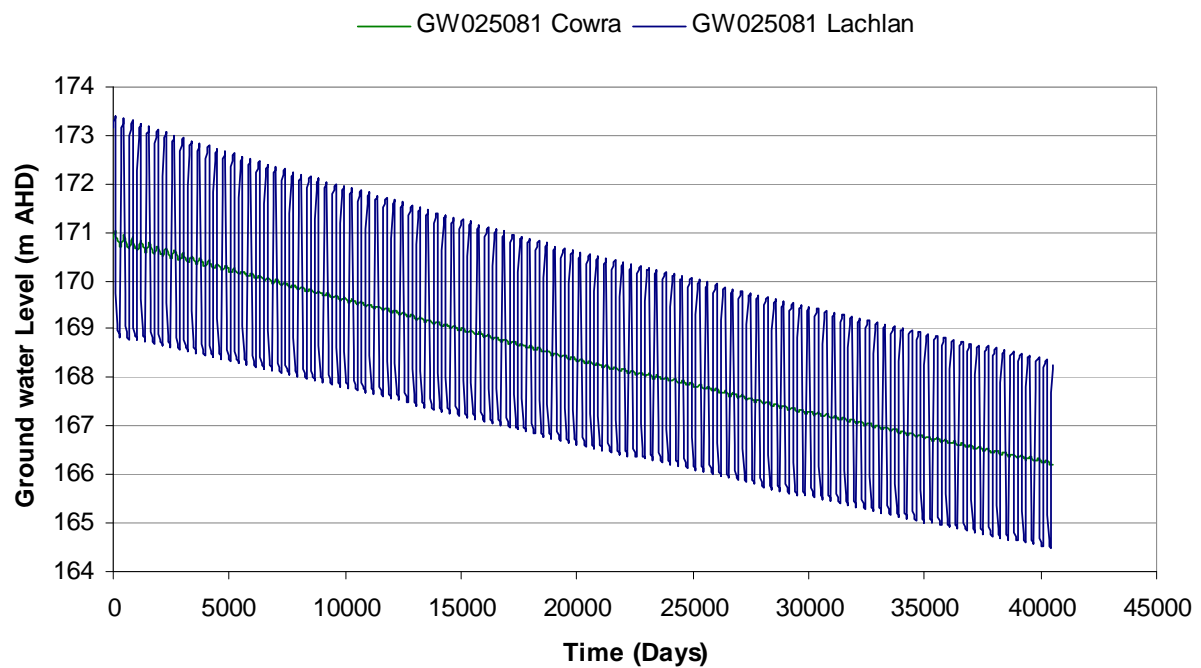


Figure 5-7. Calculated hydrograph for GW025081 under Scenario A

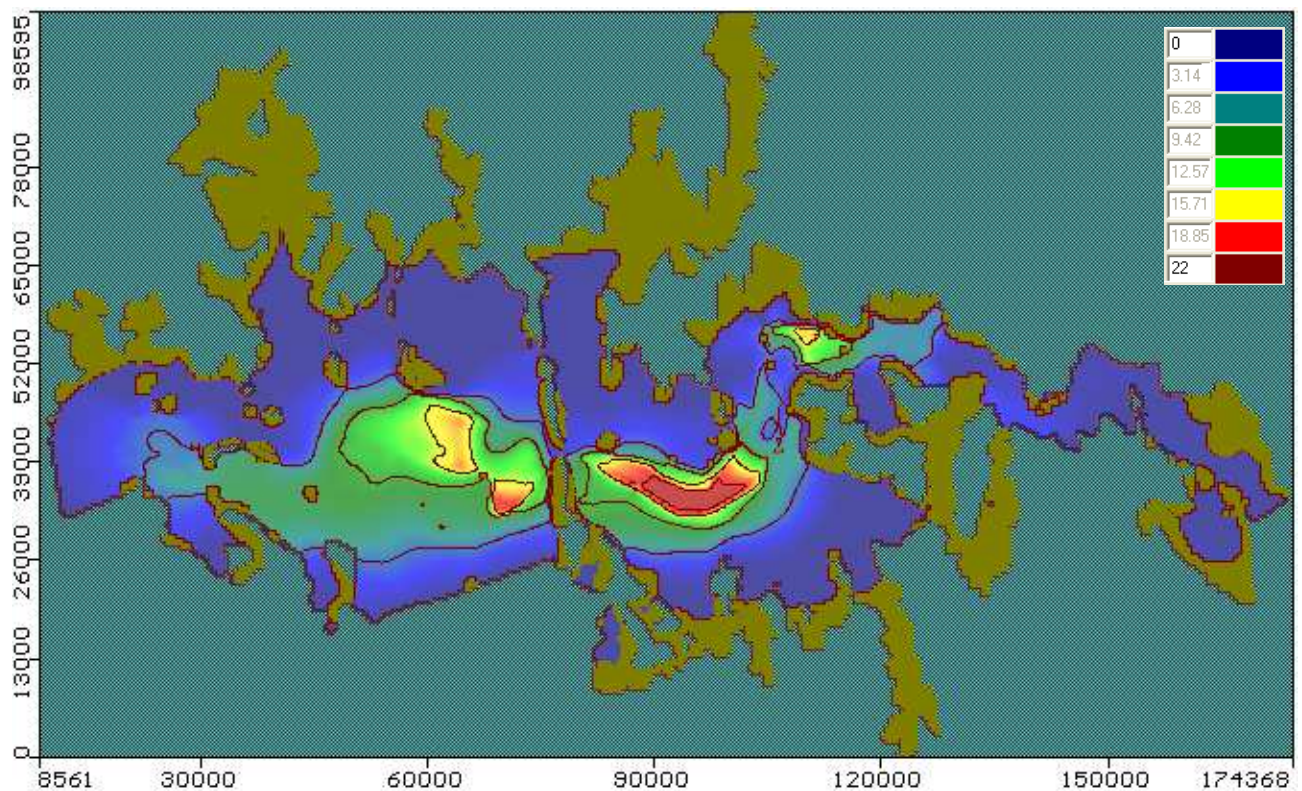


Figure 5-8. Drawdown (m) in Cowra Formation after 111 years under Scenario A (5 m contours)

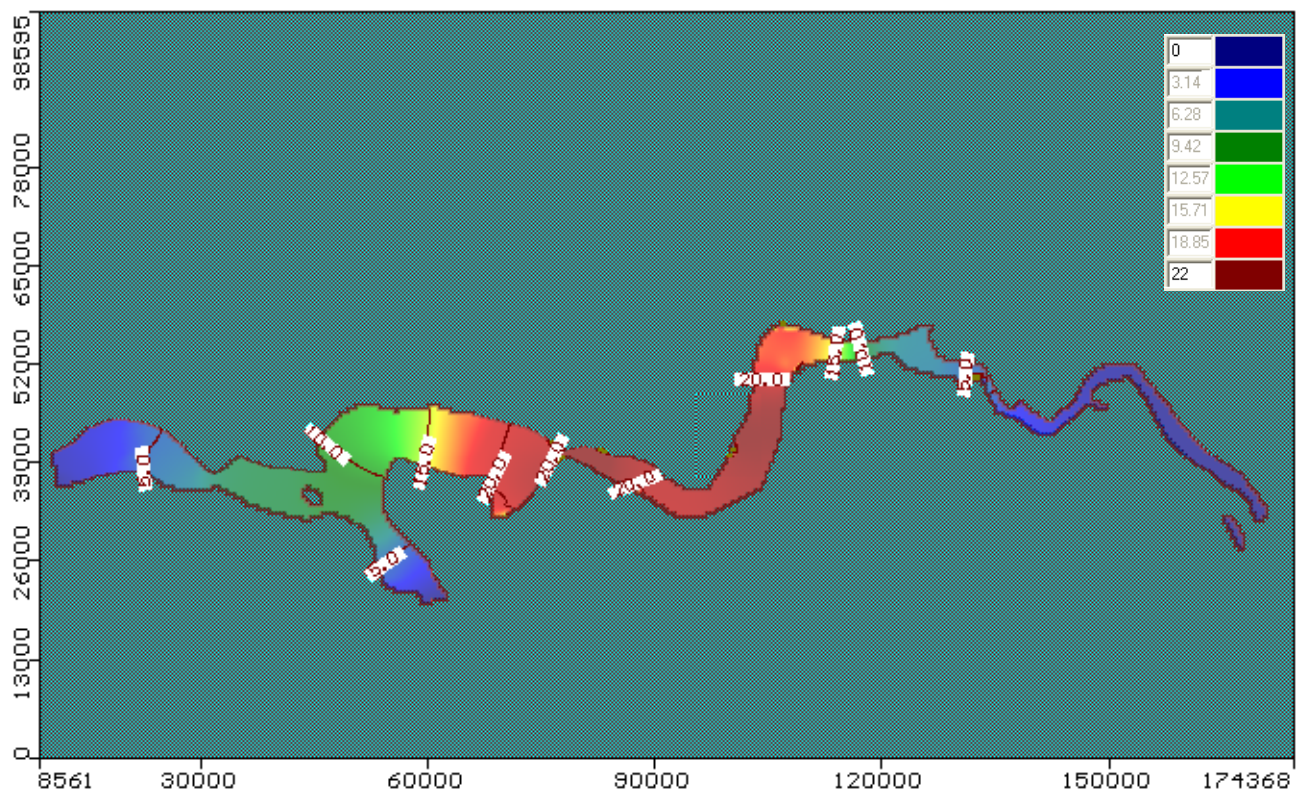


Figure 5-9. Drawdown (m) in Lachlan Formation after 111 years under Scenario A

Predicted exceedance curves for the reporting bores under Scenario A are shown in Figure 5-10 to Figure 5-14. These graphs can be used to determine the percentage of time that a given groundwater level is exceeded or alternatively the groundwater level that is exceeded for any given percentage of time. Groundwater levels as indicated by the 50%

exceedance level are compared for each of the scenarios in all reporting points in Table 5-4 suggests that the lowest heads are generally predicted under scenarios Cdry and Ddry, and the highest are predicted under scenarios Cwet and Dwet.

Table 5-5 compares the predicted hydrograph data from all reporting points under scenarios A, C and D. The table represents the median difference between the hydrographs under Scenario A and those under scenarios C and D. On average under the D scenarios water levels are more than 30 m below those of Scenario A. This large difference in groundwater head reflects the fact that the D scenarios include much higher initial rates of groundwater extraction than scenarios A and C, leading to greater drawdown and loss of water from storage.

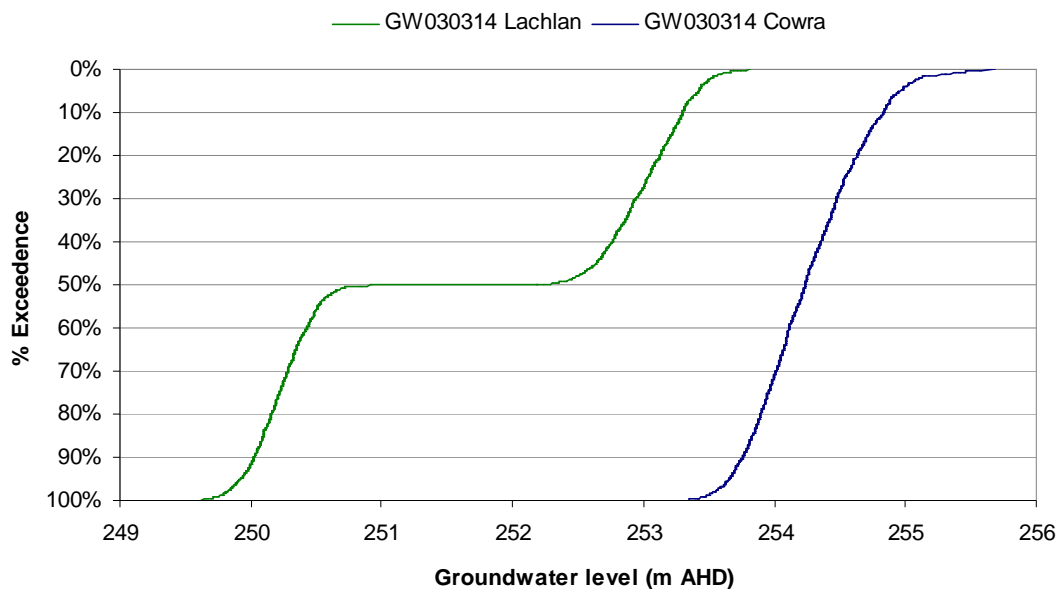


Figure 5-10. Exceedance curves for predicted hydrograph at GW030314 under Scenario A

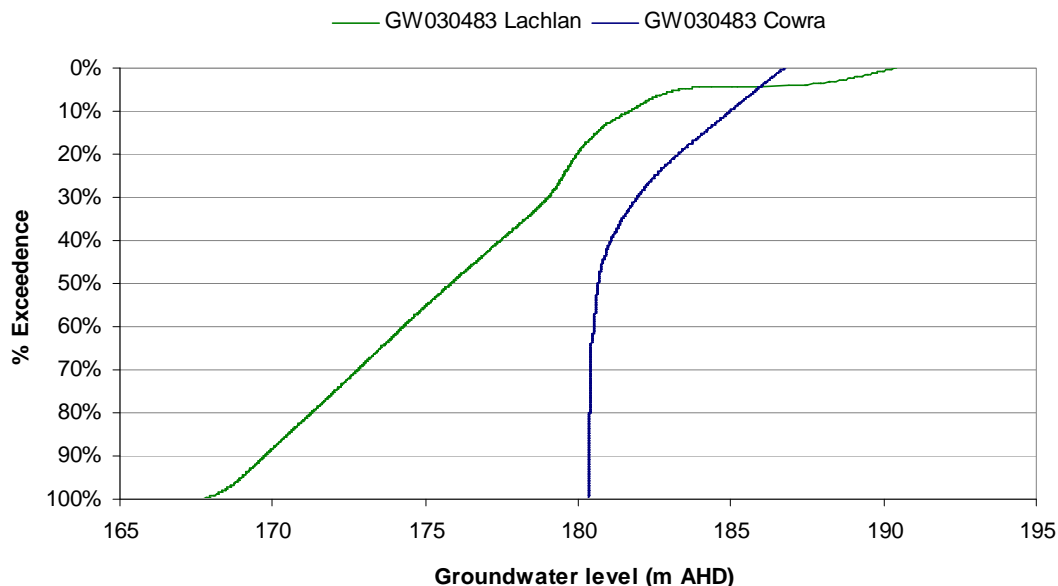


Figure 5-11. Exceedance curves for predicted hydrograph at GW030483 under Scenario A

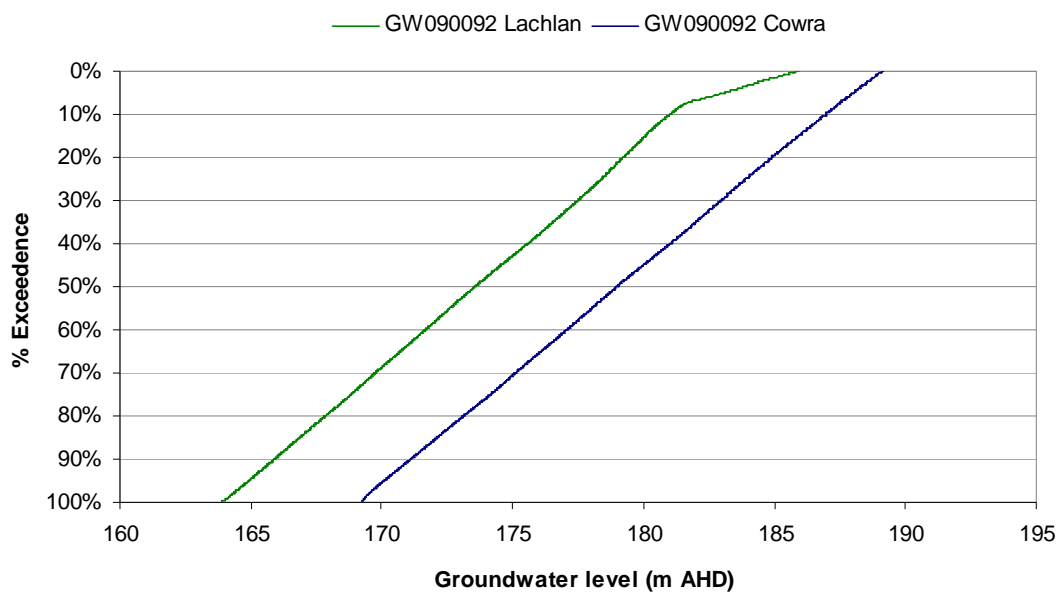


Figure 5-12. Exceedance curves for predicted hydrograph at GW090092 under Scenario A

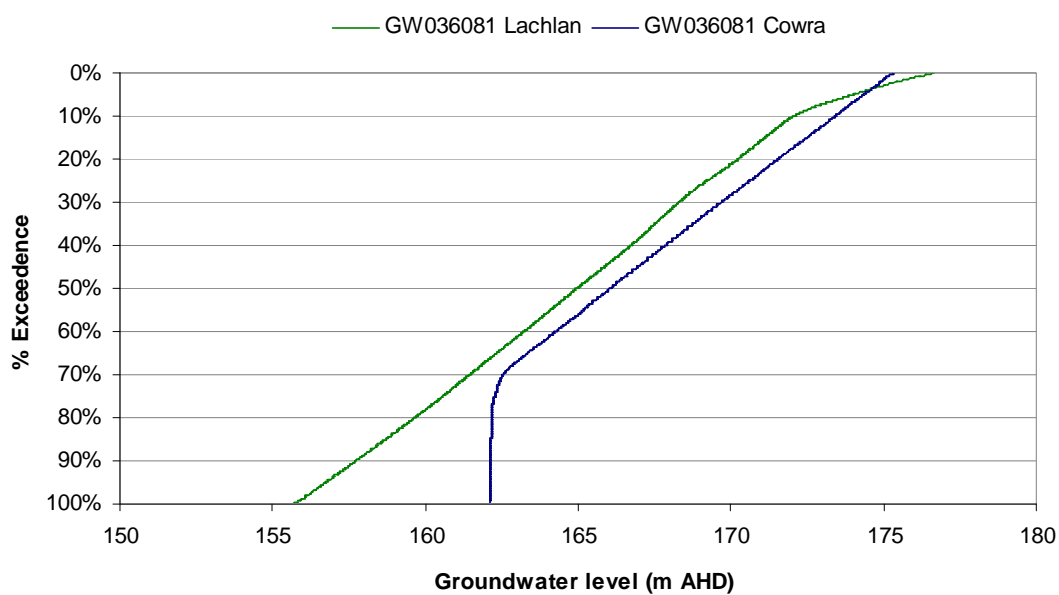


Figure 5-13. Exceedance curves for predicted hydrograph at GW036081 under Scenario A

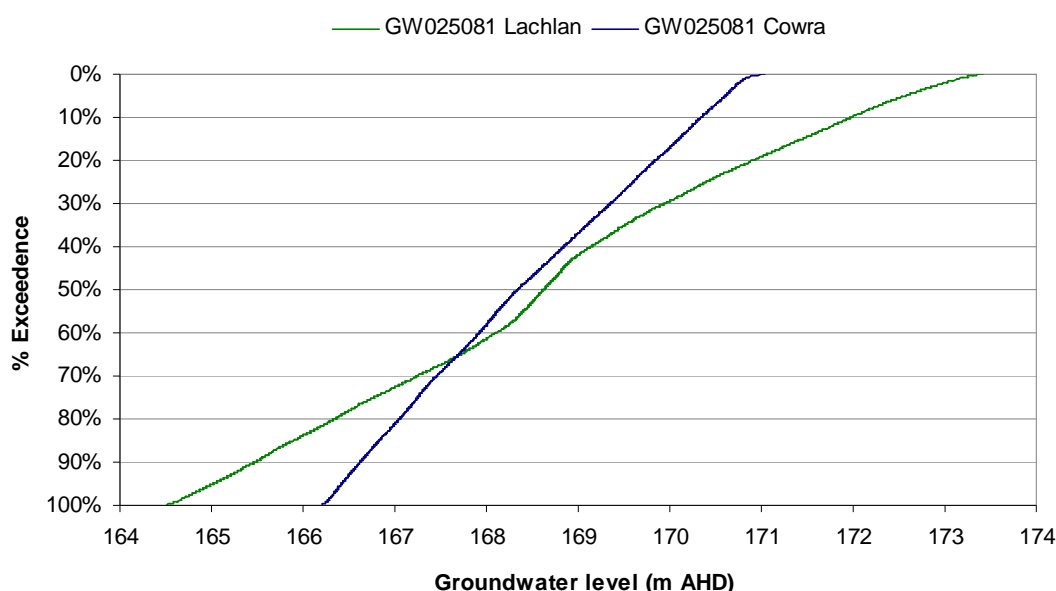


Figure 5-14. Exceedance curves for predicted hydrograph at GW025081 under Scenario A

Table 5-4. 50% Exceedance levels for all bores under scenarios A, C and D

	GW030314		GW030483		GW090092			GW036081		GW025081	
Scenario	Layer 2	Layer 3	Layer 2	Layer 3	Layer 1	Layer 2	Layer 3	Layer 2	Layer 3	Layer 2	Layer 3
A	254.2	252.2	180.6	175.8	215.7	179.0	173.6	166.1	165.0	168.3	168.6
Cdry	253.1	250.8	180.3	172.5	215.6	175.4	170.0	163.7	162.6	166.6	166.9
Cmid	254.0	252.0	180.6	175.4	215.7	178.7	173.2	165.9	164.8	168.1	168.4
Cwet	254.7	252.8	181.2	177.7	215.7	181.1	175.7	167.6	166.5	169.3	169.6
Ddry	237.7	230.8	180.3	130.3	215.6	168.1	127.9	162.1	120.5	153.6	150.1
Dmid	237.5	231.4	180.3	138.9	215.7	168.5	130.5	162.1	122.1	155.4	151.6
Dwet	237.7	233.7	180.4	139.7	215.7	168.7	131.8	162.1	123.1	156.7	152.6

Table 5-5. Median groundwater changes (m) in Upper Lachlan under scenarios A, C and D

Median groundwater level changes	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	m AHD	m AHD relative to Scenario A					
Lachlan	187.02	-2.47	-0.25	1.42	-33.92	-32.14	-30.83
Cowra	189.65	-1.83	-0.19	1.13	-9.31	-8.89	-8.51
Average	188.34	-2.15	-0.22	1.28	-21.61	-20.51	-19.67

5.2 Groundwater recharge

Figure 5-15 compares the total annual recharge included in the Scenario A model and the groundwater pumping flux. In this case total recharge includes rainfall, leakage from rivers, and lateral groundwater fluxes into the model region. The figure indicates that groundwater pumping exceeds total recharge occasionally throughout the duration of Scenario A.

The impact of anomalously high evapotranspiration fluxes from river cells should be considered in this analysis. It should be recognised that some of the river-derived recharge is lost immediately to evapotranspiration and is not available as groundwater storage. To address this issue Figure 5-16 compares the groundwater extraction fluxes and total recharge minus evapotranspiration. In this case total recharge minus evapotranspiration is assumed to provide a better estimate of the fluxes of water that enter the aquifer and are available as groundwater storage. This plot suggests that groundwater pumping almost always exceeds the effective recharge.

