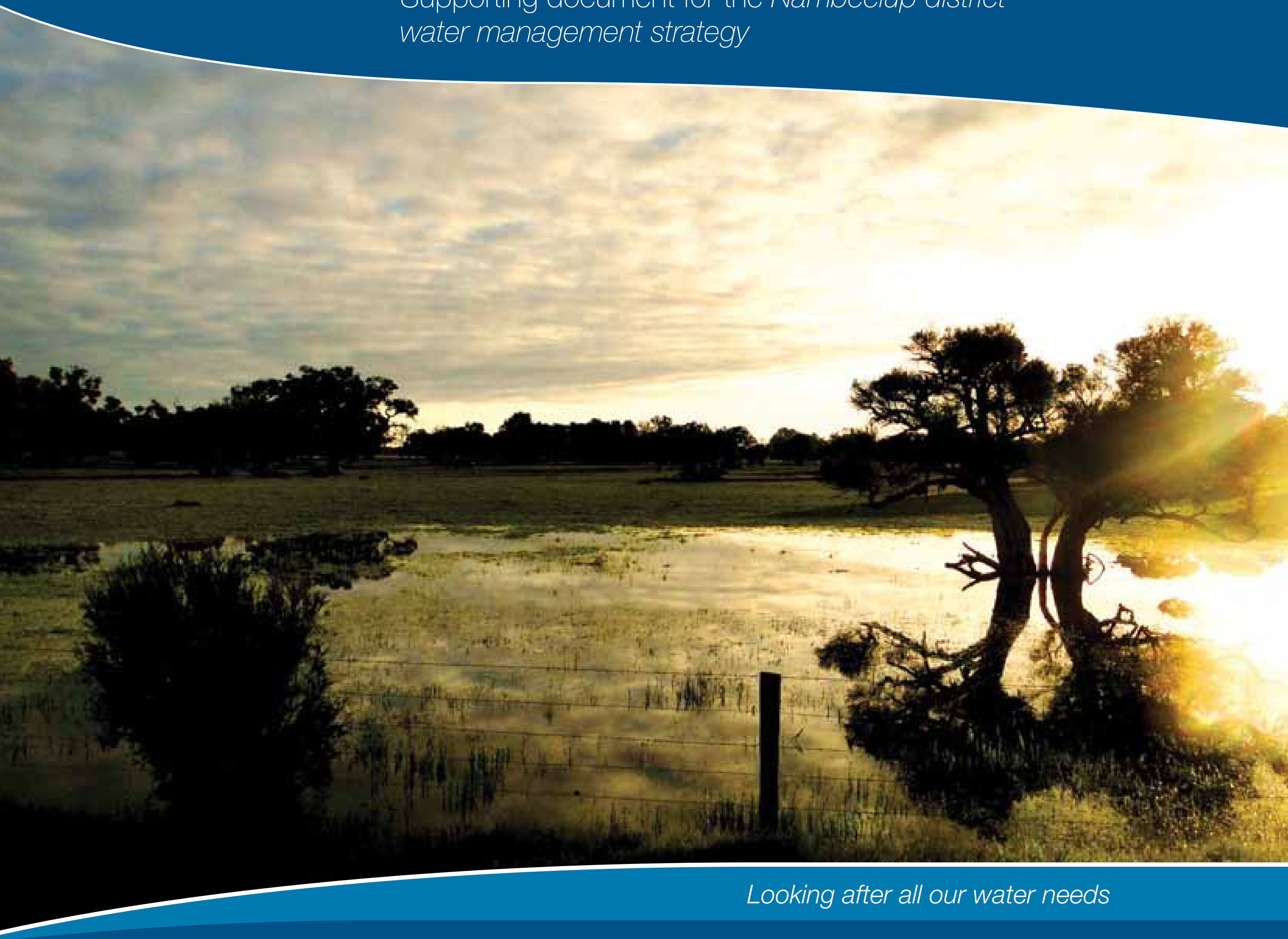
Government of **Western Australia**
Department of **Water**

Nambeelup groundwater modelling report

Supporting document for the *Nambeelup district water management strategy*



Looking after all our water needs

Water*Science*
technical series

Report no. WST 47
July 2012

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Department of Water
168 St Georges Terrace
Perth Western Australia 6000
Telephone +61 8 6364 7600
Facsimile +61 8 6364 7601
National relay service 133 677
www.water.wa.gov.au

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For more information about this report, contact Ben Marillier, Water Science Branch, Department of Water.

Cover photograph: Inundation in Nambeelup, August 2011, photo Ben Marillier

Disclaimer

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Summary

The Nambeelup area is identified in the Peel Region Scheme (WAPC 2002) as being potentially suitable for future industrial development. In order to rezone the land, the Western Australian Planning Commission (WAPC) requires the development of a district structure plan, and supporting studies, including the *Nambeelup district water management strategy* (Nambeelup DWMS) currently being developed by Jim Davies and Associates Pty Ltd (JDA).

The Nambeelup area is characterised by seasonal groundwater inundation and wetlands of significance. In regions of high watertable, groundwater modelling is a required component of a DWMS. This *Nambeelup groundwater modelling report* addresses the groundwater modelling component and is a supporting document for the Nambeelup DWMS. It considers the effect of climate change and the proposed 12.6 km^2 Nambeelup industrial estate on wetlands and superficial groundwater in the study area, as well as providing information on the pre-development condition of the site.

The Nambeelup model was constructed and calibrated using the MIKE SHE platform, and was used to simulate the Superficial Aquifer, wetland water levels and river flows in the Nambeelup area. The model achieved a calibration for the period 1980 to 2009 with a mean absolute residual error of 0.25 m based on 81 calibration bores.

Base case modelling results show that sections of the proposed development area are subject to extensive waterlogging and inundation in most winters. Shallow groundwater supports 29 “resource enhancement” and “conservation category” wetlands, which are surface expressions of superficial groundwater. Because of this, development of the Nambeelup industrial estate presents a challenge, as it is necessary to limit inundation within the development itself, manage drainage water to prevent adverse effects off-site, and prevent alteration to the hydrological regime of the wetlands that would reduce ecosystem function.

The groundwater modelling considers the effect of the proposed industrial estate on groundwater and wetlands within and around the development area. The potential effect of climate change was also considered in model simulations. The following scenarios were modelled:

- **Base case (S0)**: Current conditions
- Climate scenarios:
  - **Future wet (S9)**: 1.4% decrease in rainfall
  - **Future medium (S18)**: 8.7% decrease in rainfall
  - **Future dry (S27)**: 16.2% decrease in rainfall
- Drainage and land development scenarios:
  - **Industrial land use and controlled groundwater level (S1)**: Increased recharge from the industrial area with a controlled groundwater level (CGL) imposed using subsurface drainage, and a modified topographic surface to account for cut and fill.
  - **Industrial land use, CGL and drainage water (S2)**: The same as S1 with drainage water routed to detention wetlands to assess the effect on downstream properties.
  - **Industrial land use, CGL and future dry climate (S3)**: A combination of scenario S1 and S27 to assess the effects of a dry climate when combined with post-development conditions.

  - **Industrial land use and CGL, moderate recharge (S4)**: The same as S1 with recharge from the industrial area set to 41%, slightly above pre-development levels, based on the sizing of soak wells. Controlled groundwater level imposed using subsurface drainage, and a modified topographic surface to account for cut and fill.

The results of modelling the climate scenarios indicate that there is a large range in potential future groundwater levels based on 1.4% to 16.2% decreases in rainfall. Under the driest climate scenario, maximum winter groundwater levels are up to 1 m lower in some parts of the model. Areas of inundation (including wetlands) and shallow groundwater show less response to climate change as a result of their capacity to increase recharge as rejected recharge (runoff) is reduced.

Development scenario S1 showed that the proposed modifications to the surface topography, land use, and drainage within the Nambeelup industrial estate were unlikely to have an adverse effect on wetland water levels, and would not result in an increase in inundation off-site. The introduction of subsurface drainage generates an average of 3.5 GL/yr of water which must be managed. The main source of the additional drainage water is from reduced evapotranspiration (and therefore increased recharge) within the industrial land use. Development scenario S2 showed that routing of subsurface drainage water from part of the Nambeelup industrial estate to two wetland locations would result in an increase in winter inundation over Lot 93, which is located outside of the development area to the west. Development scenario S3 demonstrates that the increased recharge under the industrial land use acts to offset decreased recharge from reduced rainfall – provided that an appropriate CGL level is set in the development area adjacent to the wetlands. Development scenario S4 indicated that by setting recharge to slightly above pre-development rates, wetland water levels could be maintained post development, with 2.1 GL/yr of subsurface drainage water generated within the development.

Based on the scenarios modelled, the planned industrial estate will not substantially change the hydrological regime of the wetlands considered, but will result in an increase in both maximum and minimum water levels, and the length of time of inundation in winter. This is most evident in wetland UFIs 4584 and 4585 as these are located within the development.

It should be noted that changes in groundwater quality resulting from the industrial estate were not considered.

The CGL and estimated topography provided by JDA will result in 1 m of freeboard above the maximum groundwater level across the development area. The industrial estate is unlikely to increase inundation in down-gradient properties provided the estimated 3.5 GL/yr (for S1) or 2.1 GL/yr (for S4) of subsurface drainage water is adequately managed. In particular, 0.8 GL/yr which is estimated to come from catchments SR2 and SR3 based on scenario S1 will require storage, or a drainage pathway from the western edge of the development, as routing this water to wetlands in Lot 93 will result in inundation of surrounding properties. Additional overland flows generated by the development must also be adequately managed.

1 Introduction

The Nambeelup area is identified in the Peel Region Scheme (WAPC 2002) as being potentially suitable for future industrial development. In order to rezone the land, the Western Australian Planning Commission requires the development of a district structure plan. The Department of Planning, in conjunction with the Shire of Murray, are coordinating the preparation of the *Nambeelup district structure plan*. LandCorp are responsible for finalising the administration of the legal agreements for the appointment of the consultants required to prepare the structure plan. The *Nambeelup district structure plan* is one of a number of inputs required for the broader *South metropolitan and Peel structure plan* (WAPC in press).

A district water management strategy is a supporting document required for a district structure plan. The requirements for a DWMS are outlined in the Western Australian Planning Commission's *Better urban water management* document (WAPC 2008). Jim Davies and Associates Pty Ltd have been contracted by LandCorp to produce the DWMS.

The Nambeelup area is characterised by seasonal groundwater inundation and wetlands of significance. In regions of high watertable, groundwater modelling is required component of a DWMS. Groundwater modelling results are used to inform the DWMS, and aid in:

- the management of the drainage of the region
- determining controlled groundwater levels and fill requirements
- determining the quantity and timing of drainage water that is potentially available for re-use
- potential short-term or long-term mobilisation of nutrients and contaminants
- approaches that avoid adverse effects on groundwater-dependent ecosystems
- likely effects of acid sulfate soils.

An agreement between the Department of Water and the Department of Planning has led to the Water Science Branch of the Department of Water being contracted by LandCorp to produce the groundwater modelling component of the DWMS.

1.1 Study objective

The overall objective of this study was to provide the groundwater modelling requirements of the Nambeelup DWMS. In order to do this, the project:

- produced a calibrated district-scale groundwater model
- developed and ran a range of suite of post-development scenarios
- delivered associated maps and shapefiles to JDA.

The project requirements included the modelling of various climate scenarios and pre-and post-development scenarios to determine:

- absolute maximum, absolute minimum, average annual maximum and average annual minimum groundwater levels (MaxGL, MinGL, AAMaxGL and AAMinGL)
- the water balance, including changes in groundwater discharges and interaction with surface water
- likely areas of water logging
- flows in drains and tributaries

- a range of predicted future water levels based on land-use change and climate uncertainty.

1.2 Scope

The groundwater modelling project produced:

- a calibrated groundwater and surface water model in the MIKE SHE framework, at a suitable resolution for design criteria at the DWMS scale (grid spacing 40 m and average residual error of groundwater bores <30 cm).
- a pre-development scenario and six predictive scenarios including:
    - one wet and one dry climate scenario. These were the pre-development scenarios, and were based on the 10th and 90th percentile average annual rainfall from the range of 15 global climate models, which were simulated in the Peel region as part of the south-west Western Australia Sustainable Yields Project (CSIRO 2009).
    - four post-development scenarios, which included design fill requirements, and levels of subsurface drainage. The DWMS contractor (JDA) provided the Water Science Branch with the estimated level of drains, level and quantity of fill, and the appropriate climate scenario to simulate as part of these scenarios.
- for each of the scenarios, the following:
    - groundwater surfaces, including average annual maximum, average annual minimum, absolute maximum, absolute minimum and average groundwater level. These were computed for the 30-year data sequence and were produced in raster and contour ESRI format.
    - a water balance for each of the surface water and groundwater fluxes in the model. This has been provided either as an annual average or as a time series (annual, monthly or daily). For example, the water balance included the time series of subsurface drainage for the scenarios described in Section 8.
- this report on the modelling, written with regard to the draft groundwater modelling guidelines for urban drainage in areas of high watertable. The report describes the major modelling processes and findings.

1.3 Methodology

The modelling will be undertaken in conjunction with the recommendations of the Murray Darling Basin Commission's *Groundwater flow modelling guidelines* (Middlemis 2000), and the Department of Water's draft *Groundwater modelling guideline for urban drainage in areas of high watertable* (Department of Water in press).

2 Literature review

Murray hydrological studies: surface water groundwater and environmental water (Hall et al 2010a, b and c)

The Murray hydrological studies were undertaken in 2010 to support the *Murray drainage and water management plan* (DoW 2010). The study focused on development of an integrated surface and groundwater model to provide groundwater information at a regional scale. The study followed the procedure for model development recommended in the Murray Darling Basin Commission guidelines for groundwater flow modelling (Middlemis 2000).

Outcomes of the project included provision of groundwater levels and water balances related to current conditions, and several climate, drainage and land development scenarios. The model was also downscaled to a finer grid to model eight wetlands and support environmental water requirement studies. The model achieved an RMS error of 0.80 m, and a mean absolute error of 0.55 m for the calibration period.

The input datasets developed for the Murray regional model were designed in a way that allowed downscaling to local area models. This has also been done with the Nambeelup model. The Murray regional model forms the conceptual and structural basis for the Nambeelup model. The literature review conducted for the Murray hydrological studies is relevant to the Nambeelup model, and Hall et al. (2010a) should be used as the main literature reference for this report. Hence, only site specific data is discussed in the remainder of the literature review.

Nambeelup groundwater study (Parsons Brinkerhoff 2002)

In 2002 Parsons Brinkerhoff was commissioned to conduct a pre-development groundwater assessment in the Nambeelup area for the planned Lakes Road industrial site. The project included installation of monitoring bores (NB series), and soil and groundwater sampling.

The report discusses the soil and landscape mapping of the area, and identifies three main units, including the Bassendean Sand, Guildford Clay underlying Bassendean Sand, and swamp depressions. However, given the distance from the Darling Scarp, it is unlikely that the clay sediments intercepted in drilling were Guildford Clay, and more likely that the clay lenses are associated with alluvial deposits from the Serpentine River. Similarly, it is suggested that the Guildford Clay acts as an aquitard limiting vertical flow. However, recent monitoring data from paired bores in the area HS097 (Rockingham Aquifer) and HS97A (Superficial Aquifer) indicate connectivity. Lenses of ferricrete and organics were intercepted sporadically in the area.

A preliminary estimate of average annual maximum groundwater level was made based on a limited dataset of groundwater level readings, and this surface was used for inundation mapping. The results showed inundation across much of the study area, including the airport wetlands, low-lying areas close to the Nambeelup Brook and Serpentine River, and several inter-dunal depressions. Groundwater nutrient sampling indicated high phosphorus concentrations associated with the Wandalup Farms shallow bores. Nitrogen concentrations were generally below detection limits.

Estimated groundwater levels were revised by Parsons Brinkerhoff (2008) using data from 2007 and 2008. Groundwater was at the surface over much of the study area, consistent with the 2002 study. It appears that the drainage network was not considered in interpreting the groundwater levels, and therefore areas of inundation were likely to be over estimated.

Nambeelup hydrogeological investigations (RPS-BBG 2006)

This report includes bore completion diagrams for the LP series bores in the Lexington Park area. Most of the site was composed of sandy soil profiles, with underlying cemented coffee rock or coffee sands, and some clayey sections. It is noted that most shallow sandy profiles were permeable and would infiltrate rainwater except when inundated.

A preliminary estimate of groundwater levels at the time of construction is included in the report. However, given that 2006 had a dry start to winter, the estimated groundwater level was quite low. Hence, areas of winter inundation were determined by adding 1.5 m and 2 m to the groundwater surface. This indicated large areas of inundation along the Nambeelup Brook and in wetland areas. However, these area likely to be over estimates as the influence of drainage and fine-scale topographic changes were not accounted for.

Revised average annual maximum groundwater level estimate – Nambeelup Lifestyle Estate (Groundwater Consulting Services 2007)

Groundwater Consulting Services installed thirty monitoring bores in 2007 to aid estimation of average annual maximum groundwater level for the Nambeelup Lifestyle Estate. The study area encompasses a section of the Nambeelup modelling area considered in this study.

An estimate of the average annual maximum groundwater surface was generated using observed data from a number of different monitoring bores including T series (installed in 2007 by RPS), LP series (2006, RPS-BBG) and NB series (2002, Parsons Brinkerhoff). The surface was generated by manually drawing cross-sectional elevation and water levels, digitising these cross-sections, and interpolating a contoured surface. Drain levels were considered in the interpretation. The average annual maximum groundwater level surface was used to generate a gridded depth to groundwater for the study area.

The results show a very shallow watertable across much of the study area, with water at the surface in wetlands and depressions, as well as along the Nambeelup Brook. The section of the study area which includes the planned Nambeelup industrial estate is Lot 221, and this area shows a depth to watertable of up to 5 m underneath dune formations, trending to water at the surface in low lying parts in the east of Lot 221.

3 Data collection

Most input data for the model was obtained from the Murray regional model (Hall et al. 2010a, b and c). The origins of this data can be found in this document. Rainfall and evaporation data (Penmen Monteith evaporation) was updated, and taken from the SILO datadrill series (QDERM, 2011) The inflow data to the Nambeelup model was taken from the SQUARE (Streamflow quality for rivers and estuaries) surface water model developed by the Department of Water (Kelsey et al. 2010). There were various data sources for the calibration data, including Parsons Brinkerhoff (2002), the Department of Water, and JDA. These are explained in detail in Section 6: Calibration and validation. Bore completion reports are listed in the literature review in the previous chapter. All data is displayed and analysed in Section 4: Conceptual model. All sources of input data used in model construction are listed in Table 3.1.

Table 3.1 Sources of data used in model construction

Dataset	Source	Year or date range	Reference
Climate	SILO gridded data	1/1/1900 - 23/8/2010	http://www.derm.qld.gov.au/
Land use	Murray regional model	2010	Hall et al. (2010b)
Mike11 rivers and drains	DoW Swan Coastal Plain LiDAR	2008	-
Nambeelup Brook inflow data	SQUARE modelled data	1/1/1975 - 23/8/2010	Kelsey et al. (2010)
Soils	Murray regional model	2010	Hall et al. (2010)
Geology	Murray regional model	2010	Hall et al. (2010)
Abstraction	DoW - WRL dataset	2010	-
Model boundary conditions	Murray regional model	2010	Hall et al. (2010)
Calibration data	*See 'Calibration and validation' section of report*		
Scenario rainfall and PET	Murray regional model	2010	Hall et al. (2010)
Scenario CGL & topography	JDA	2011	-
Scenario land use	JDA	2011	-
Scenario development aea	JDA	2011	-
Mike 11 Drain 3 - Fiegert	Survey WA PTY Ltd (via JDA) Fiegert Drain	2009	-
Topography (pre-development)	DoW Swan Coastal Plain LiDAR	2008	-

4 Conceptual model

4.1 Climate

The Nambeelup area has a Mediterranean climate which is typical of the south-west of Western Australia. It experiences hot, dry summers, and cool, wet winters, with most rainfall being delivered as winter cold fronts push up from the south-west. Intermittent summer rainfall can occur, generally as a result of ex-tropical cyclones moving south.

SILO gridded rainfall and evaporation data is available from the Murray regional model across the Nambeelup area, from 1900 to 2010. This data has been analysed using the grid cell located at 32° 55’ south, 115° 85’ east, which covers most of the modelling area. Figure 4.1 shows the monthly average rainfall and FAO56 potential evaporation for the period 1970 to 2009. The average annual rainfall is 829 mm and potential evaporation exceeds this at 1351 mm. The wettest year recorded since 1970 was 1991, with 1051 mm of rainfall, and the driest year was 2006 with 538 mm.

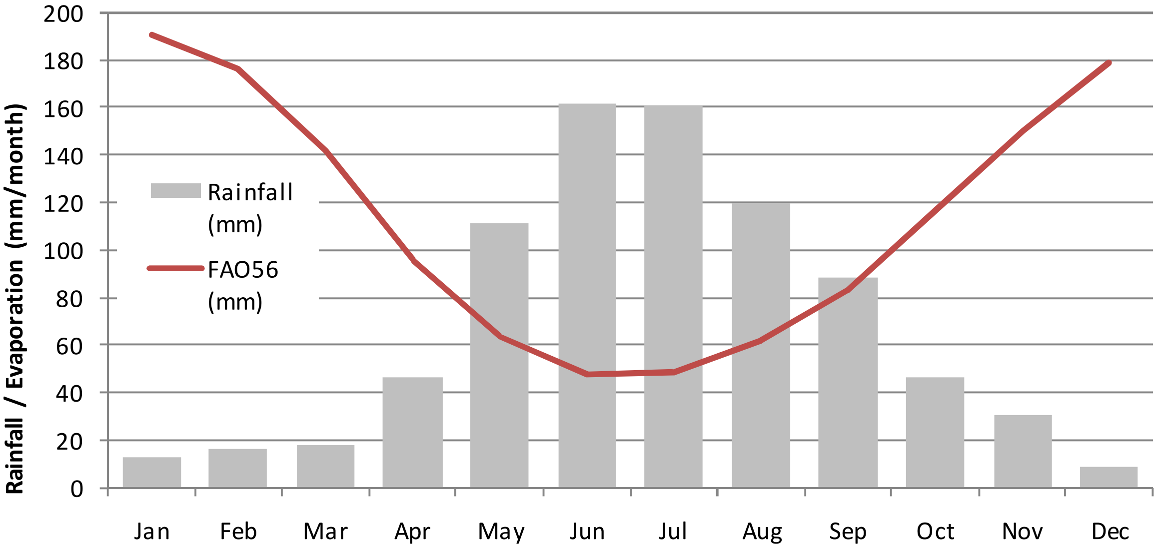


Figure 4.1 Monthly rainfall and FAO56 potential evaporation (SILO gridded data)

4.2 Topography and hydrology

The Nambeelup study area is situated between the Serpentine River and the Nambeelup Brook as shown in Figure 4.2. The area is defined by a drop in elevation from east to west, with marked increases around dunes of Bassendean Sand close to the airport and Wandalup piggery. Between these dunes are localised depressions which contain several conservation category wetlands, including the Greyhound Road Wetland (wetland UFI 5032 in the DEC geomorphic wetlands database), the Phillips Road Wetland (UFI 5056) and the Airfield Wetland (UFI 4835). All of these wetlands are ephemeral, through-flow wetlands which intercept groundwater during most winters. In addition to these wetlands, much of the study area is subject to seasonal inundation, as was demonstrated with the Murray regional model (Hall et al. 2010b) (Figure 4.3). The south-west corner is the area subject to the most waterlogged areas based on the results of the regional model. However, delineation of waterlogged areas will be improved with the local scale Nambeelup model.

An estuarine portion of the Serpentine River is at or below 0 m AHD along the western edge of the modelling boundary, and receives lateral groundwater flows from the Superficial Aquifer. It is not included within the modelling area and will not be discussed in detail.

The Nambeelup Brook is incised into the superficial sediments at around 2.5 m depth below the surrounding land along the southern and eastern edge of the model boundary, and receives baseflow from the Superficial Aquifer along its length. Its catchment area includes both the coastal plain and the scarp, and totals 115.5 km^2. Hence much of the surface water catchment for the brook is located outside the Nambeelup study area. A Department of Water gauging station is located on the brook (614063) and is suitable for use in model calibration and data analysis. Using the data from this gauge, baseflow separation shows an average groundwater contribution of 69% and a coefficient of runoff of 21% (see Figure 4.4). A surface water model has previously been developed for the Nambeelup Brook using the SQUARE model (Kelsey et al. 2010), and is suitable for use in providing boundary conditions of flow for the Nambeelup Brook.

In addition to the main rivers, a small network of agricultural drains act to control groundwater and wetland water levels in some areas. However, many drains are disconnected from the main drainage network, and are ineffective in controlling groundwater levels. These drains are typically less than 0.5 m deep. There are several drains within the study area which are important for controlling groundwater levels, and these are shown in Figure 4.2. They include the Gull Road drain which runs east–west just north of Wandalup piggery (Drain 1), three drains in the south-west of the model which limit the maximum level of inundation in the area (drains 2 to 4), and two drains which influence wetland maximum water levels on the raised section of the study area (drains 5 and 6).