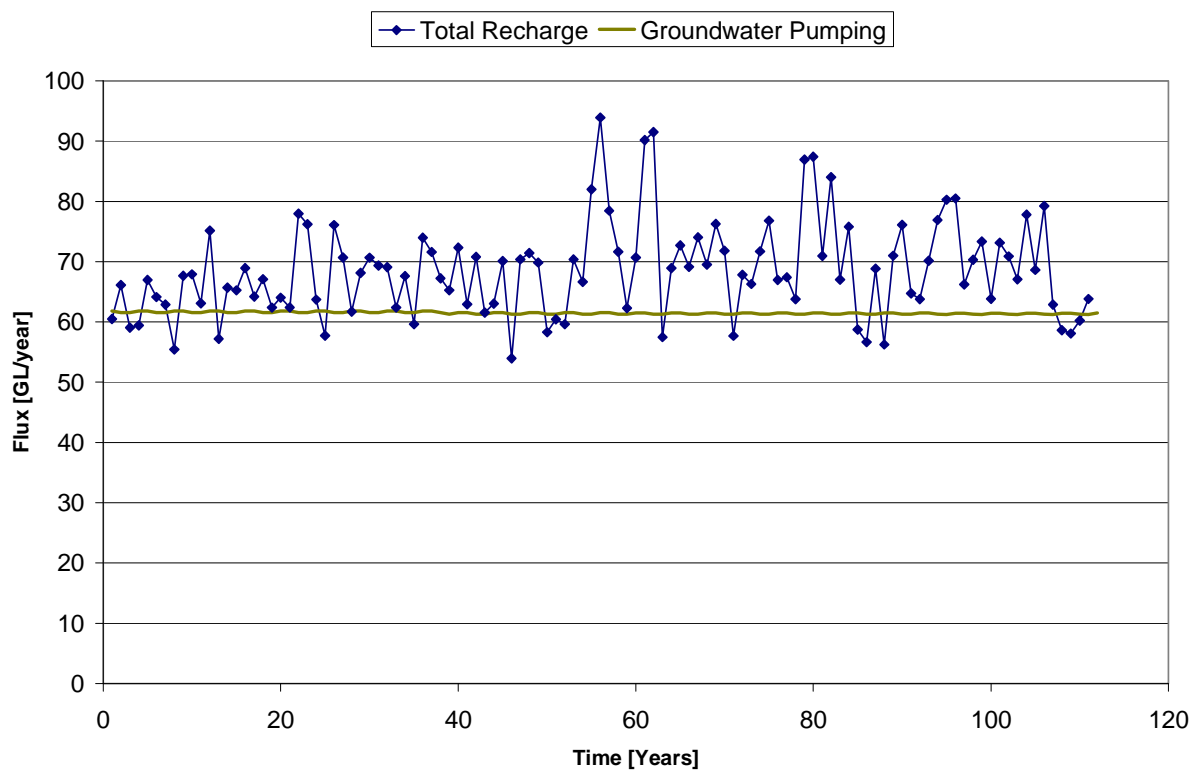


Figure 5-15. Total recharge compared to groundwater extraction under Scenario A

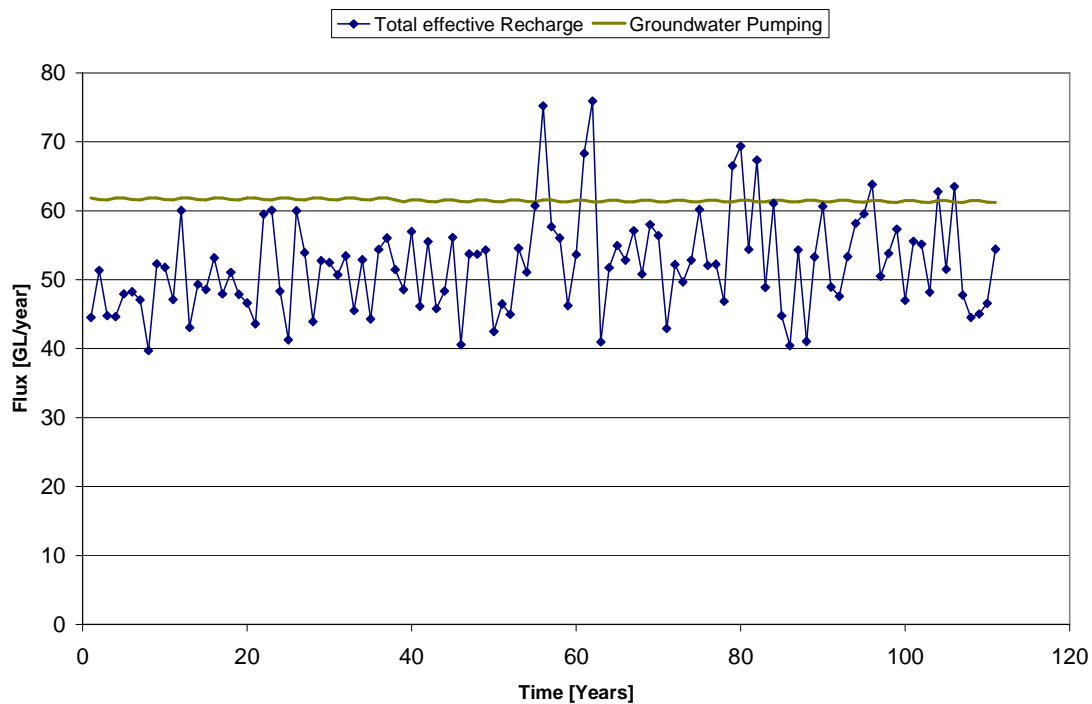


Figure 5-16. Total recharge minus evapotranspiration compared to groundwater extraction under Scenario A

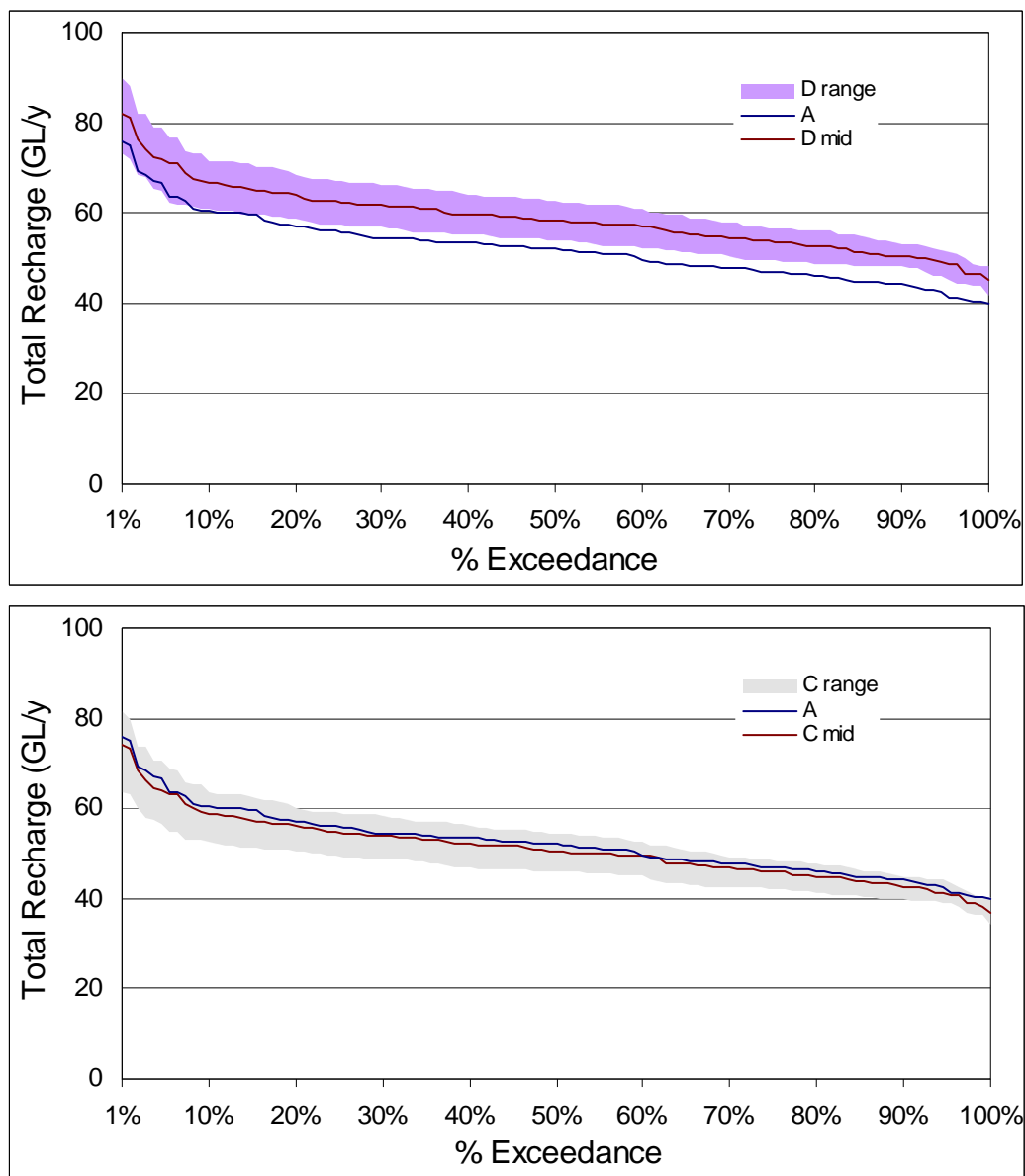


Figure 5-17. Exceedance probability curve for total annual recharge (minus evapotranspiration) under scenarios A, C and D

Table 5-6 estimates the proportion of time that the total groundwater recharge exceeds groundwater pumping under the various development scenarios considered in this project. The analysis is shown for total groundwater recharge and for recharge less evapotranspiration. Removing evapotranspiration from the total recharge takes account of the fact that not all of the water recharging the aquifer is available for extraction. When recharge is reduced by the evapotranspiration flux it can be seen that the extractions exceed total recharge almost all of the time. This result suggests that, once anomalous recharge fluxes are removed from the analysis, the effective groundwater recharge is not sufficient to meet the demand as represented by groundwater extraction. This conclusion is reinforced by hydrograph plots and drawdown maps that show continued decline in groundwater levels (and associated change in storage) continuing throughout the scenario duration.

Table 5-6. Annual average total recharge, evapotranspiration and net loss of river flow

Scenario	Total recharge	Recharge from river	Evapotranspiration	% of years recharge exceeds pumping	% of years recharge (less ET) exceeds pumping
	GL/y			percent	
A	68.5	44.2	19.8	82%	6%
Cdry	62.5	42.9	17.5	59%	0%
Cmid	67.3	43.3	19.4	77%	5%
Cwet	71.1	43.8	21.1	84%	6%
Ddry	70.4	47.6	17.0	75%	9%
Dmid	75.1	47.8	18.6	81%	9%
Dwet	79.3	48.7	20.2	84%	12%

5.3 Groundwater–river interaction

To illustrate the net impact of groundwater extraction on river flows, a without-development scenario was run (using the Scenario A climatic data). Net impacts on the river were determined by comparing river losses under Scenario A with those under the without-development scenario. The results are shown in Figure 5-18 and Figure 5-19. In this case no allowance has been made in the without-development scenario for the impacts of changing land use on recharge (e.g. deforestation and land clearing leading up to current vegetative cover). Figure 5-18 shows the net river losses under both scenarios. Both models start with about 40 GL/year of groundwater inflow from the river. As the models progress they diverge, with increasing losses under Scenario A and declining losses under the without-development scenario. Figure 5-19 compares the river losses under Scenario A and the without-development scenario. It indicates the additional river flow that would have been measured had there been no groundwater extraction over the duration of Scenario A. Both figures show the warm-up period as well as the ‘dynamic equilibrium’ period. It can be seen that the impacts of groundwater development as indicated by a loss of river flow approaches a dynamic equilibrium at about 17 GL/year.

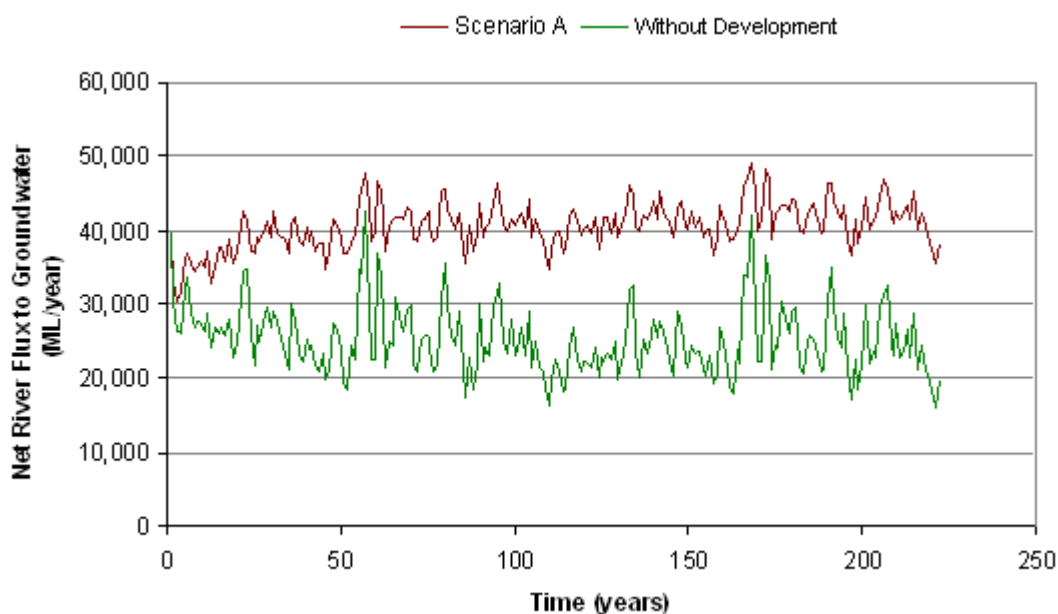


Figure 5-18. Net groundwater flux from rivers to groundwater under Scenario A and the without-development scenario

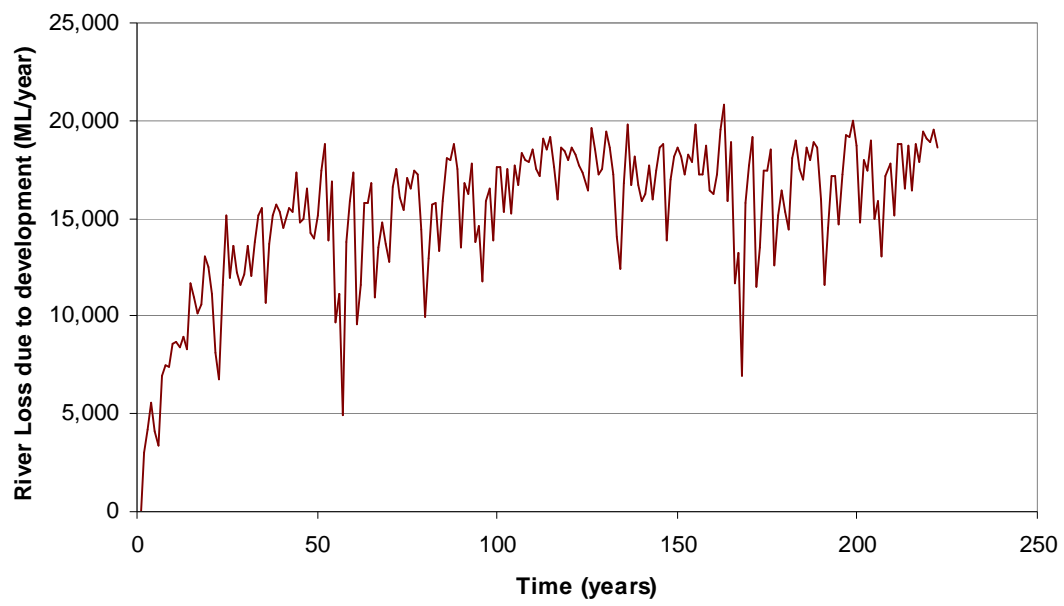


Figure 5-19. Reduction in river flow due to development under Scenario A

6 Conclusions

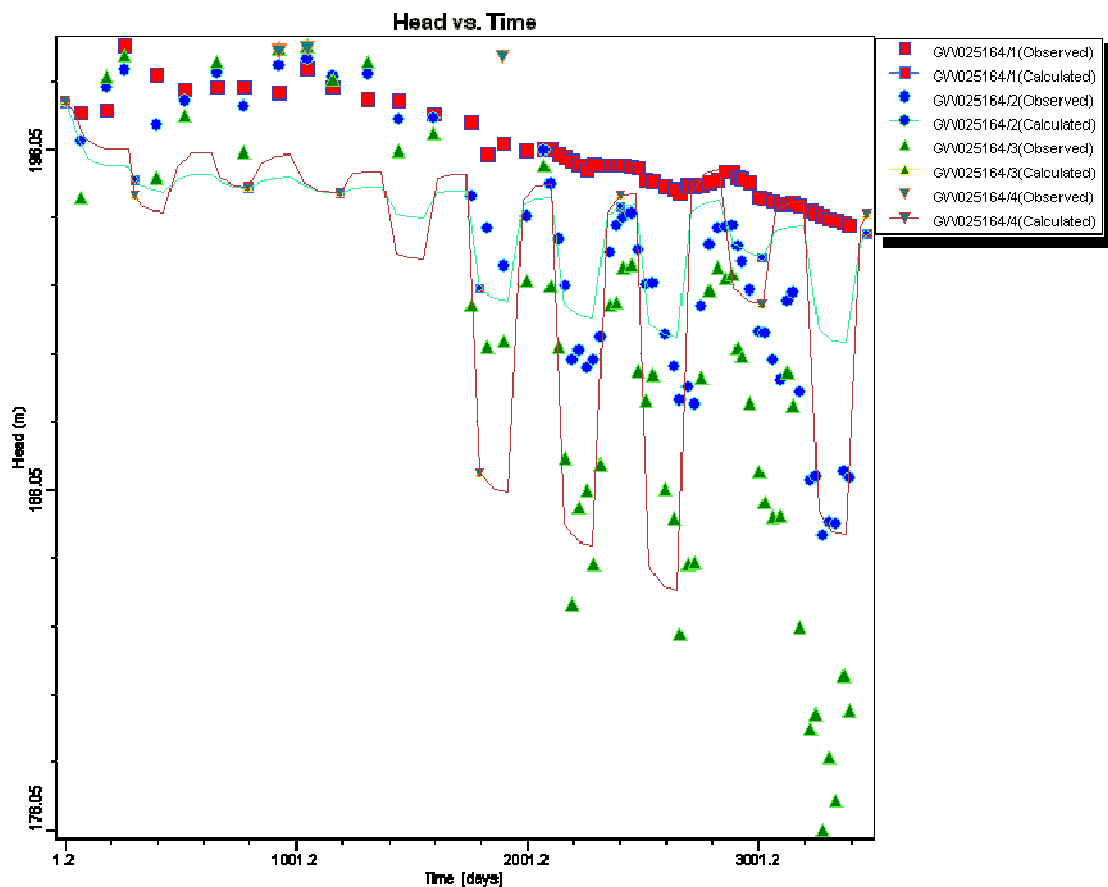
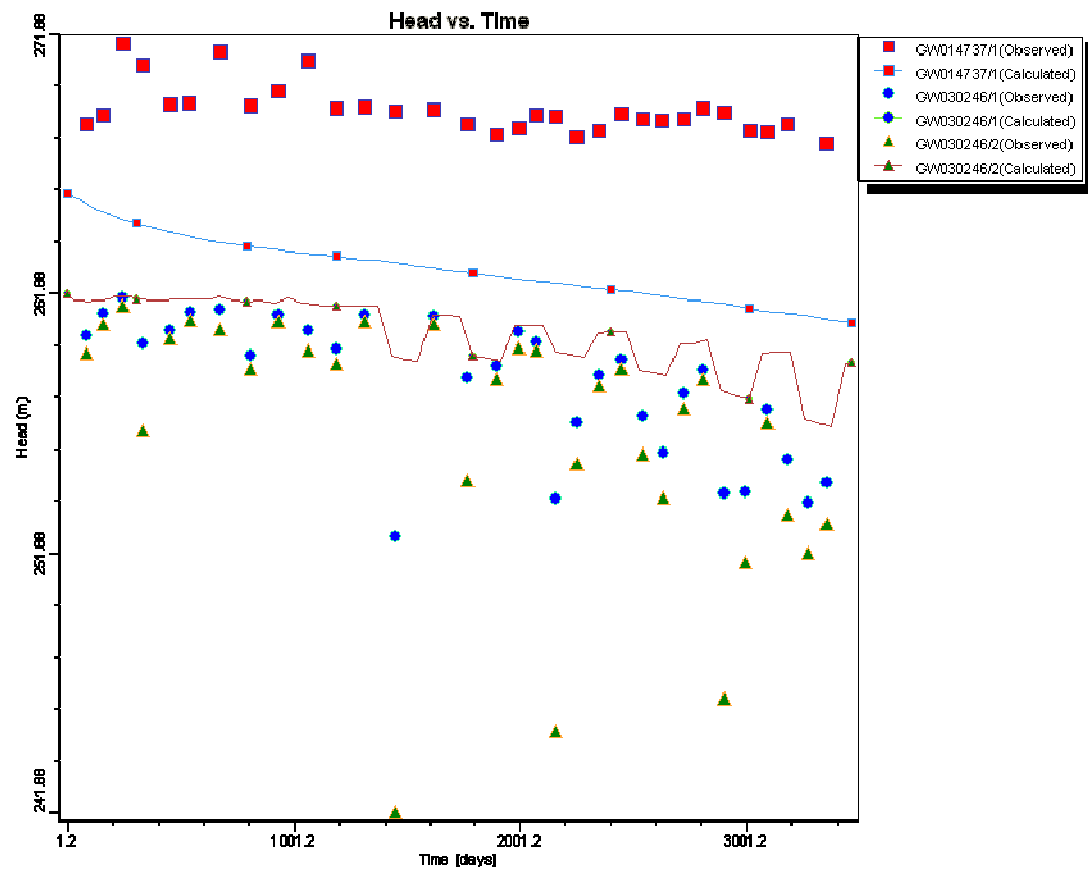
Analysis of fluxes in the groundwater models of the Upper Lachlan Valley have been complicated by the fact that evapotranspiration fluxes are in places superimposed on river boundary cells. This has resulted in anomalous fluxes of water into the model from river cells and out of the model from evapotranspiration. In order to fully understand the implications of the scenario models run for this project it has been necessary to take account of these anomalous modelling artefacts by subtracting the evapotranspiration fluxes from the total recharge fluxes in all mass balance analysis. Once this correction is made it becomes apparent that the applied groundwater extraction fluxes (65 GL/year under Scenario A and the three C scenarios and 120 GL/year under the D scenarios) are not sustainable at dynamic equilibrium. Although the models are able to sustain average extractive fluxes of about 65 GL/year for the duration of the scenarios, results show that drawdown in groundwater level (and associated release of water from storage) persists for the duration of the model runs. Results also illustrate that the long-term average level of groundwater recharge (after correction for evapotranspiration) amounts to about 50 GL/year. It is assumed that this level of extraction can be sustained at dynamic equilibrium.

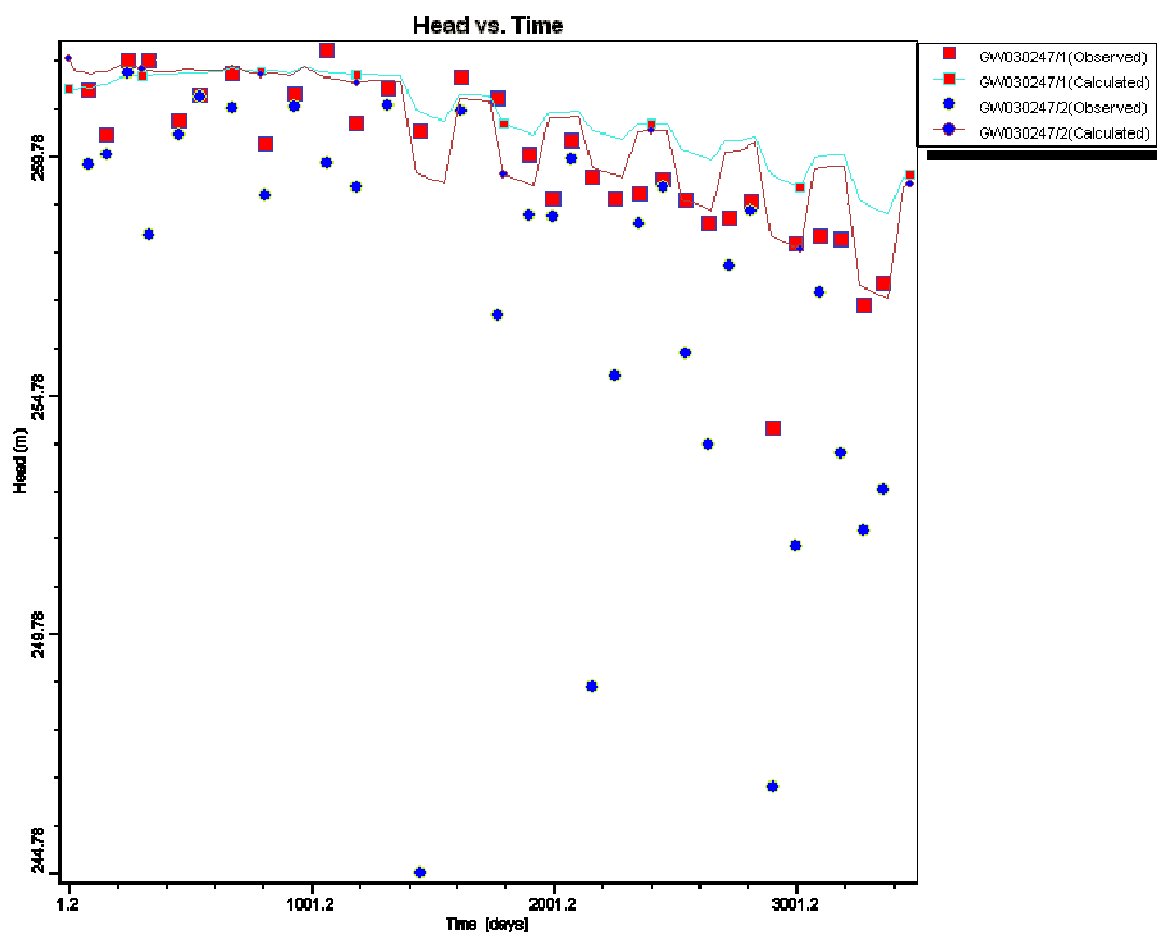
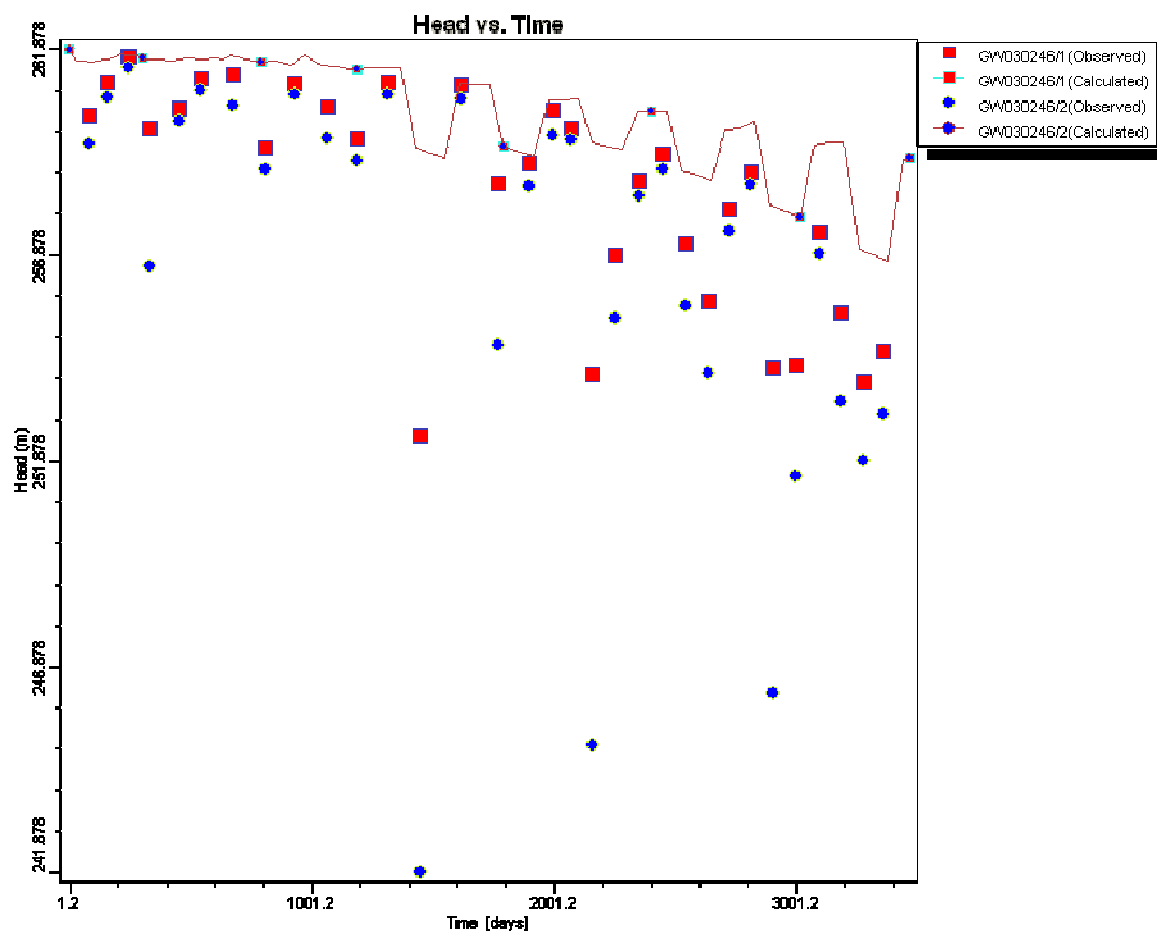
The modelling suggests that groundwater extractions of about 60 GL/year under Scenario A are supported by a reduction in river flow of about 17 GL/year. The remainder of the extracted water is derived from loss of storage and reduction in evapotranspiration.