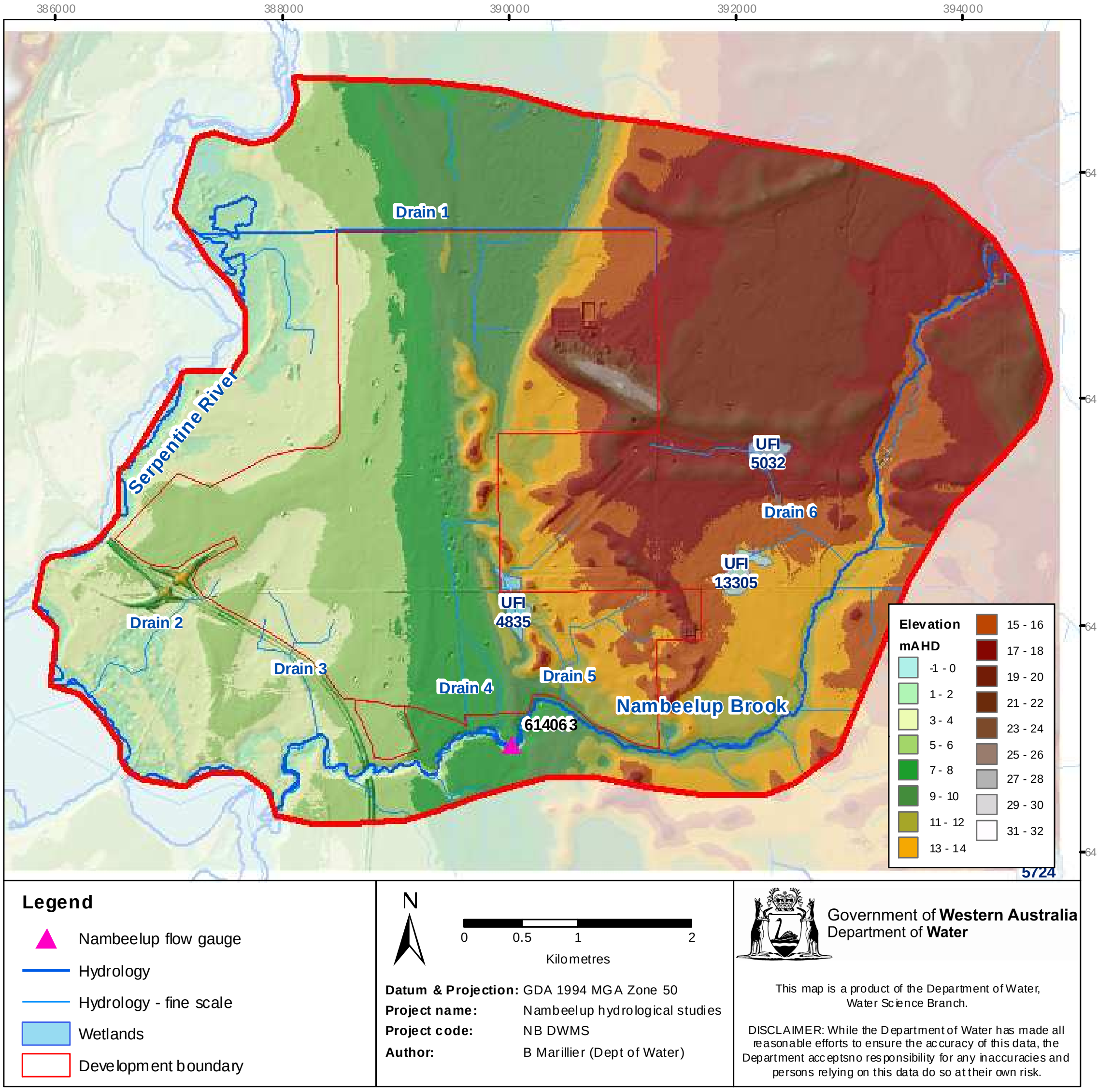
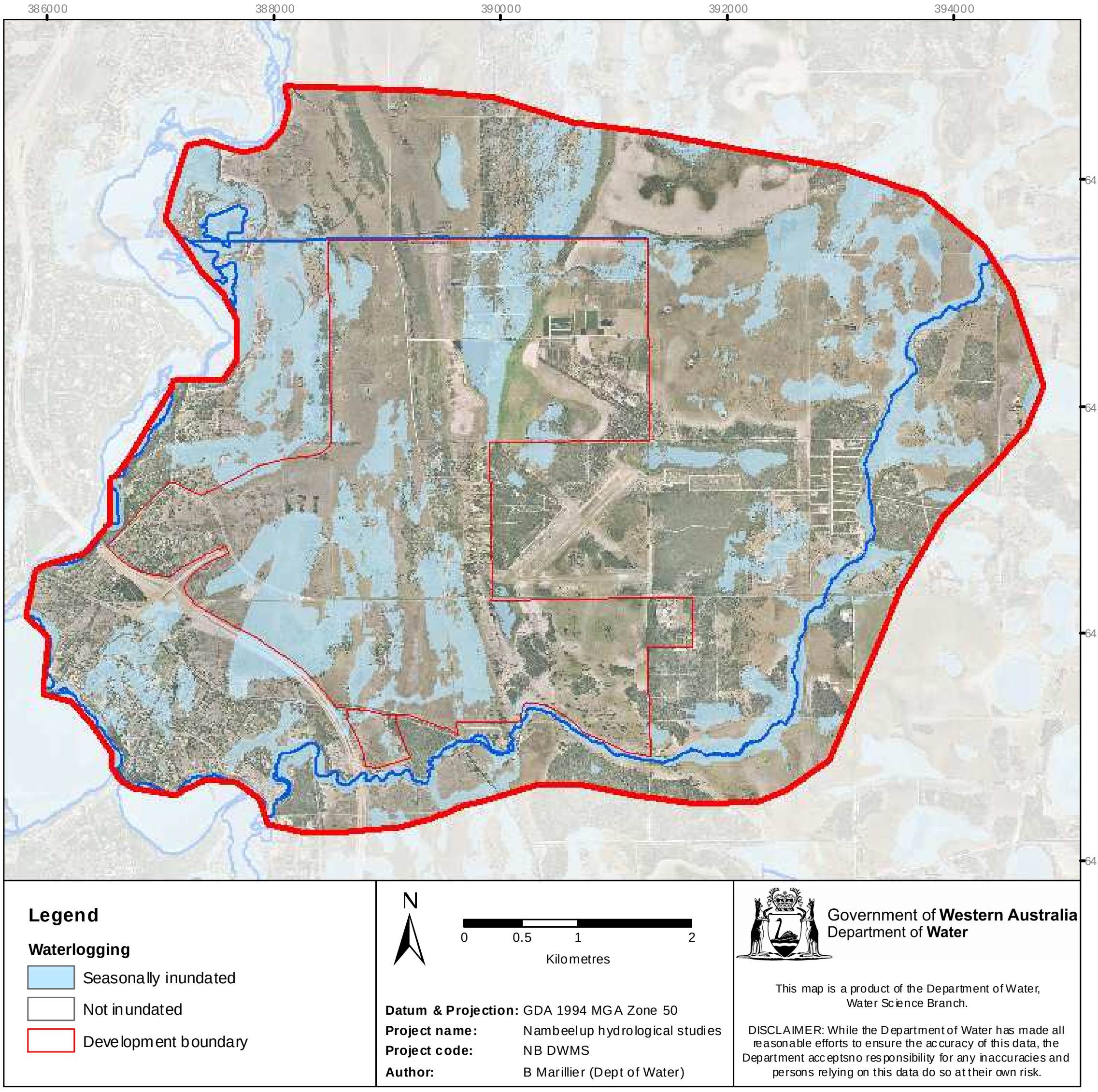


Figure 4.2 Topography and hydrology



Datum & Projection: GDA 1994 MGA Zone 50
Project name: Nambeelup hydrological studies
Project code: NB DWMS
Author: B Marillier (Dept of Water)

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Figure 4.3 Areas of inundation based on the Murray regional model AAMaxGL 1978–2007

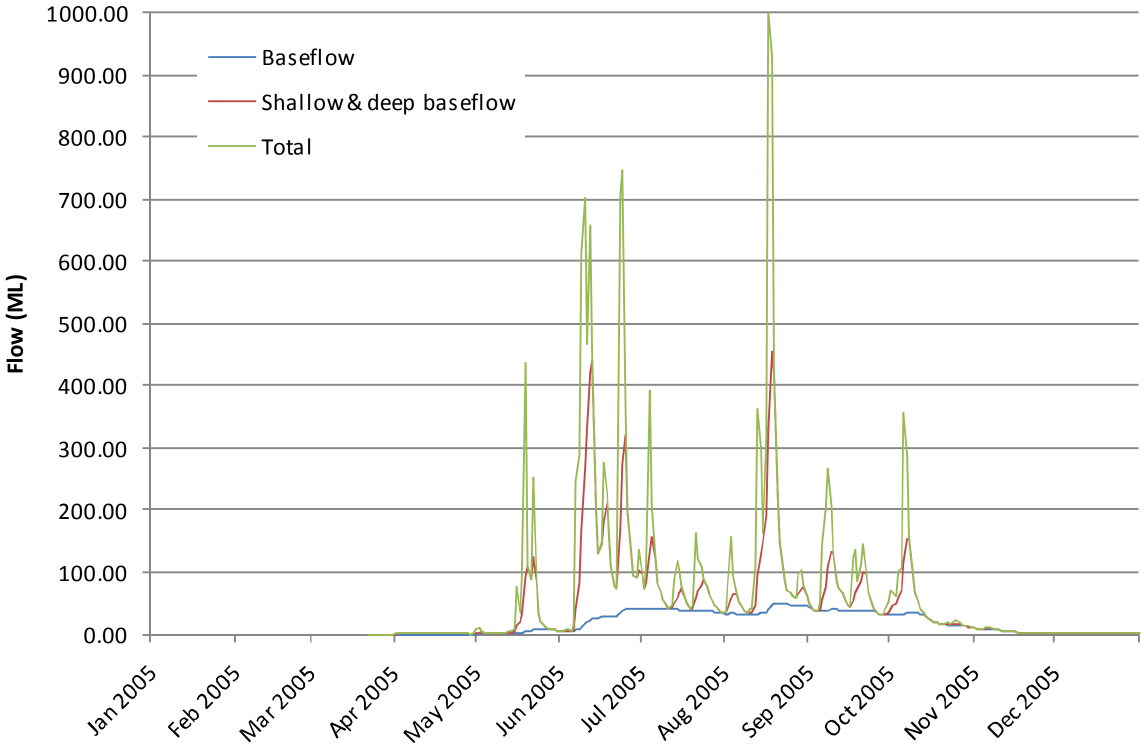

Figure 4.4 Baseflow separation and hydrograph for Nambeelup Brook (614063)

Table 4.1 Flow summary from Nambeelup Brook (614063)

Year	Rainfall (mm)	Baseflow (ML)	High flow (ML)	Total flow (ML)	C.R.*	Baseflow % of total
1991	1051	29923	14585	44508	37%	67%
1992	964	16803	6834	23638	21%	71%
1993	695	8155	4270	12426	16%	66%
1994	742	13531	5576	19108	22%	71%
1995	883	13236	7438	20674	20%	64%
1996	901	16994	7547	24541	24%	69%
1997	782	25533	6155	31688	35%	81%
1998			*Data unavailable*			
1999						
2000						
2001						
2002						
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2004						
2005						
2006	538	2199	1492	3691	6%	60%
2007	775	8220	3920	12140	14%	68%
2008	833	10141	4423	14564	15%	70%
2009	706	10851	4944	15795	19%	69%
Average	806	14144	6108	20252	21%	69%

**C.R. Coefficient of runoff, total flow divided by rainfall*

4.3 Geology

The dominant geological formation at the surface is the Bassendean Sand, with some smaller areas consisting of estuarine, wetland or alluvial deposits. Hall et al. (2010a) developed a geological model for the Quaternary formations across the area. It consists of a veneer of Bassendean Sand, overlying Gnangara Sands, with some alluvial deposits along the Serpentine River and Nambeelup Brook, with the Rockingham Sands present in a palaeochannel beneath the Gnangara Sands in the west. Recently, Kretschmer (2011) has identified the Rockingham Sand as an equivalent of the Wanneroo Member to the west of the Mandurah Fault. Using this interpretation for the study area, the Rockingham Sand directly underlies the Gnangara Sand to the west of the Mandurah Fault, and the Pinjar Member is present beneath the superficial sediments to the east of the fault.

Parsons Brinckerhoff (2002) drilled a number of bores within the study area to support the development of the Lakes Road industrial site. They conceptualised the model area as a veneer of Bassendean Sands overlaying Guildford Clay. Given the distance from the Darling Scarp, the clay encountered along the Serpentine River is probably alluvial in nature, and is not as thick or widespread as the Guildford Clay commonly encountered along the eastern fringe of the Swan Coastal Plain. Most of the NB bores did not intercept significant clay layers consistent with the Guildford Clay. Further to this, recent drilling by Western Irrigation at Lot 530 shows a clear sequence of sands through the Bassendean Sands at the surface, to the Rockingham sands to 69 m depth, where the green clay marker bed of the Mariginiup Member is intercepted, with no Guildford Clay intercepted at any point.

The Quaternary sediments which are of interest in the study area are discussed briefly below.

Bassendean Sand

The Bassendean Sand is a pale grey to white, and occasionally brown, moderately-sorted, fine to medium-grained quartz sand with traces of heavy minerals (Deeney 1989). A layer of friable, mostly weakly limonite cemented sand known as ‘coffee rock’ is commonly present at or near the watertable. However, this does not occur in all locations across the study area.

Gnangara Sand

The Gnangara Sand is described as consisting of pale grey, fine to very coarse grained, very poorly sorted, sub-rounded to rounded quartz and abundant feldspar. It can be of bimodal consistency, composed of both fine and very coarse grains. It is predominantly of fluvial origin, although it is more likely to be estuarine in areas containing bimodal deposits. The Gnangara Sand underlies the Bassendean Sand across most of the study area, and intermittently contains sandy clay and organic lenses.

Alluvium, estuarine and swamp deposits

The alluvium, estuarine and swamp deposits are associated with the Serpentine River, Nambeelup Brook and the wetlands that exist within the study area. These deposits consist of clays, silts and sand, which is angular to rounded, poorly sorted and often containing gravel and pebbles (Pennington Scott 2008). Peaty and sandy swamp deposits are associated with the wetlands, often having a dark brown, grey to black colour and are organic rich.

4.4 Land use

A land-use map of the study is shown in Figure 4.5. Much of the area is used for agricultural purposes, and consists of pasture used for grazing of beef cattle. The Murrayfield Aerodrome is located in the centre of the study area, and is surrounded by low-lying uncleared native vegetation. The Wandalup piggery is located on Readheads Road to the north of the airport and contains several large wastewater treatment ponds, and the Lakes Road abattoir is located immediately to the south of the airport. Some rural residential properties are present along the Nambeelup Brook, the Serpentine River, and to the west of the airport.

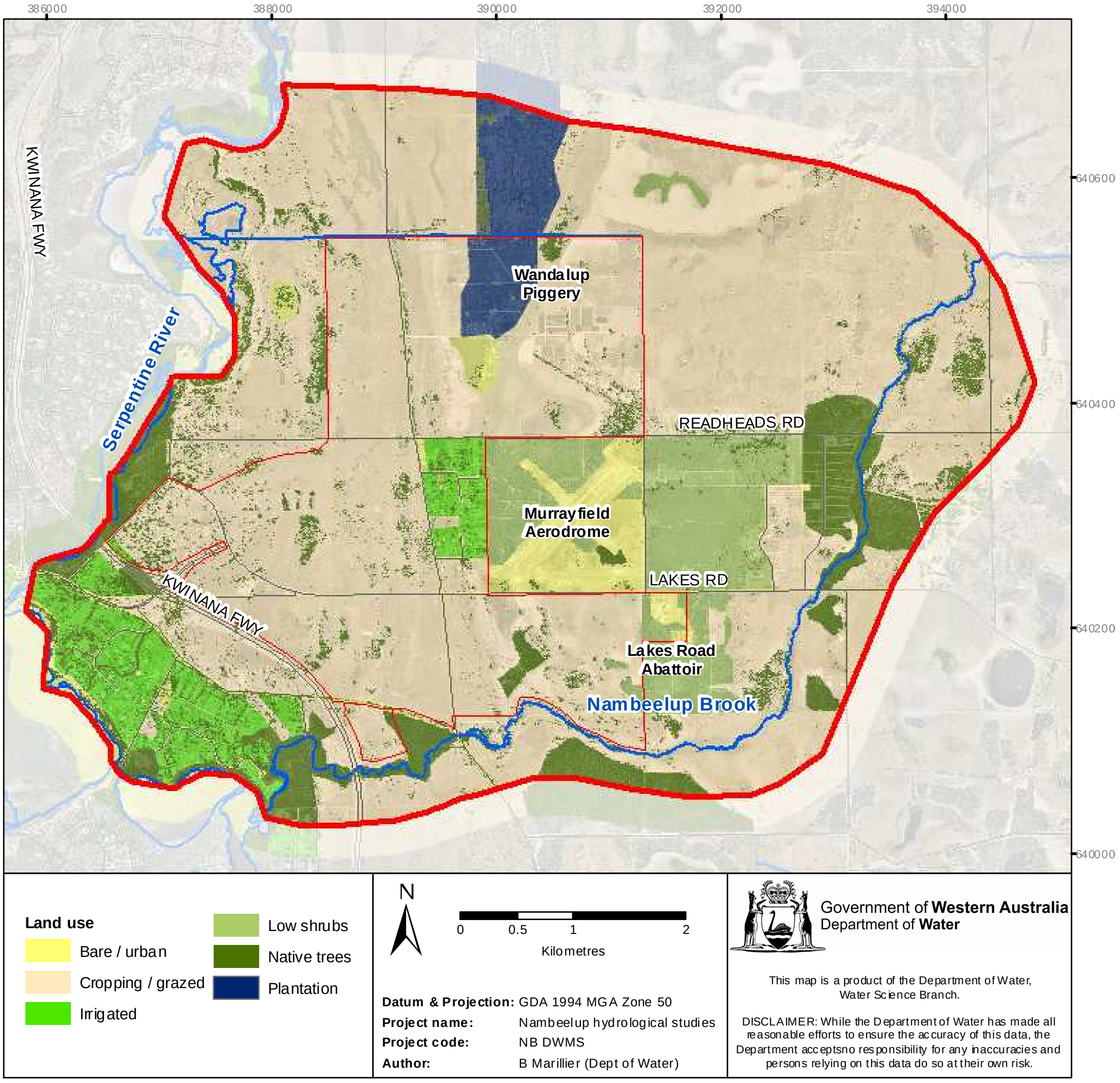

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Figure 4.5 Land use within the Nambeelup study area

4.5 Hydrogeology

In the study area, the Superficial Aquifer is consistent with the Quaternary sediments, which include the Bassendean Sands and Gnangara Sands. The phreatic surface of the Superficial Aquifer approximates the local topography, as shown in regional modelling results reported by Hall et al. (2010b) (see Figure 4.6). The Serpentine River intercepts groundwater flowing from east to west, and the Nambeelup Brook shows a pronounced influence as a gaining reach on the superficial groundwater levels. Groundwater hydraulic gradients are steepest close to the Nambeelup Brook, and through the centre of the study area, where the Bassendean Sand dunes slope downwards to the flat area adjacent to the Serpentine River.

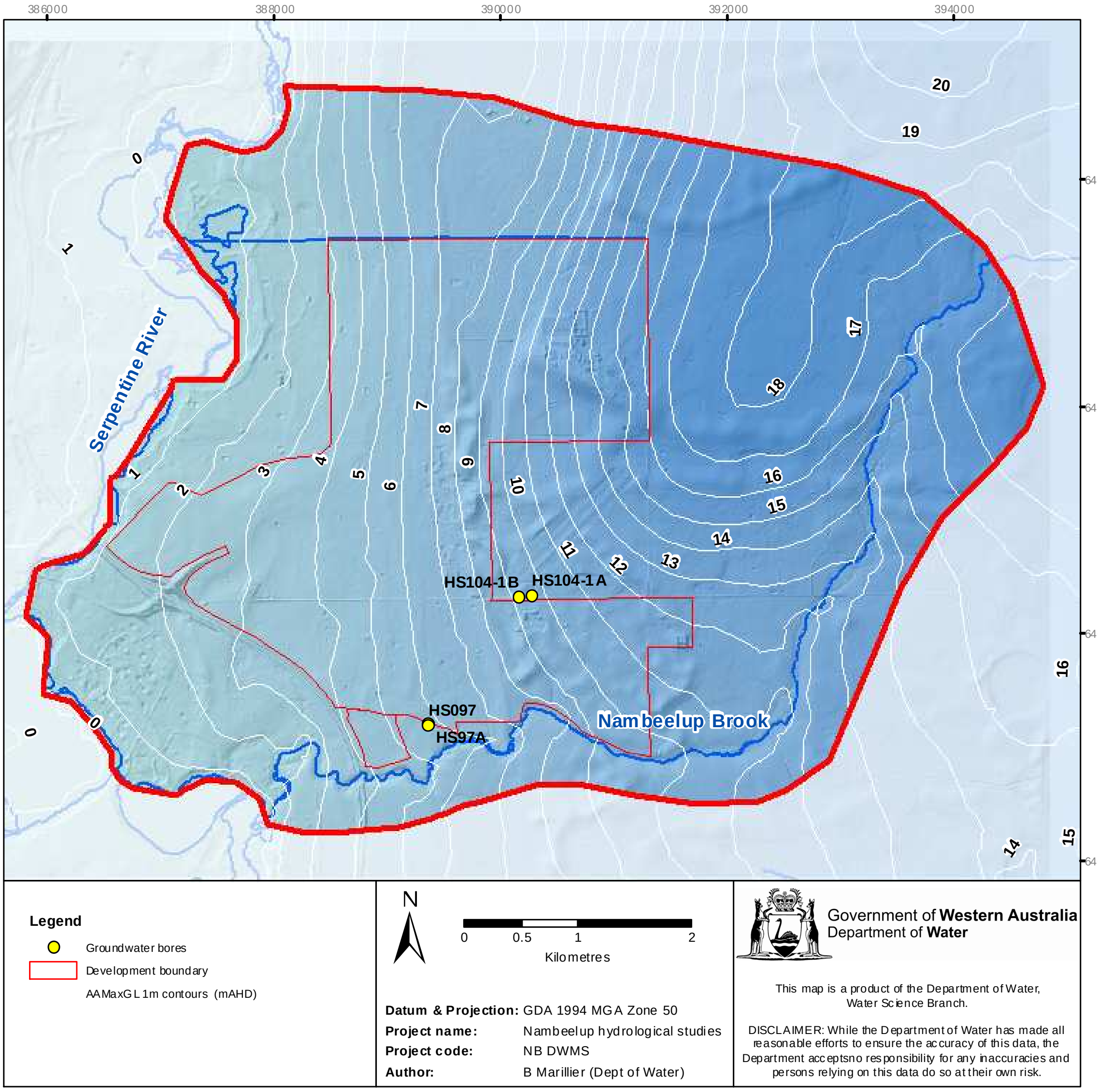


Figure 4.6 Superficial Aquifer phreatic surface (modelled AAMaxGL 1977–2007)

Recharge to the Superficial Aquifer occurs via direct rainfall through the sandy, well-drained soil profile. Therefore, large Bassendean Sand dunes act as preferential recharge areas. Hall et al. (2010b) estimated gross recharge in the Murray regional model at 41% of rainfall, which is equivalent to 334 mm, or 14 GL for the Nambeelup area. In a similar fashion, net recharge (gross recharge minus evapotranspiration from groundwater) can be estimated as 12.3% of rainfall, or 100 mm (4.2 GL).

The Superficial Aquifer to the west of the Mandurah Fault is in hydraulic continuity with the Rockingham Aquifer, as indicated by bores HS097 (screened in the Rockingham) and HS97A (screened in the Superficial), shown in Figure 4.7. However, vertical recharge from the Superficial Aquifer to the Rockingham Aquifer is minimal compared with the large horizontal inflows from the Leederville Aquifer. To the east of the Mandurah Fault, the Superficial Aquifer overlies the upper Leederville Aquifer, consisting of the Pinjar and Wanneroo members. In this area the Pinjar Member acts as an aquitard as a result of the low vertical hydraulic conductivities associated with the siltstone beds. Therefore, exchange is limited between the two aquifers despite the difference in head of 3.2 m between bore HS104-1A (Superficial) and HS104-1B (Leederville), as shown in Figure 4.8.

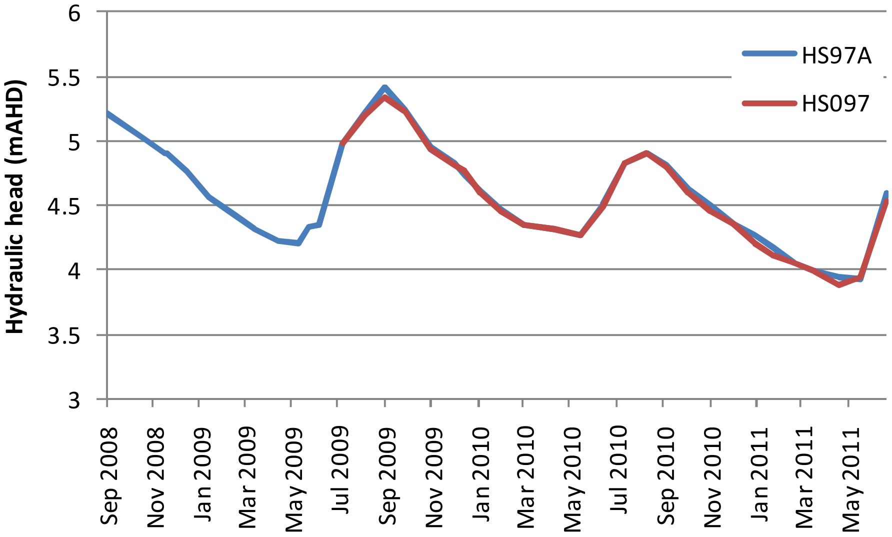


Figure 4.7 Comparison of hydraulic head between HS97A and HS097

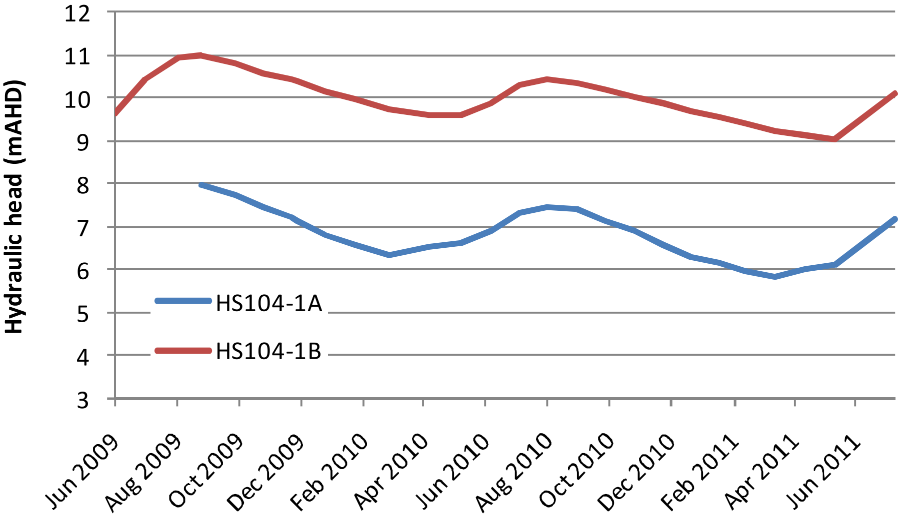


Figure 4.8 Comparison of hydraulic head between HS104-1A and HS104-1B

4.6 Conceptual water balance

The Nambeelup conceptual model is based on the Murray regional conceptual model (Hall et al. 2010a). As the study area is completely contained within the Murray regional model area, it was possible to downscale the input data from the regional model for the Nambeelup model. The only significant variation made is that the Rockingham Aquifer has been excluded from the Nambeelup model, as the downward flux from the Superficial Aquifer to the Rockingham west of the Mandurah Fault is a negligible component of the water balance compared with the other fluxes.

A conceptual diagram of the Nambeelup model is shown in Figure 4.9. This identifies all of the major fluxes into and out of the Superficial Aquifer in the area. The groundwater flow can be characterised as three-dimensional, and so the model consists of two computational layers, with the upper layer representing the Bassendean Sands and alluvial deposits, and the lower layer representing the Gnangara Sands. The base of the model is set as the base Quaternary unconformity.

The model assumes no vertical leakage between the Superficial Aquifer and the underlying aquifers. Although there is likely to be some exchange with the Rockingham Aquifer, it is likely to be a very small component in the water balance, and is not important for a groundwater study focused on drainage.

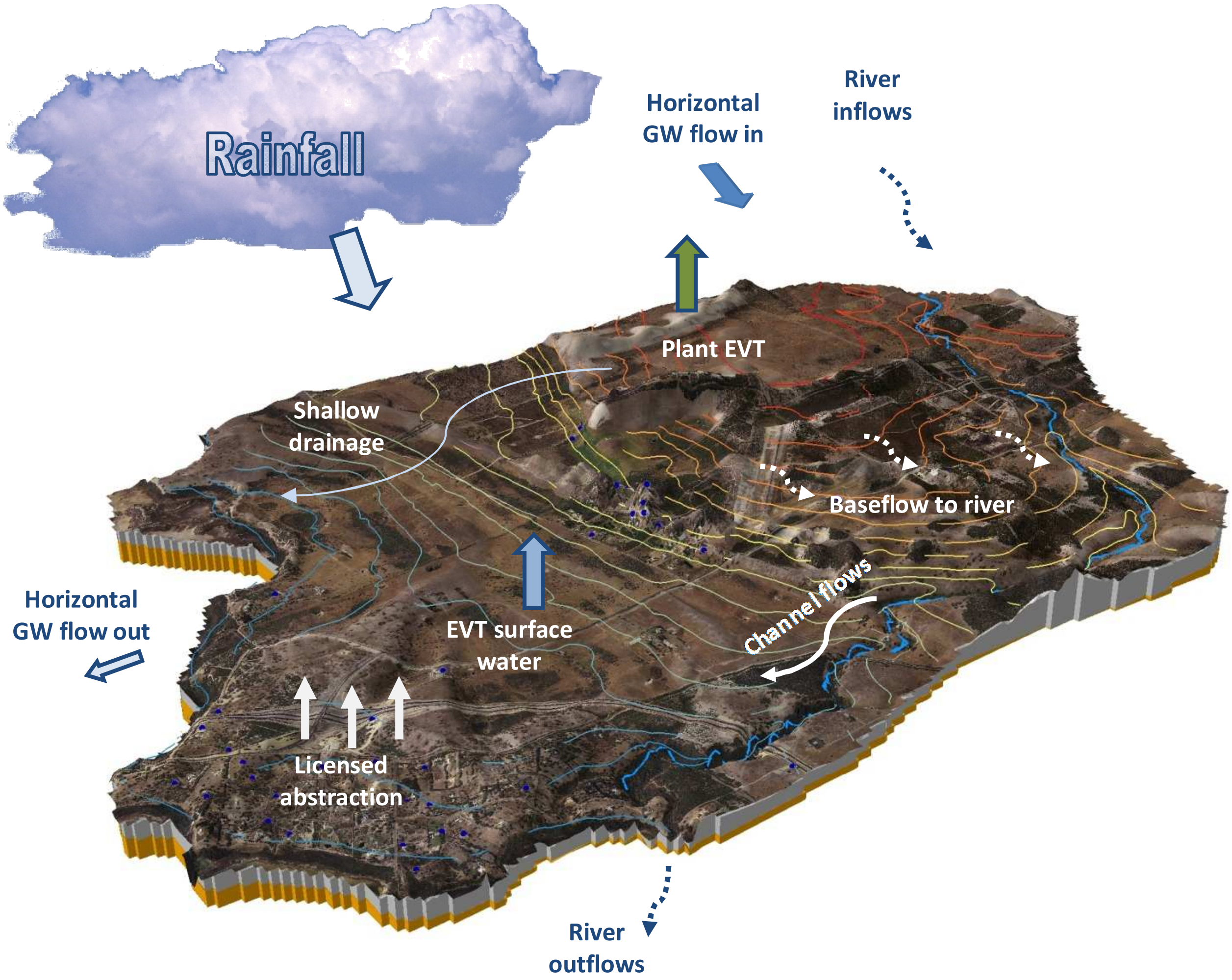


Figure 4.9 Nambeelup conceptual model

A simple conceptual water balance was developed to describe the major hydrological fluxes into and out of the Superficial Aquifer within the study area. The steady state water balance should satisfy the following equation:

$$RE_G - \Delta Ly - \Delta D - EVT - \Delta Lz + I_{re} - A = 0$$

Where:

RE_G = gross recharge from rainfall to the Superficial Aquifer (ML/yr)

ΔLy = net horizontal flow of groundwater across the model boundaries (ML/yr)

ΔD = net drainage from groundwater to surface water (ML/yr)

EVT = evapotranspiration from the groundwater (ML/yr)

ΔLz = net leakage to confined aquifers (ML/yr)

A = groundwater abstraction (ML/yr)

I_{re} = groundwater recharge return from irrigation (ML/yr)

The gross recharge and evapotranspiration components can be estimated using the Murray regional model, which showed a gross recharge of 41% of rainfall, and an evapotranspiration flux from groundwater of 30% of rainfall. The water balance tool within MIKE SHE was used to estimate the horizontal groundwater flow into and out of the Nambeelup study area, using the Murray regional model results. Inflows were calculated at 1.6 GL/yr and outflows as 2.3 GL/yr. Drainage to the Nambeelup Brook was determined by first performing a baseflow separation on the observed flow data, which indicated a baseflow of 69% of total flow. Around 20% of the Nambeelup Brook catchment area is located within the model area, so the baseflow component was scaled accordingly. Abstraction data was obtained directly from the Department of Water's water resource licensing allocation database from the area, and 20% of this was assumed to result in irrigation recharge. Vertical leakage to the Leederville Aquifer was calculated on the eastern side of the Mandurah Fault, assuming a vertical conductivity in the Pinjar Member of 5×10^{-4} m/day, a saturated thickness of 150 m and a head difference of 3.2 m (based on bores HS-104-1A and HS104-1B). As no head difference was observable between the Rockingham Aquifer and the Superficial Aquifer, no vertical leakage was calculated.

The water balance is shown in Table 4.2. The largest input to the Superficial Aquifer is rainfall recharge. As the model has time-varying heads as boundary conditions on all sides, horizontal groundwater inflows make up 10% of inputs to the aquifer, with irrigation recharge negligible. Boundary conditions are likely to affect modelling results within the Nambeelup model. However, the Murray regional model can provide simulation results for future climate scenarios, and therefore, reasonable boundary conditions are available for scenario modelling at the local scale.

The largest loss from the Superficial Aquifer is evapotranspiration from groundwater, which totals 67% of total outputs. Drainage to the Nambeelup Brook, and horizontal groundwater discharge (mostly to the Serpentine River in the west) make up a further 18% and 15% of losses from the aquifer, and accurate simulation of these fluxes is an important component of a realistic simulation. Losses to vertical leakage and abstraction are negligible in comparison to the other fluxes. Some additional losses may occur via the shallow drainage network which were not included in drainage calculations, and these probably account for the 3% error in the steady state water balance.

Table 4.2 Conceptual water balance

Model area (km^2) *42.2*

Flux	mm	%	ML	Notes
Rainfall	829	100%	34999	*SILO data drill*
Recharge	340	90%	14350	*Recharge estimated as 41% rainfall (MRM)*
Horizontal flow in	39	10%	1649	*Water balance extraction from MRM*
Irrigation	0	0%	5	*Estimated as 20% of abstraction*
EVT (GW)	245	67%	10325	*EVT (GW) estimated as 30% of rainfall (MRM)*
Drainage	67	18%	2829	*Baseflow separation of Nambeelup gauge*
Horizontal flow out	55	15%	2311	*Water balance extraction from MRM*
Abstraction	1	0%	26	*Based on DoW's WRL database*
Vertical leakage	0	0%	24	*Calculated using Darcy's equation*
Error	12	3%	513	

5 Model construction

The model was constructed within MIKE SHE and MIKE 11 using spatial and time-series datasets developed for the Murray regional model. Spatial datasets were originally produced at a 10 m grid resolution for the Murray conceptual model, and were resampled to the required resolution for the Nambeelup model. The Murray regional model was updated with new time series of climatic data and tidal data, in order to extend the modelling period to the 23 August 2010, and provide boundary conditions for the Nambeelup model. Similarly, the surface water model SQUARE was used to model the Nambeelup Brook for the same period to provide boundary conditions for MIKE 11.

Technical descriptions of the component models described below can be found in the MIKE SHE, MIKE 11 and MIKE Zero reference manuals.

5.1 Simulation periods

The period January 1980 to August 2009 was used as the calibration period, and the period August 2009 to August 2010 used for model validation. Only two long term T series bores are present in the modelling area. To achieve good spatial coverage it was necessary to include data to the end of August 2009 within the calibration dataset, which incorporated Harvey Shallow (HS) series, wetland level, and consultant bores. A period of five years (1980 to 1985) was used to stabilise stores and initial conditions within the model.

5.2 Model domain and grid

A grid resolution of 40 x 40 m was used for the Nambeelup model. This represents a significant improvement over the resolution of the regional model, which is 200 m x 200 m. The resolution was chosen to accommodate fine scale variations in topography and land use, while maintaining short model run times for calibration, and ensuring model stability. The model domain is shown in Figure 5.1. Coordinates, values and parameters relating to the model domain and grid are shown in Table 3.1. All model layers have consistent map projections of GDA 1994 MGA Zone 50. However, MIKE SHE was configured in non-UTM mode to avoid grid alignment difficulties.

Table 5.1 Model domain and grid values

Cell size	40 m x 40 m
Map projection	GDA 94 MGA Zone 50
X minimum	385798
X maximum	394798
Y minimum	6400252
Y maximum	6406852
Total model area	42 km^2
Number of cells in x direction	225
Number of cells in y direction	165

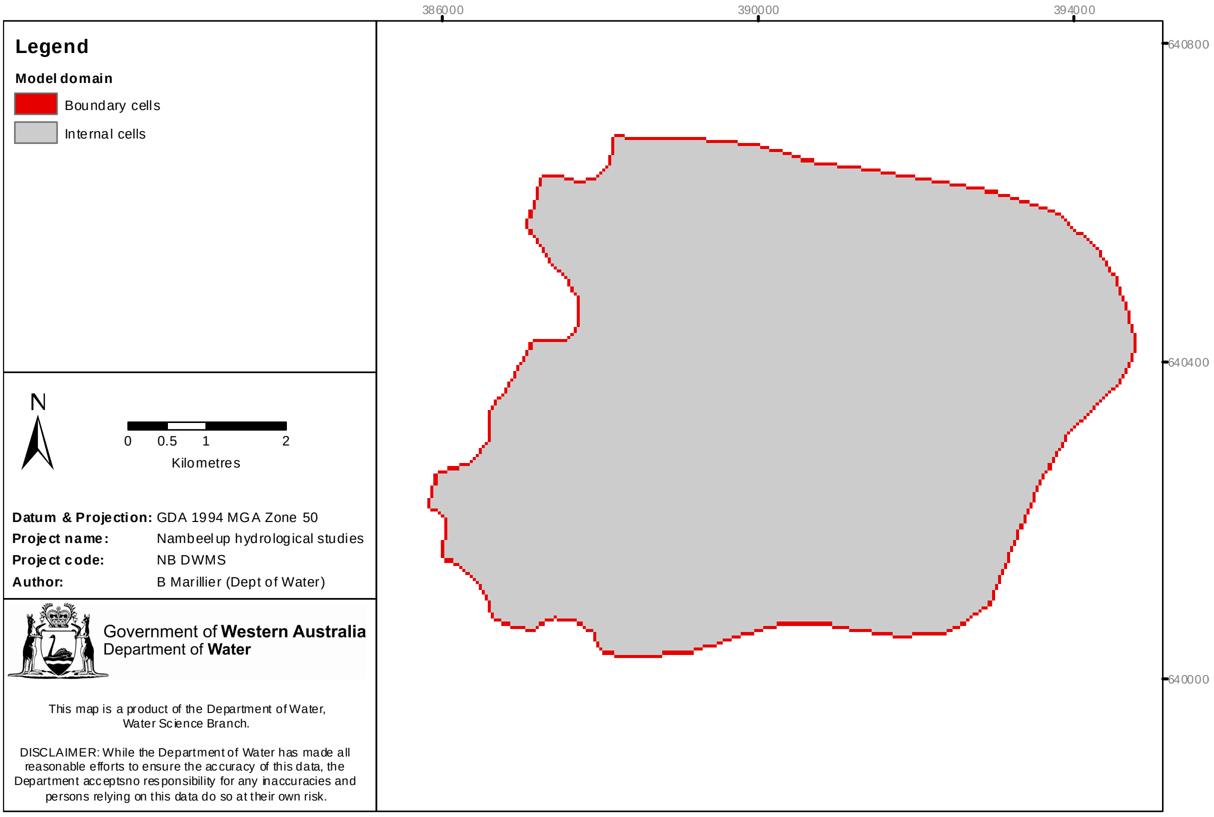


Figure 5.1 Model domain

5.3 Topography

The Department of Water 1 m resolution LiDAR data was re-sampled to the 40 m model grid. The re-sampled topography for the model grid is shown in Figure 5.2.

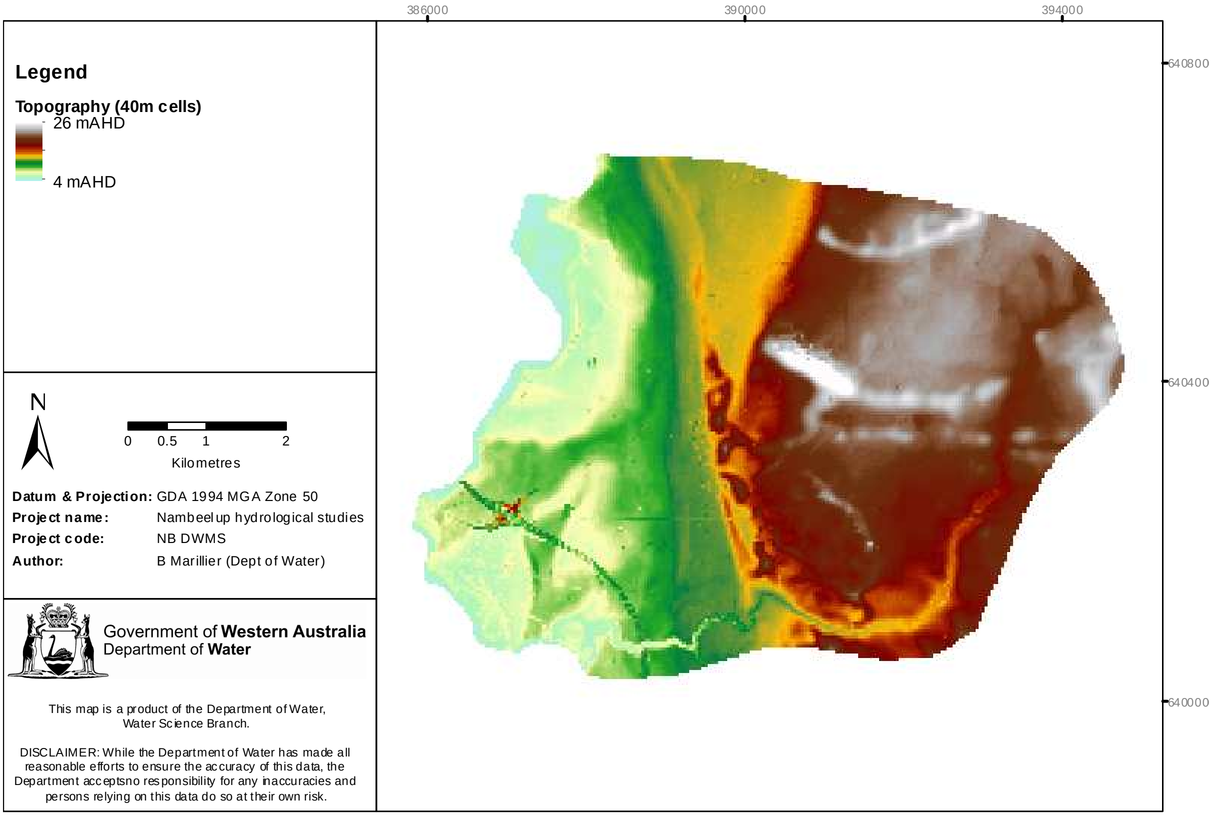


Figure 5.2 Model topography

5.4 Rainfall and evapotranspiration

Rainfall and Penmen-Monteith evapotranspiration data was obtained from SILO data drill locations. The Nambeelup model area was divided into four climate zones based on the site distribution (this represents a sub-set of the nine stations used for the regional model). This was converted into a 40 m resolution grid for the numerical model as shown in Figure 5.3. Climate zones two and five comprise most of the model area.

Figure 5.3 Climate zones

5.5 Evapotranspiration model

The requirements for the evapotranspiration model include root depth and leaf area index (LAI). The catchment land use was divided into six categories, each with corresponding values for LAI and deep rooted vegetation. The land use for the Nambeelup study area was derived from the Murray conceptual model. During calibration an additional land-use category was added to the model to account for low shrubs in the area. Initial values for LAI and root depth were derived from the calibrated Murray regional model. Initial values for the ‘low shrubs’ land use were taken from the Lakes Road wetland model. These are shown in Table 5.2, and mapped in Figure 5.5.

Table 5.2 Initial values for leaf area index and average root depth estimates from the Murray regional model and Lakes Road wetland model

Land use	**Leaf area index**	**Rooting depth mm**
Bare/urban	2	1000
Cropping/grazed	0–3	800–1300
Irrigated	3	1200
Low shrubs*	1.5	1300
Native trees	1.5	2000
Plantation	1.5	2000

**Parameters obtained from Lakes Road model*

With the exception of annual pasture, all land-use classes use a constant LAI and root depth throughout the simulation. The values for LAI are subject to calibration in the model within the bounds of available literature. For annual pasture, an annual trend of LAI is assigned that follows normal pasture growth and senescence in monthly increments (Xu et al. 2009). The annual LAI profile for pasture is shown in Figure 5.4.

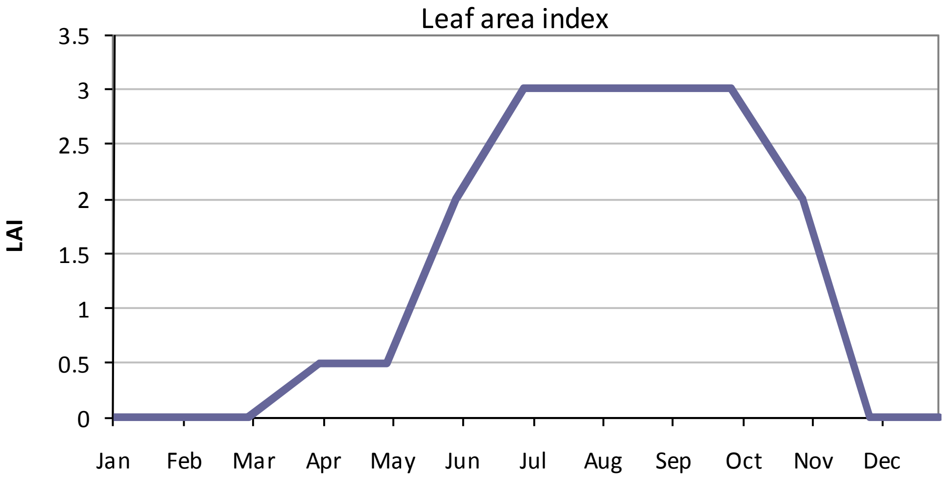


Figure 5.4 Annual rotation scheme for grazing land use (non-irrigated) leaf area index

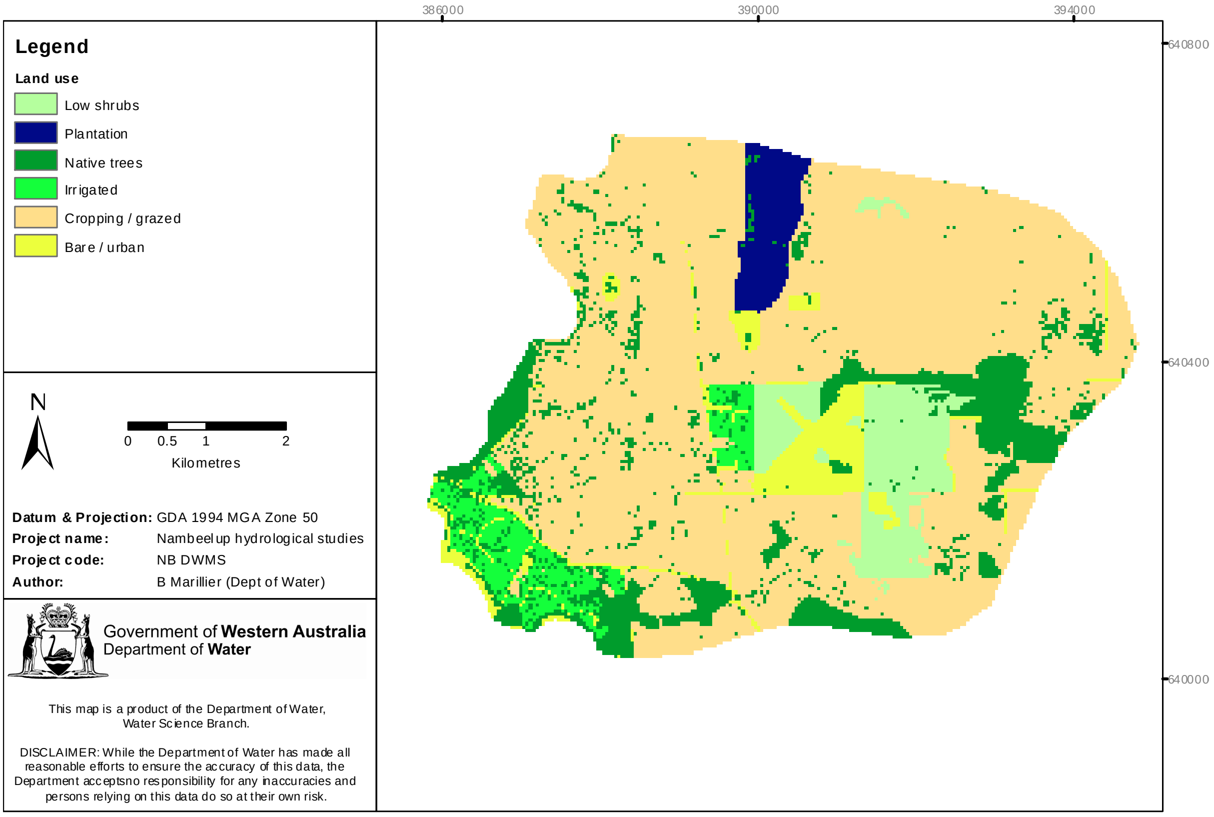


Figure 5.5 Unsaturated zone land-use classes

5.6 Channel flow model (MIKE 11)

The MIKE 11 network in the Nambeelup model consists of eight branches, 173 h-points (stage) and 160 Q-points (discharge). These include the Nambeelup Brook, five drains which discharge to the brook, the Gull Road drain, and a single drain which runs to the Serpentine River in the south-west. Culverts, weirs, bridges and other control structures were not included in the MIKE 11 model. Incorporation of these structures in the hydraulic model is not critical to calculation of groundwater levels and long-term water balance.