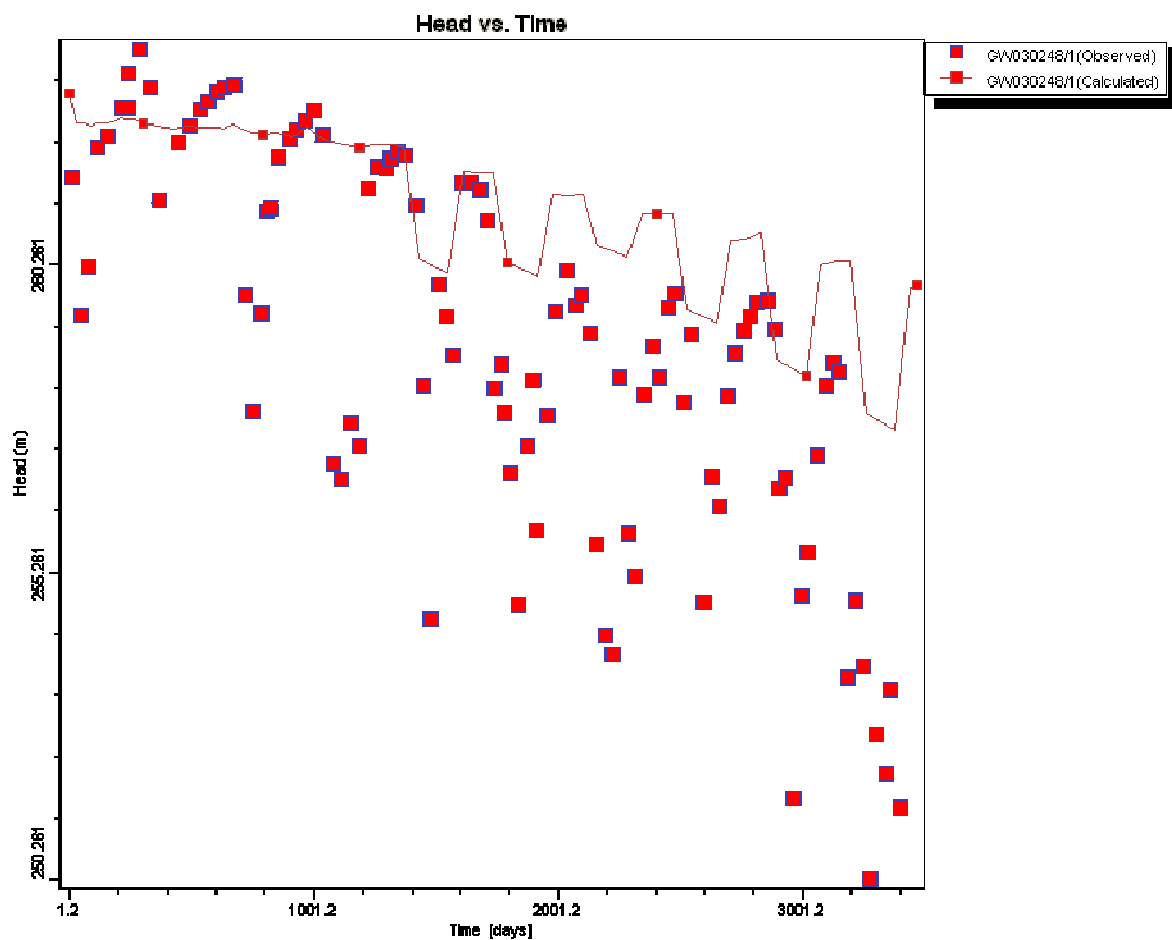
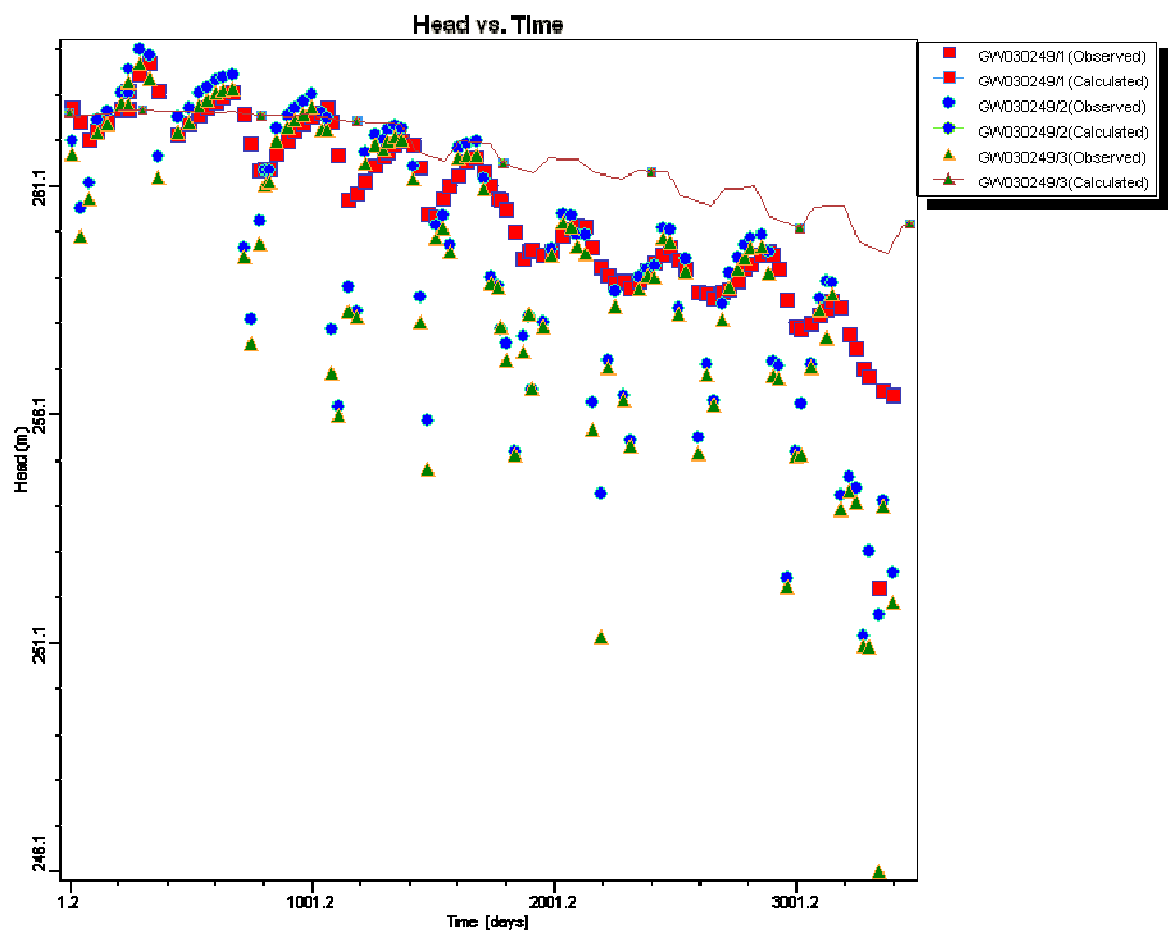
7 References

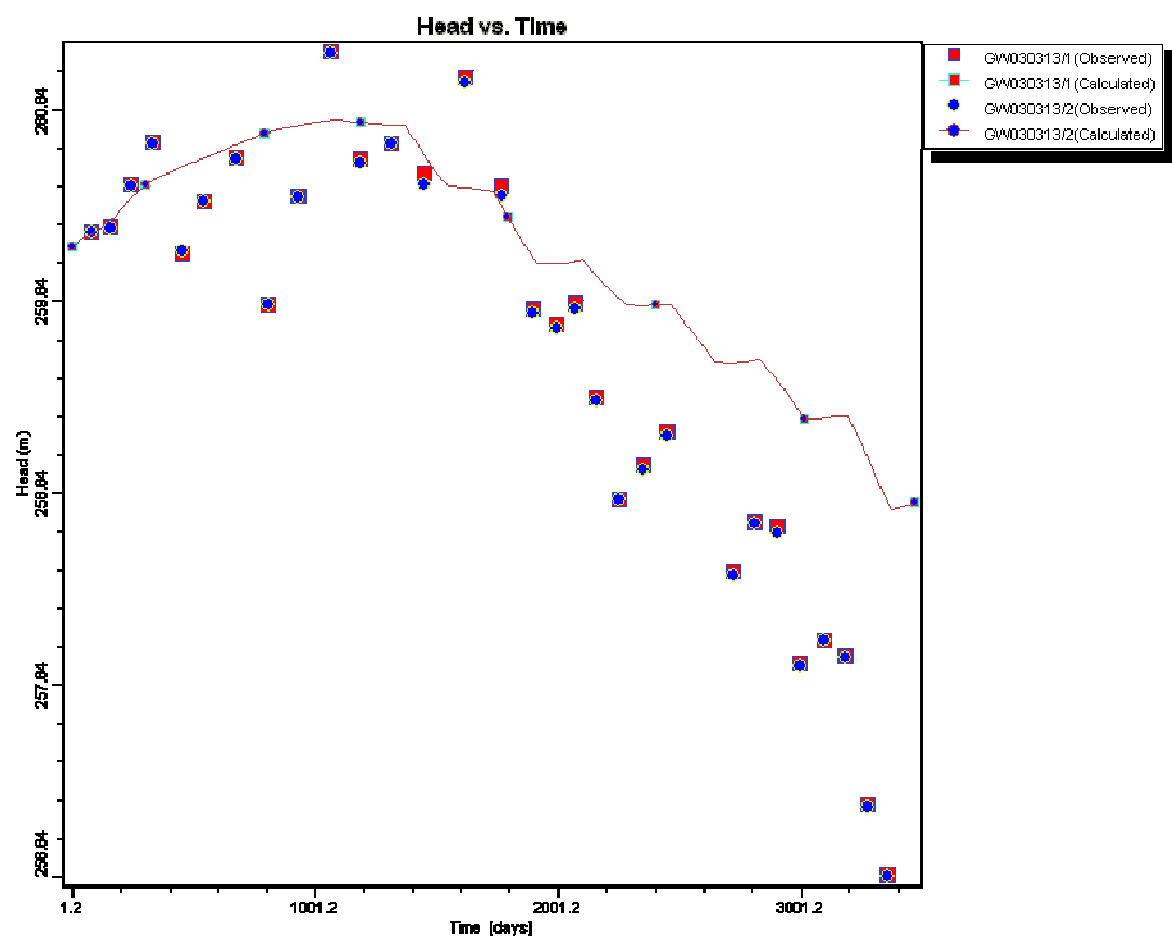
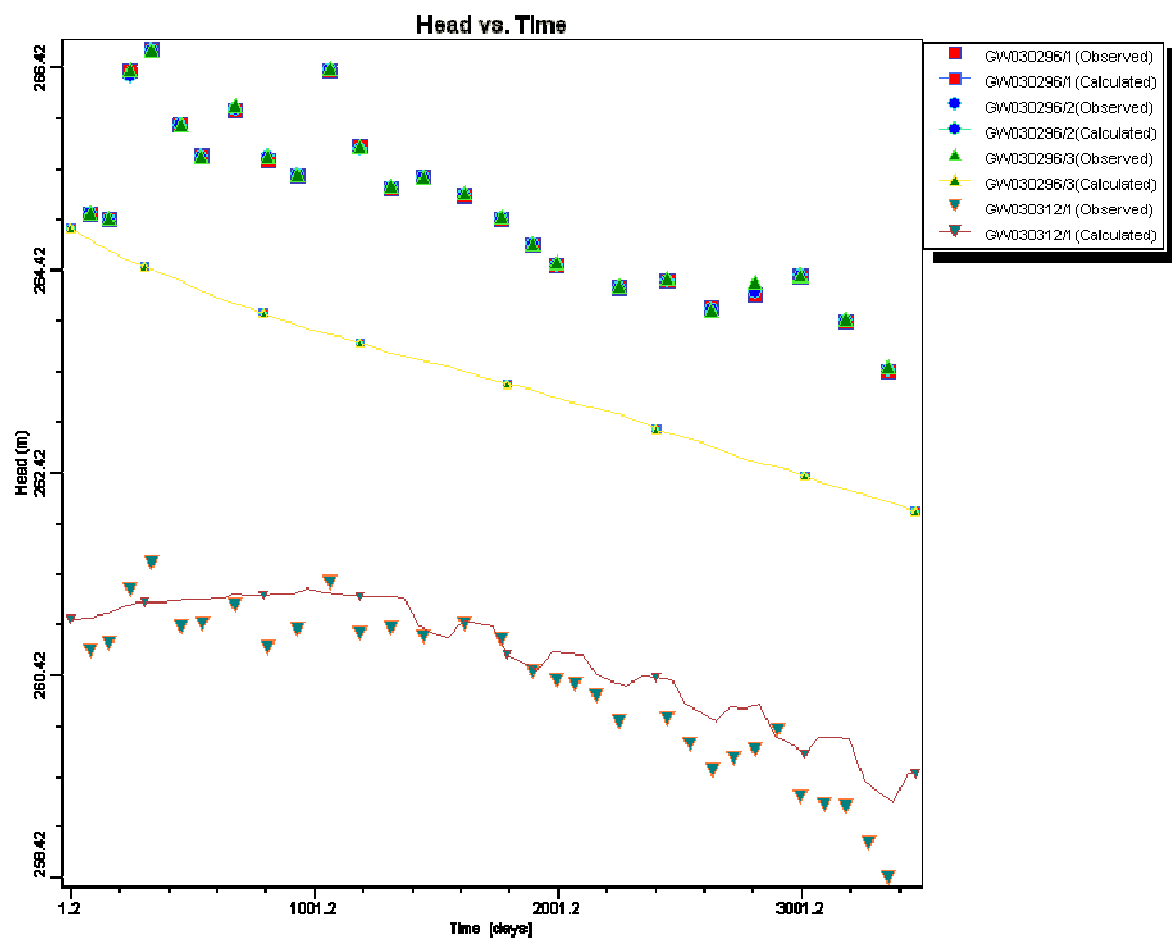
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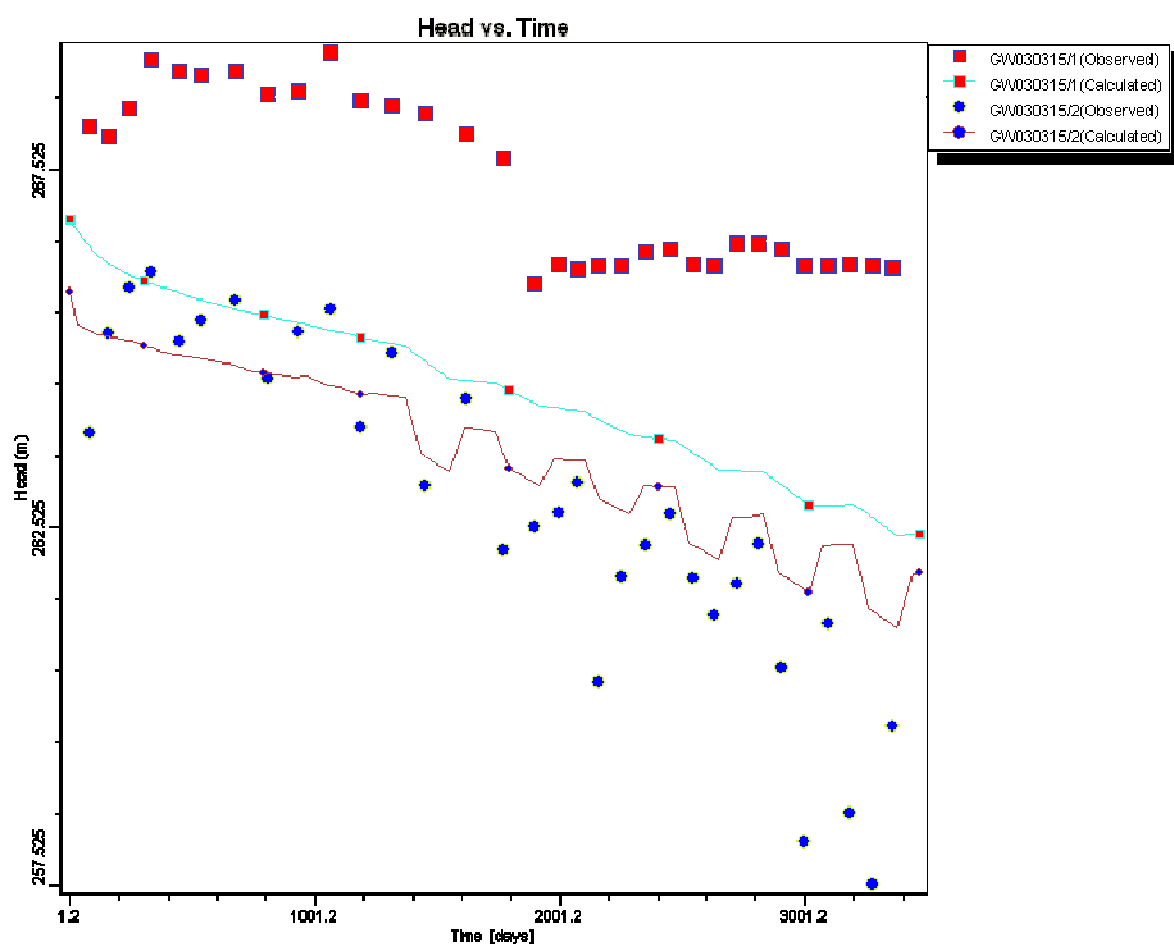
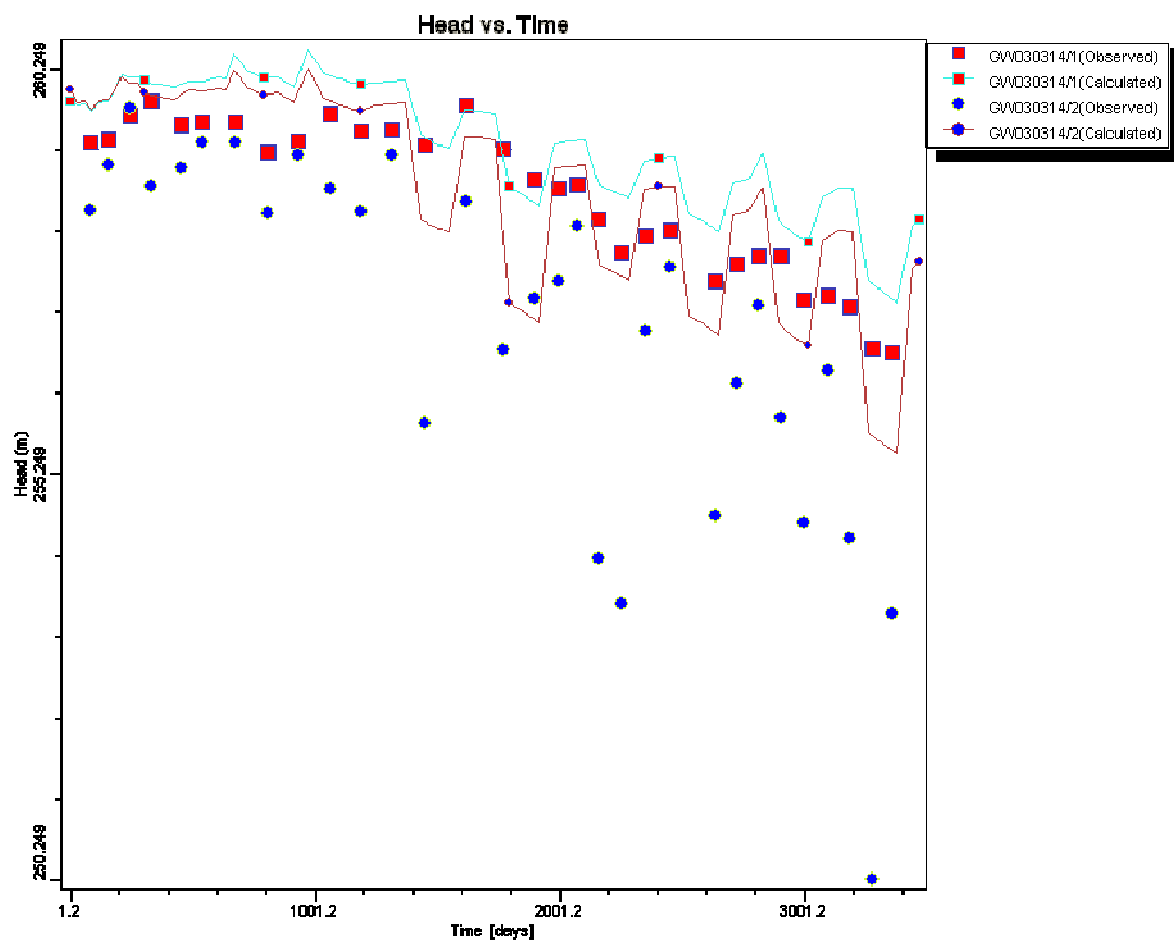
Appendix A Calibration bore hydrographs

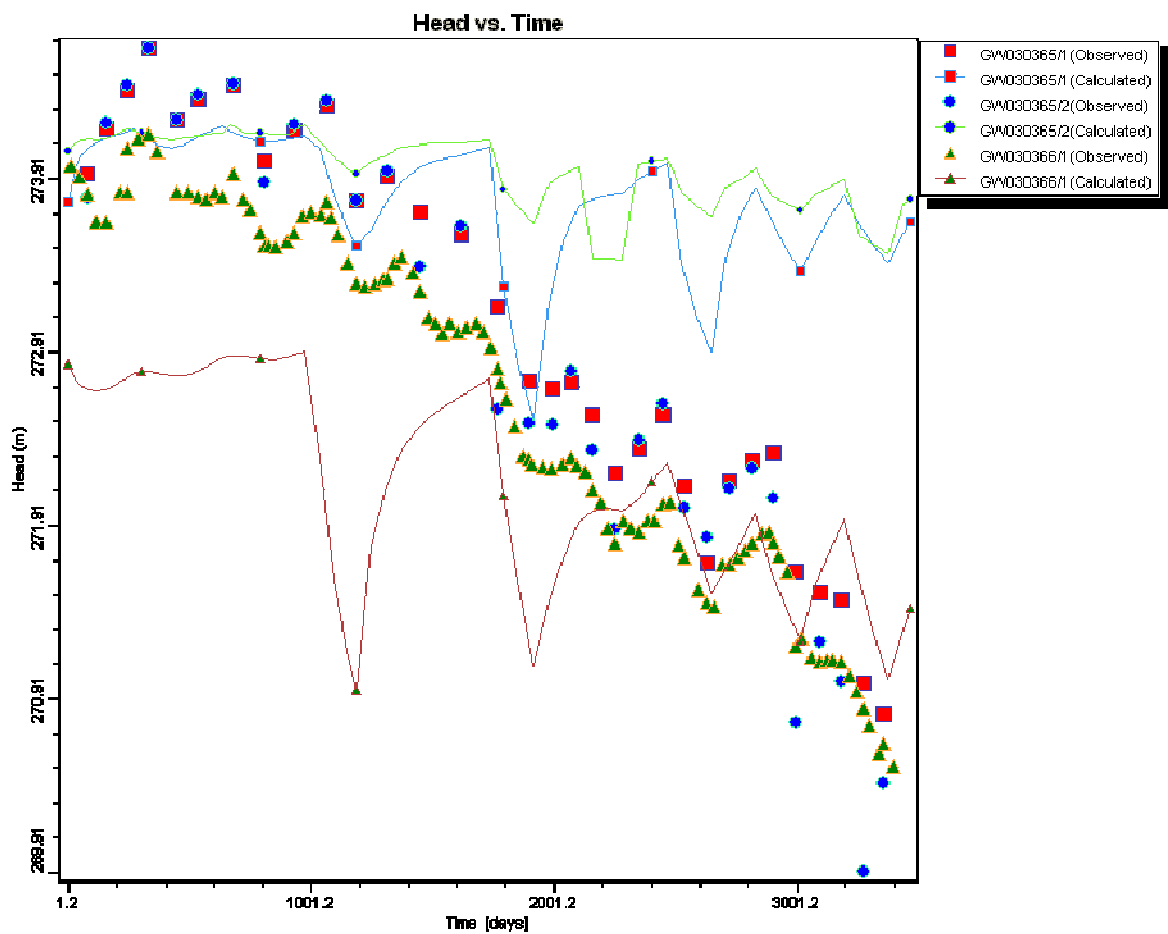
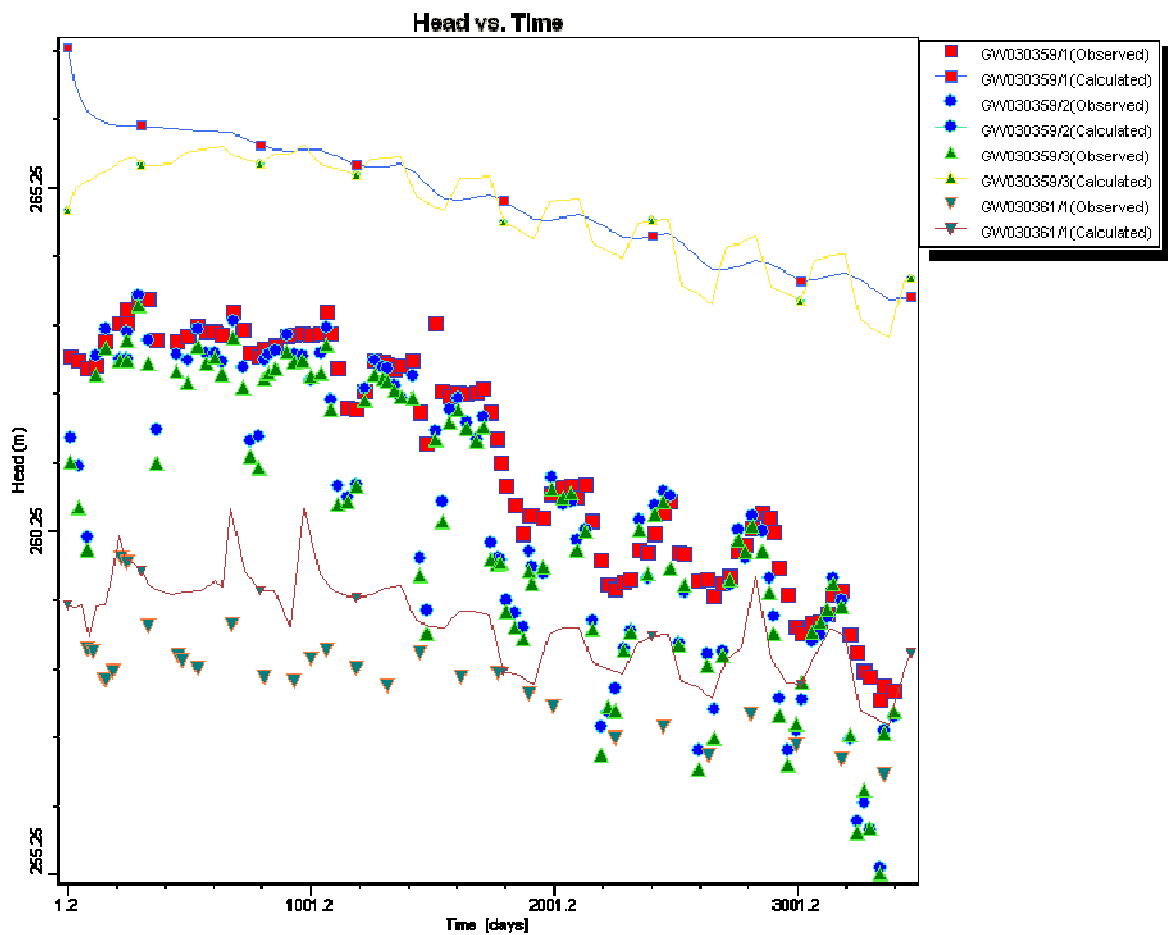