MIKE 11 GIS was used within ESRI's ArcMap to define both the MIKE 11 channel network, and extract cross-sections directly from the 1 m resolution LiDAR dataset. The MIKE 11 network was then imported to MIKE SHE. The MIKE 11 network is shown in Figure 5.6.

MIKE 11 requires boundary conditions at inflows and outflows of defined reaches. For the Nambeelup Brook, a daily time series of inflow was defined at the upper end of the reach. The time series was obtained from the calibrated Nambeelup SQUARE model. For the remaining drains within the model area, inflow boundaries were set to zero. At the lower end of all terminating reaches the outflow boundary was set to qH (stage–discharge), which is estimated using conveyance within MIKE 11.

The Manning's roughness coefficient 'n' was used to define bed roughness, and a global value of 0.035 was used for rivers and drains. Due to the low hydraulic gradients of drains in the study area, the fully dynamic wave solution (first order) was necessary for the model, with a maximum time step of 1.5 minutes to ensure model stability.

5.7 Overland flow model

The successive over-relaxation method of solving the finite difference equations for overland flow was used for the Nambeelup Brook model. The Manning 'M' (inverse of the commonly used Manning n) was set to a global value of 20 for the Nambeelup model, which is typical of pasture and sparse vegetation.

Detention storage accounts for depressions and ponds which are smaller than the grid cell. Detention storage was set to 2 mm for the Nambeelup model, meaning that surface water must pool to a depth of greater than 2 mm before overland flow will occur.

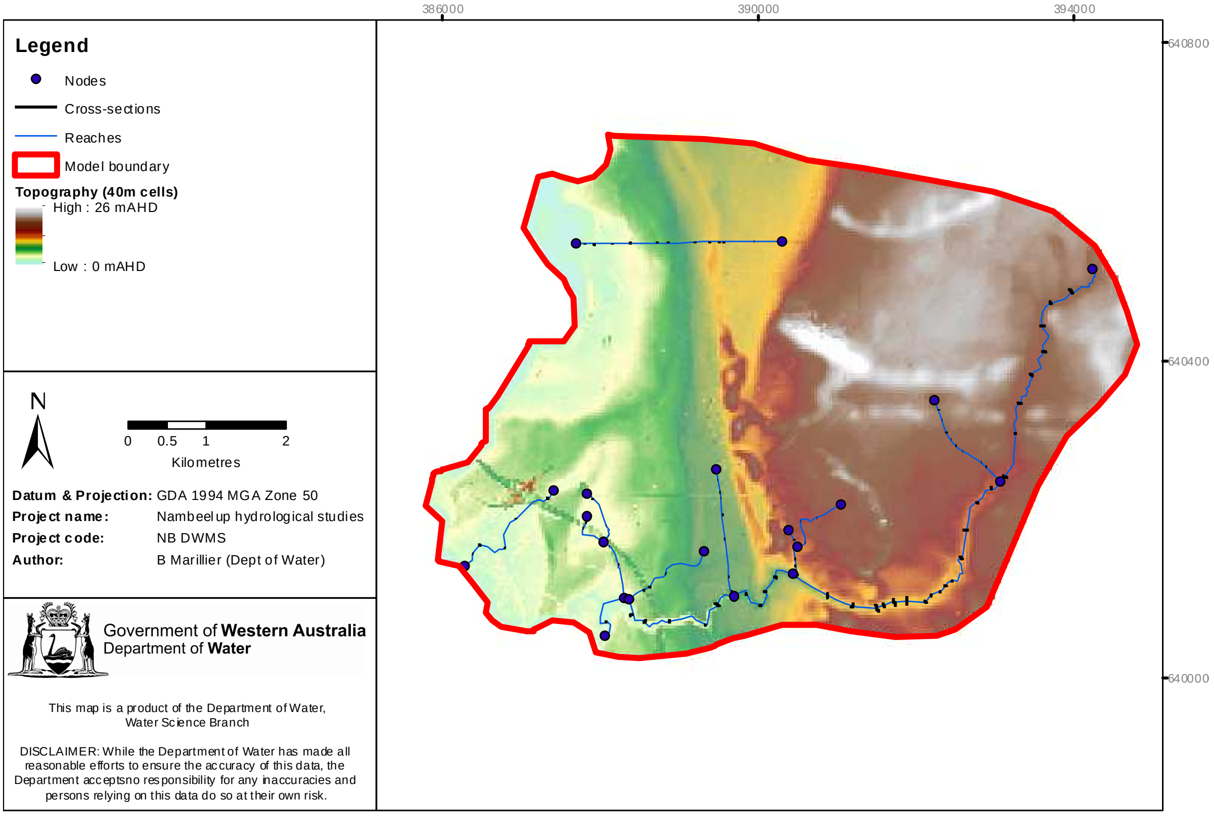


Figure 5.6 MIKE 11 network

5.8 Unsaturated flow model

Soil zones for the unsaturated flow model were obtained from the Murray regional conceptual model. This classification was based on the existing soil units in the Department of Agriculture and Food's Soil Landscape Units dataset. The study area consisted primarily of the Bassendean soil unit, with small patches of wetland or alluvial soils. Thus only one soil zone was used within the model area – the 'Bassendean' soil zone.

The 'two-layer UZ' solution was used within MIKE SHE to simulate the unsaturated zone.

5.9 Saturated flow model

Geological layers

In MIKE SHE, each aquifer is required to span the entire model domain, and is entered as a 'geological layer'. Only one geological layer was entered into the model and was labelled the 'superficial' layer, representing the Superficial Aquifer. The conceptual geology and hydrogeology was later entered as aquifer units, labelled 'geological lenses' in MIKE SHE, which form within the geological layer.

Geological lenses

The Murray conceptual model was used as a template for the Nambeelup study area. The model conceptualisation differs from the regional model, in that the lower level of the model domain is defined as the base quaternary unconformity.

Excluding the Rockingham Formation, the Nambeelup model area intersects three geologic members, which are:

- **Bassendean Sand** which covers most of the study area. Bassendean Sand is pale grey to white, and occasionally brown, moderately-sorted, fine- to medium-grained quartz sand with traces of heavy minerals. A layer of friable, mostly weakly limonite cemented sand known as 'coffee rock' is commonly present at or near the watertable. The sand is present is distributed as a thin layer across most of the study area, but is thicker in dune systems in the west of the study area, north of the Nambeelup Brook. The extent of the Bassendean Sand within the model is consistent with the first computational layer, except in areas where alluvium, estuarine and swamp deposits occur (see Figure 5.7 and Figure 5.8).
- The **alluvium, estuarine and swamp deposits** which are associated with the many rivers, lakes and wetlands that exist within the study area. These deposits consist of clays, silts and sand, which is angular to rounded, poorly sorted and often containing gravel and pebbles (Pennington Scott 2008). Peaty and sandy swamp deposits are associated with the numerous wetlands, often having a dark brown, grey to black colour and being organic rich. The distribution of the alluvium, estuarine and swamp deposits, as represented in the numerical model, is shown in Figure 5.9 and Figure 5.10. They are focused around wetlands, the Nambeelup Brook, and the Serpentine River.
- The **Gnangara Sand***,* which is a medium-grained sand. All regions in the superficial layer that were not assigned to a specific lens were assigned the properties of Gnangara Sand, thus ensuring there were no voids within the geologic model. In the Nambeelup model, the Gnangara Sand is consistent with the lower computational layer.

The top and bottom of each of these formations was resampled from a grid size of 10 m, to 40 m, consistent with the model domain. Table 5.3 shows typical values of hydraulic conductivity and specific yield for the selected formations. The calibrated values from the Murray regional model have also been included, and these were used as initial values for the Nambeelup model.

Table 5.3 Hydraulic parameter ranges for geological lenses within the Superficial Aquifer

Stratigraphy	**K_H (range) (m/day)**	**K_Z (range) (m/day)**	**S_Y**	**S_S**
Gnangara	20	2	0.22	$1x10^{-6}$
Bassendean	5 to 15	0.5 to 1.5	0.22	$1x10^{-6}$
Alluvium	0.1 to 12	0.01 to 0.12	0.20	$5x10^{-5}$
Gnangara*	8	1.2	0.25	$1x10^{-6}$
Bassendean*	10	0.1	0.21	$1x10^{-6}$
Alluvium*	10	0.05	0.20	$1x10^{-6}$

**Calibrated parameters for the Murray regional model*

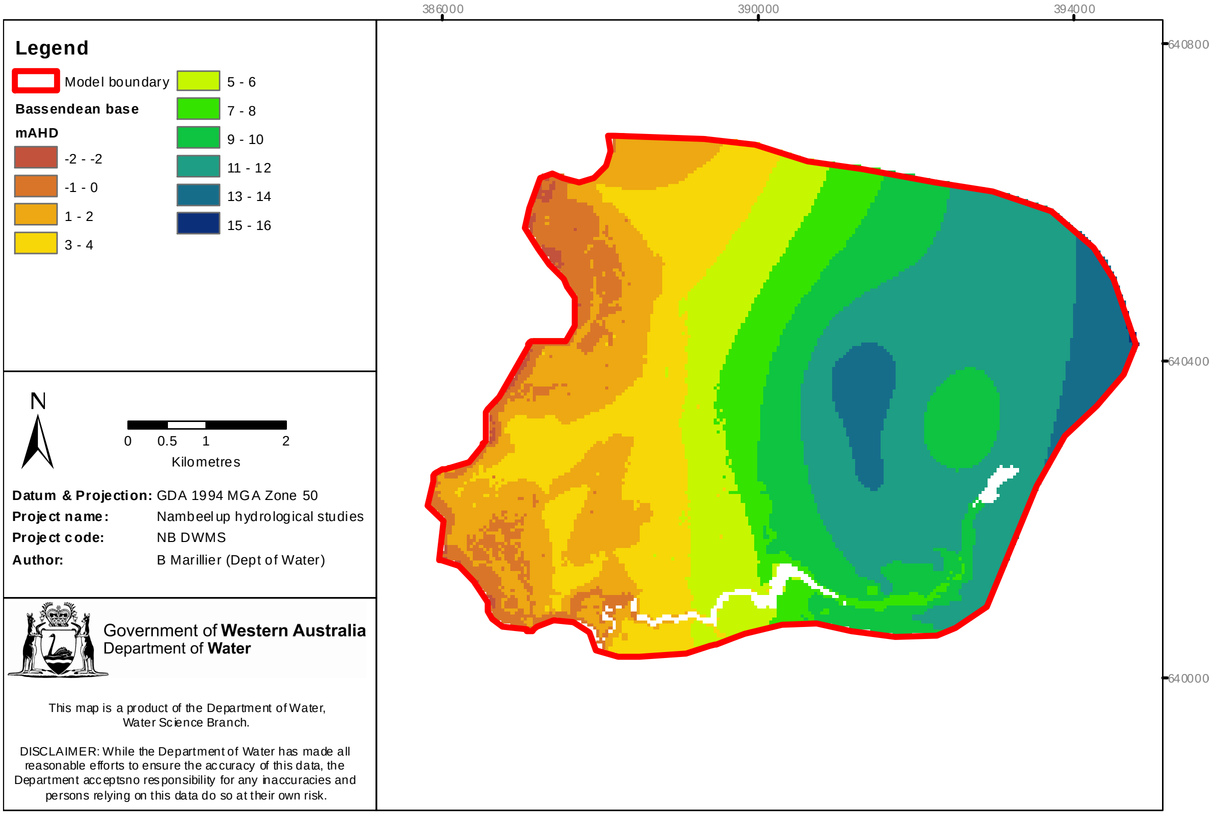


Figure 5.7 Bassendean Sand lower level

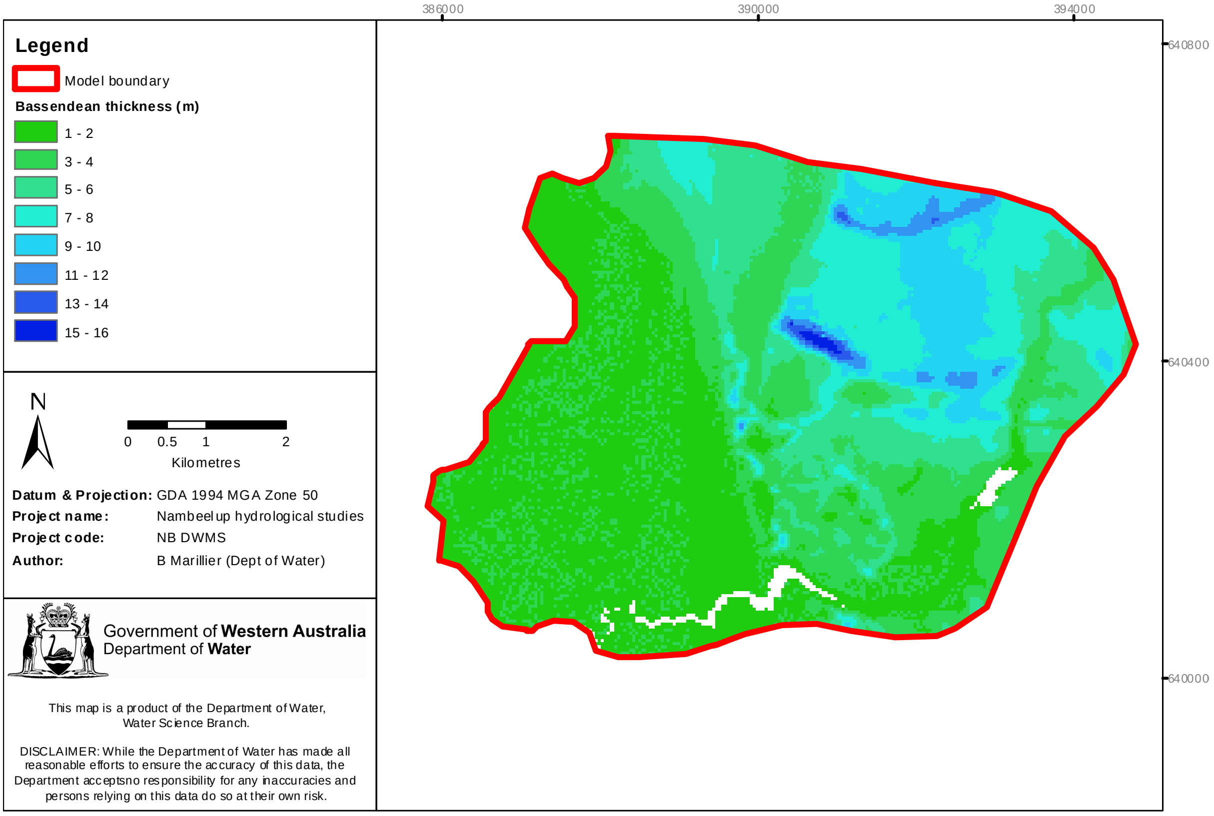


Figure 5.8 Bassendean Sand thickness

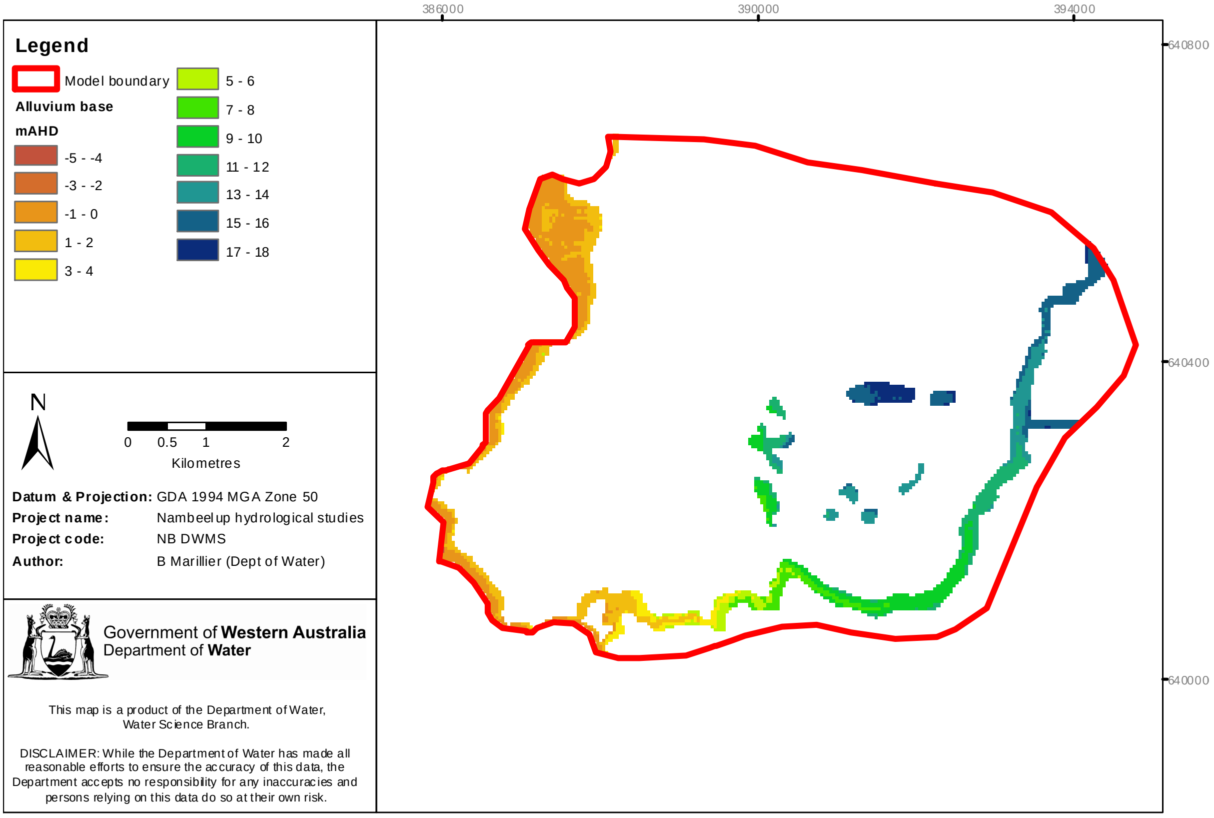


Figure 5.9 Alluvium swamp and estuarine sediments, lower level

Figure 5.10 Alluvium swamp and estuarine sediments, thickness

Groundwater abstraction

There were 44 abstraction bores within the Nambeelup study area. Each was modelled as an individual draw point at the location of the bore. Abstraction was assumed to occur between November and April, at a constant rate, to the maximum allocation for the draw point. The location of the abstraction bores are shown in Figure 5.11.

Computational layers (vertical discretisation)

The Nambeelup model consists of two computational layers – these are designed to capture head differences in the paired bores within the Superficial Aquifer.

A surface 2 m below the minimum groundwater level was used to define the base of the first computational layer. The extra two metres below the minimum groundwater level was used to ensure that water levels did not fall below the base of the first computational layer during predictive scenarios. The elevation of the base of the first computational layer is shown in Figure 5.12.

The base of the second computational layer was defined by the top of the Leederville and Rockingham formations, and is the base of the numerical model (Figure 5.13). As discussed, the Rockingham Aquifer was not modelled for the Nambeelup area.

Boundary conditions

Saturated zone boundary conditions were defined by the Murray regional model for the outer bounds of the Nambeelup model for the two computational layers. MIKE SHE has the capacity to sample saturated zone heads from the regional model results files directly to the defined boundary of the Nambeelup.

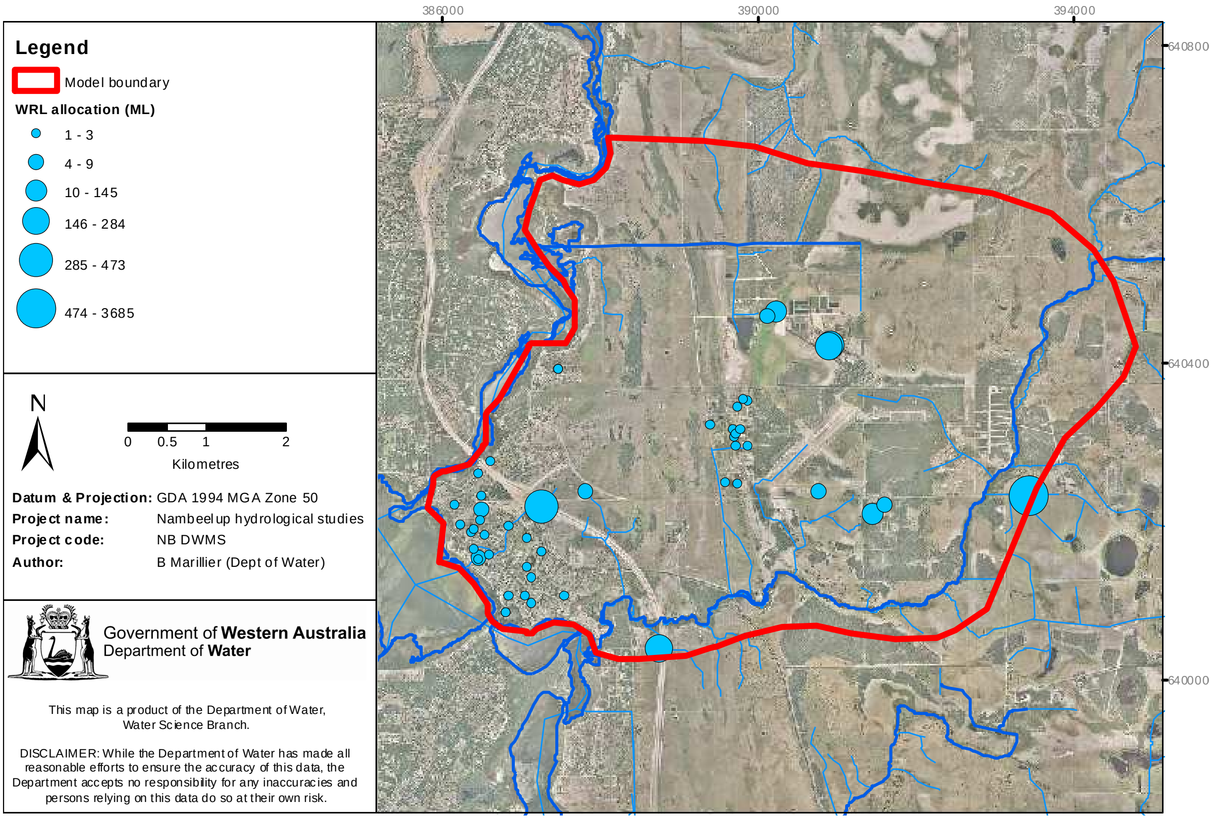


Figure 5.11 Production bores and licensed allocation

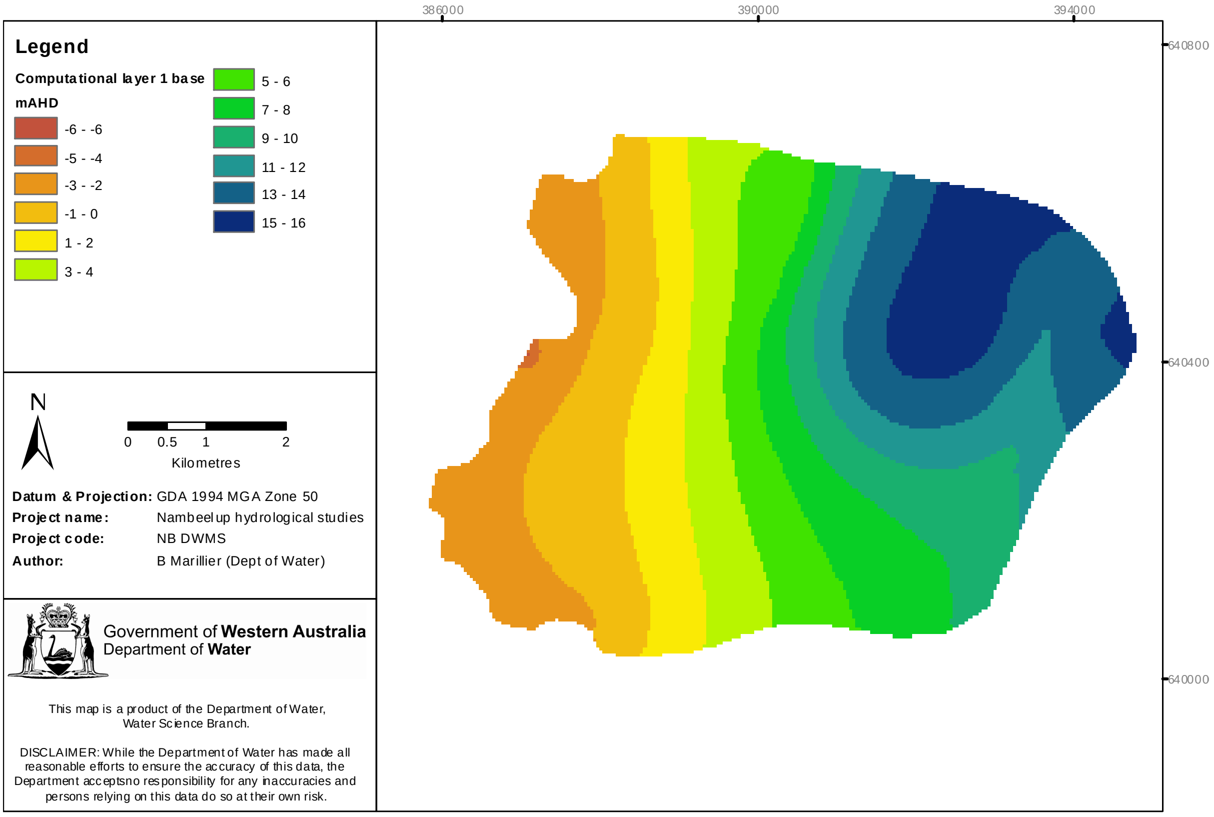


Figure 5.12 Computational layer 1 – lower level

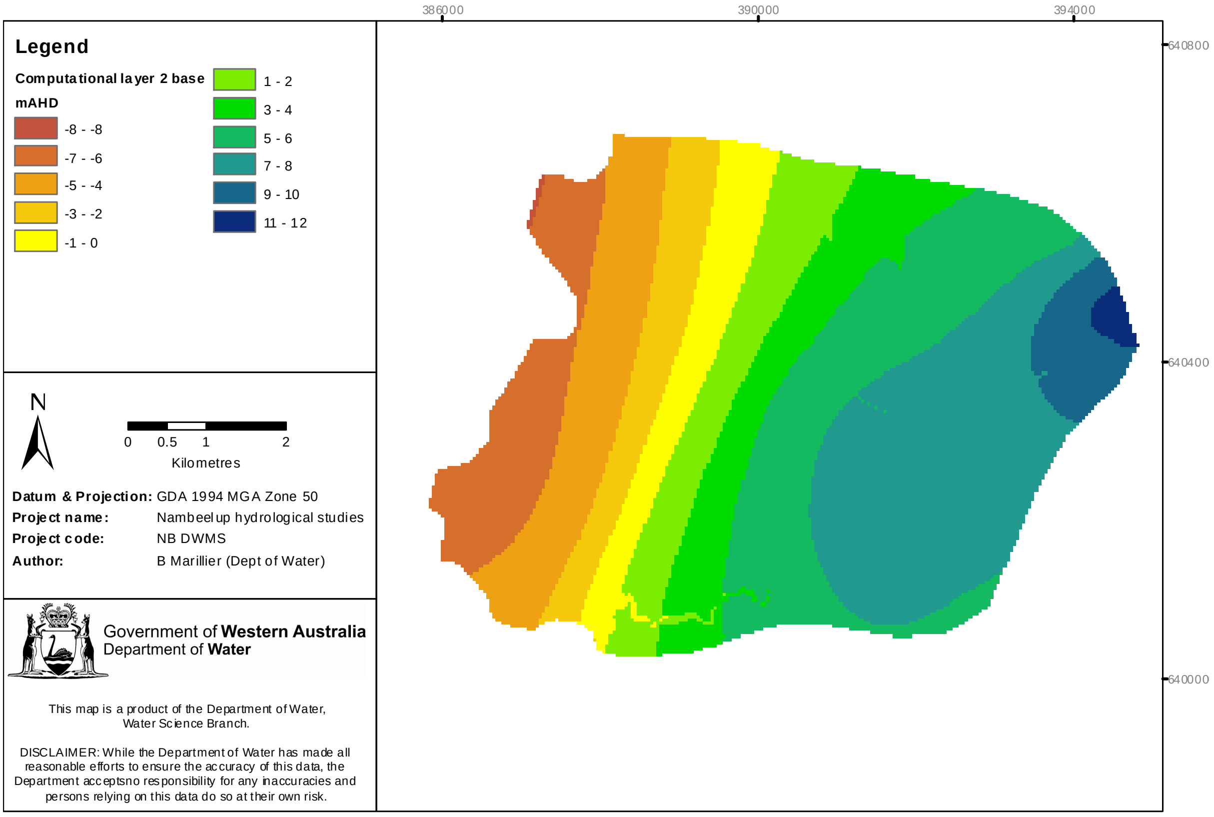


Figure 5.13 Computational layer 2 – lower level

6 Model calibration and validation

Model calibration and validation methods were based on the Murray-Darling Basin Commission's *Groundwater flow modelling guidelines* (Middlemis 2000). Initial values for calibrated parameters in the Nambeelup model were taken directly from the Murray regional model. This is a better base for calibration, which substantially reduced the iterations required to meet calibration criteria. Similarly, the sensitivity analysis used in the Murray regional model was used to guide calibration.

The following criteria were used to assess the calibration results:

- **Water balance:** the single maximum cumulative error of the water balance of the Superficial Aquifer of less than 1%. The difference between the total modelled inflow and the total modelled outflow (water balance error) will be less than 0.1%.
- **Iteration residual error:** the iteration convergence criterion should be one or two orders of magnitude smaller than the head resolution. Here the criterion is <0.1%.
- **Qualitative measures:**
  - modelled versus measured groundwater hydrographs for each calibration bore
  - residual error plot for each calibration bore
  - scattergram of measured versus modelled heads.
- **Quantitative measures:**
  - Root mean square (RMS) error between measured hydraulic head and modelled hydraulic head will be less than 5% of the measured hydraulic head drop across the model area. The error will not be spatially biased. Final calibration results will report the RMS error, mean absolute error, the mean error and the coefficient of determination.
  - Final calibration for each bore will report mean error, mean absolute error, RMS error, standard deviation of residuals, correlation coefficient (R), and Nash Sutcliffe efficiency (R^2).

In the case of the Nambeelup model, which was developed primarily to guide drainage design, the RMS error criteria of 5% is insufficient. With a maximum head drop of 17 m within the model area, the criteria represents an allowable error of 0.85 m. It is desirable that an RMS error of 2% is reached, which results in a smaller RMS criteria of 0.34 m.

6.1 Calibration methods

The Nambeelup model was calibrated for the period of 1 January 1980 to 31 August 2009. This leaves data from August 2009 to August 2010 for validation. A structured, manual iterative approach was used to calibrate the model over 21 model runs. A calibration journal was maintained which lists issues or errors associated with each model run, changes in model parameters and the problems which they aim to address, and running statistics for all model runs.

After each model run a number of different methods were used to assess the quality of the calibration. They are:

- assessing error statistics against the calibration criteria
- examining spatial autocorrelation of errors within the model area
- calculating the water balance and ensuring it was consistent with observations in the area
- assessing dynamics within individual bores
- examining animations of areas of inundation and cross-sections of simulated heads
- identifying any errors in construction such as incorrect bore locations
- checking for numerical instabilities.

6.2 Calibration and validation bores

Time-series data from 87 bores was used for calibration and validation of the Nambeelup model. Data for the calibration bores was obtained from the Department of Water monitoring bores, and bores which have been installed and monitored by consultants working within the modelling area on behalf of land holders. A summary of bores used in calibration is shown in Table 6.1 and the spatial distribution of these bores is shown in Figure 6.1. Some bores have only been monitored recently and data from them is outside the modelling period. Levels at these bores can be compared visually with model results from earlier years, but cannot be included in calibration. Bore construction information is available from the Department of Water for the T and HS series bores, from RPS-BBG (2006) for the LP series bores, from Parsons Brinkerhoff (2002) for the NB series bores, and from JDA for the JDA, LA, NBB and SH bores. No construction information was available for the remaining calibration bores.

Table 6.1 Calibration and validation bore summary details

Bore prefix	Name	Source	Installation	Earliest record	Latest record
T	Lake Thomson	DoW	DoW	15/06/1975	Present
HS	Harvey Shallow	DoW	DoW	29/10/2008	Present
LP		JDA	RPS-BBG	22/06/2006	Present
T (consultant)		JDA	RPS	14/03/2007	Present
NB		JDA	PB	26/08/2004	Present
PLI (wetlands)		DoW	DoW	20/08/2009	Present
JDA		JDA	JDA	5/08/2010	Present
LA		JDA	JDA	15/03/2011	Present
NBB		JDA	JDA	24/07/2009	Present
SH		JDA	JDA	3/06/2010	Present
MB		JDA	(Ken Brown Geotechnical) Now - TME	5/08/2010	Present
MW		JDA	Unknown	22/06/2010	Present

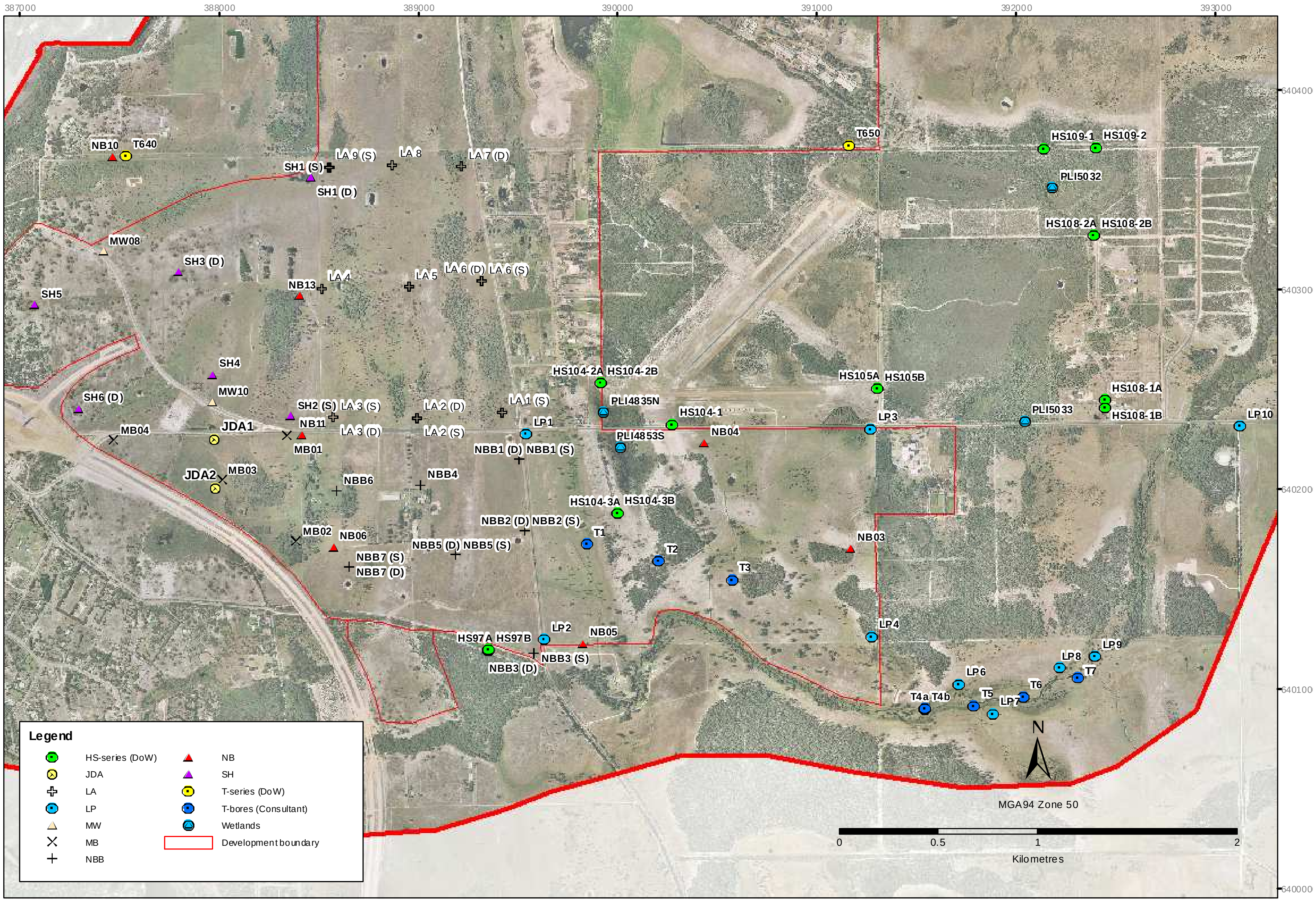


Figure 6.1 Calibration and validation bores

6.3 Calibration results

The model's performance met the calibration criteria described above, as shown in Table 6.2. The RMS error is 0.33 m and the scaled RMS error is 1.9%. The MSR is lower at 0.25 m and is more indicative of the overall model performance, as it is less sensitive to outliers. The maximum positive and negative errors are 1.28 m (at T650) and –1.08 m (at T2). However, the positive error appears to be an outlier and may be an erroneous value in the observed dataset. Figure 6.3 and Figure 6.1 graph the modelled and observed groundwater levels and residual error.

Comparisons of time series for modelled heads and observed heads for the full modelling period are included in Appendix A.

Table 6.2 Calibration statistics (1 January 1980 to 31 August 2009)

Description	**Symbol**	**Value**
Count	n	1065
Sum of squares (m^2)	SSQ	113
Mean sum of squares (m^2)	MSSQ	0.11
Root mean square (m)	RMS	0.33
Scaled root mean square (%)	SRMS	1.94
Sum of residuals (m)	SRMS	267.0
Mean sum of residuals (m)	MSR	0.25
Scaled mean sum of residuals (%)	SMSR	1.49
Maximum positive error (m)	MR+	1.28
Maximum negative error (m)	MR-	-1.08
Coefficient of determination ()	CD	1.00

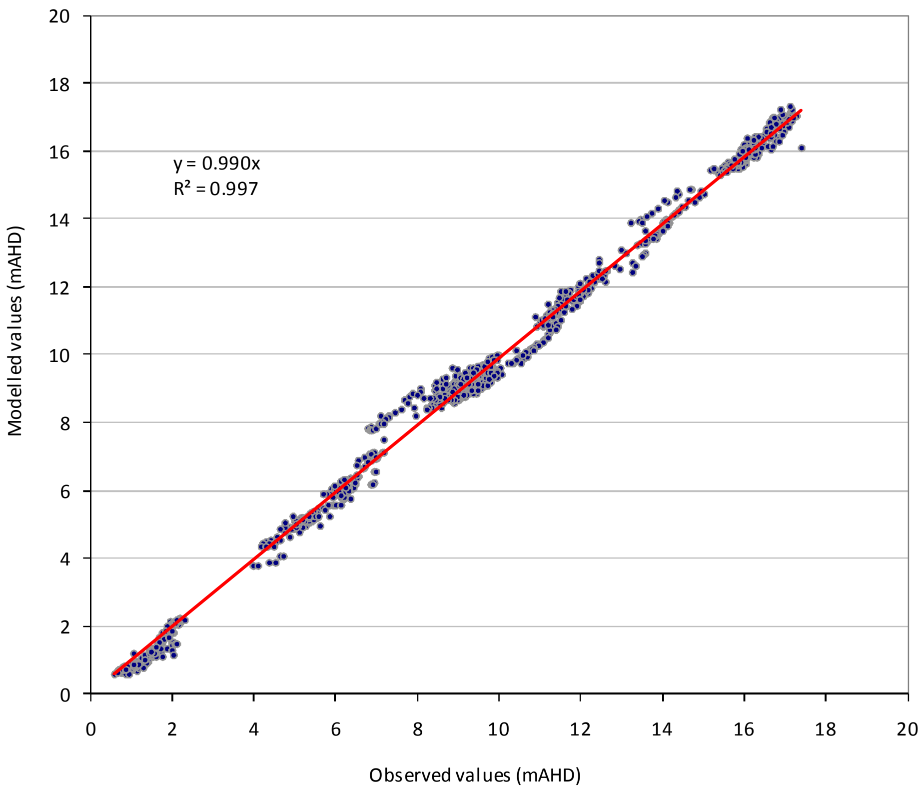


Figure 6.2 Calibration modelled versus observed values

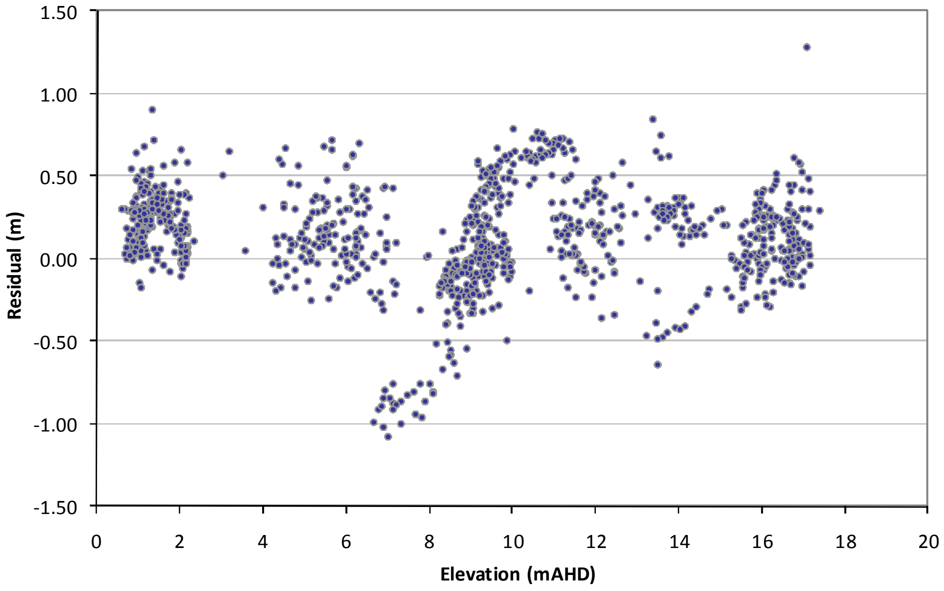


Figure 6.3 Calibration residual error versus elevation

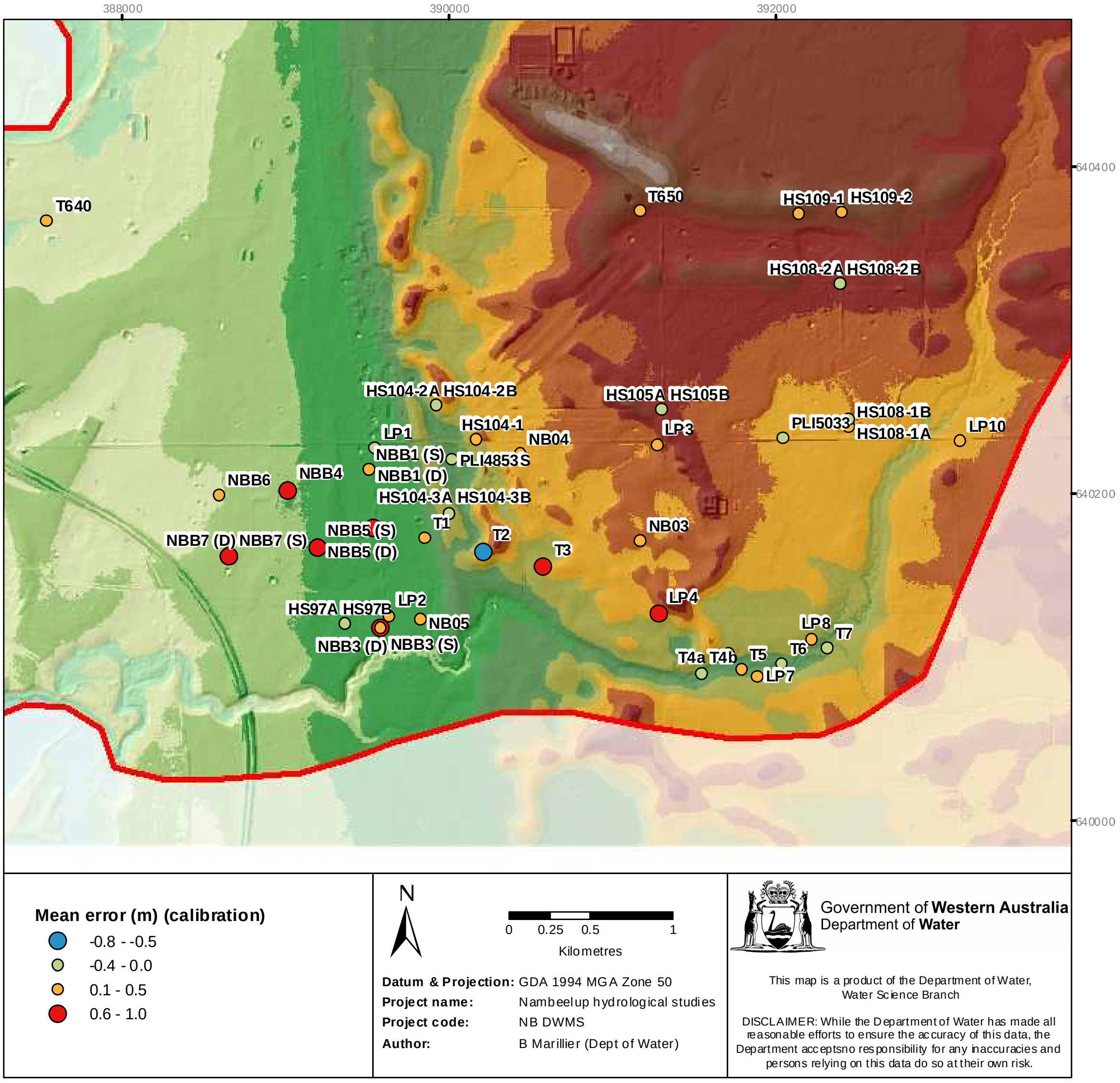


Figure 6.4 Calibration distribution of error (red indicates model under prediction)

6.4 Validation results

Validation statistics were slightly worse than those of calibration, with an RMS error of 0.37 m and an MSR of 0.31 m. These are still very good results given that many of the validation bores were not used in calibration, as no data was available for the calibration period. Validation results are shown in Table 6.3 and graphed in Figure 6.5 and Figure 6.6.