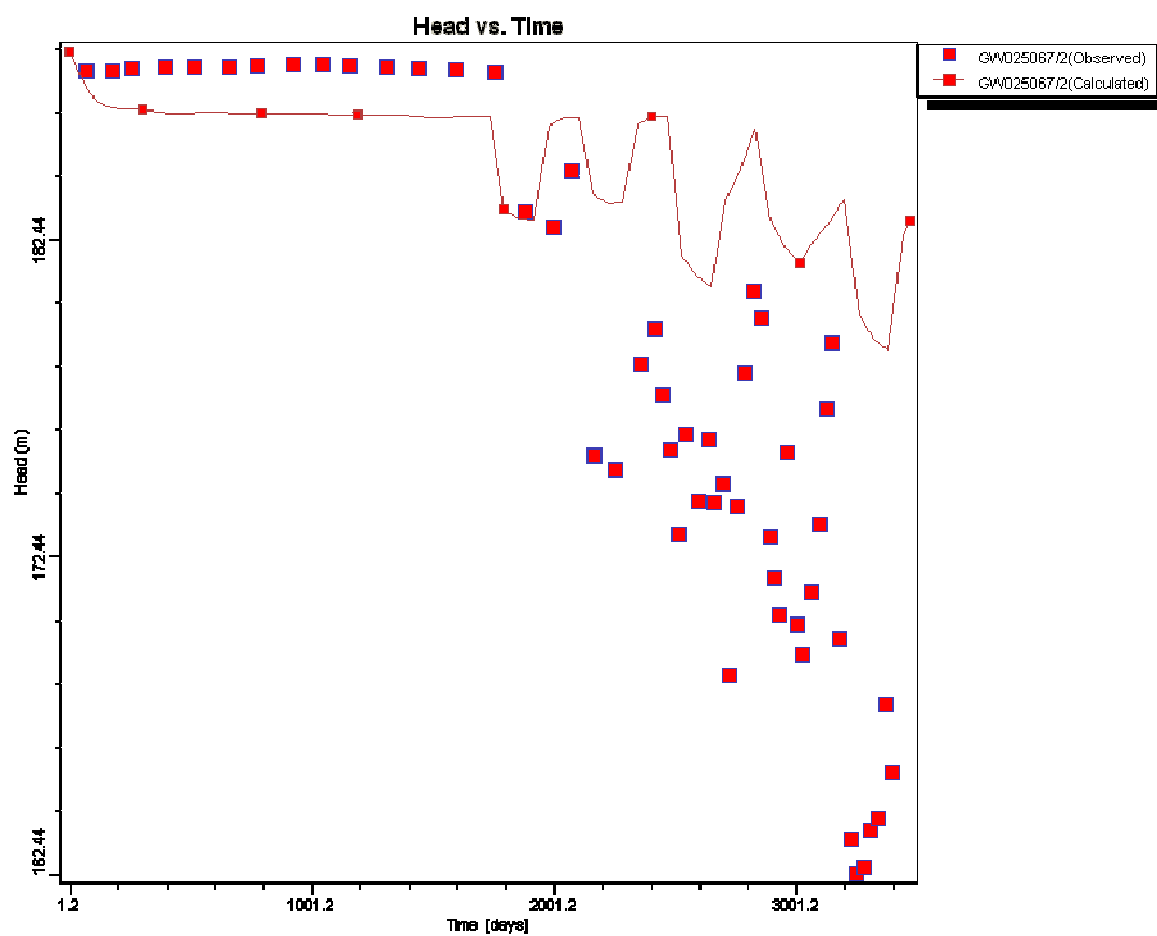
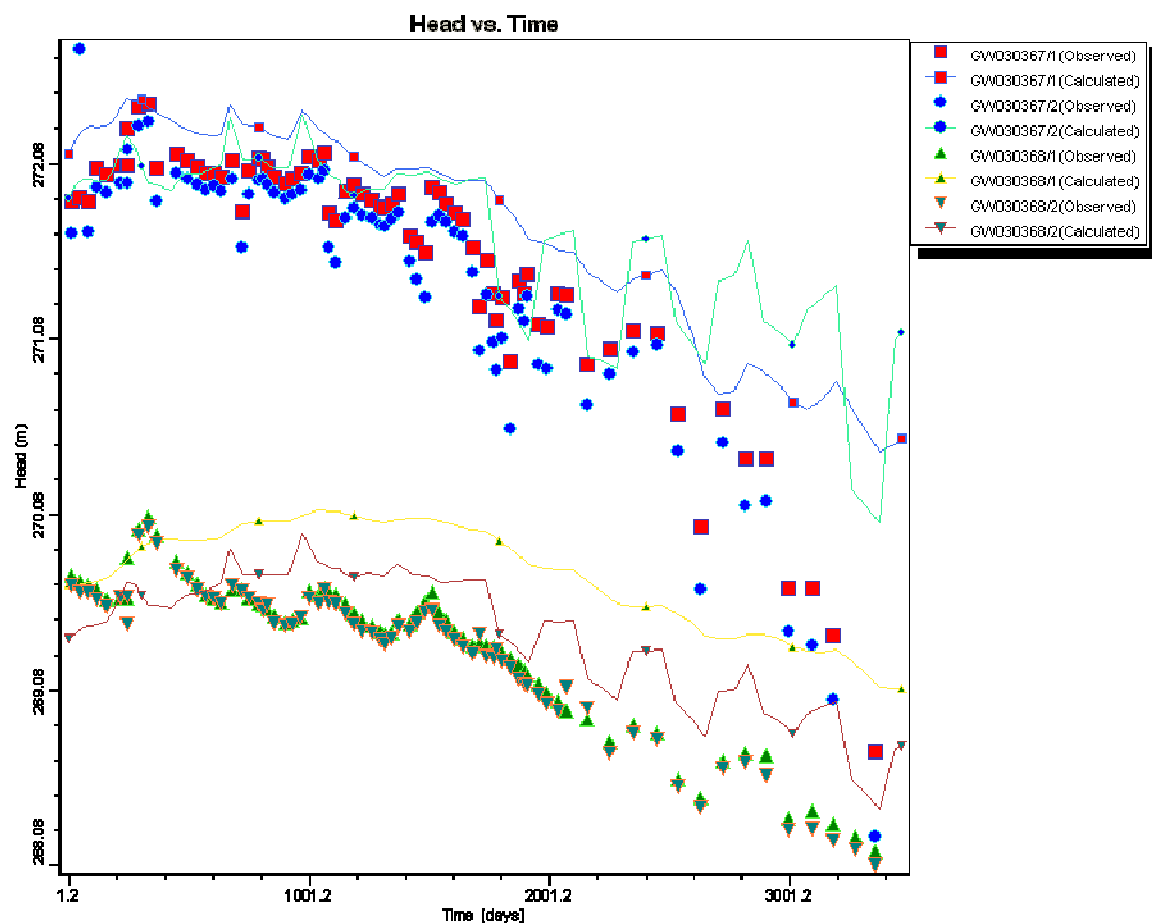


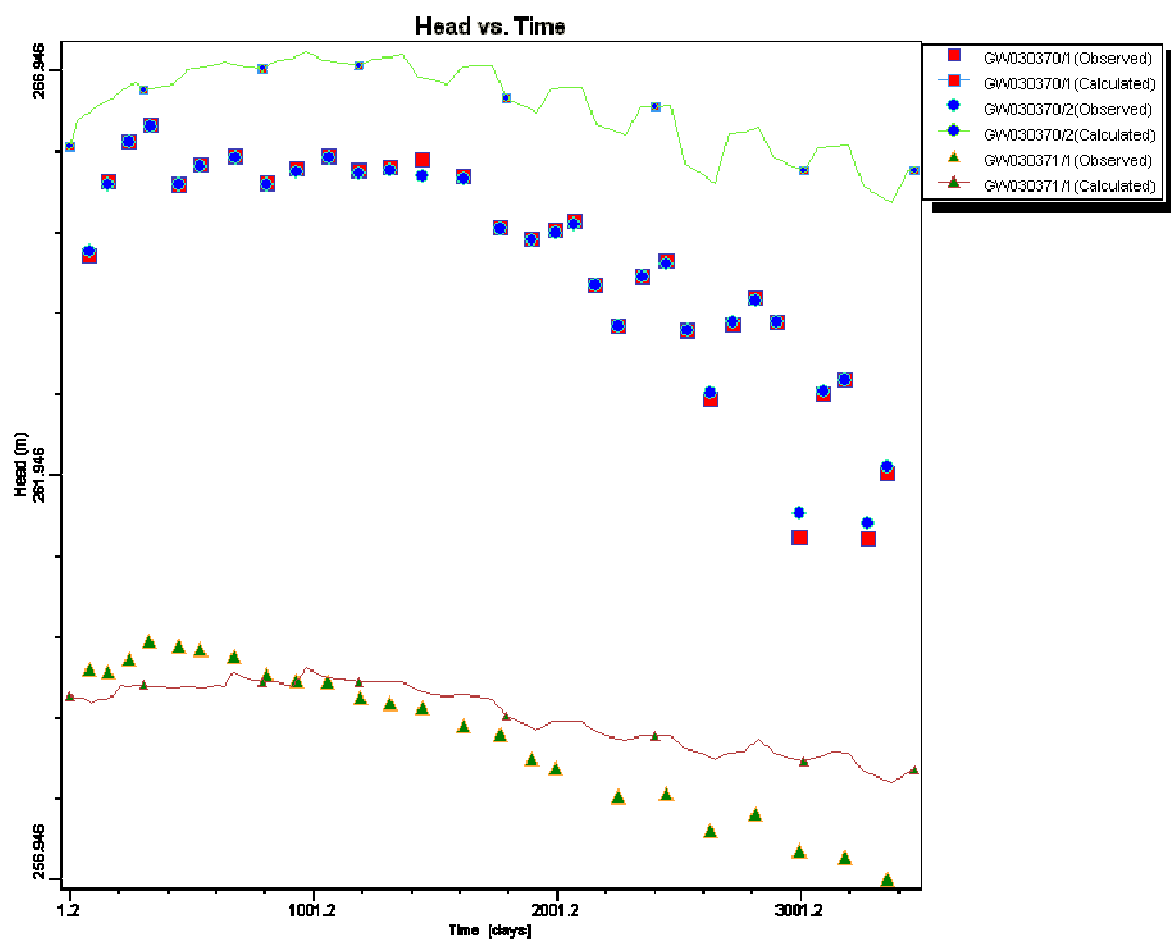
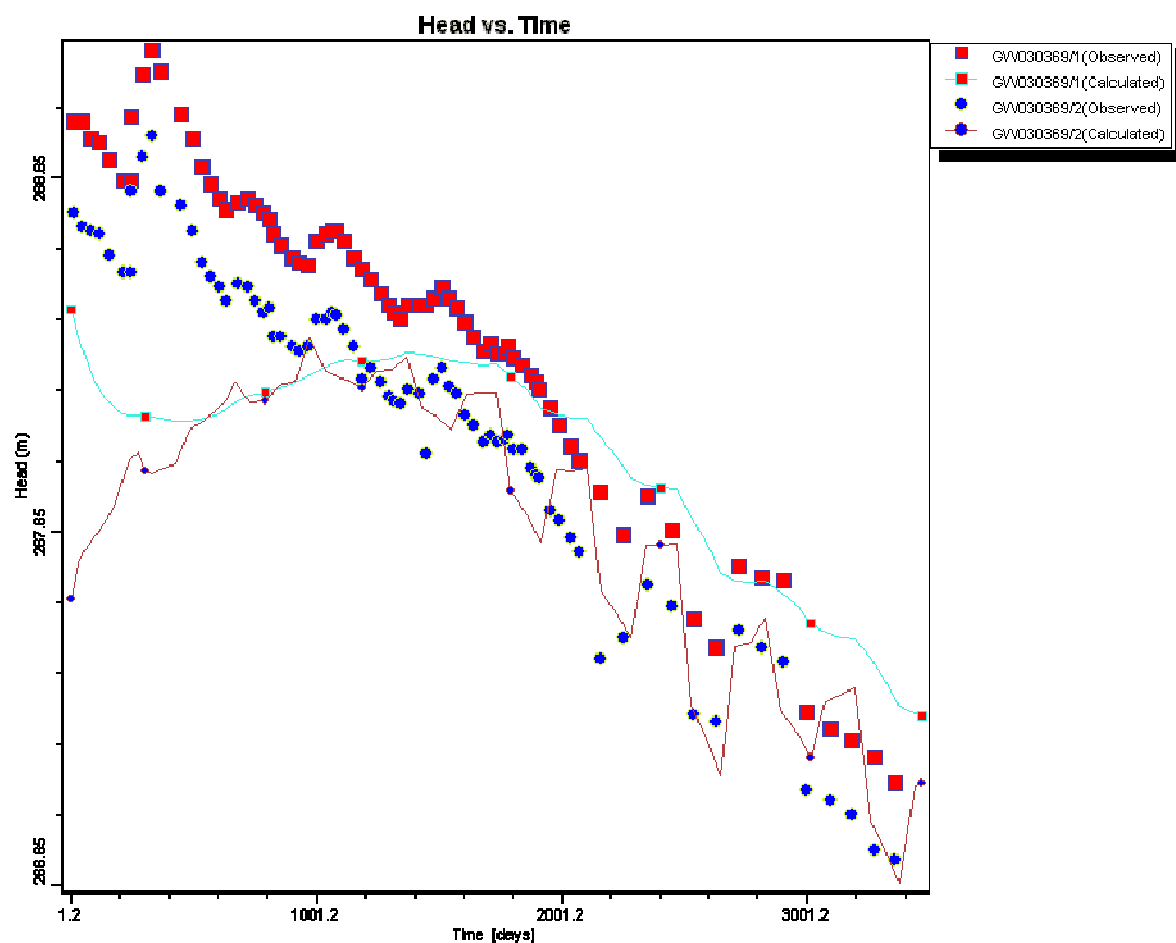


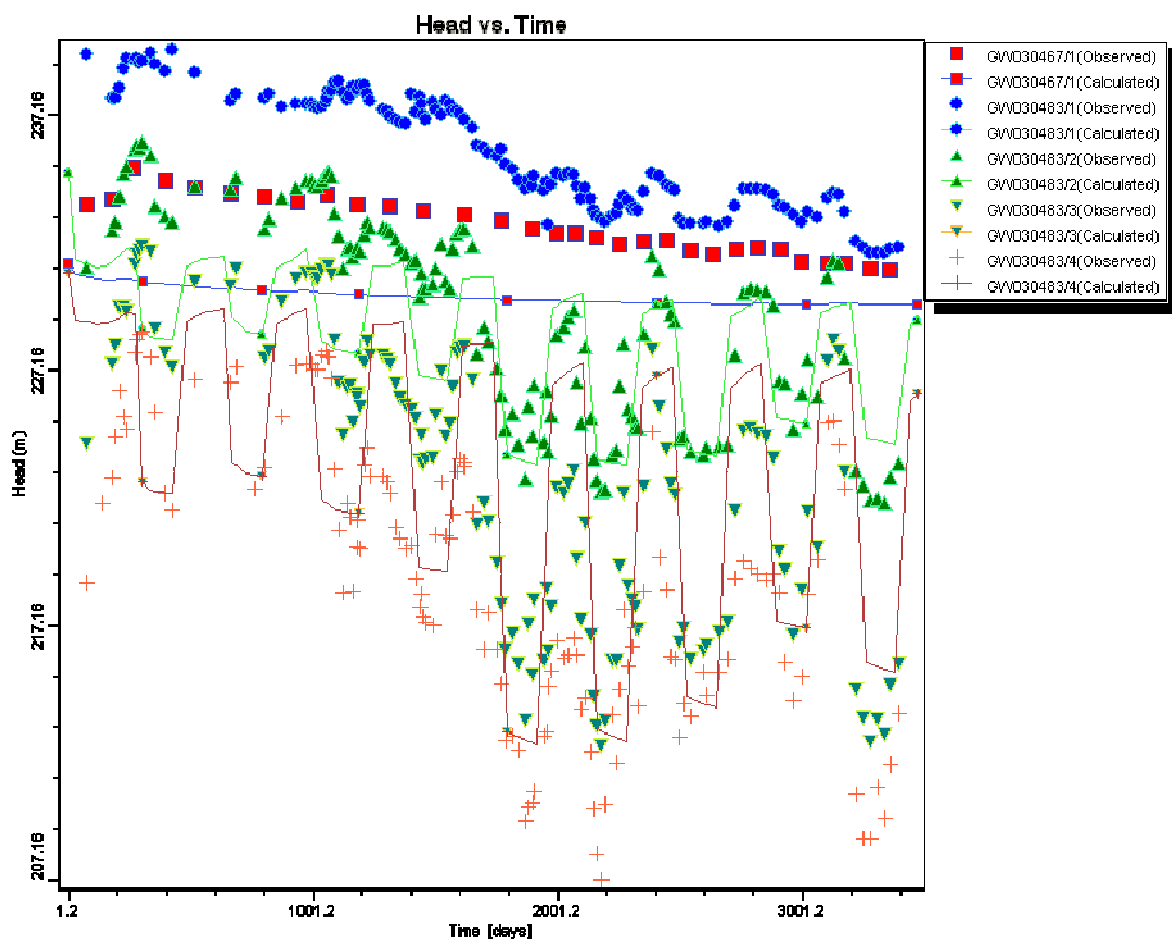
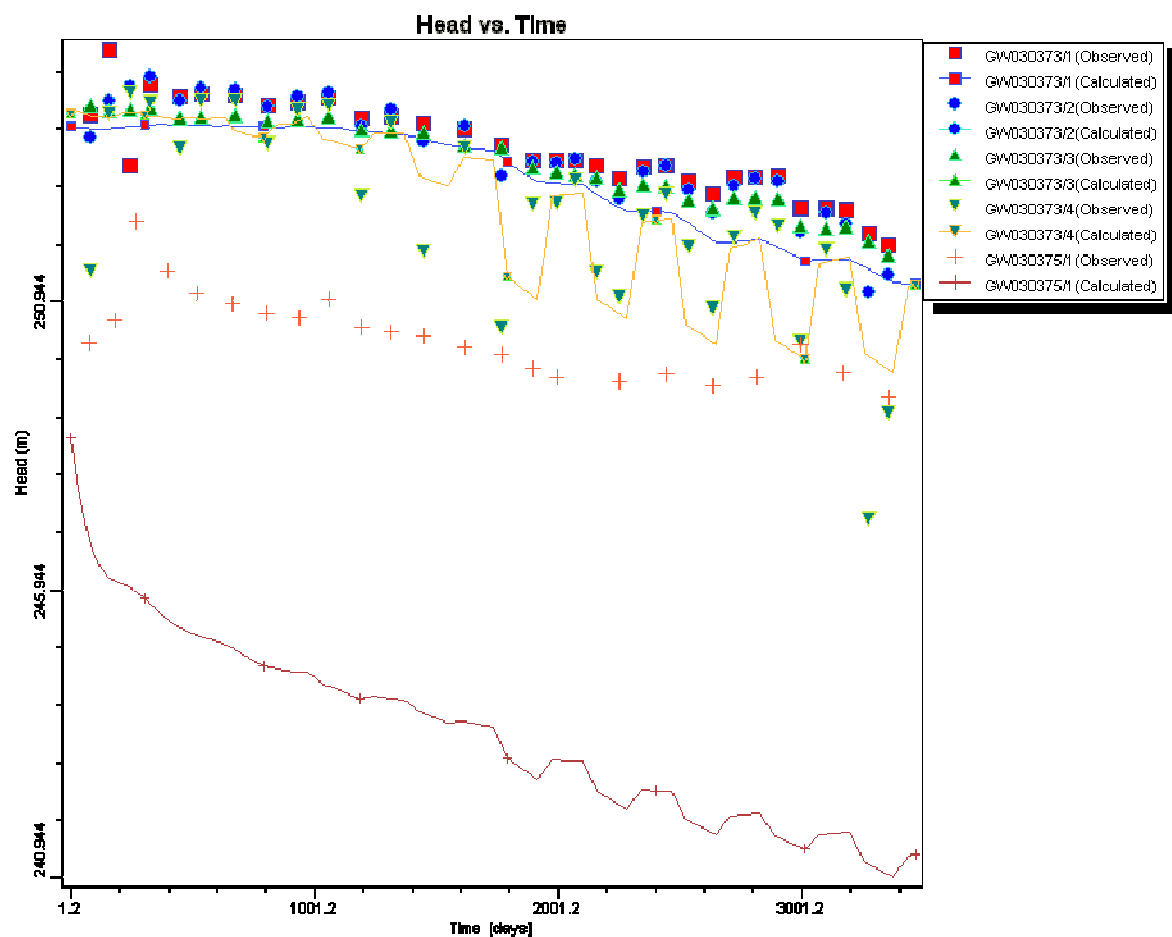