Table 6.3 Validation statistics (1 September 2009 to 23 August 2010)

Description	Symbol	Value
Count	n	363
Sum of squares (m^2)	SSQ	50
Mean sum of squares (m^2)	MSSQ	0.14
Root mean square (m)	RMS	0.37
Scaled root mean square (%)	SRMS	2.20
Sum of residuals (m)	SRMS	110.9
Mean sum of residuals (m)	MSR	0.31
Scaled mean sum of residuals (%)	SMSR	1.82
Maximum positive error (m)	MR+	0.77
Maximum negative error (m)	MR-	-1.08
Coefficient of determination ()	CD	0.99

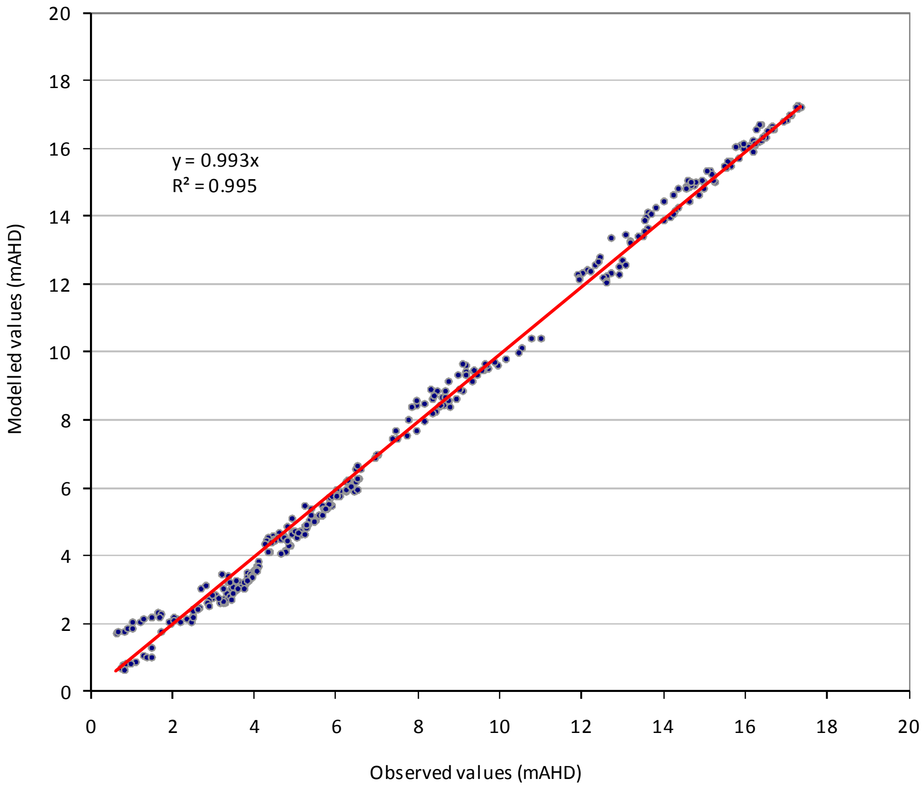


Figure 6.5 Validation modelled versus observed values

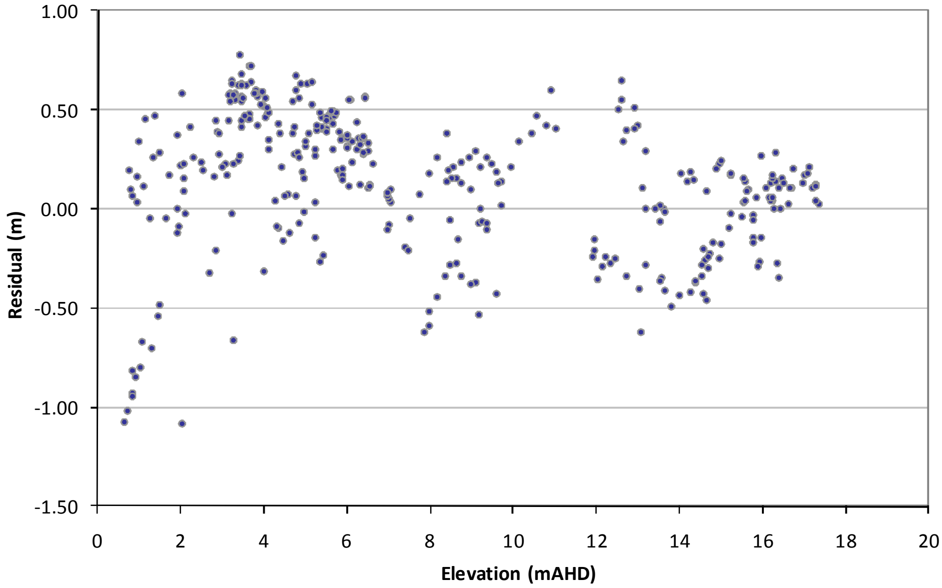


Figure 6.6 Validation residual error versus elevation

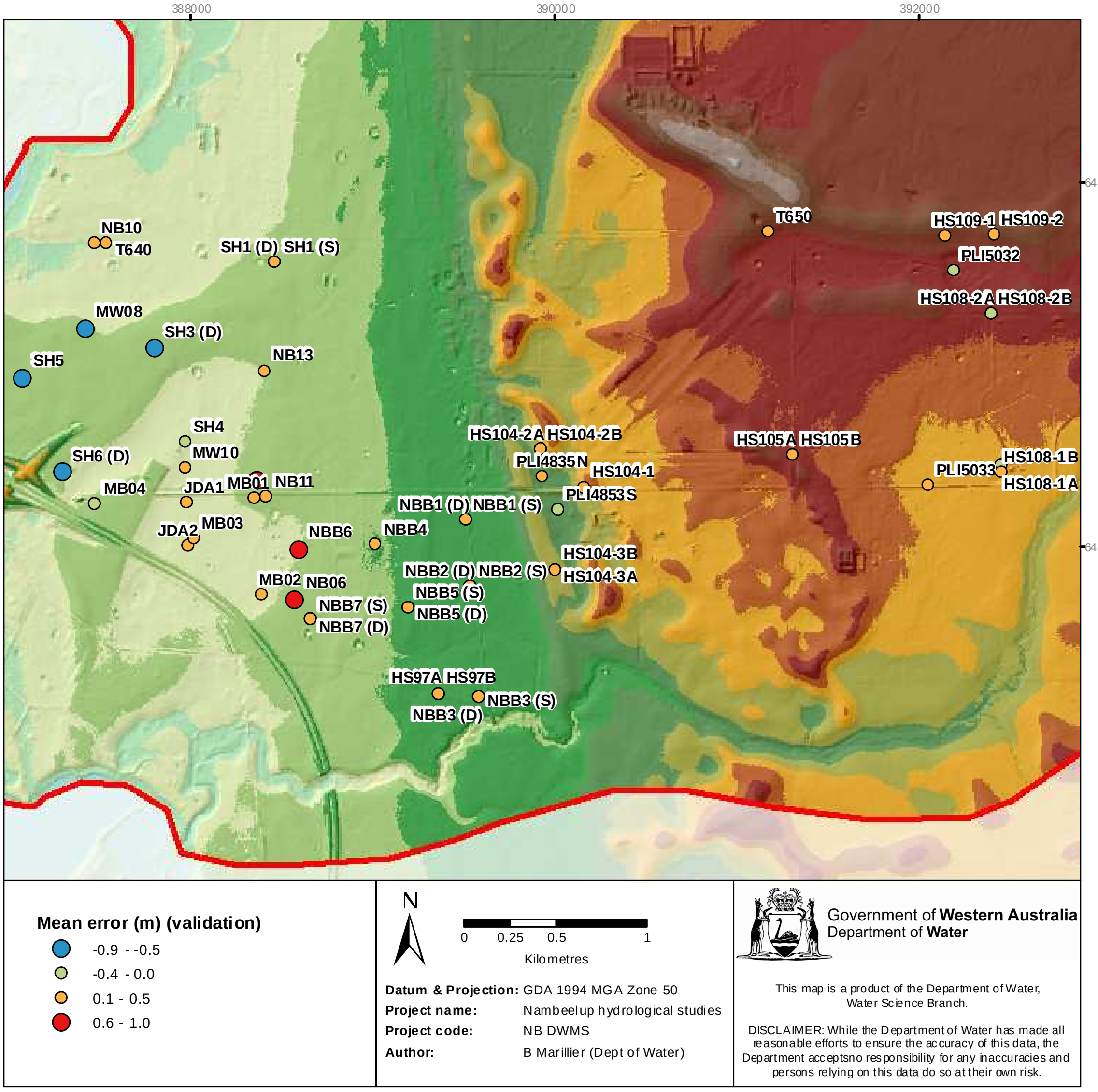


Figure 6.7 Validation distribution of error (red indicates model under prediction)

6.5 Calibrated parameters

The final calibrated parameters for each component model are listed in Table 6.4. No parameters were calibrated outside appropriate ranges.

Table 6.4 Calibrated model parameters

Overland flow

Class / layer	Parameter	Value	Units
Universal	Manning's M	20	$m^{(1/3)}/s$
	Detention storage	2	mm
	Initial water depth	0	m

Rivers and lakes

Class / layer	Parameter	Value	Units
Universal	Leakage coefficient	5.00E-06	
	Manning's n	0.035	$1/m^{2(1/3)}/s$

Unsaturated zone

Class / layer	Parameter	Value	Units
Gnangara Sands	Kh	6	m/day
	Kz	1	m/day
	Sy	0.25	
	Ss	1.00E-06	1/m
Swamp, estuary & alluvium	Kh	4	m/day
	Kz	0.1	m/day
	Sy	0.2	
	Ss	1.00E-06	1/m
Bassendean Sands	Kh	10	m/day
	Kz	1	m/day
	Sy	0.2	
	Ss	1.00E-06	1/m

Unsaturated zone land use

Class / layer	Parameter	Value	Units
Bare / urban	LAI	1	m^2/m^2
	RD	700	mm
Cropping / grazed	LAI	0-2.7	m^2/m^2
	RD	648-1053	mm
Irrigated	LAI	2.5	m^2/m^2
	RD	1000	mm
Native trees	LAI	1.5	m^2/m^2
	RD	2000	mm
Plantation	LAI	1.5	m^2/m^2
	RD	2000	mm
Low shrubs	LAI	1.5	m^2/m^2
	RD	800	mm

Unsaturated zone soils

Class / layer	Parameter	Value	Units
Bassendean Sands	Wcs	0.27	
	Wcfc	0.07	
	Wcwp	0.03	
	Ksat	1	m/day
Universal	ET surface depth	0.3	m

Overland flow parameters

The model is insensitive to the overland flow parameters due to the high infiltration rates of the Bassendean Sands, so the Manning’s M and detention storage were kept consistent with the Murray regional model.

MIKE 11 parameters

Manning’s n was set to 0.035 s/m$^{1/3}$ which is the same as in the Murray regional model. However, the leakage coefficient, which determines the rate at which groundwater is exchanged with the MIKE 11 channel network was calculated differently. The ‘Bed only’ leakage option was selected, so that the leakage coefficient could be set explicitly. Based on advice from DHI, this was set to 1×10^{-6} which is appropriate for sandy channels. This results in higher connectivity between groundwater and rivers in comparison to the Murray regional model, and therefore, a higher baseflow contribution to rivers and drains.

Unsaturated zone soil parameters

The model was most sensitive to the soil and land use parameters, as these control recharge. The model is particularly sensitive to the water content at wilting point (Wcwp), saturation (Wcs), and field capacity (Wcfc) of the Bassendean Sands. The difference between Wcs and Wcf is equivalent to the specific yield of the upper computational layer, which influences the amplitude of the groundwater signal, and is equivalent to 0.20 for the calibrated parameters. The difference between Wcfc and Wcwp is the plant available water, which controls plant evaporation within the model, and is 0.04 for the calibrated model. The plant available water is slightly reduced compared to the Murray regional model, resulting in increased recharge.

Unsaturated zone land use parameters

These parameters are largely consistent with those used in the calibrated Murray regional model. The main difference is the introduction of an additional land use zone, 'Low shrubs' to account for shallower rooting depth of vegetation around the airport. This results in slightly greater recharge in these areas. Also, the leaf area index for the 'Bare / urban' land use was set to 1 m^2/m^2, as the value of 2 m^2/m^2 used in the regional model was unrealistic. Table 6.5 shows the average modelled recharge under the various land-use classes for the calibrated model. Note that the recharge will vary depending on other factors such as the rainfall duration and intensity and depth to watertable.

Table 6.5 Recharge estimates for calibrated land use parameters

Class	Parameter	Value	Units	Modelled recharge % of rainfall
Bare / urban	LAI	1	m^2/m^2	43%
	RD	700	mm	
Cropping / grazed	LAI	0-2.7	m^2/m^2	35%
	RD	648-1053	mm	
Irrigated	LAI	2.5	m^2/m^2	40%
	RD	1000	mm	
Native trees	LAI	1.5	m^2/m^2	29%
	RD	2000	mm	
Plantation	LAI	1.5	m^2/m^2	23%
	RD	2000	mm	
Low shrubs	LAI	1.5	m^2/m^2	37%
	RD	800	mm	

Saturated zone parameters

Distributed aquifer conductivity values are shown for each computational layer in Figure 6.8.

The value for Kh given to the Bassendean Sands is 10 m/day, and the Kz 1 m/day. The low value of Kh was necessary to replicate the steep gradient in groundwater head sloping towards the Nambeelup Brook.

The Kh for the Gnangara Sands was is also comparatively low compared to previous work, at 6 m/day. This is to account for the heterogeneous nature of the sands, which contain numerous sandy clay lenses within the study area. As the lower computational layer consists of a mixture of Gnangara Sands, coffee rock, clay lenses and alluvial deposits, a lower Kh was necessary.

The Kh and Kz associated with the surface swamp, estuarine and alluvial deposits were set to 4 m/day and 0.1 m/day. The lower Kh slightly reduces horizontal groundwater movement towards the Nambeelup Brook and Serpentine River as is evident in Figure 6.6.

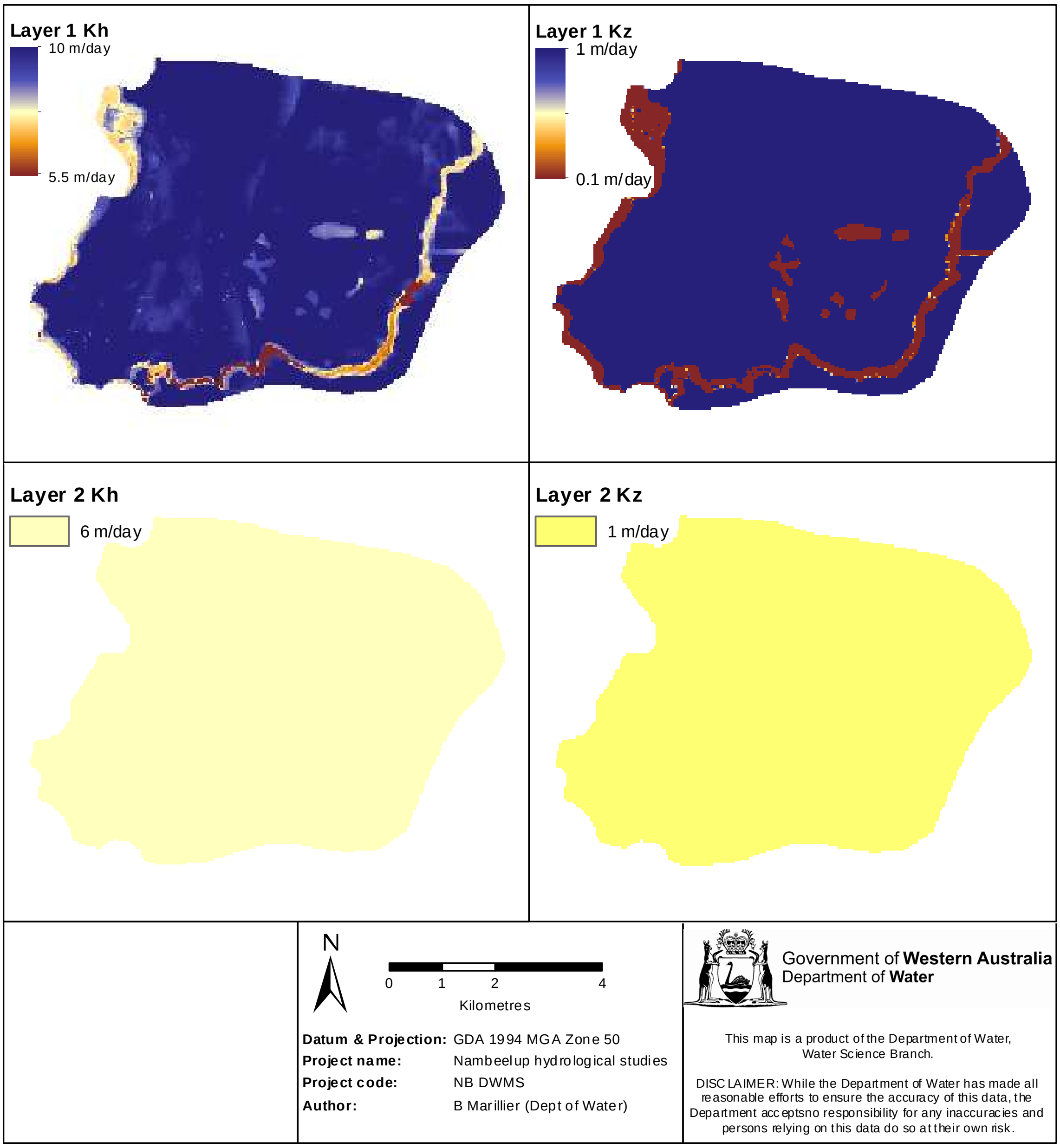


Figure 6.8 Vertical and horizontal conductivity of computational layers

6.6 Calibration discussion

The model area consists of just over 42 km^2 and contains 87 calibration and validation points, including wetland water gauge boards and superficial monitoring bores. Given the considerable volume of calibration data and inherent simplifications of real-world phenomena in the model, simulated heads are unlikely to be perfect in all areas.

A large portion of the calibration data was obtained from sources other than the Department of Water, and the accuracy of survey and screen levels, and water level readings is an unknown, in comparison with the Department of Water HS and T series bores. Therefore, calibration focused first on achieving calibration at Department of Water bores, while using externally obtained data as a secondary calibration target.

All of the Department of Water T and HS series bores, and the wetland PLI locations achieved acceptable calibration, with both the amplitude and absolute level of the groundwater signal very close to observed values, as shown in Appendix A.

Of the consultants' bores, the majority were well calibrated. However, in many cases less than one year of data was available for the simulation period. Some isolated bores had significant errors in absolute level. However, the amplitude of the groundwater signal was accurate in all cases. There was no spatial autocorrelation in the residual, which indicates either insufficient detail in the model conceptualisation, or errors in the source data.

Note that the LA series bores have collected data for 2011 only. However, these have been included as time-series graphs in Appendix A for illustration purposes. The absolute level of groundwater across all LA bores modelled for 2010 appears to be broadly consistent with the observed levels from 2011.

Based on the model structure, the results of the calibration and the limitations of the model, the Nambeelup model is suitable to be used to determine changes in wetland water levels, groundwater level in the Superficial Aquifer, river and drain flows, and water balance. The model is appropriate for:

- simulation of climate change scenarios based on changes in rainfall and potential evaporation
- simulation of land-use change scenarios
- simulation of changes in surface and subsurface drainage resulting from urban development
- determination of likely volumes of drainage water and reliability of supply for managed aquifer recharge.

The Nambeelup model should **not** be used for:

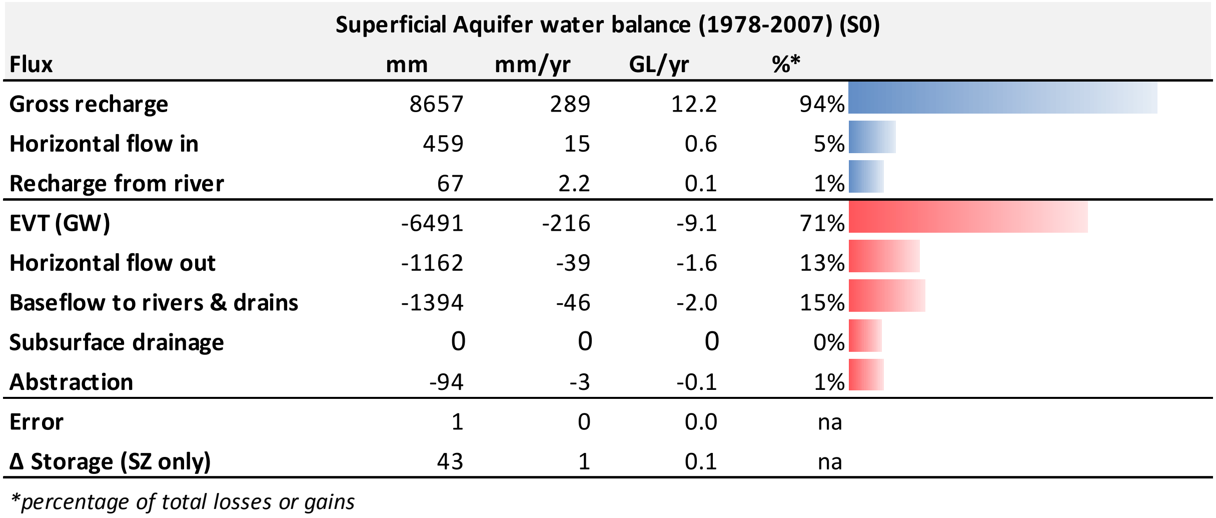
- flood modelling
- analysis of abstraction and determination of allocation limits
- simulation of managed aquifer recharge
- surface water environmental water requirement studies for Nambeelup Brook.

7 Water balance

7.1 Model water balance

The MIKE SHE water balance tool was used to extract water balance information from the base case model (S0) for the period 1978 to 2007. Two water balances were calculated across the entire model area, and these are presented in Table 7.1. The first of these is for fluxes associated with the Superficial Aquifer only, the second shows all fluxes within the system modelled, and represents the entire hydrological cycle for the Nambeelup model.

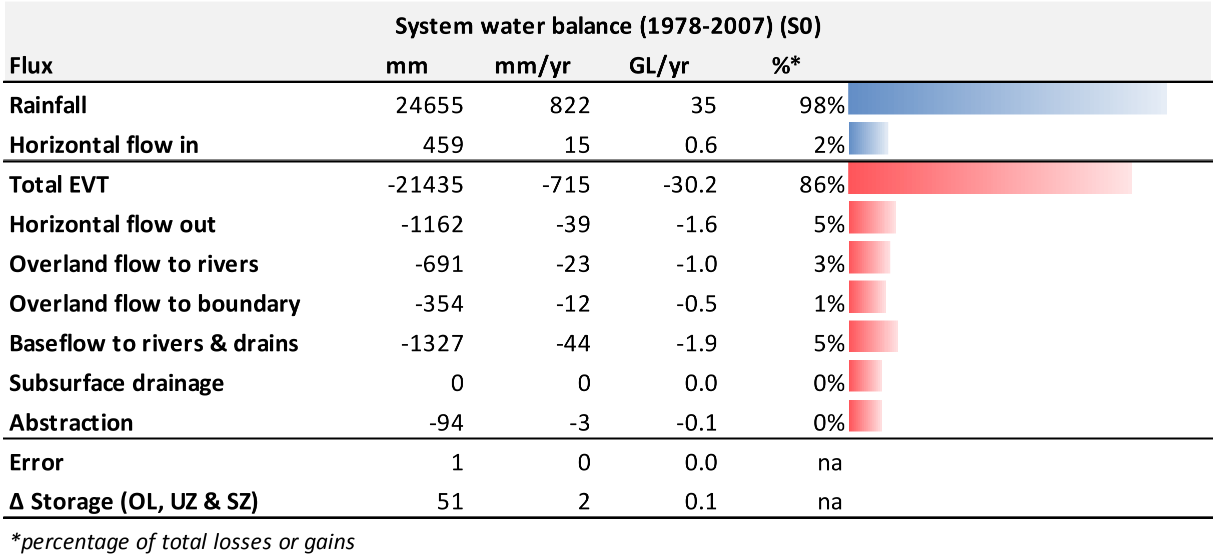
Table 7.1 Model area water balance



Superficial Aquifer water balance (1978-2007) (S0)

Flux	mm	mm/yr	GL/yr	%*
Gross recharge	8657	289	12.2	94%
Horizontal flow in	459	15	0.6	5%
Recharge from river	67	2.2	0.1	1%
EVT (GW)	-6491	-216	-9.1	71%
Horizontal flow out	-1162	-39	-1.6	13%
Baseflow to rivers & drains	-1394	-46	-2.0	15%
Subsurface drainage	0	0	0	0%
Abstraction	-94	-3	-0.1	1%
Error	1	0	0.0	na
Δ Storage (SZ only)	43	1	0.1	na

**percentage of total losses or gains*



System water balance (1978-2007) (S0)

Flux	mm	mm/yr	GL/yr	%*
Rainfall	24655	822	35	98%
Horizontal flow in	459	15	0.6	2%
Total EVT	-21435	-715	-30.2	86%
Horizontal flow out	-1162	-39	-1.6	5%
Overland flow to rivers	-691	-23	-1.0	3%
Overland flow to boundary	-354	-12	-0.5	1%
Baseflow to rivers & drains	-1327	-44	-1.9	5%
Subsurface drainage	0	0	0.0	0%
Abstraction	-94	-3	-0.1	0%
Error	1	0	0.0	na
Δ Storage (OL, UZ & SZ)	51	2	0.1	na

**percentage of total losses or gains*

The Superficial Aquifer water balance shows that gross recharge is 12 GL/yr (35% of rainfall) which is less than the estimate of 41% given by the Murray regional model. This results from the significant areas of inundation in the lower portion of the model, which causes recharge rejection during winter. As expected, evapotranspiration from groundwater is the main outward flux from the model. Lateral movement of groundwater through the western model boundary to the Serpentine River accounts for 13% of losses, and baseflow to the

Nambeelup Brook, and the various drains account for an additional 15%. Abstraction is negligible in the area.