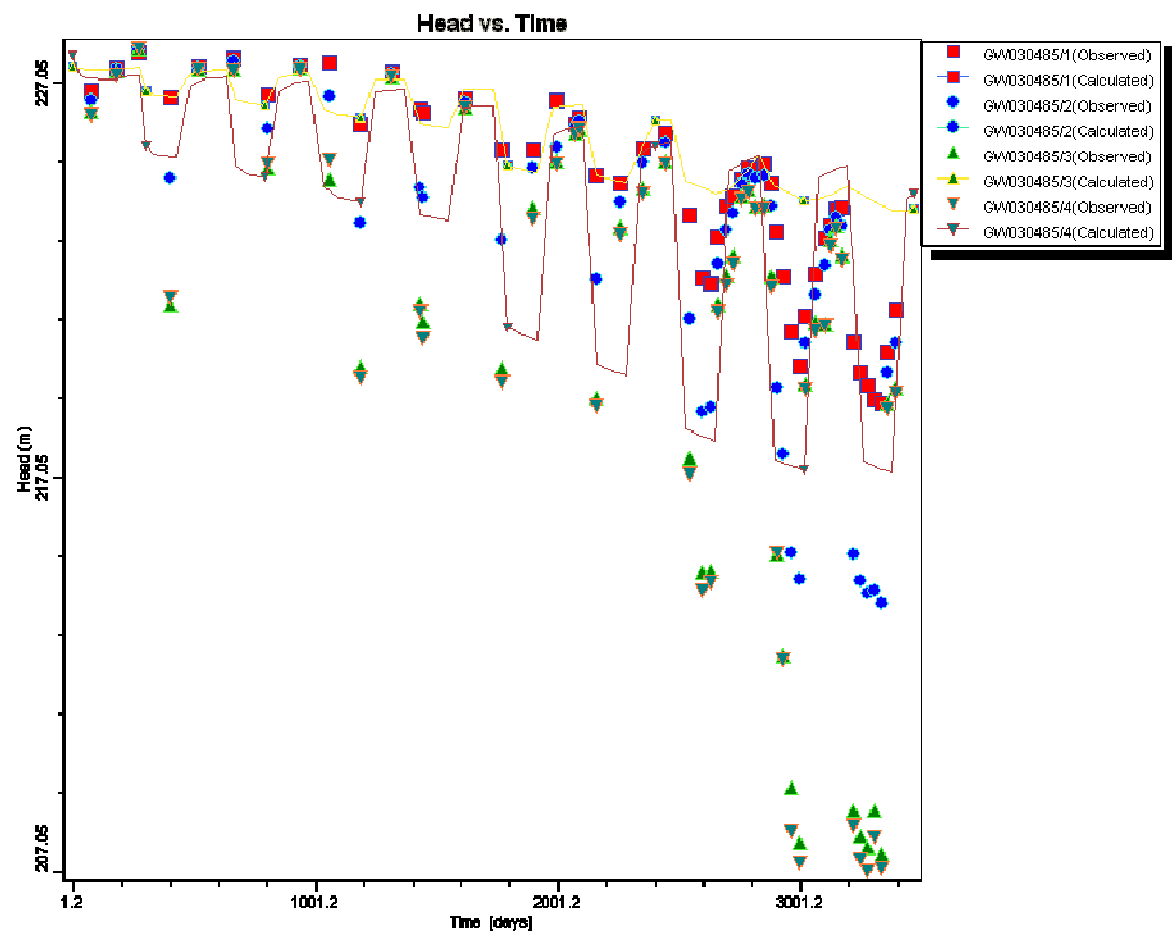
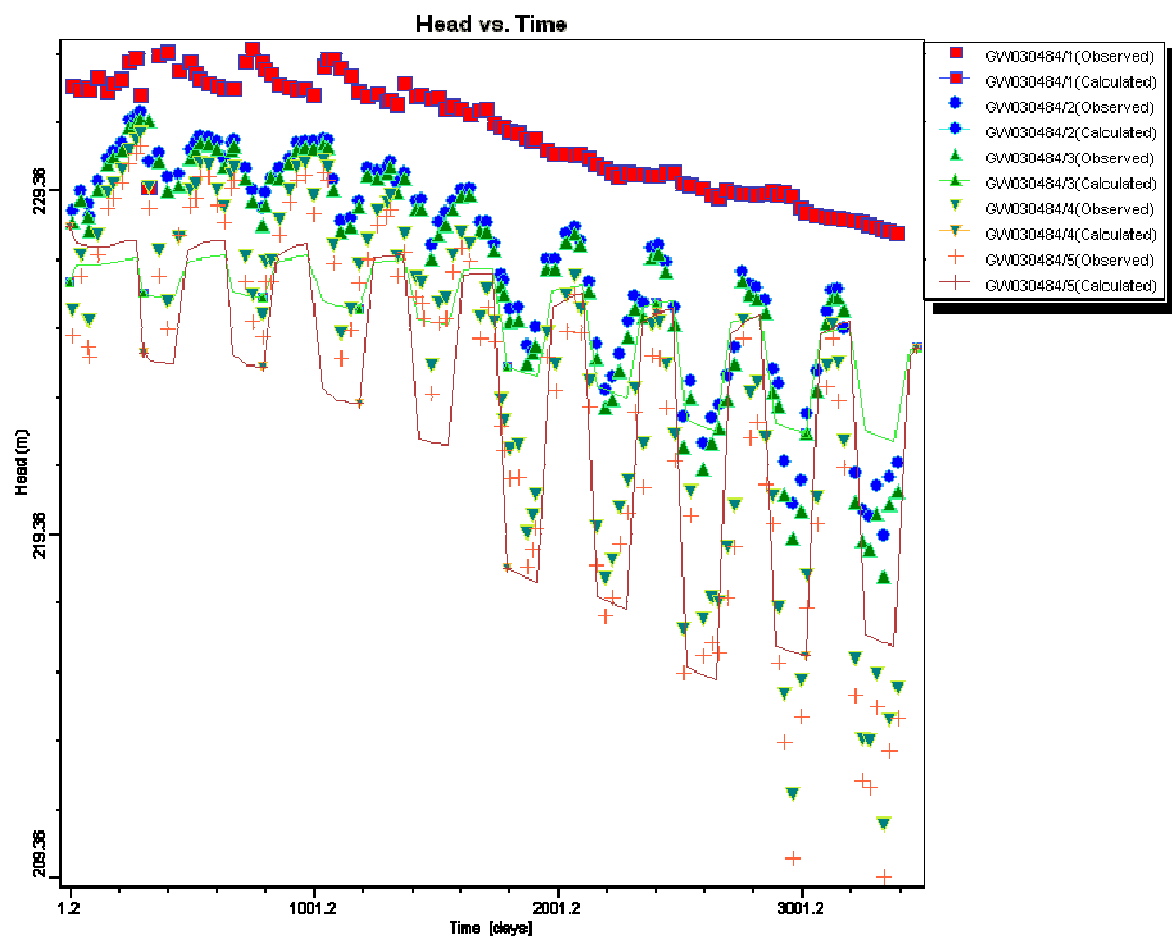


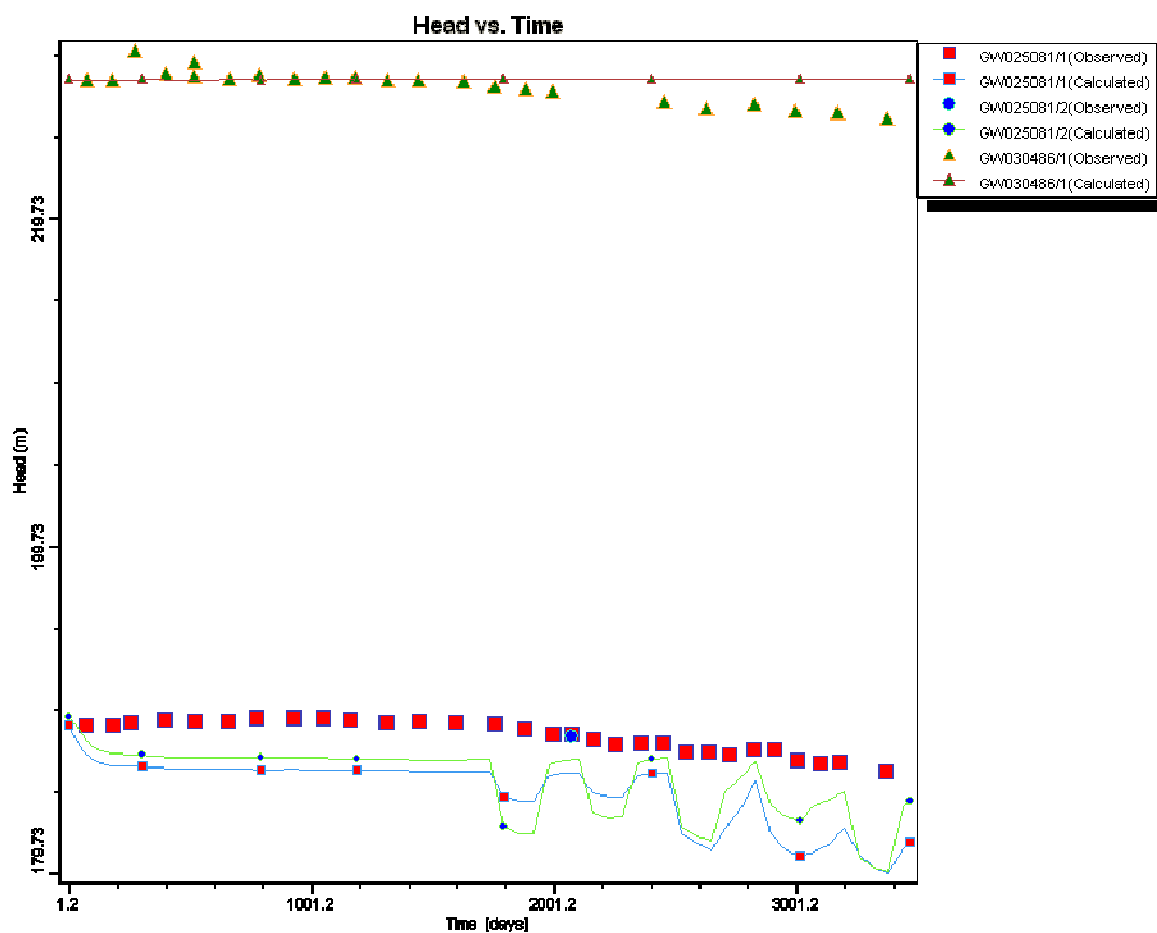
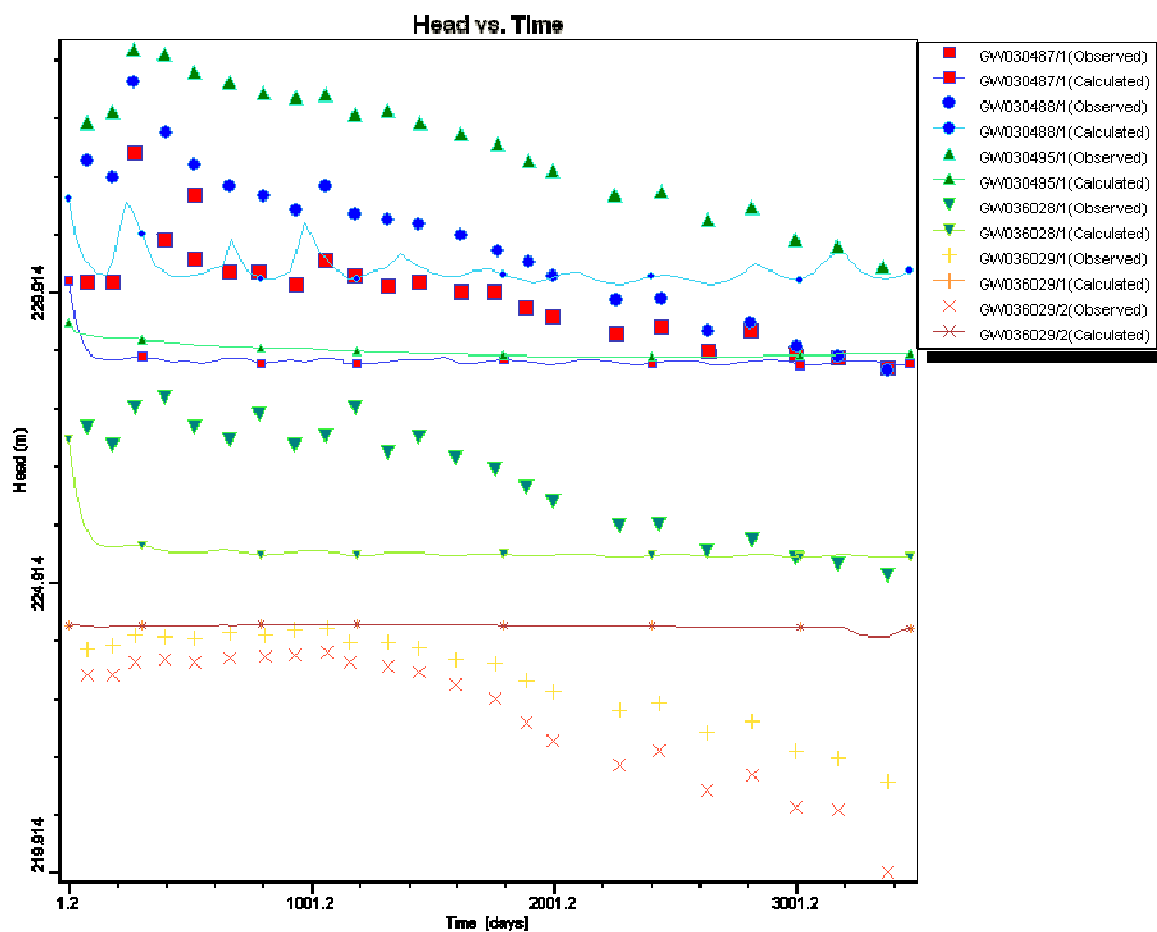


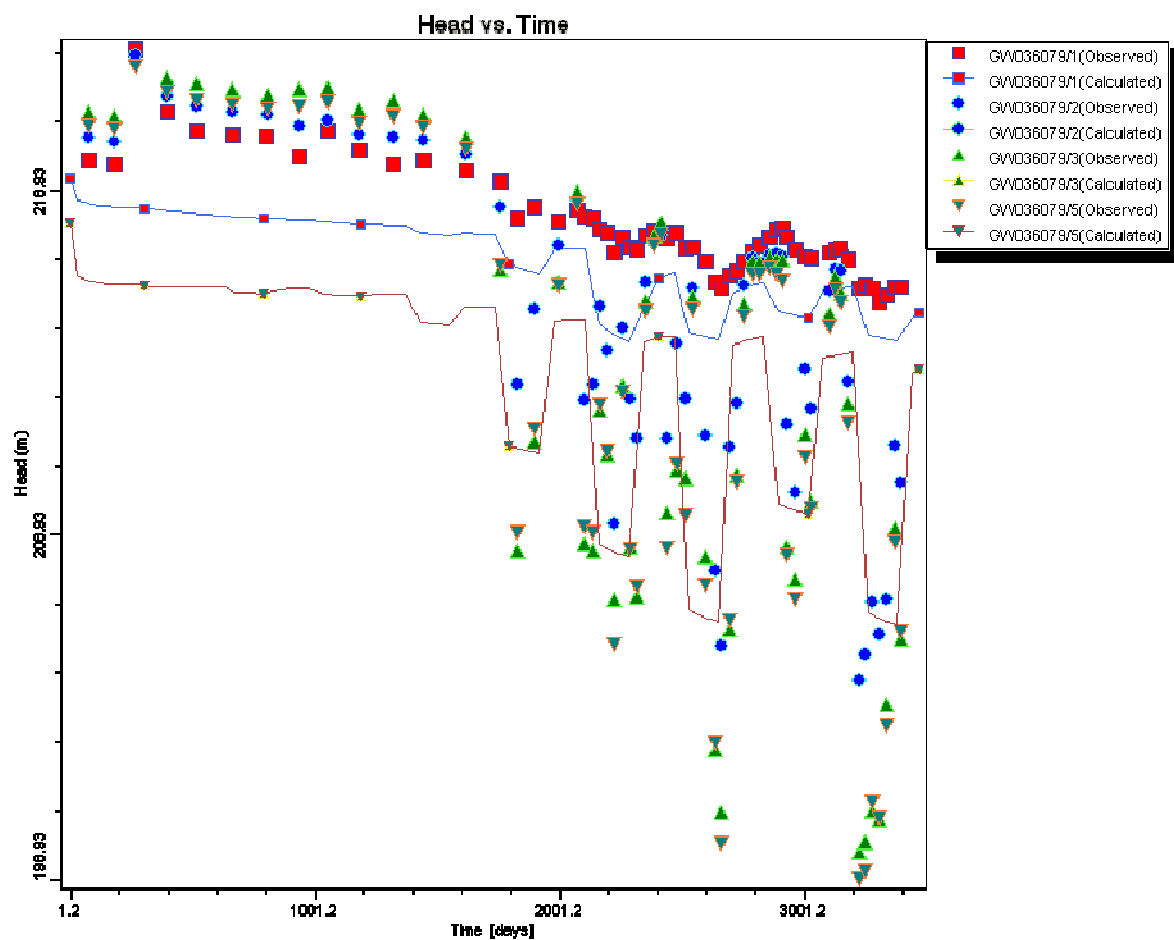
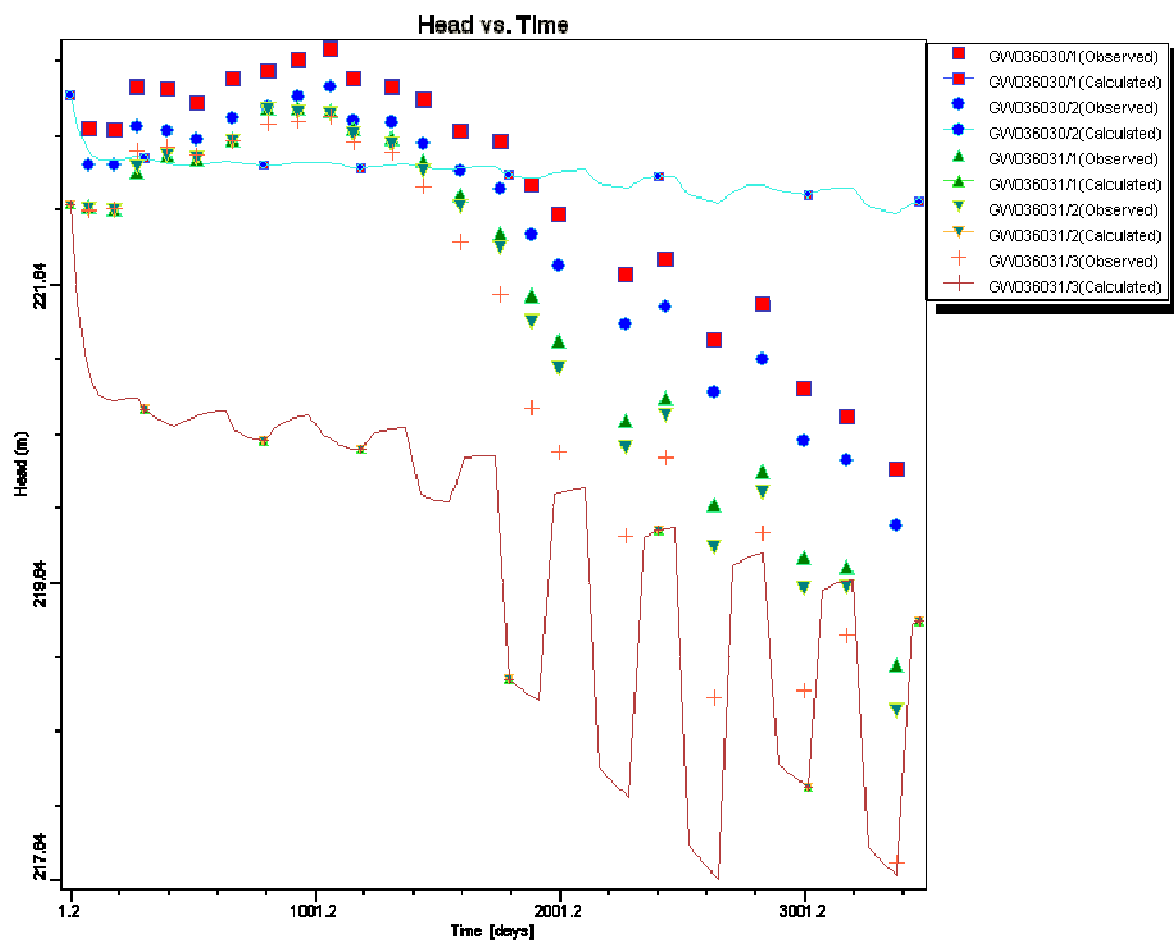


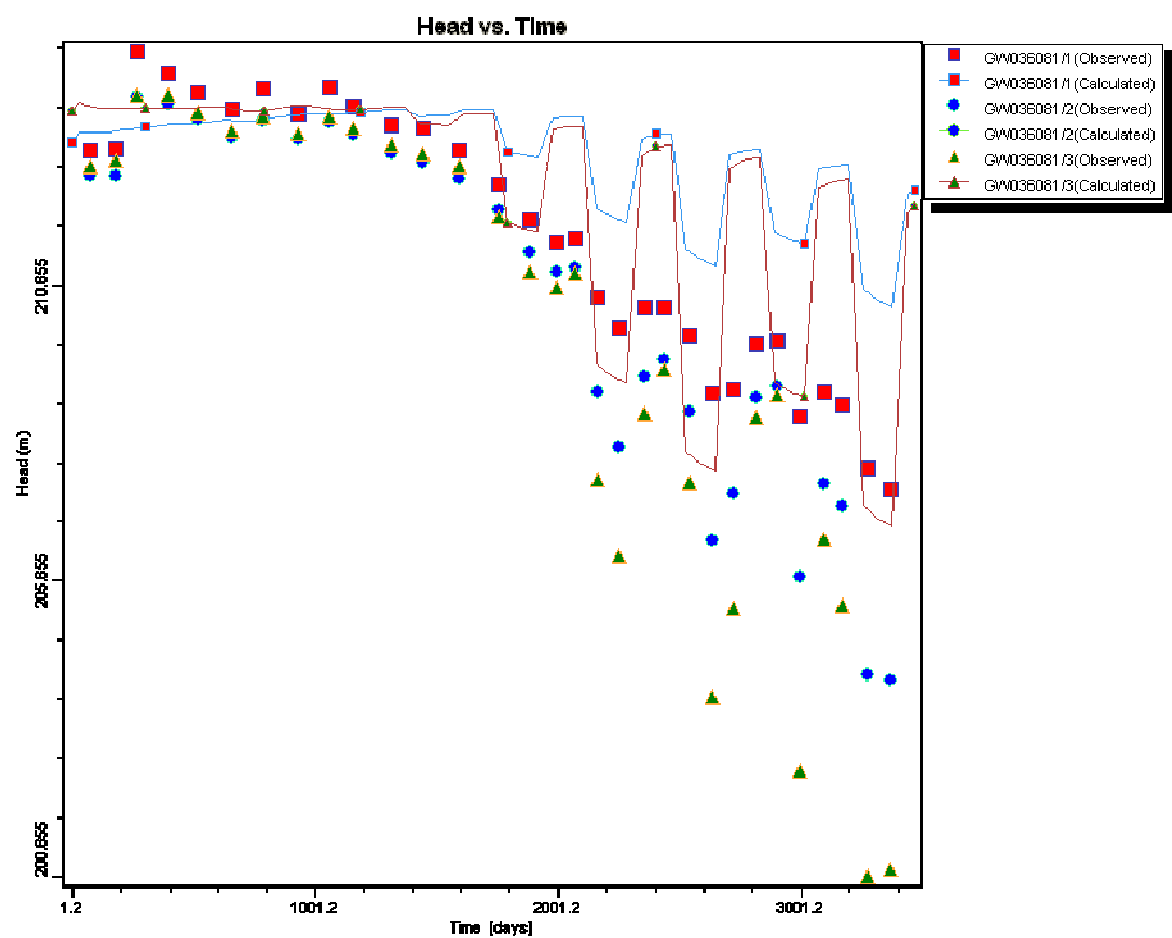
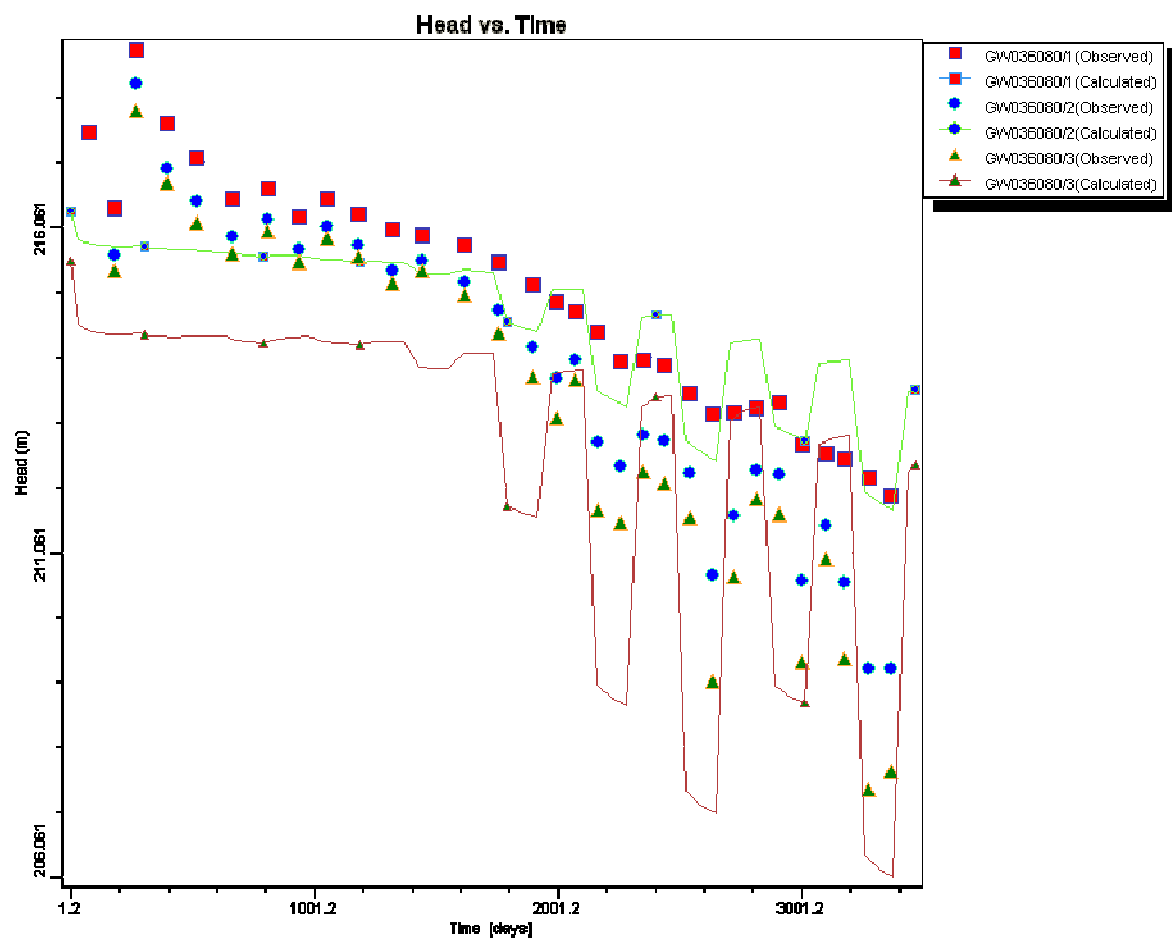