The system water balance shows that rainfall and total evapotranspiration are the two major fluxes from the system. Overland flow to rivers and over the model boundary accounts for 4% of losses from the system, and the baseflow component of river and drain flows is a further 5%. This gives an annual coefficient of runoff of 9% for the model area, which is lower than in other parts of the Swan Coastal Plain, due to the substantial amount of lateral groundwater flow through the western model boundary (5% of the system water balance).

7.2 Development area water balance

The development area water balance is shown in Table 7.2. The major fluxes of the development area water balance are rainfall and total evapotranspiration. Total Evapotranspiration was 88.3% of rainfall, of which 29.1% occurs directly from the groundwater and the remainder from overland water and the unsaturated zone. Overland outflows to rivers, drains and boundaries, plus baseflow to rivers/drains totalled an average of 9.1% of annual rainfall for the 1978 to 2007 period. 2.6% of annual rainfall is lost via horizontal aquifer outflow minus inflow (1.7%) and abstraction (0.9%).

Gross recharge equates to 35% of average rainfall and net recharge (gross recharge less evapotranspiration from groundwater) is 9% of average rainfall for the 1978 to 2007 simulation period.

There are several differences between water balance of the development area and the wider model area. Overland outflow is higher at 7% in this area as a result of winter inundation in low-lying parts of the development area. The horizontal groundwater inflows (8%) and outflows (9%) are a more substantial portion of the water balance as the development area is nested within the model. This shows that lateral groundwater flow to the Serpentine River is an important component of the water balance. There is smaller baseflow to rivers and drains, as the development area doesn't directly intersect Nambeelup Brook, and only the smaller tributary drains are within the area. .

Table 7.2 Development area water balance

Superficial Aquifer water balance (1978-2007) (S0)

Flux	mm	mm/yr	GL/yr	%*
Gross recharge	8727	291	3.7	85%
Horizontal flow in	1490	50	0.6	15%
Recharge from river	2	0	0.0	0%
EVT (GW)	-7185	-240	-3.0	71%
Horizontal flow out	-2420	-81	-1.0	24%
Baseflow to rivers & drains	-354	-12	-0.1	3%
Subsurface drainage	0	0	0	0%
Abstraction	-214	-7	-0.1	2%
Error	-2	0	0.0	na
Δ Storage (SZ only)	45	2	0.0	na

**percentage of total losses or gains*

System water balance (1978-2007) (S0)

Flux	mm	mm/yr	GL/yr	%*
Rainfall	24746	825	10	92%
Horizontal flow in	2008	67	0.8	8%
Total EVT	-21832	-728	-9.2	82%
Horizontal flow out	-2420	-81	-1.0	9%
Overland flow to rivers	-1314	-44	-0.6	5%
Overland flow to boundary	-562	-19	-0.2	2%
Baseflow to rivers & drains	-354	-12	-0.1	1%
Subsurface drainage	0	0	0.0	0%
Abstraction	-214	-7	-0.1	1%
Error	-2	0	0.0	na
Δ Storage (OL, UZ & SZ)	55	2	0.0	na

**percentage of total losses or gains*

8 Scenario modelling

This section discusses the eight scenarios which were modelled to assess potential future effects on groundwater levels and wetlands within the Nambeelup area. The following scenarios were modelled:

- **Base case (S0):** Current conditions
- Climate scenarios:
  - **Future wet (S9):** 1.4% decrease in rainfall
  - **Future medium (S18):** 8.7% decrease in rainfall
  - **Future dry (S27):** 16.2% decrease in rainfall.
- Drainage and land development scenarios:
  - **Industrial land use and CGL (S1):** Increased recharge from the industrial area with a controlled groundwater level imposed using subsurface drainage, and a modified topographic surface to account for cut and fill.
  - **Industrial land use, CGL and drainage water (S2):** The same as S1 with drainage water routed to detention wetlands to assess the effects on downstream properties.
  - **Industrial land use, CGL and future dry climate (S3):** A combination of scenario S1 and S27 to assess the effects of a dry climate when combined with post-development conditions.
  - **Industrial land use and CGL, moderate recharge (S4):** The same as S1 with recharge levels maintained slightly above pre-development levels through the sizing of soak wells. CGL imposed using subsurface drainage, and a modified topographic surface to account for cut and fill.

The effect of each scenario on groundwater and water levels in wetlands of interest was considered. The wetlands of interest include 29 conservation category and resource enhancement wetlands, as shown in Figure 8.1.

The climate scenarios use the same rainfall dataset which was used for the south-west sustainable yields project, which are available for the period 1975 to 2007 only. Hence, the period 1978 to 2007 was used for all scenarios to make comparative analysis possible, allowing three years for the model to stabilise. The following information is presented for each of the scenarios.

- The difference in the AAMaxGL (1978 to 2007) relative to the Base case (S0) scenario.
- Time-series graphs of the water levels of six significant wetlands, reported for the low point of each wetland, plotted against the elevation of the low point and the average elevation of the wetland. A table of changes in AAMaxGL and AAMinGL for all 29 wetlands is provided in Appendix B.

Additional information is reported for some scenarios in the following sections.

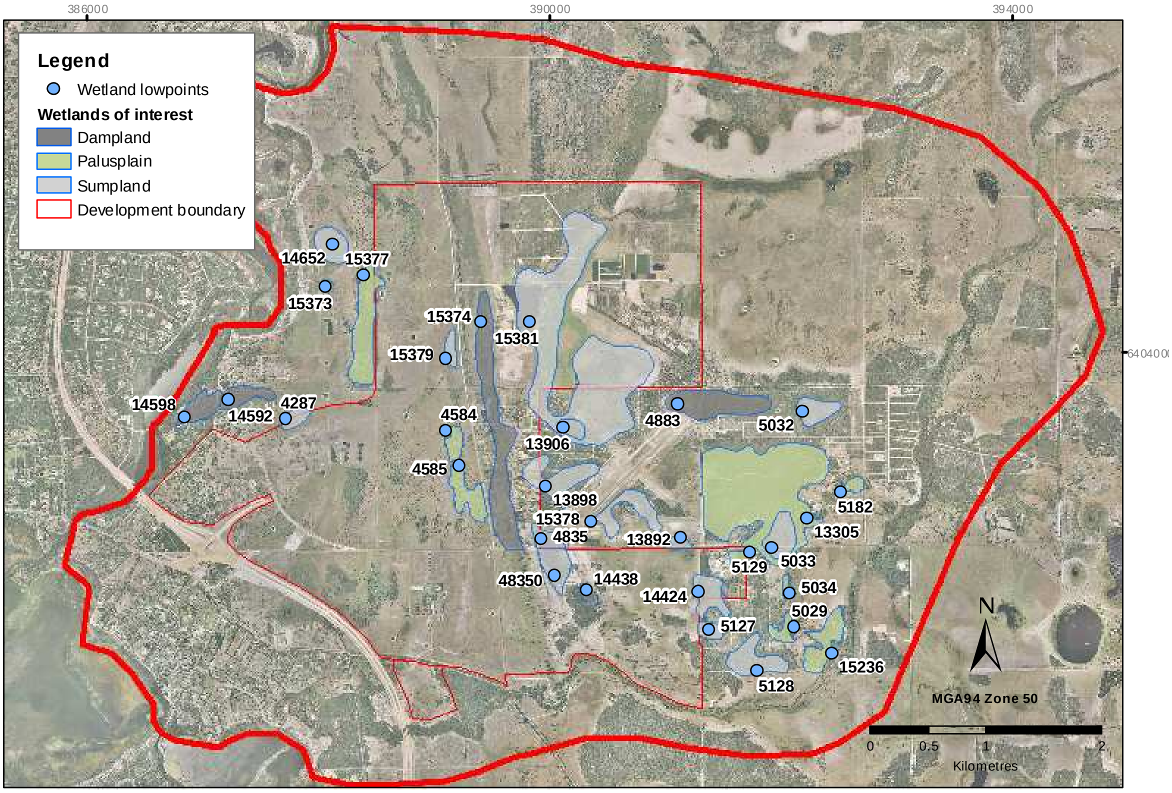


Figure 8.1 Wetlands of interest

8.1 Base case (S0)

Scenario configuration and inputs

The base case scenario is the final calibrated model based on the observed climatic and land use data from 1975 to 2010 inclusive. All summary datasets from the base case scenario are reported for the years 1978 to 2007 inclusive.

Scenario results

Groundwater levels for the upper computational layer were calculated using statistical tools with MIKE ZERO, including:

- maximum groundwater level (MaxGL)
- average annual maximum groundwater level (AAMaxGL)
- average groundwater level (AveGL)
- average annual minimum groundwater level (AAMinGL)
- minimum groundwater level (MinGL)
- depth to groundwater using MaxGL (DTGW MaxGL)
- depth to groundwater using AAMaxGL (DTGW AAMaxGL)
- inundation using AAMaxGL.

Discussion

The calculated MaxGL for the Nambeelup area shows that in very wet years, much of the study area will have water at, or just below the surface. Only the dune formations have sufficient elevation above the maximum groundwater level to avoid inundation. The AAMaxGL is a better representation of average seasonal inundation. It shows that in most years all of the lots within the planned Nambeelup industrial estate are seasonally inundated in some areas. All of the wetlands, the Nambeelup Brook, and some seep areas adjacent to sand dunes show inundation with the AAMaxGL surface. The area which receives the maximum inundation is the south-west corner of Lot 604, and most of Lot 602.