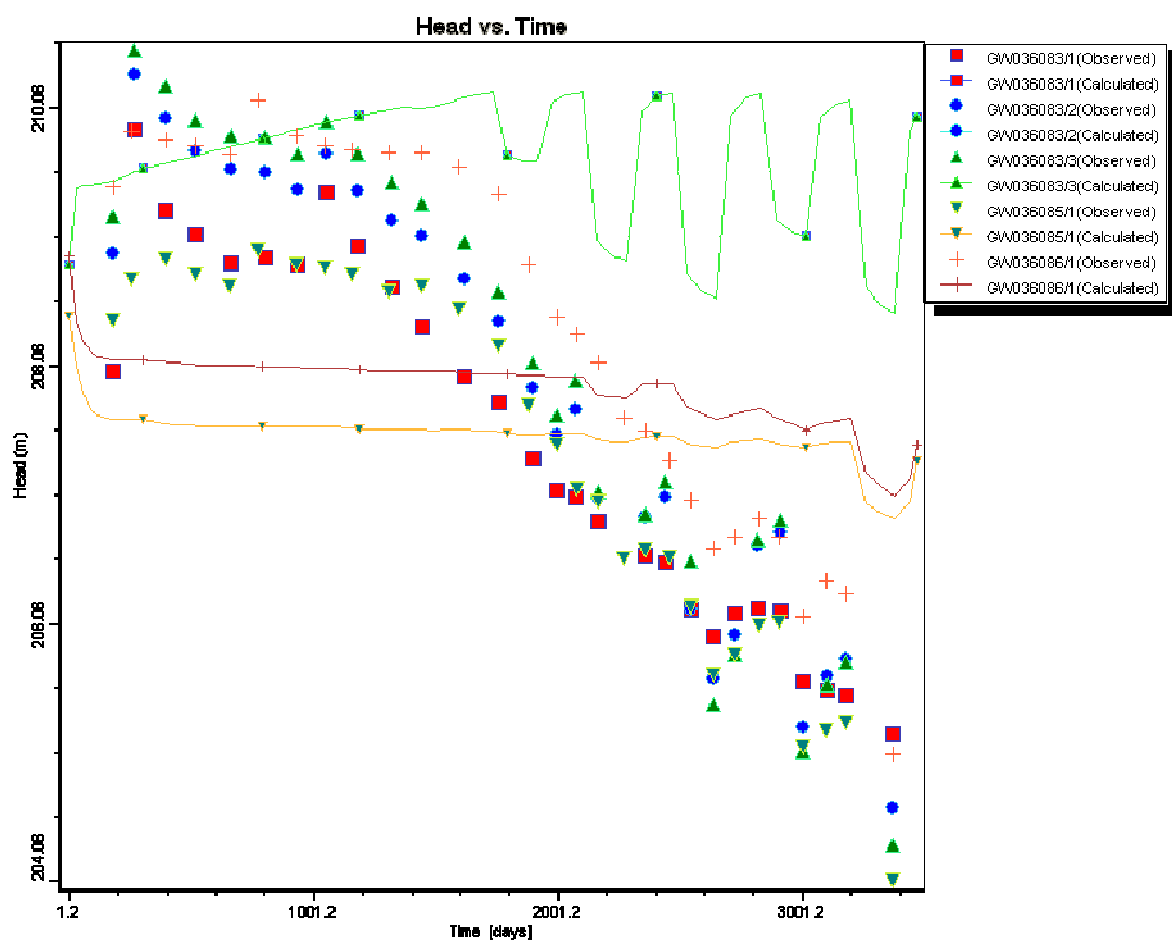
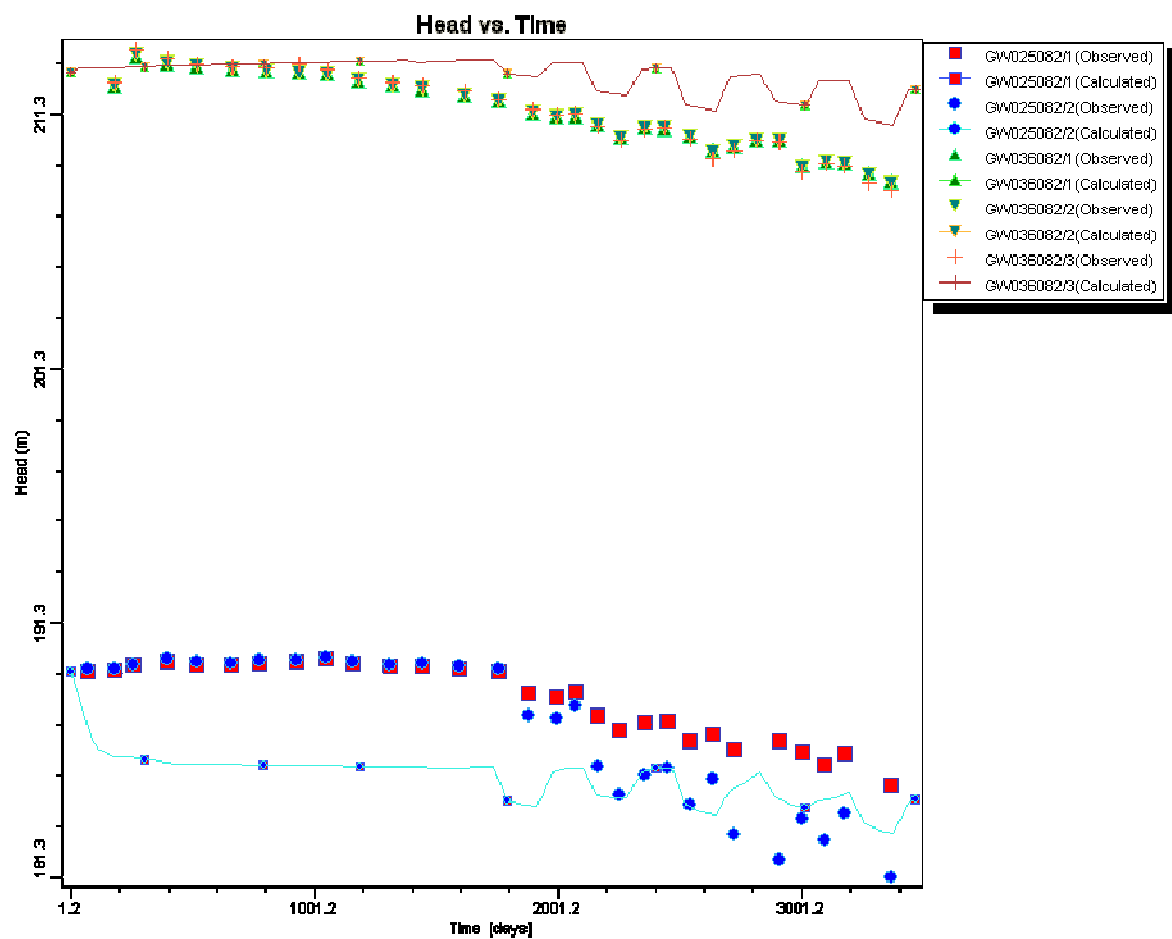


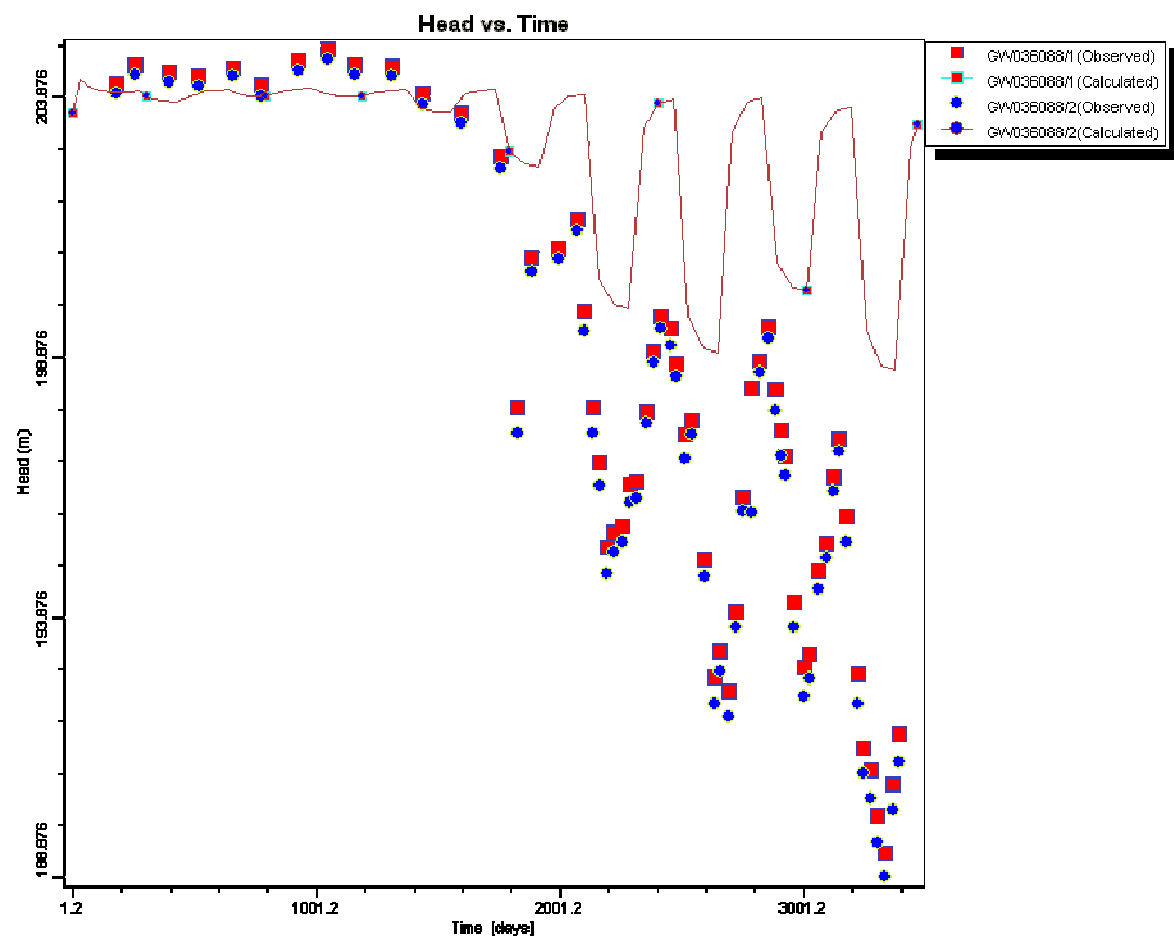
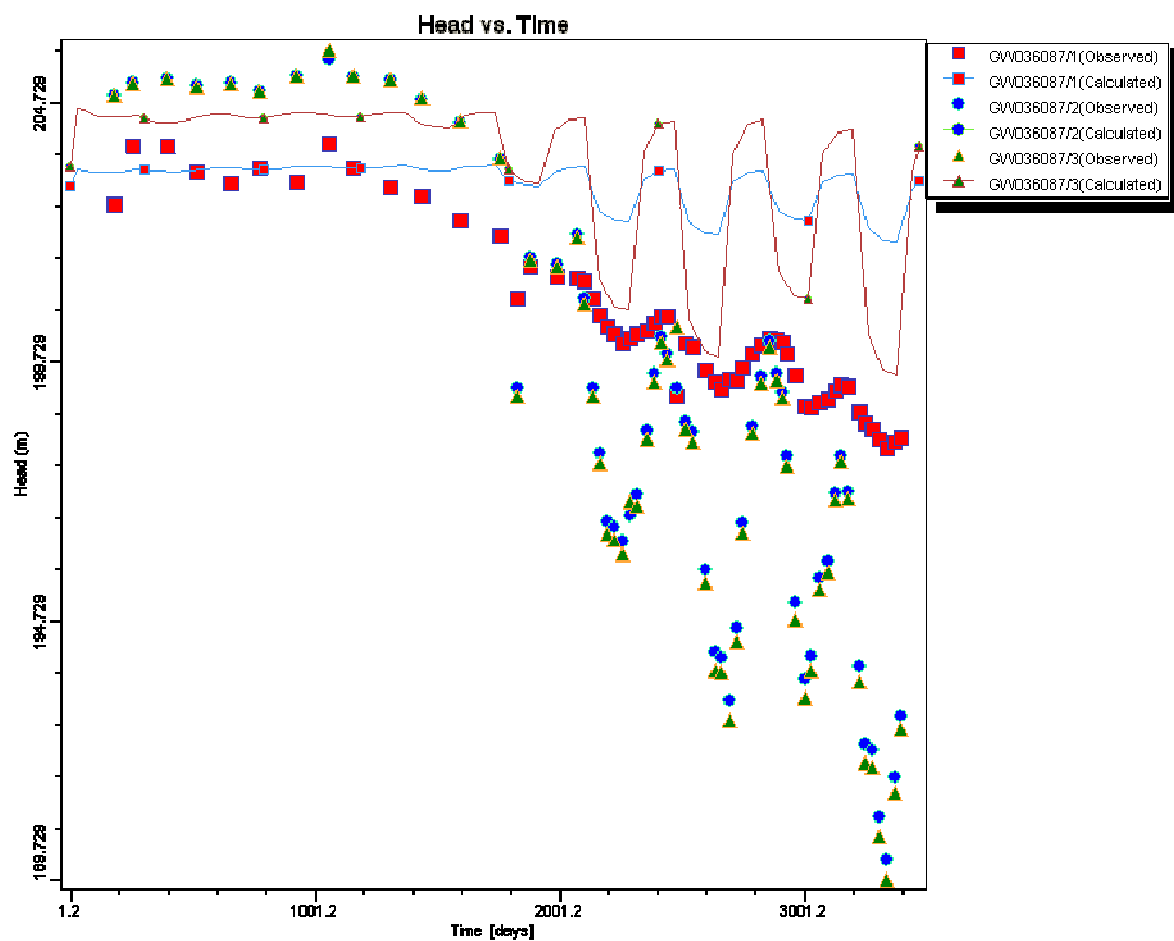


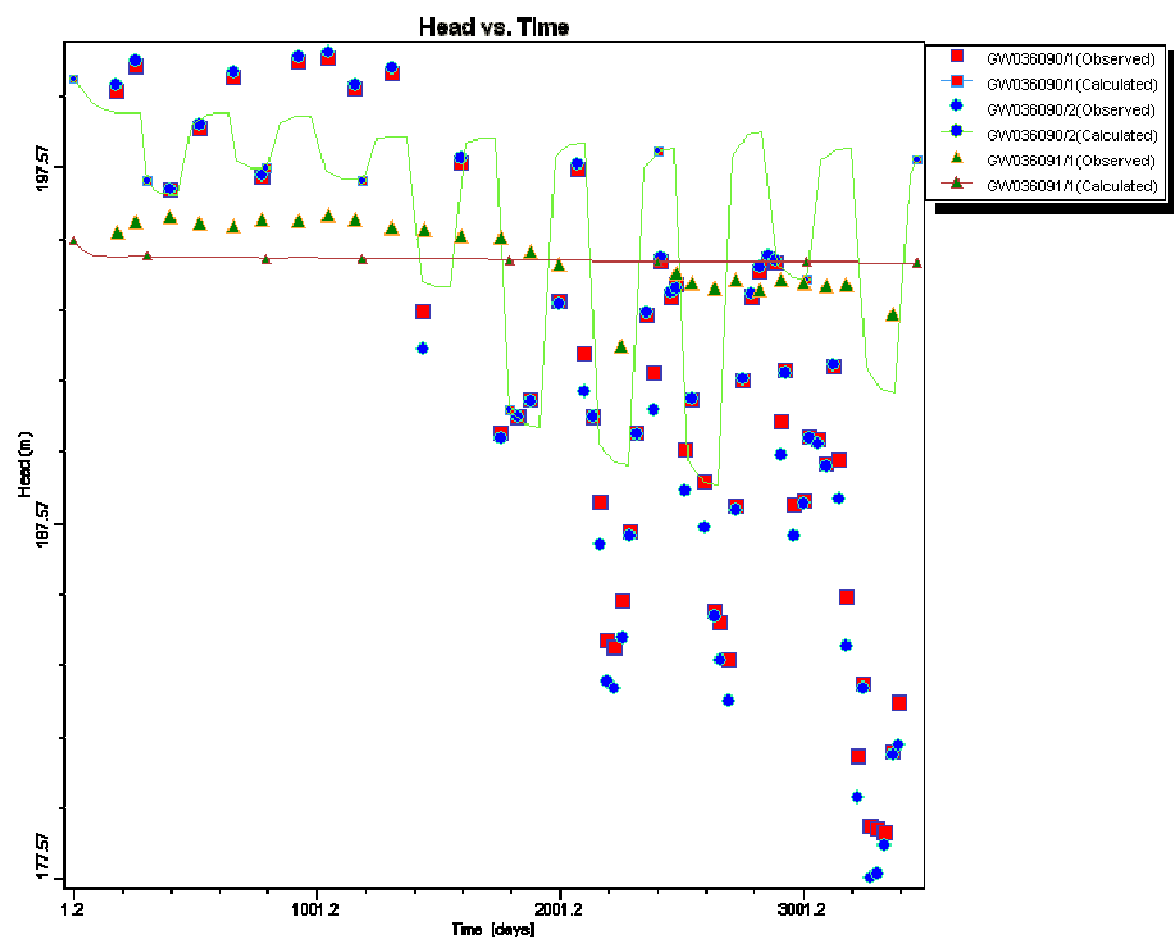
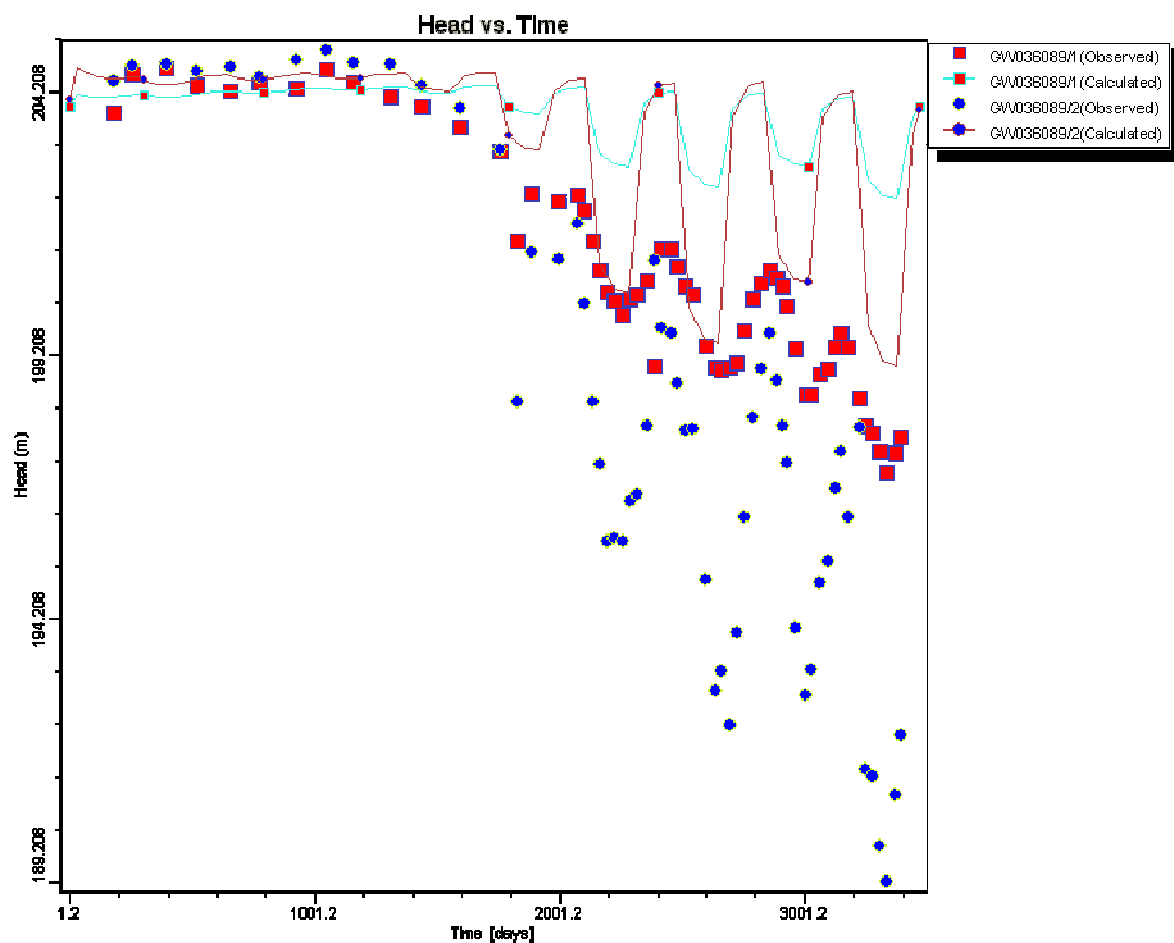


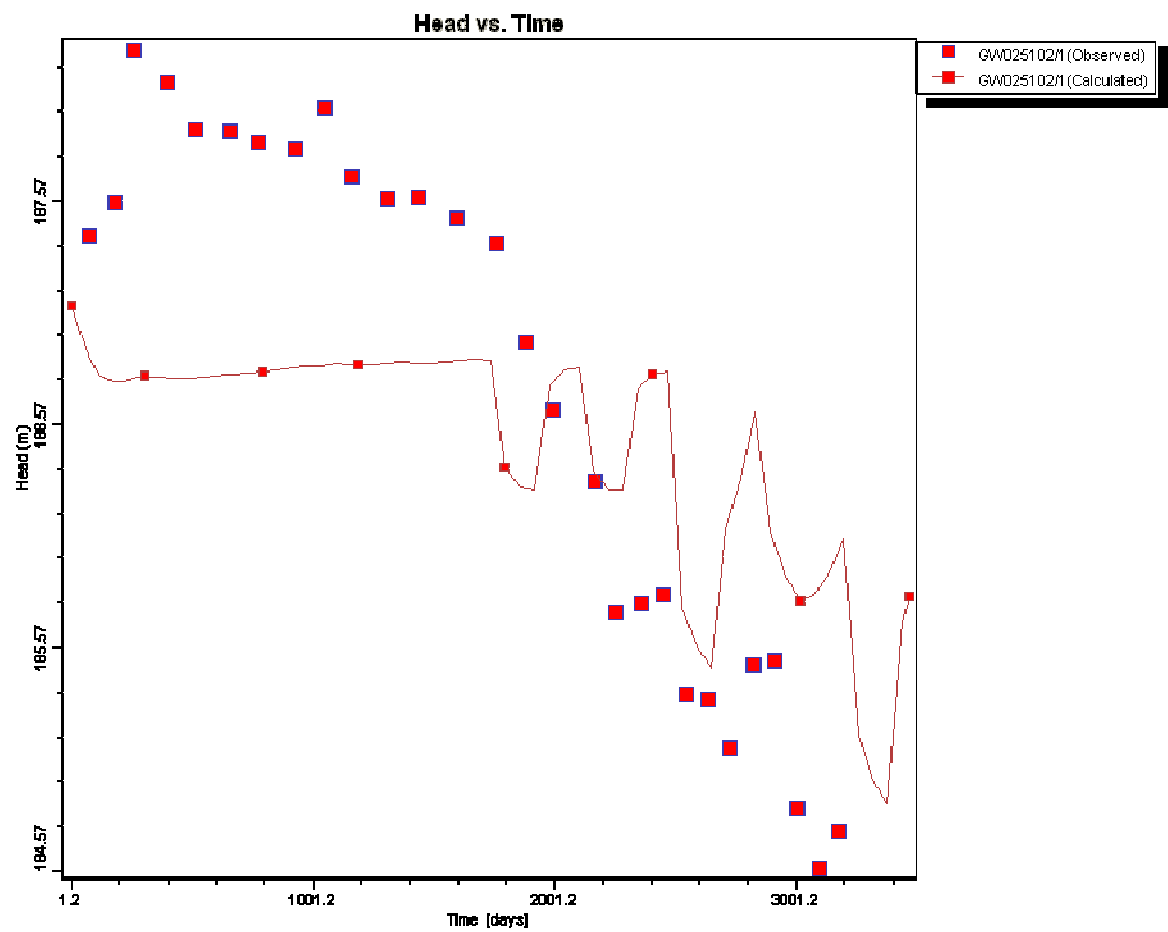
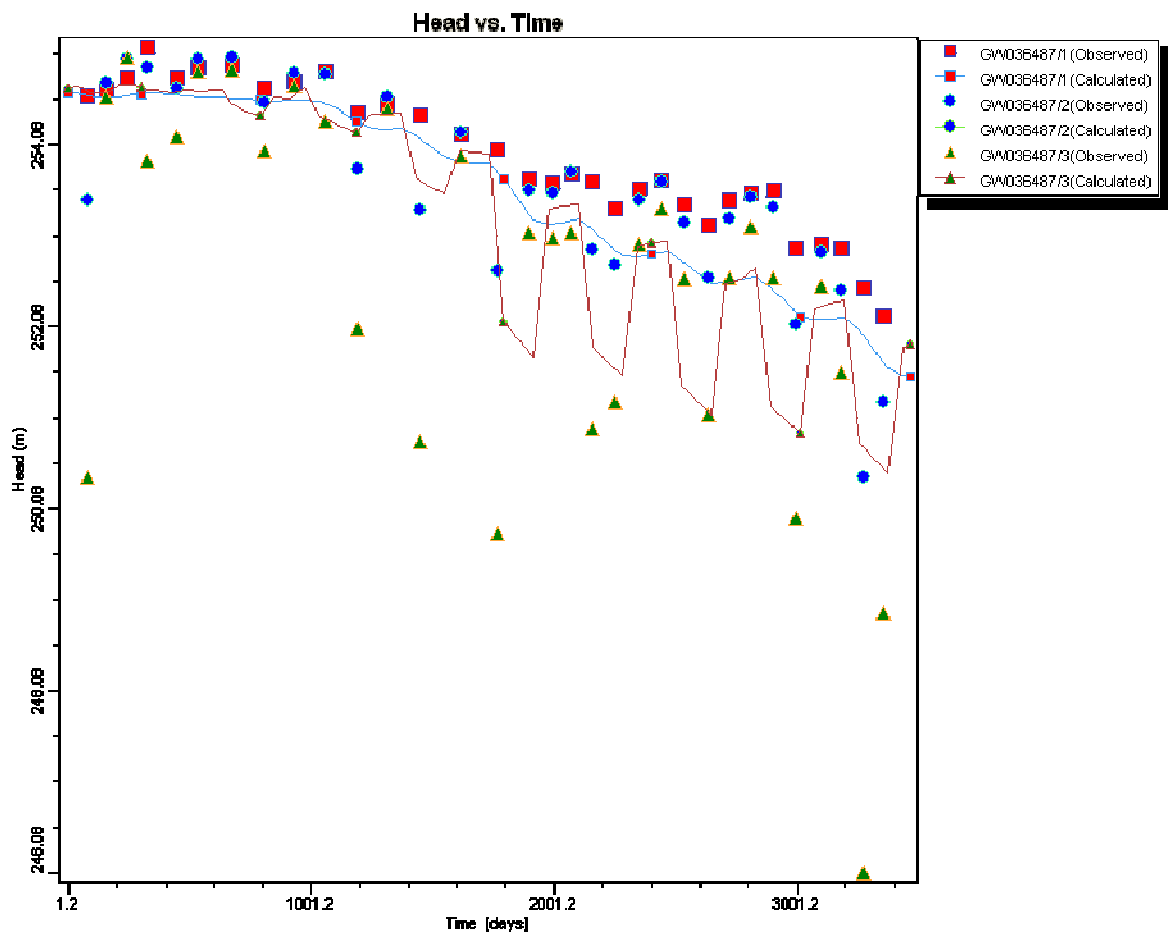


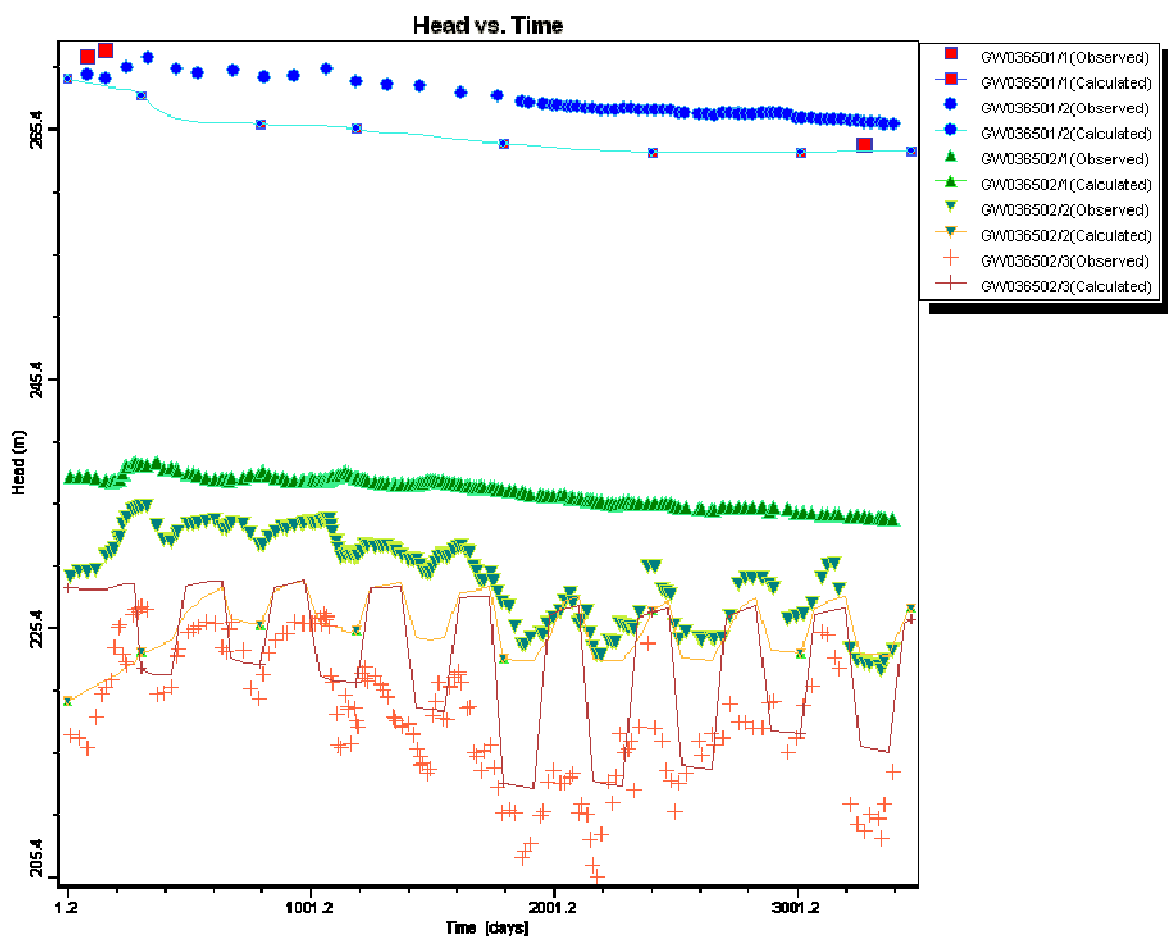
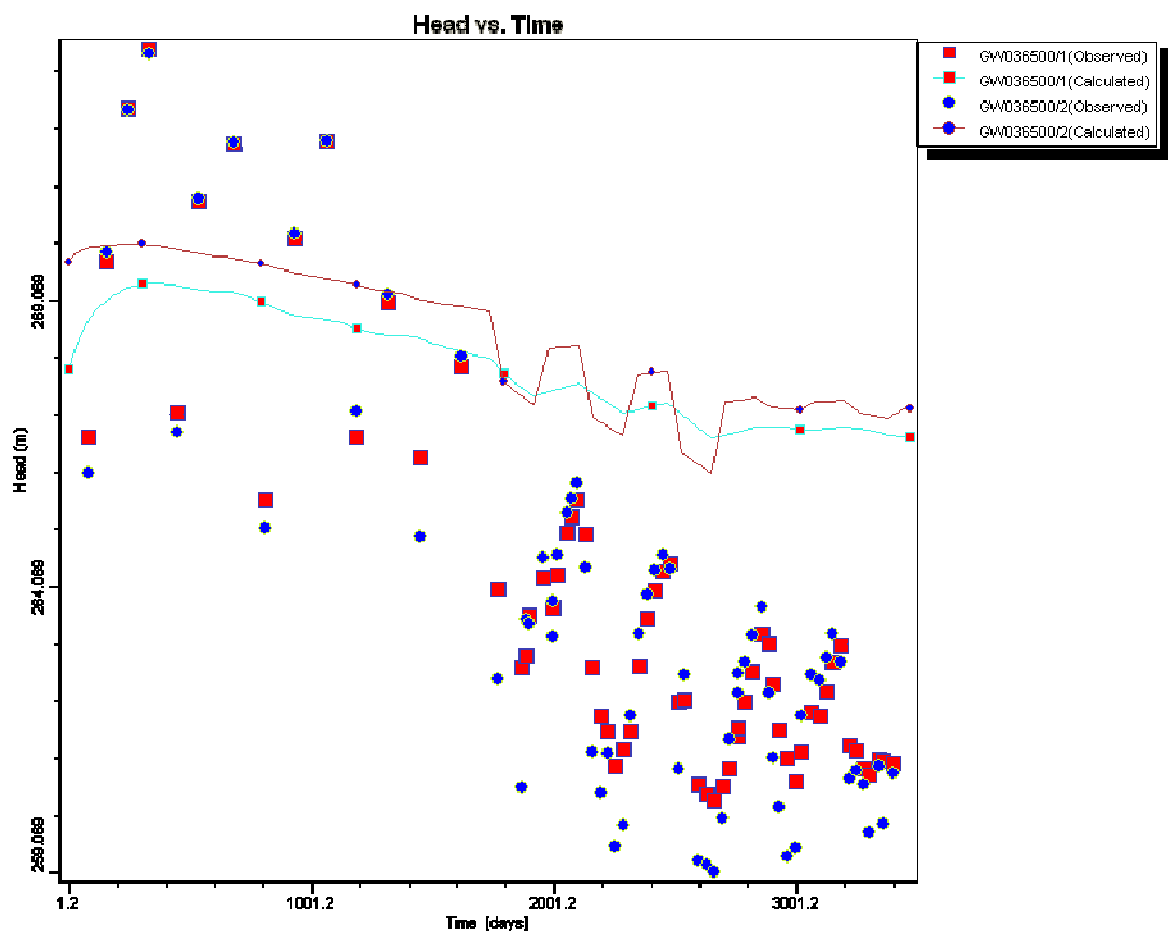


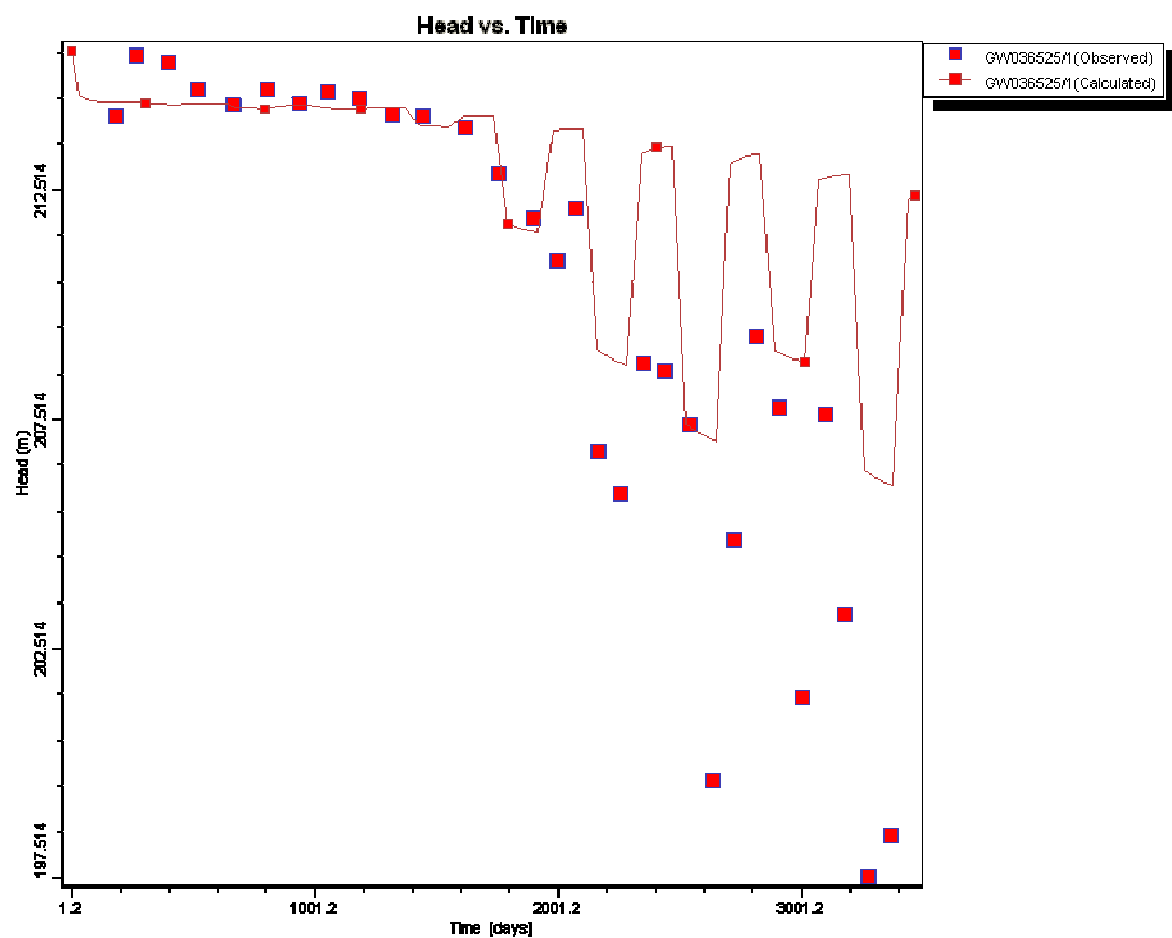
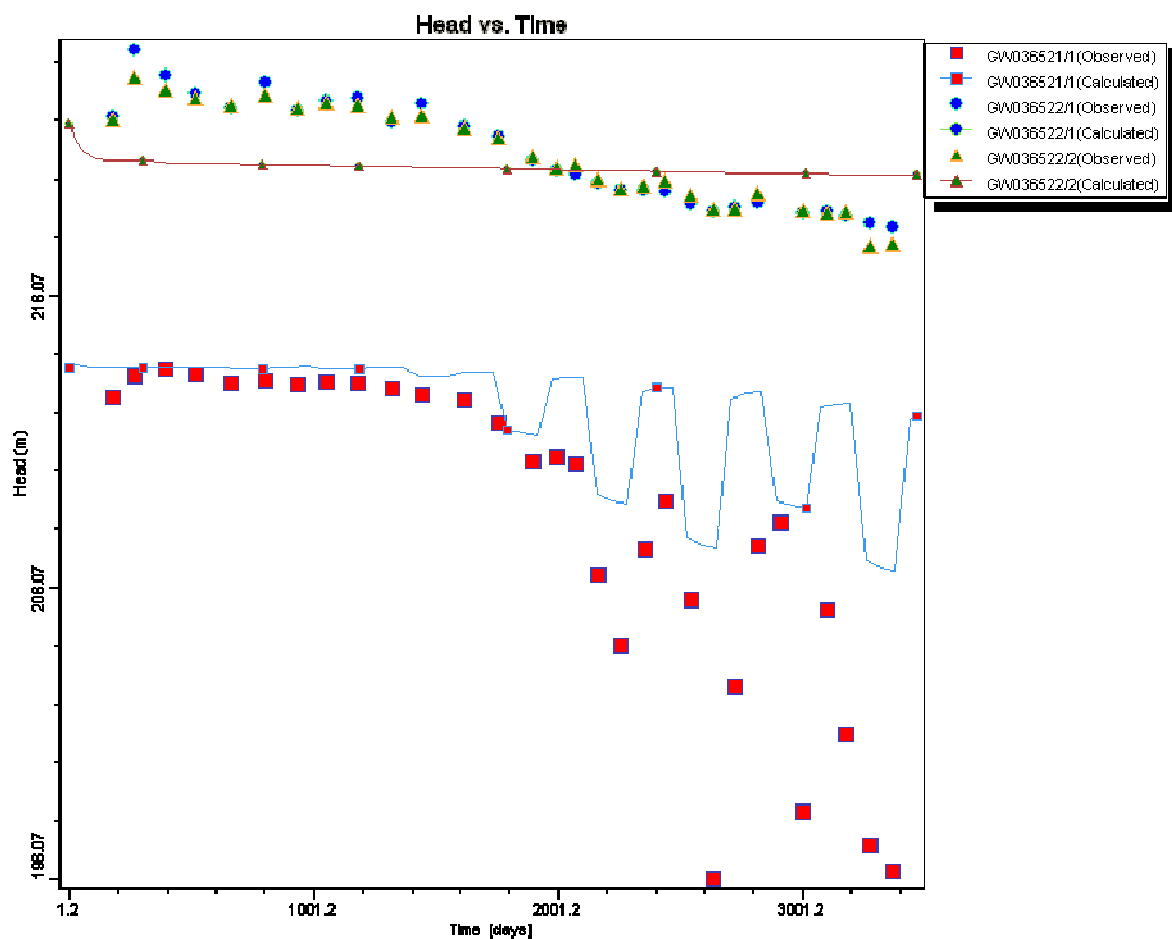


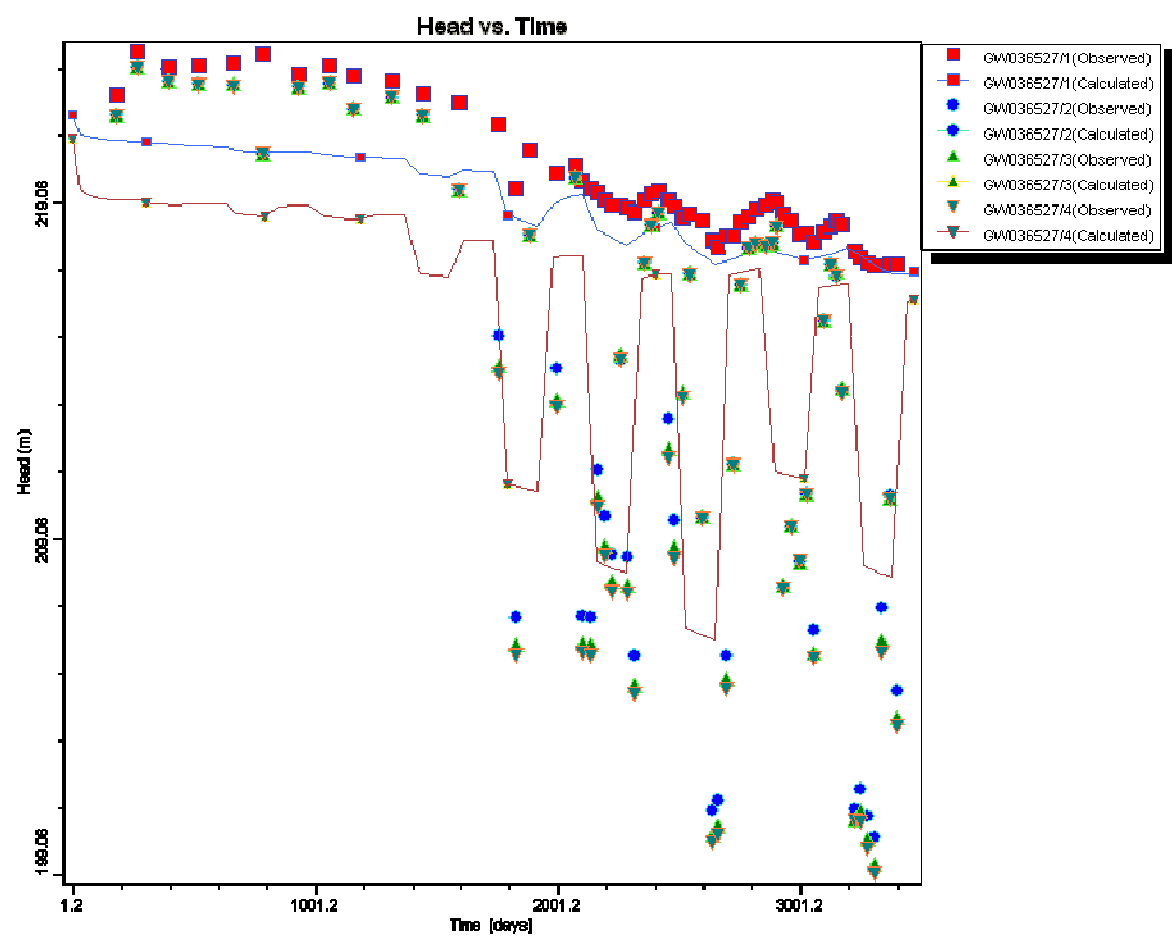
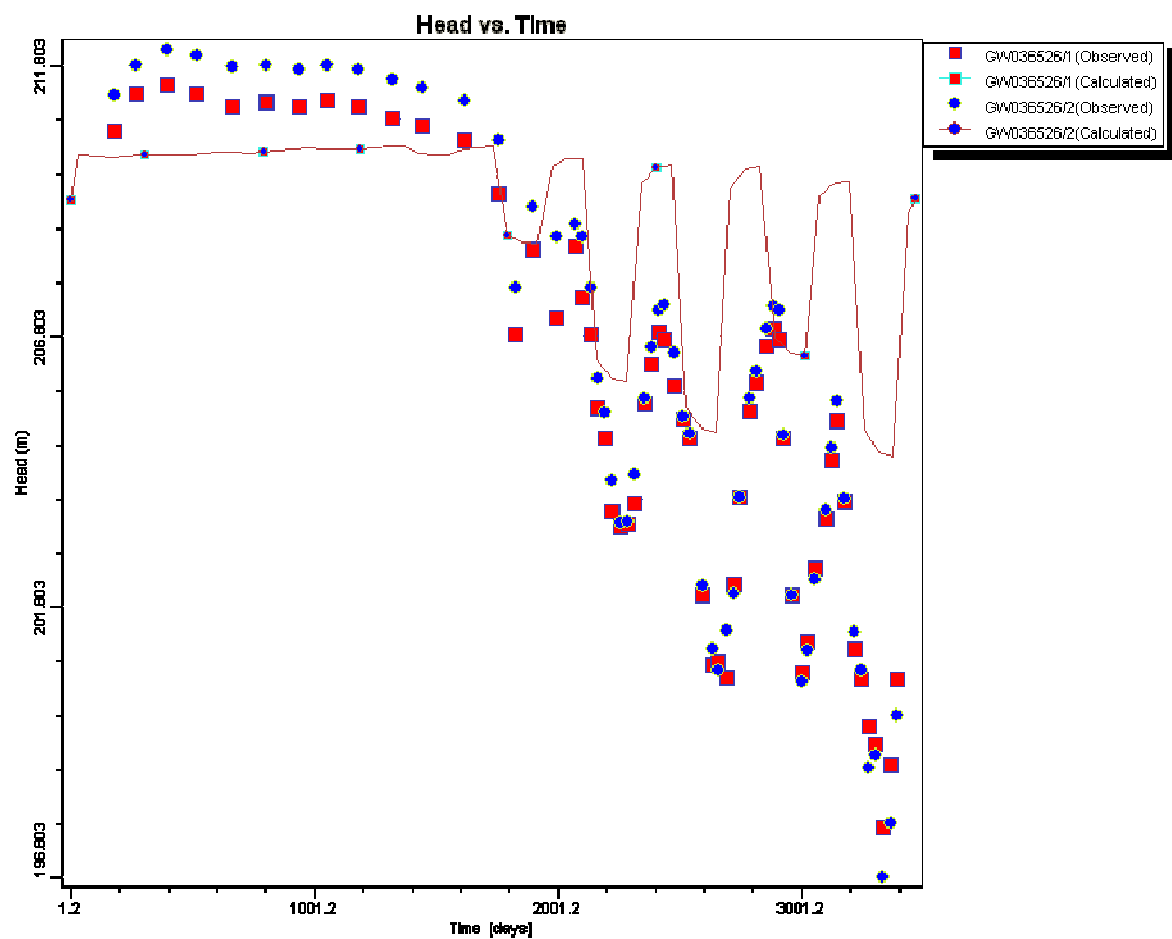


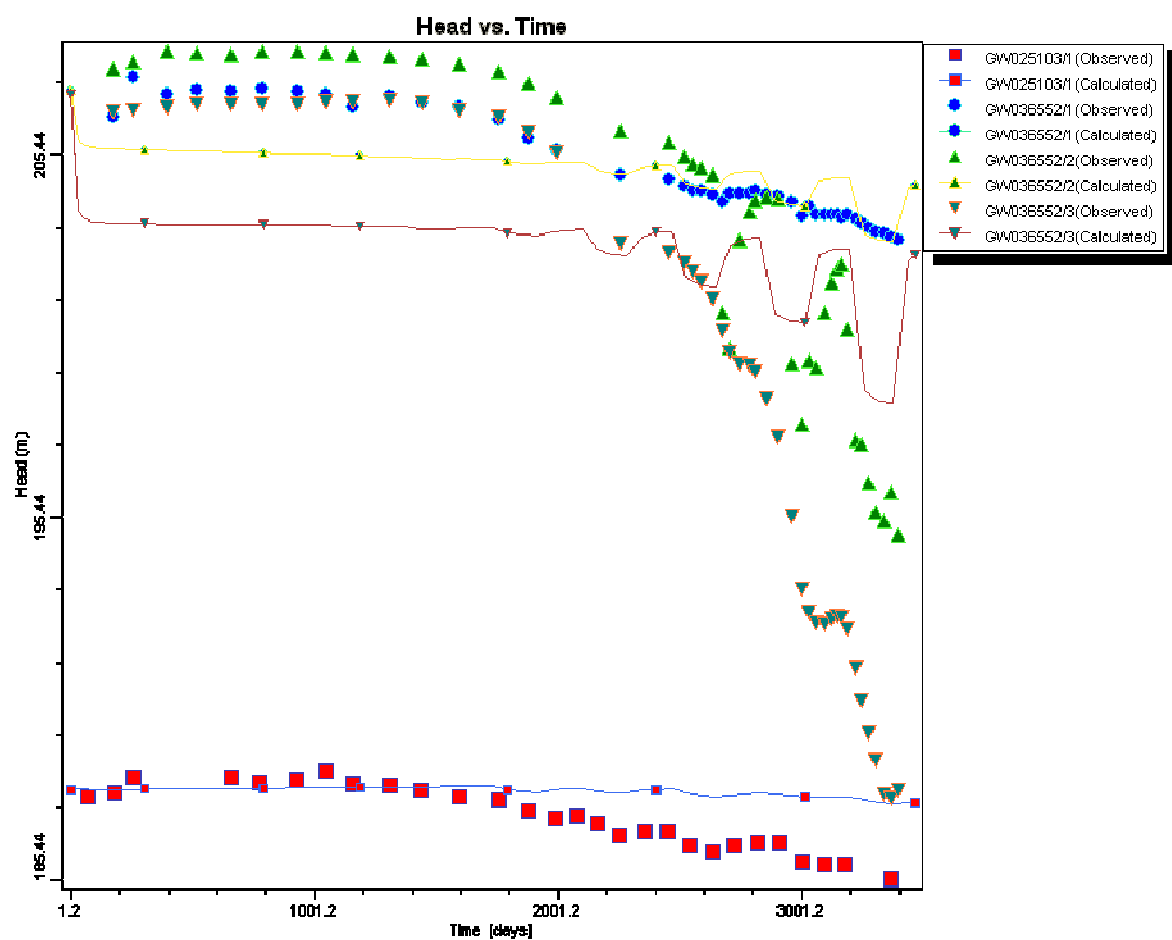
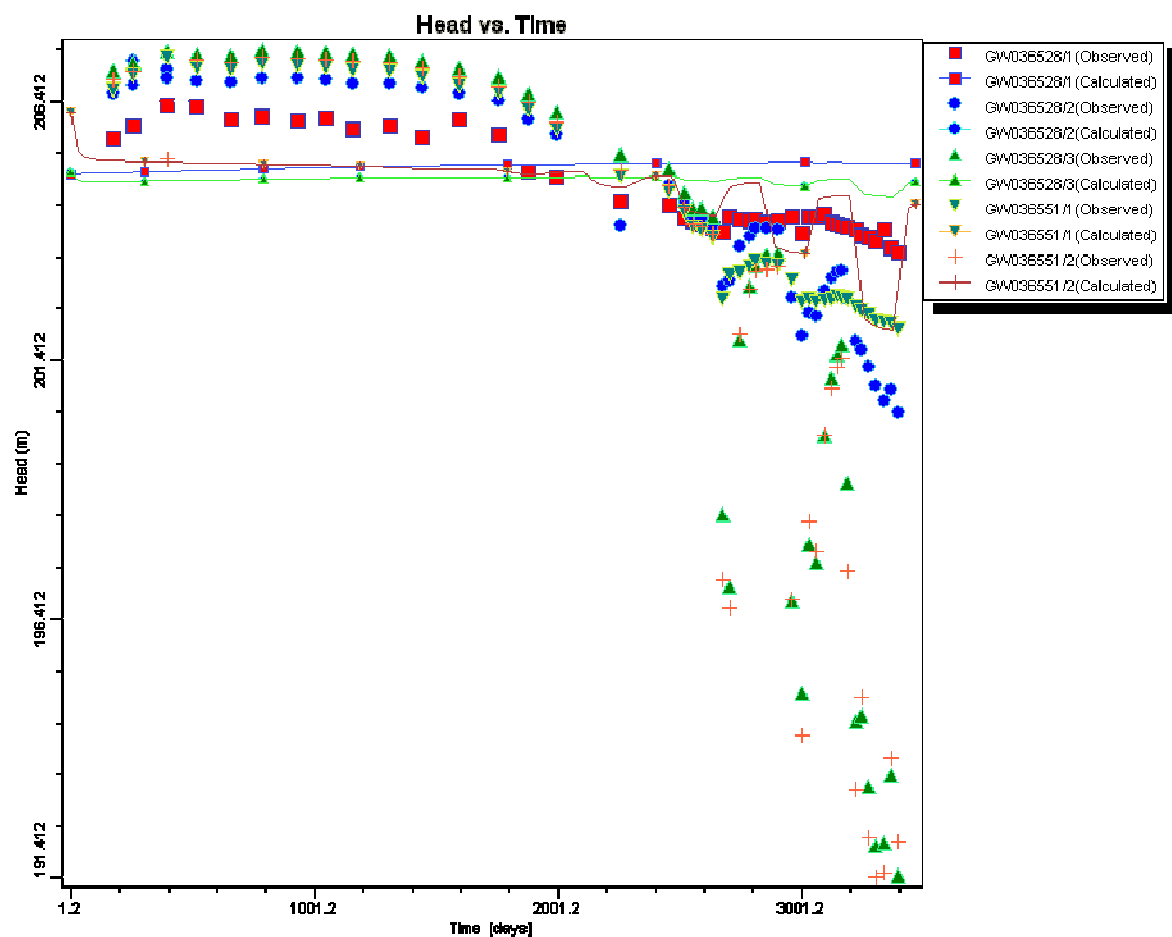


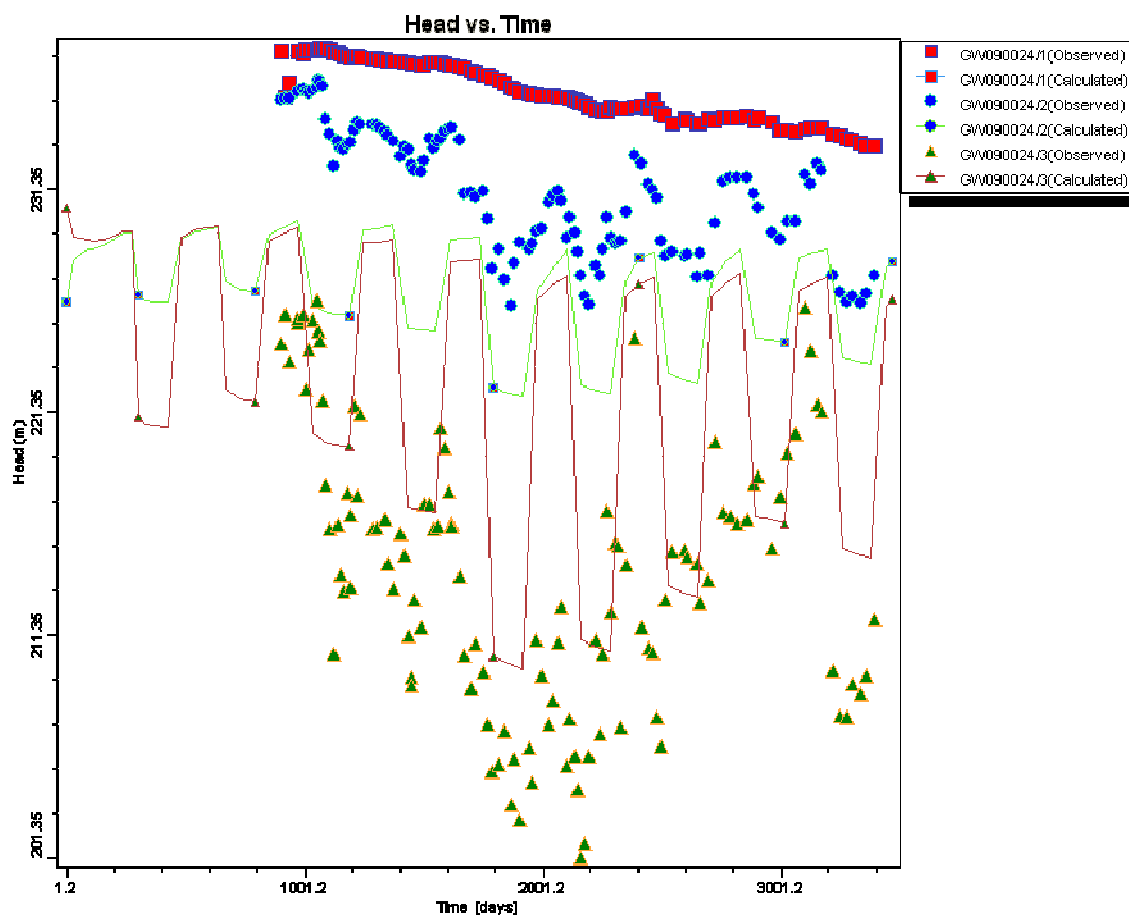
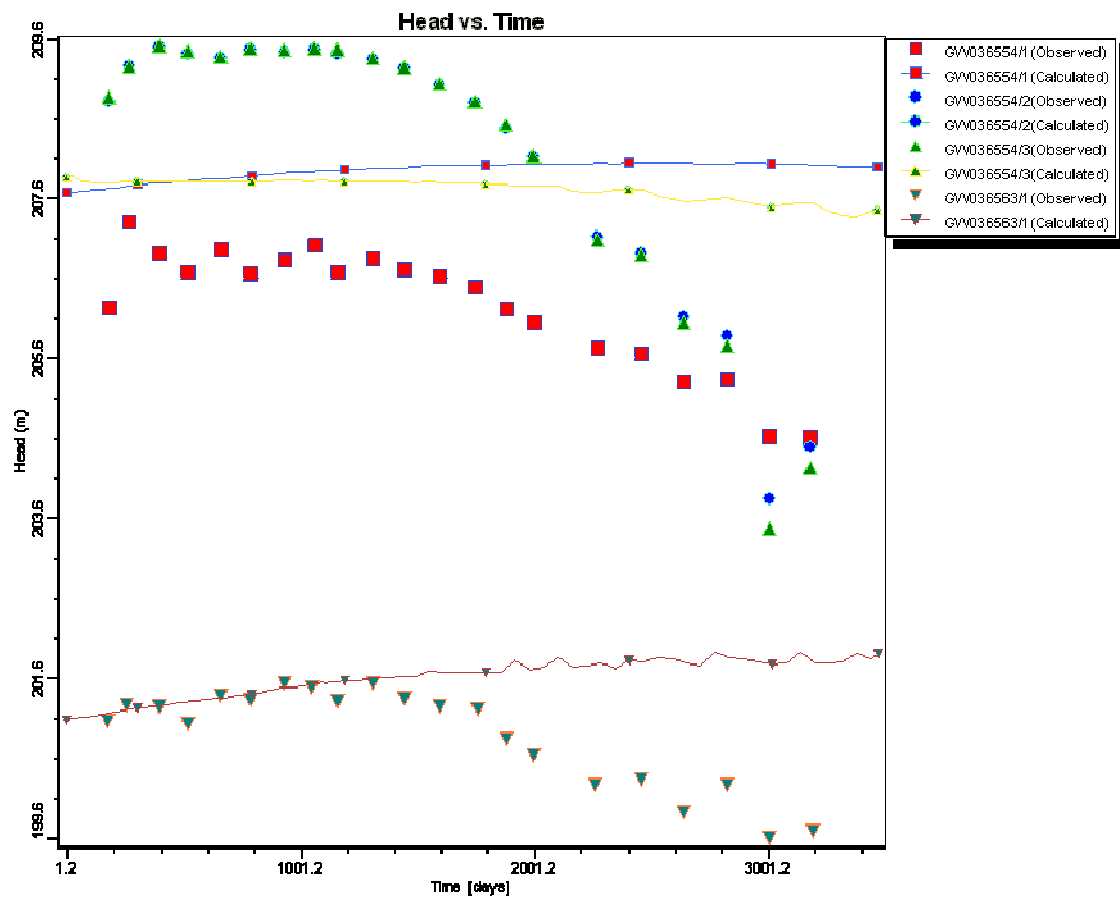


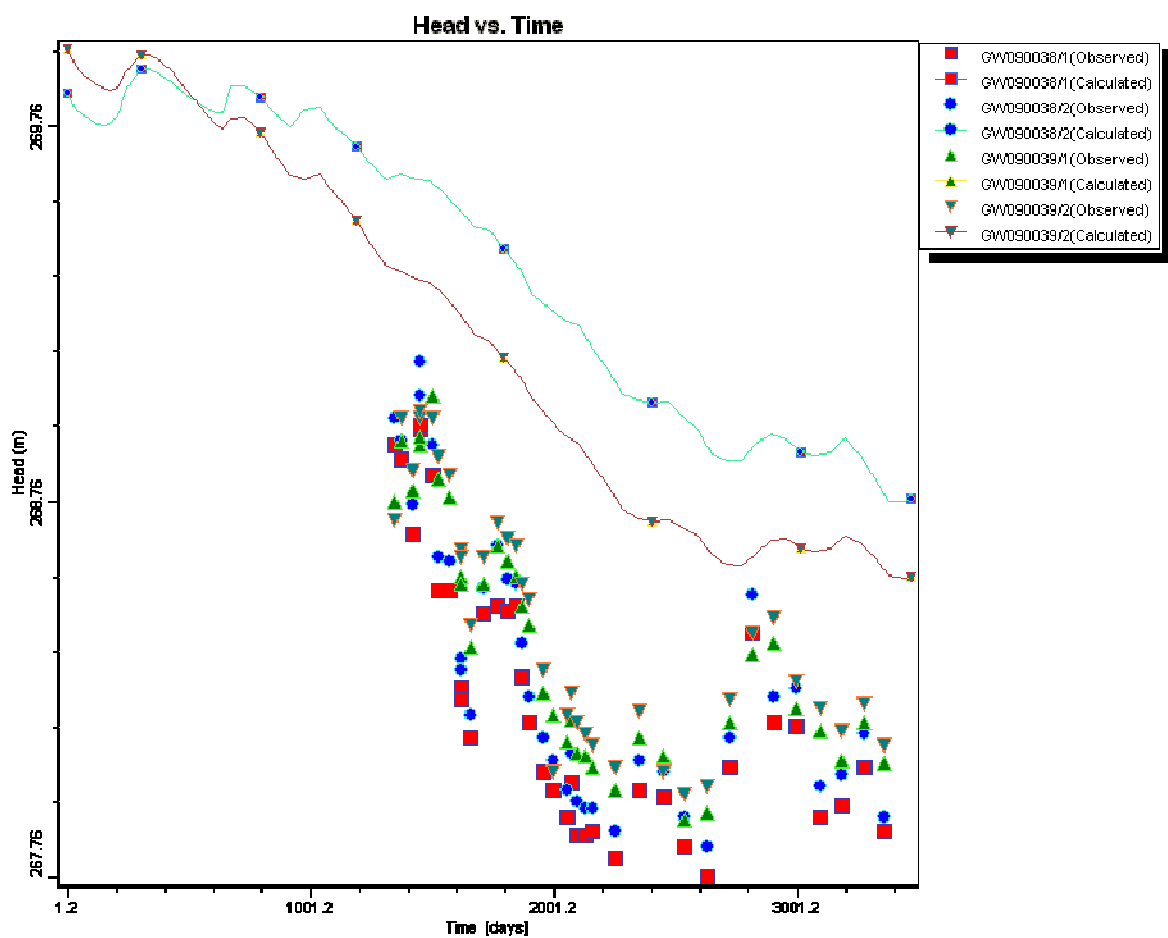
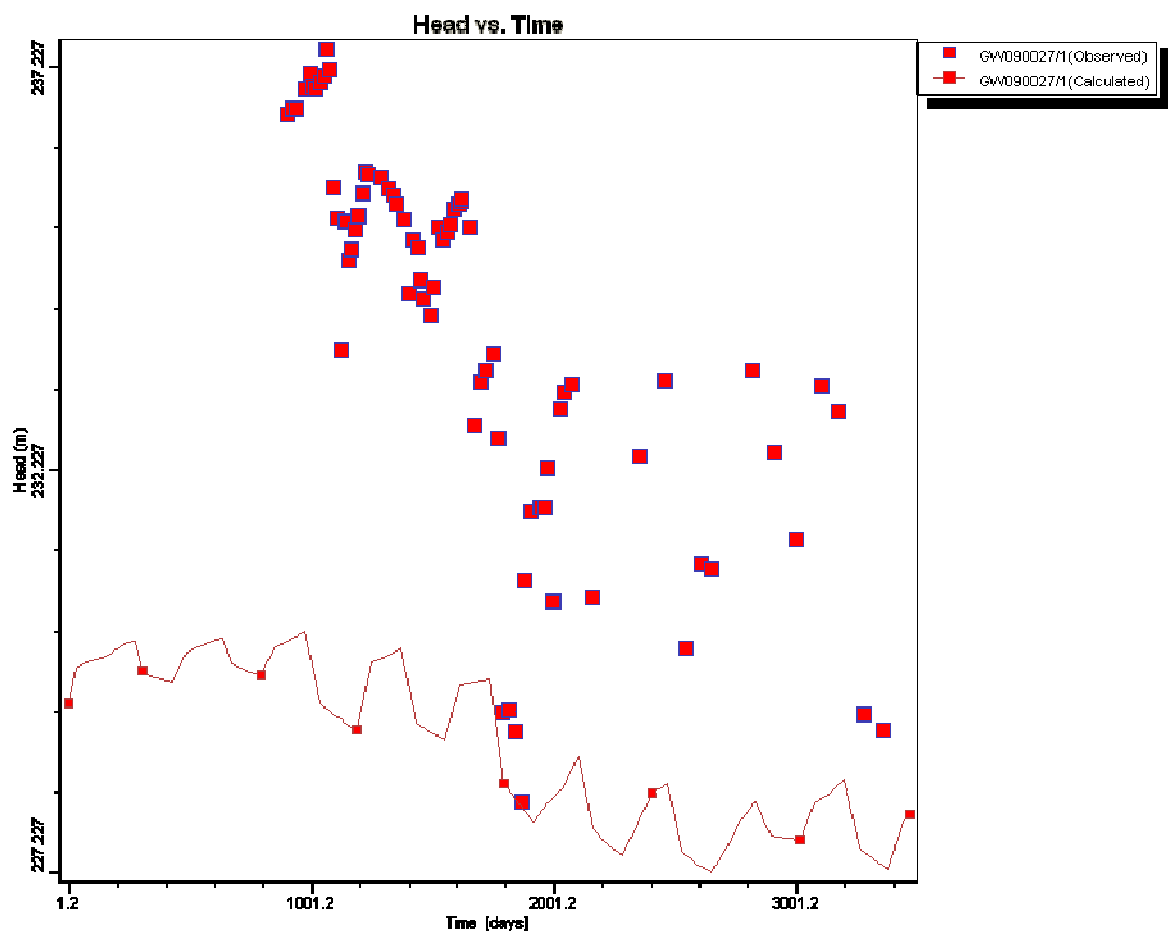


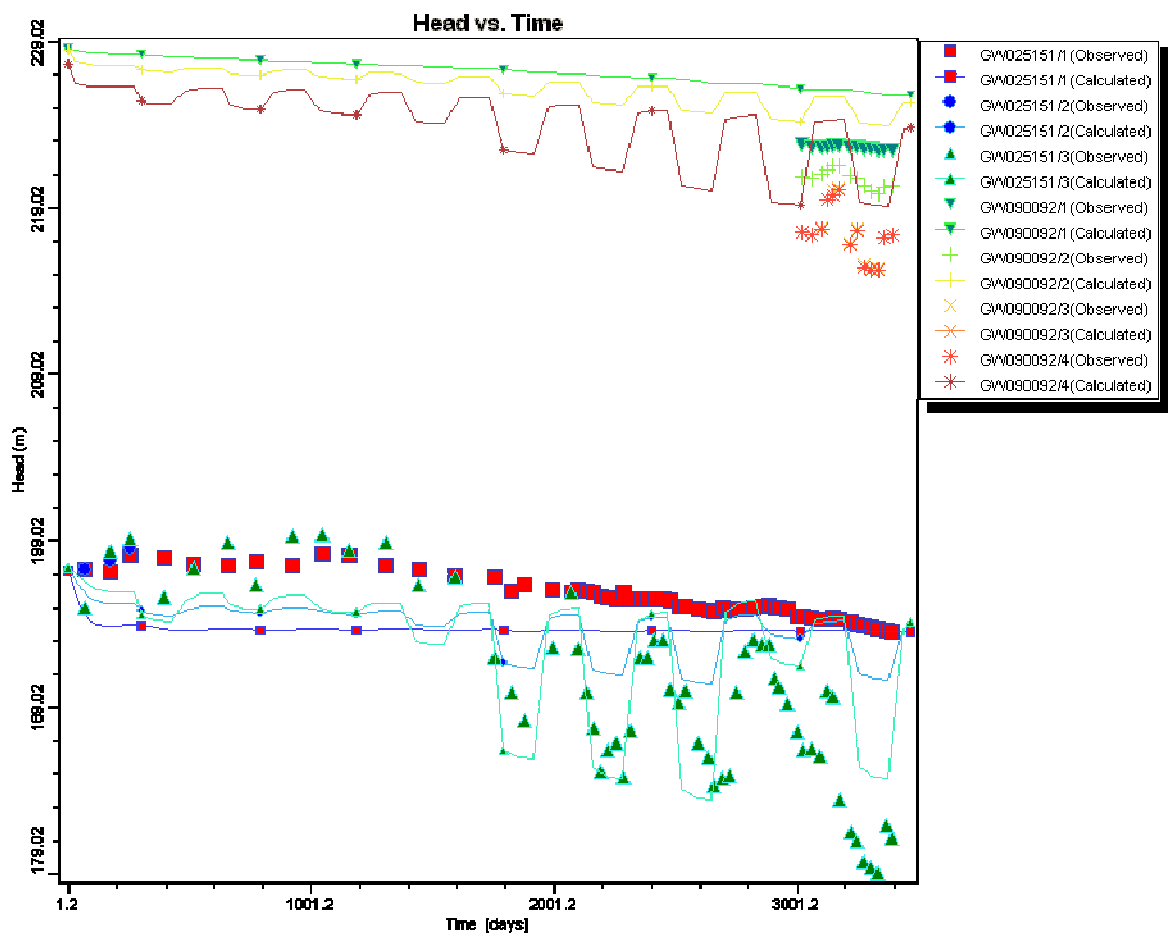
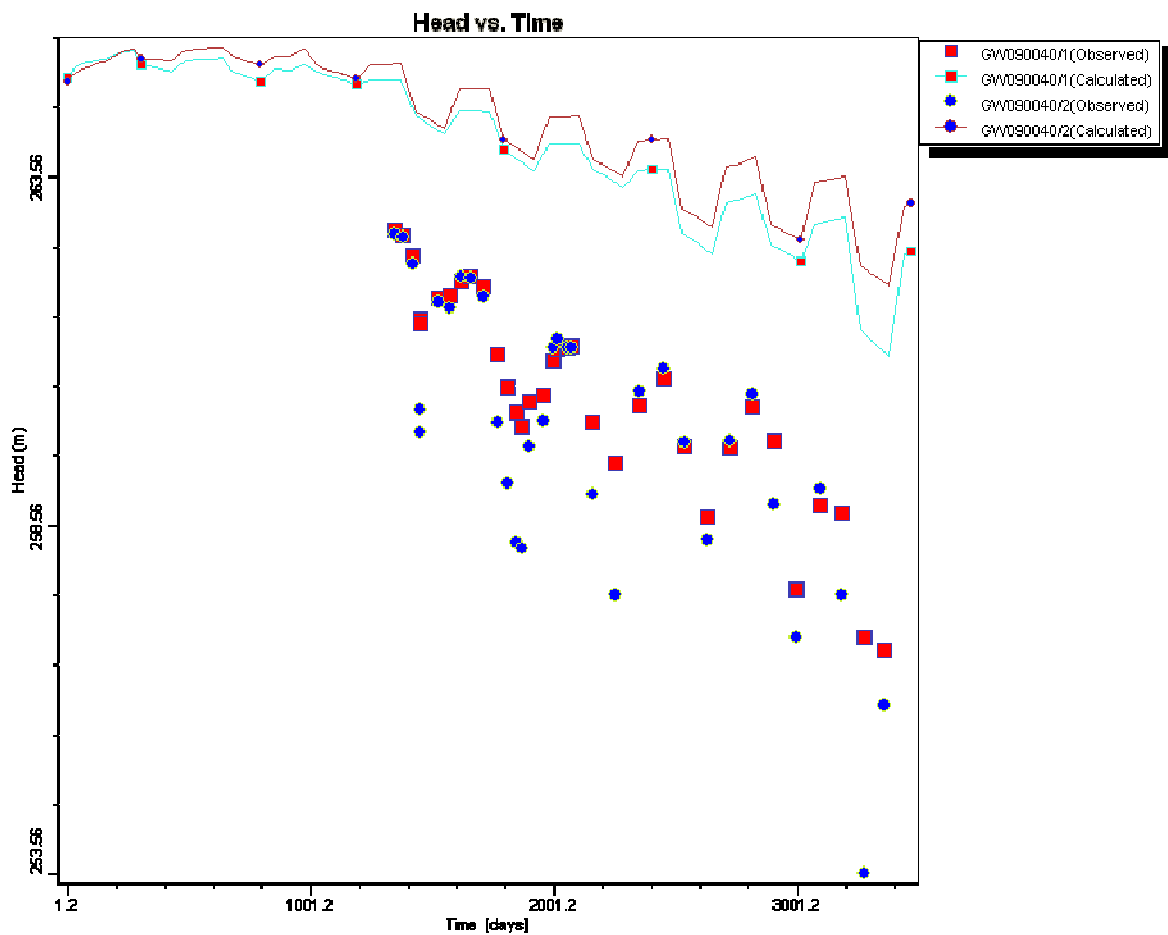


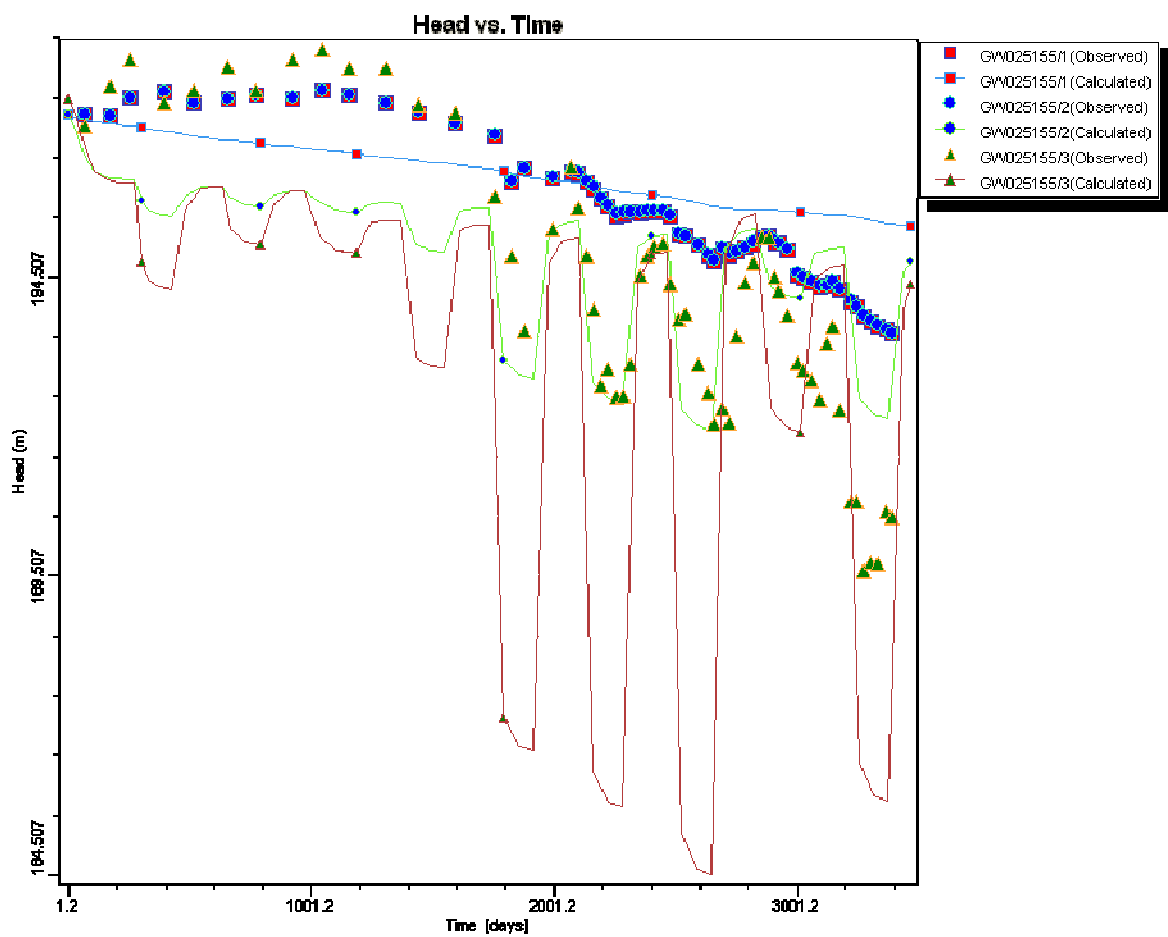














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