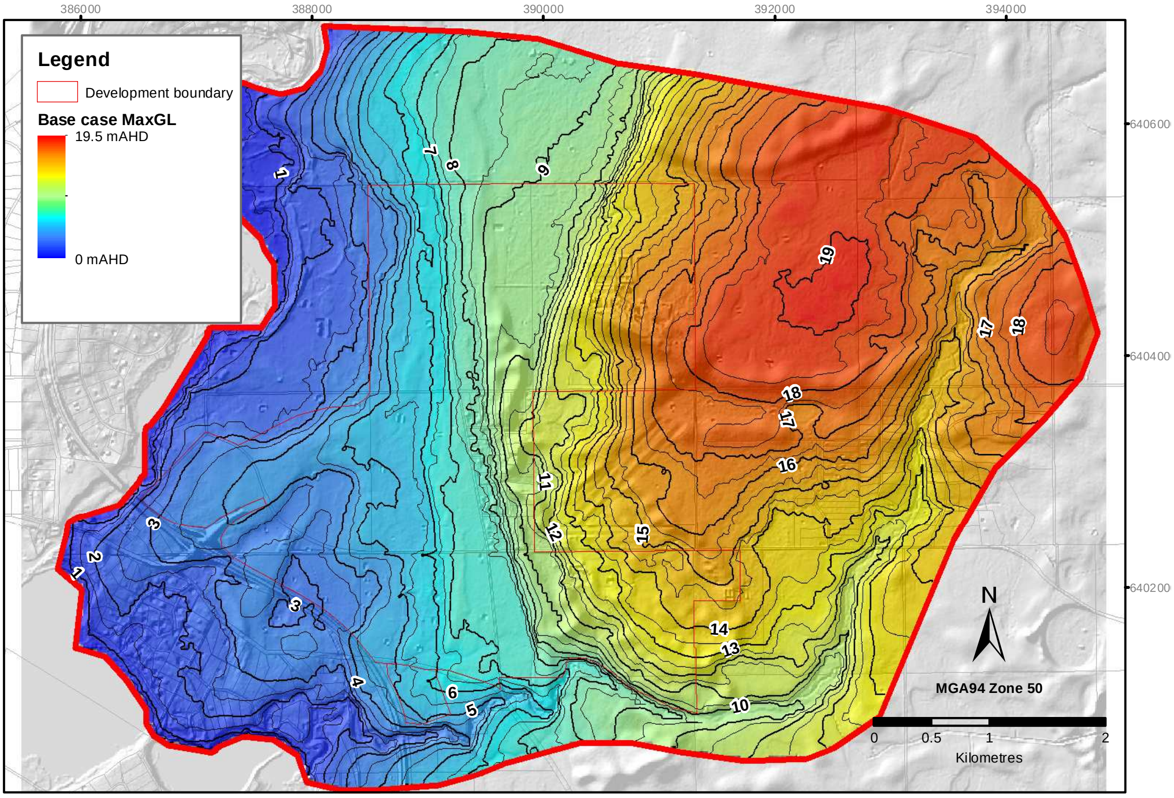


Figure 8.2 Base case MaxGL

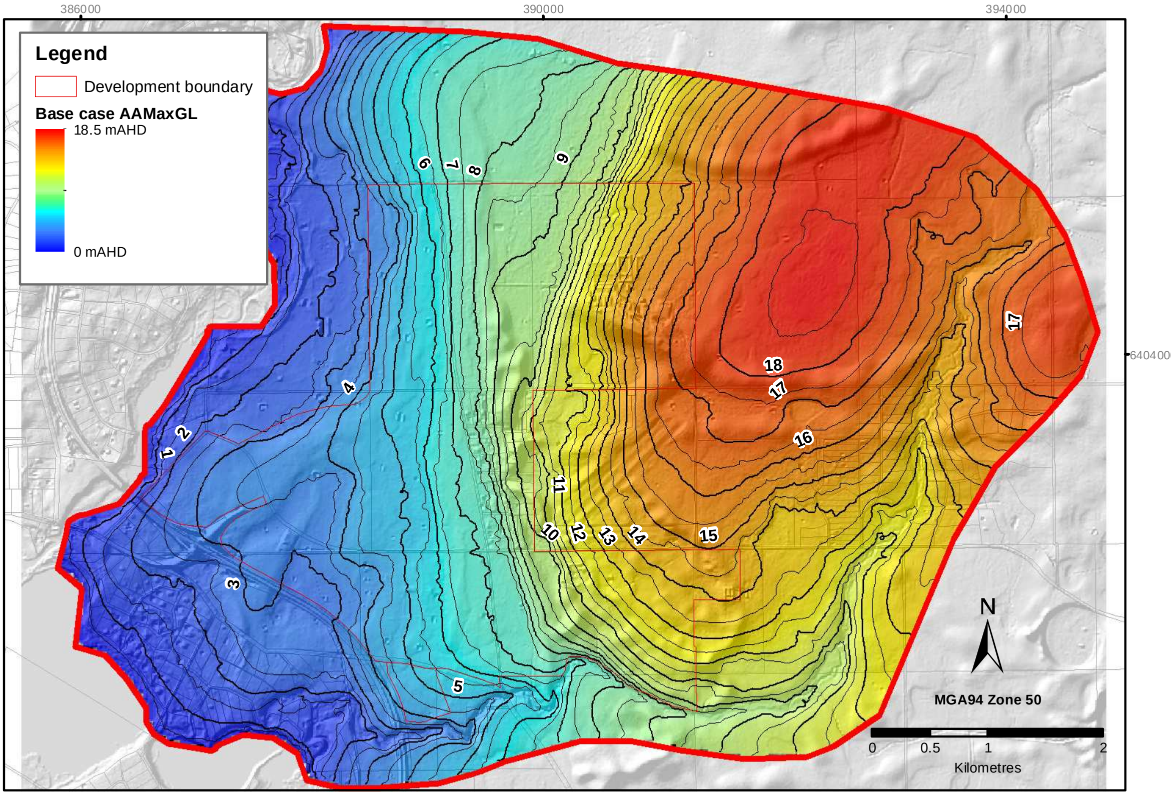


Figure 8.3 Base case AAMaxGL

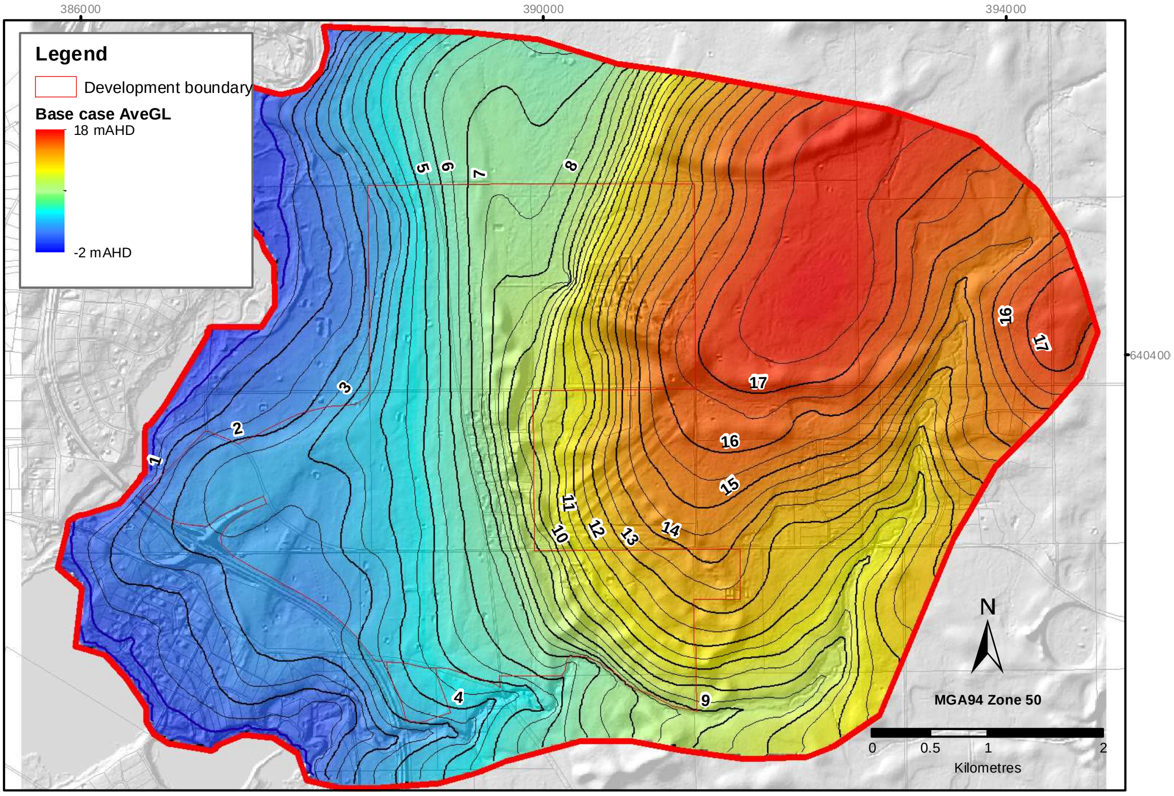


Figure 8.4 Base case AveGL

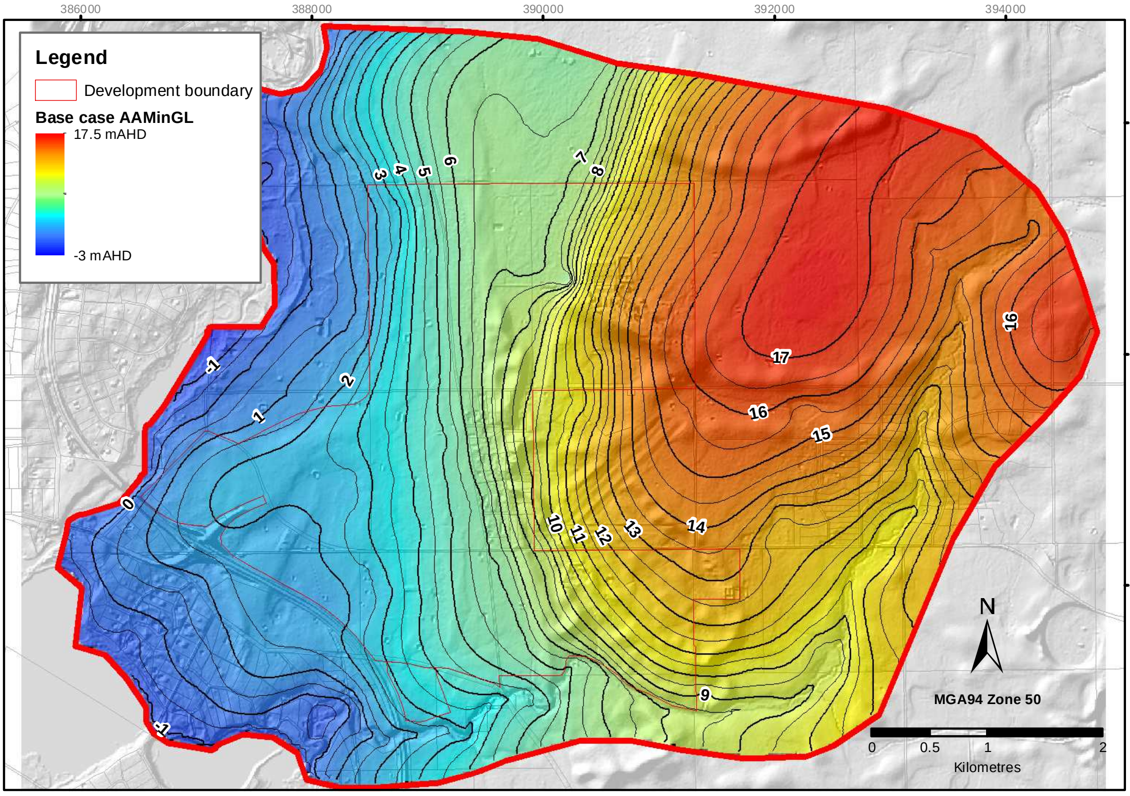


Figure 8.5 Base case AAMinGL

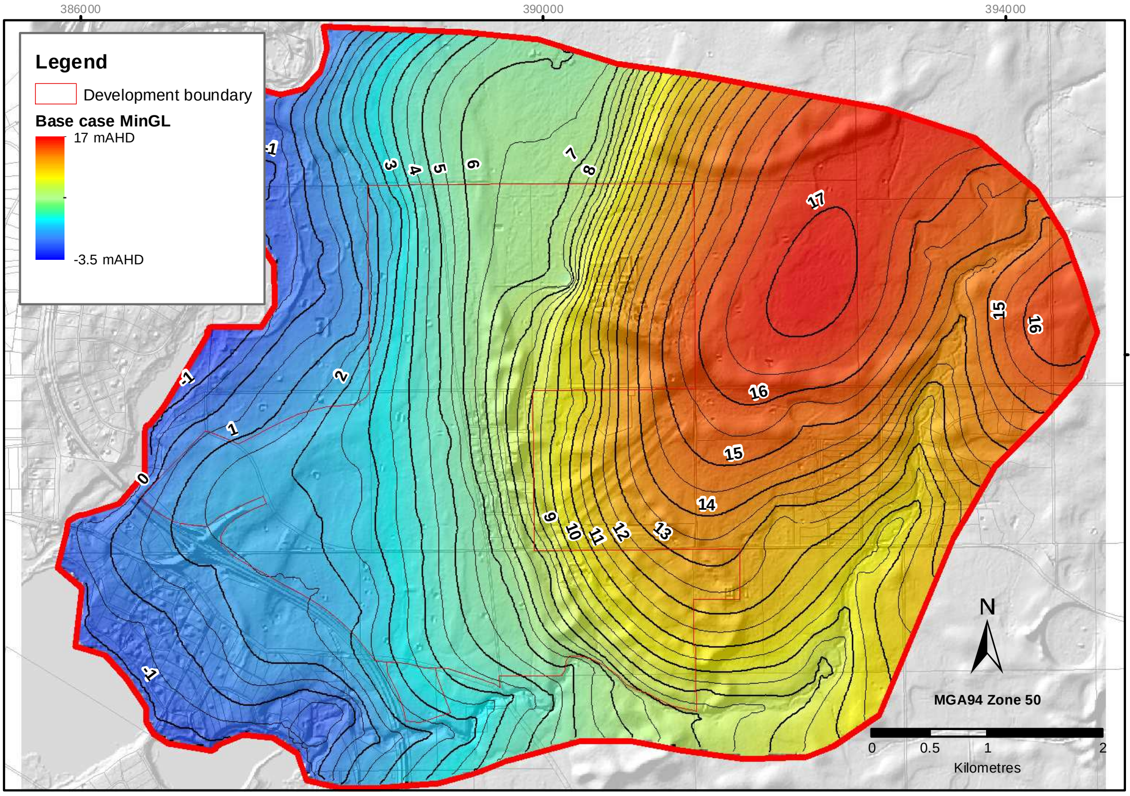


Figure 8.6 Base case MinGL

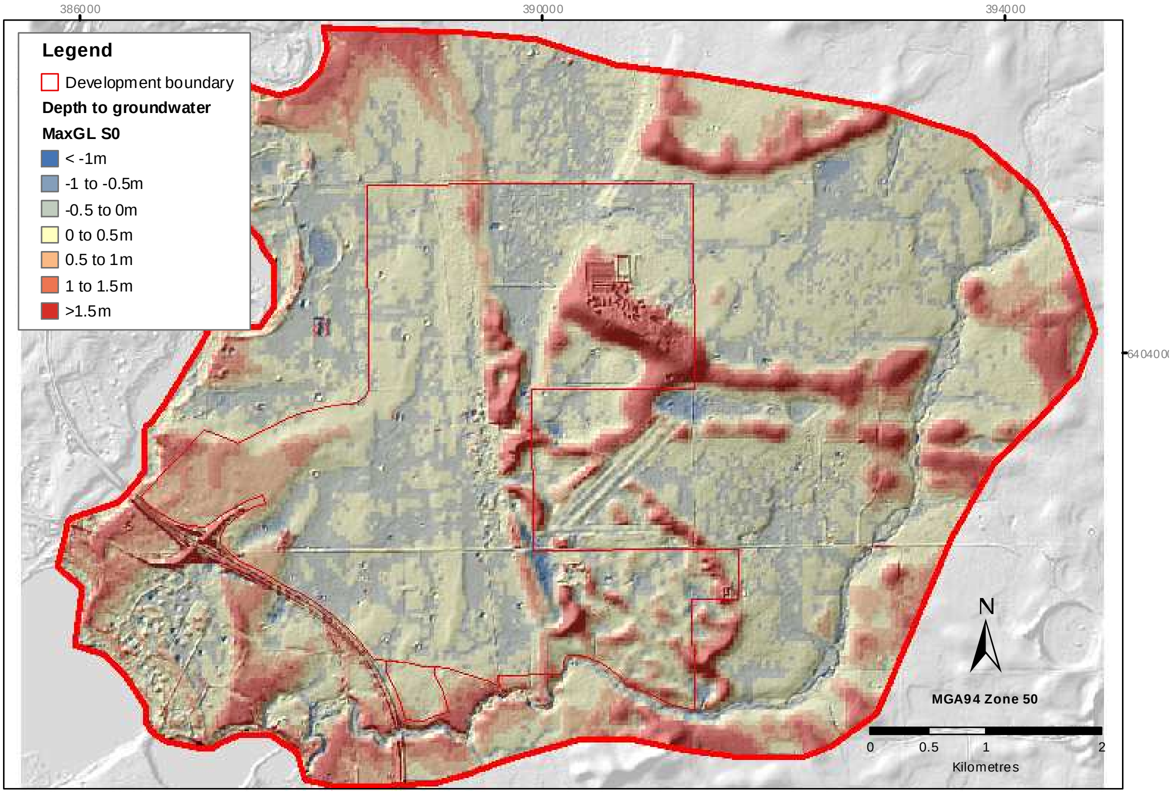


Figure 8.7 Base case depth to groundwater based on MaxGL

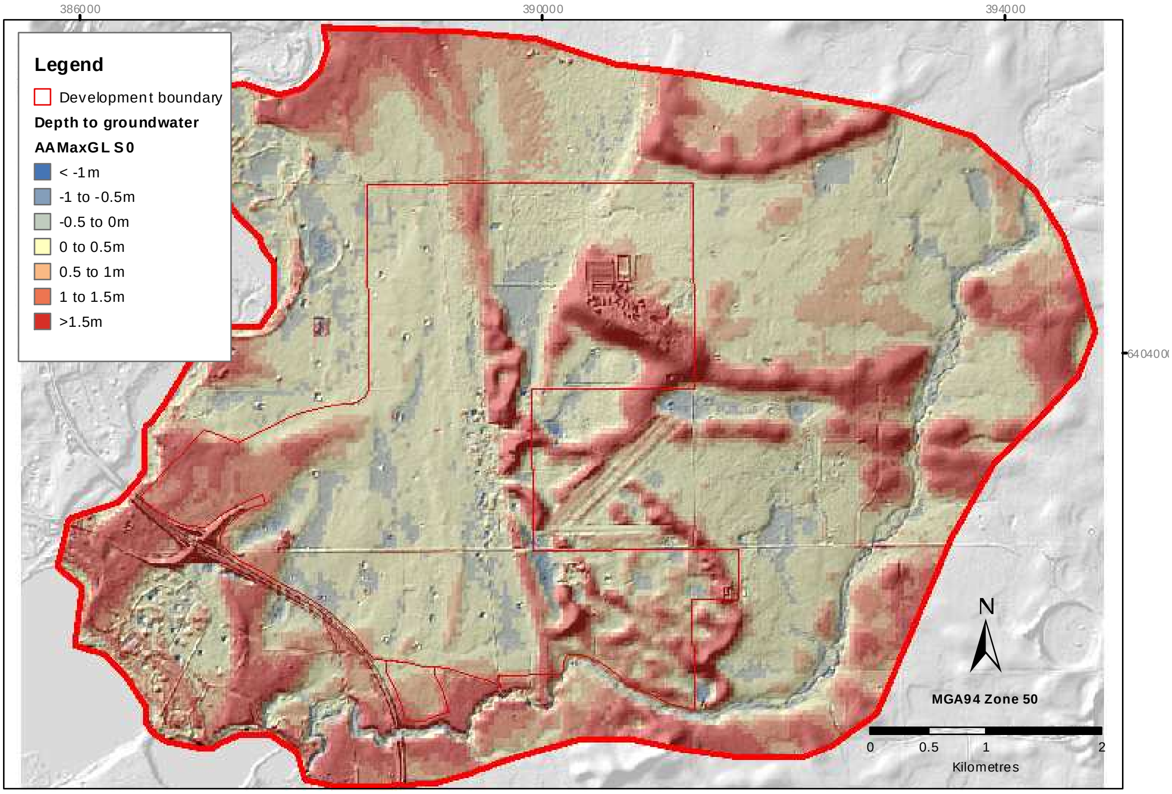


Figure 8.8 Base case depth to groundwater based on AAMaxGL

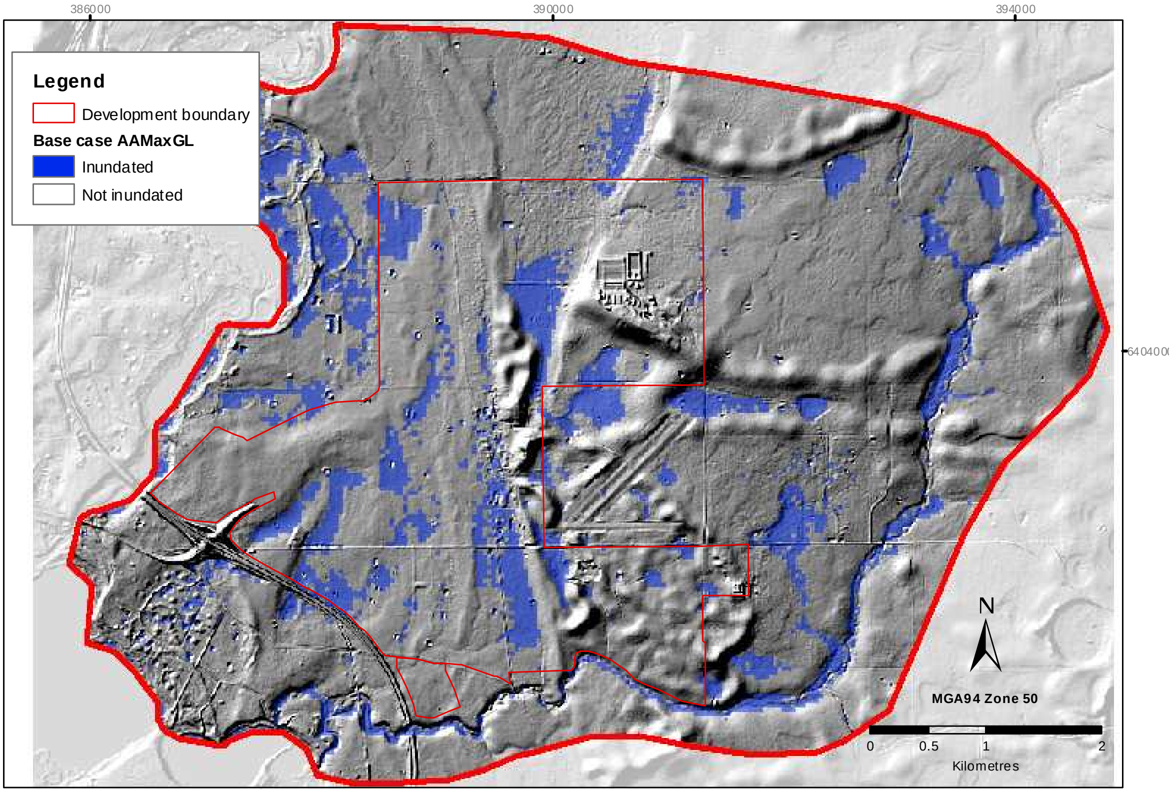


Figure 8.9 Base case inundation based on AAMaxGL

8.2 Climate scenarios

Three climate scenarios were modelled. These correspond directly to a subset of the scenarios documented in the report *Murray hydrological studies: land development, drainage and climate scenario report* (Hall et al. 2010c). The climate scenarios which were simulated using the Nambeelup model were:

- a future wet climate (S9) which corresponds to a 1.4% decrease in average annual rainfall, with scaling factors derived from the NCAR PCM global circulation model with 1°C warming
- a future medium climate (S18) which corresponds to an 8.7% decrease in average annual rainfall, with scaling factors derived from the MRI global circulation model with 0.7°C of warming
- a future dry (S27) which corresponds to a 16.2% decrease in average annual rainfall, with scaling factors derived from the MRI global circulation model with 1.3°C of warming.

In order to simulate these scenarios within the Nambeelup model, the following changes were made to the base case scenario:

- input rainfall and potential evapotranspiration time series were scaled using a monthly factor, which corresponds to reductions or increases in rainfall and potential evapotranspiration predicted by the selected global circulation models for the year 2030

- the boundary conditions for the model were updated using the simulated groundwater levels from the Murray Regional Model that correspond to the relevant climate scenario.

For each scenario the following information is presented:

- difference in AAMaxGL between the base case (for the years 1978 to 2007) and climate scenario (using the 1978 to 2007 climate series scaled for the effects of climate change)
- change in wetland water levels for four conservation category wetlands within the study area demonstrated with time-series data from the base case and climate scenarios.

Future wet climate (S9)

The future wet climate scenario represents the lowest reduction in rainfall of the three scenarios modelled. Across the model area, the groundwater level is generally less than 10 cm lower when compared to the base case scenario. Under the future wet climate, water levels in the wetlands, and low-lying inundated areas show only a 1 to 3 cm reduction in water level.

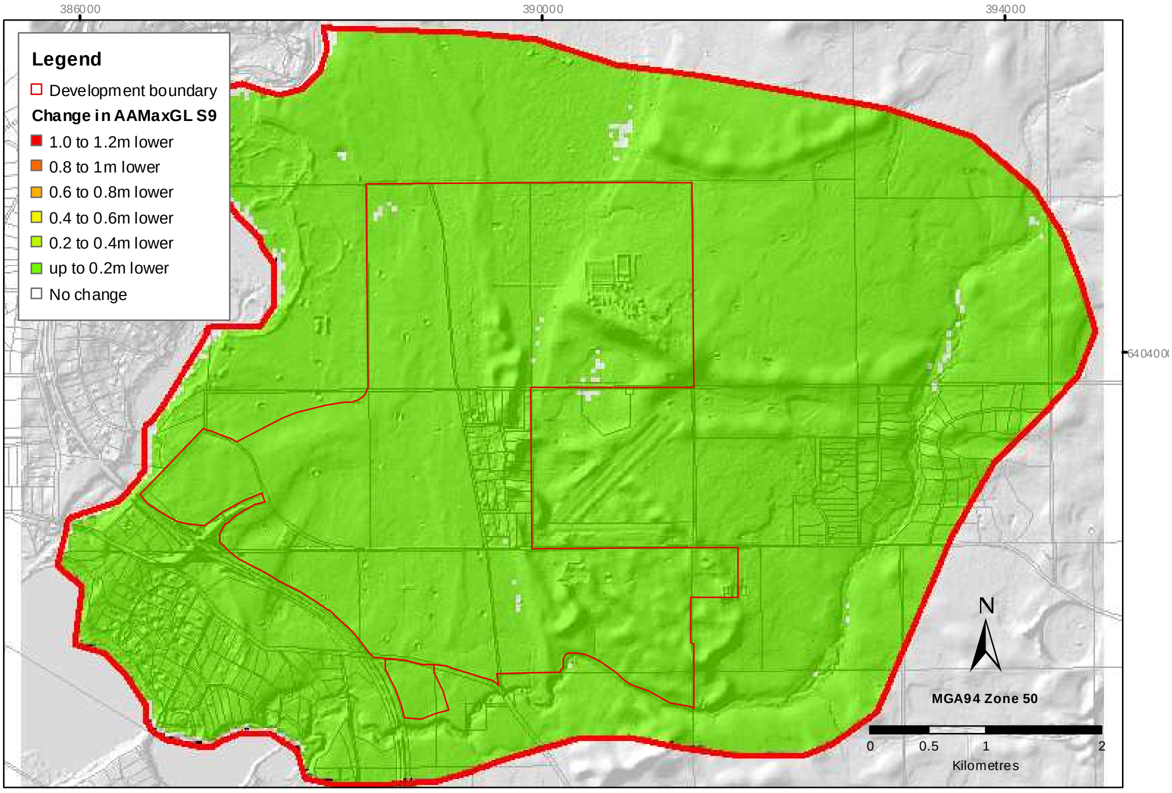


Figure 8.10 Future wet climate (S9): Change in AAMaxGL relative to the base case scenario

Future medium climate (S18)

The future medium climate scenario represents the middle of the range of reduction in rainfall of the three scenarios modelled. Across the model area the reduction in groundwater level varies between 1 and 50 cm compared to the base case scenario. Generally the low-lying areas and wetlands show a reduction in water level of 2 to 5 cm. The AAMaxGL is 25 cm to 30 cm lower underneath some sand dunes with greater depth to watertable.

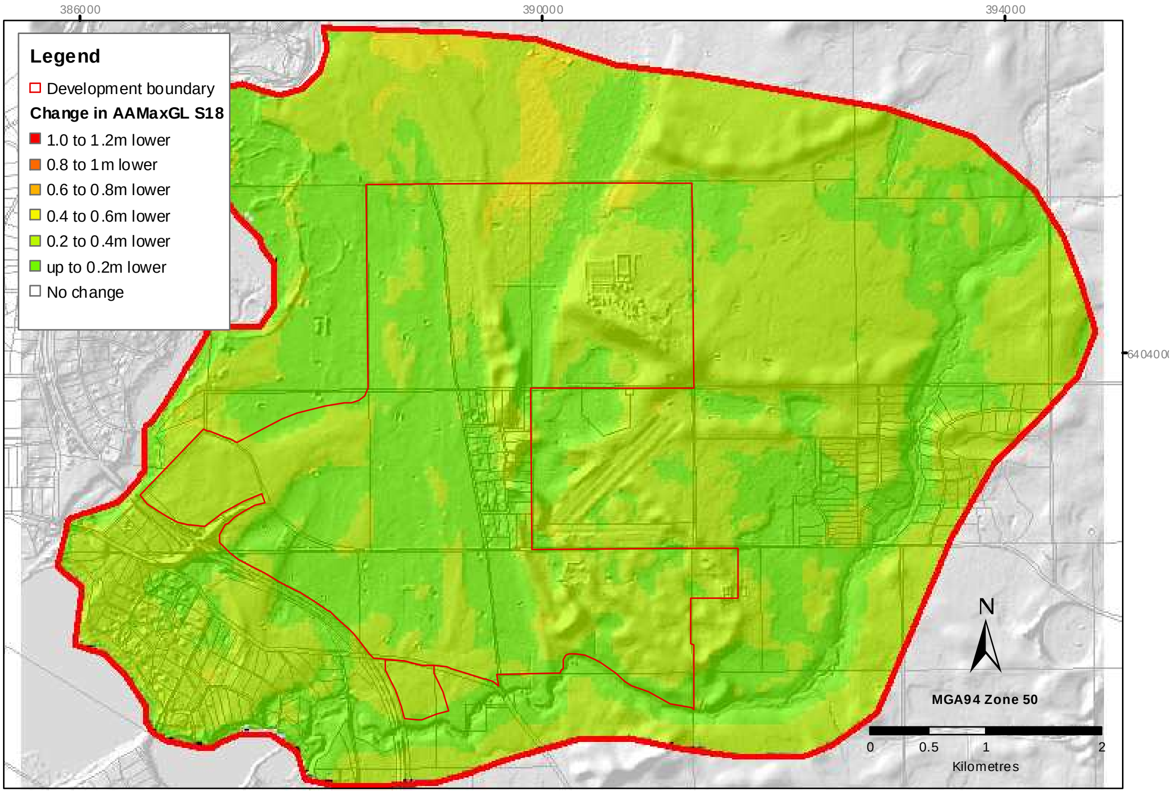


Figure 8.11 Future medium climate (S18): Change in AAMaxGL relative to the base case scenario

Future dry climate (S27)

The future medium climate scenario represents the high end of the range of reduction in rainfall of the three scenarios modelled. Across the model area the groundwater level is between 5 and 100 cm lower than in the base case scenario. The seasonally inundated areas show much less change in response to reduced rainfall when compared to the dune areas. Most of the wetlands show a reduction in AAMaxGL of between 5 and 35 cm under the future dry climate.

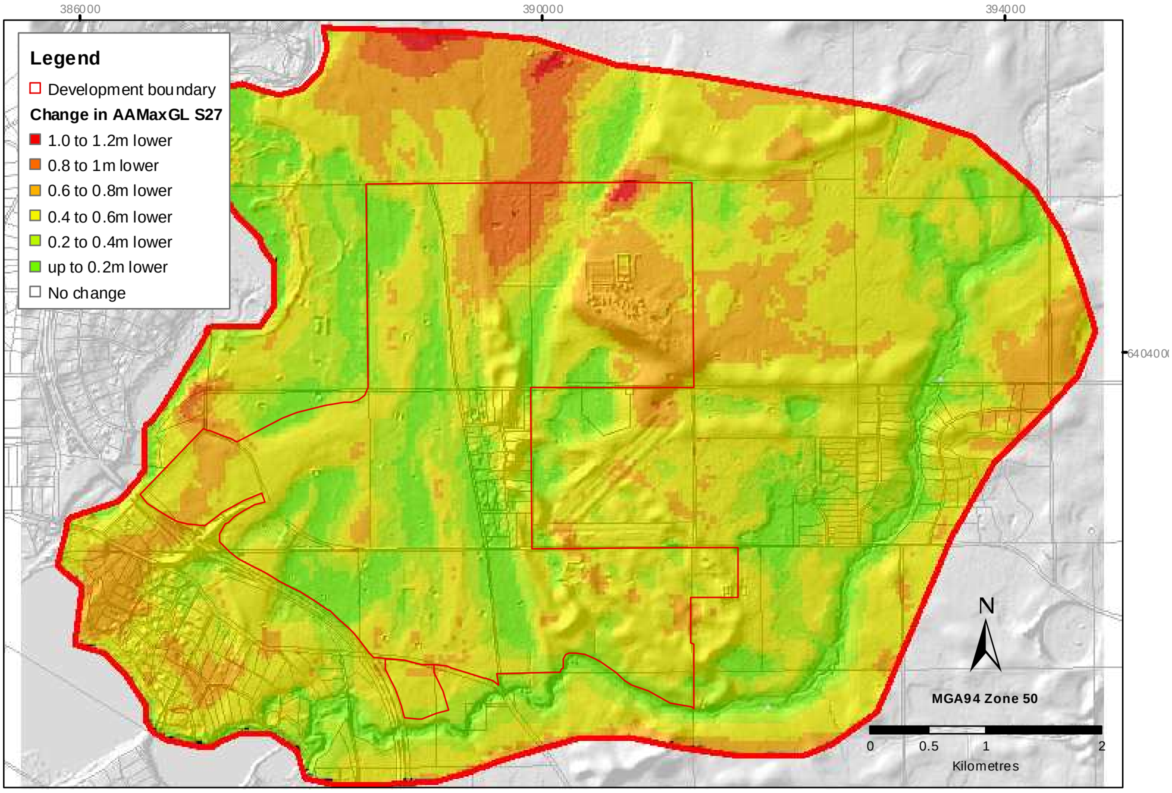


Figure 8.12 Future dry climate (S27): Change in AAMaxGL relative to the base case scenario

Climate scenarios: conclusions

Under the driest climate scenario modelled, with an annual reduction in rainfall of 16.2%, groundwater levels may be as much as 1 m lower in some parts of the study area. It is notable however, that the seasonally inundated areas show much less response to climate change. This is shown by the change in depth of the wetland water levels in the deeper, circular wetlands such as the Greyhound wetland (5032), which shows a decline in water level at AAMaxGL of only 7 cm under the driest climate scenario. As groundwater levels become lower in the inundated areas, it is possible for additional water to infiltrate which would normally be lost to runoff. Hence there is less rejected recharge in these areas, and this acts to maintain the groundwater level. The relatively high dune areas experience the greatest reduction in groundwater level under climate change as they are not seasonally inundated, and so have no capacity to increase recharge as the groundwater level declines.

Figure 8.13 shows the water levels for wetlands for the climate scenarios relative to the base case scenario. All wetlands show a incremental lowering of water level associated with progressively larger reductions in rainfall. Generally the maximum water level shows a greater reduction, and the effect is most noticeable in dry years such as 2001 and 2006. Wetland UFIs 5032 and 5033 show less response to climate change than wetland UFIs 4835N and 4835S, which experience a lowering of the AAMaxGL of around 40 cm under the driest scenario. The minimum water levels show less response to climate change, with the reduction in the AAMinGL less than 20 cm. Appendix B reports results for the remaining wetlands.

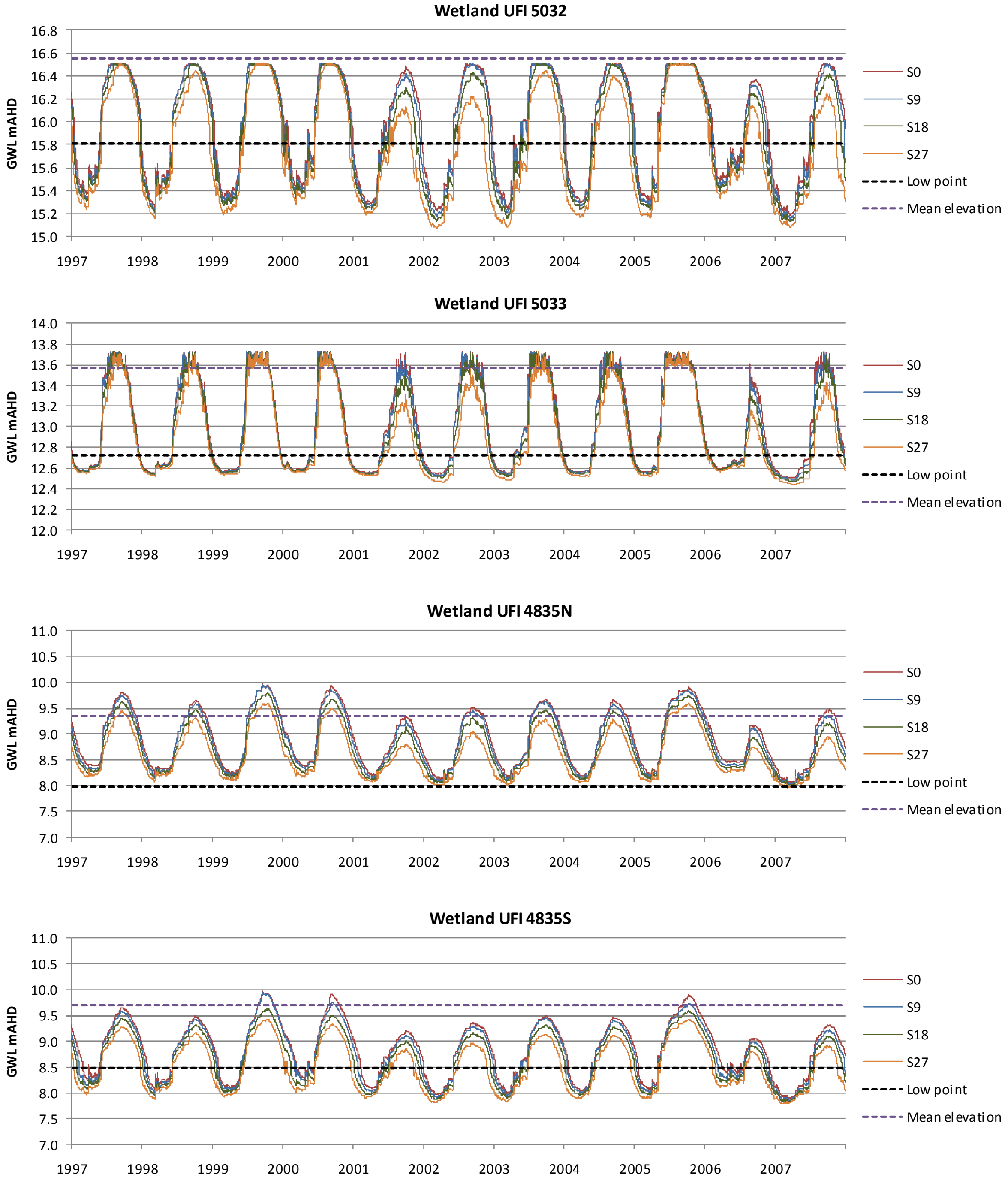
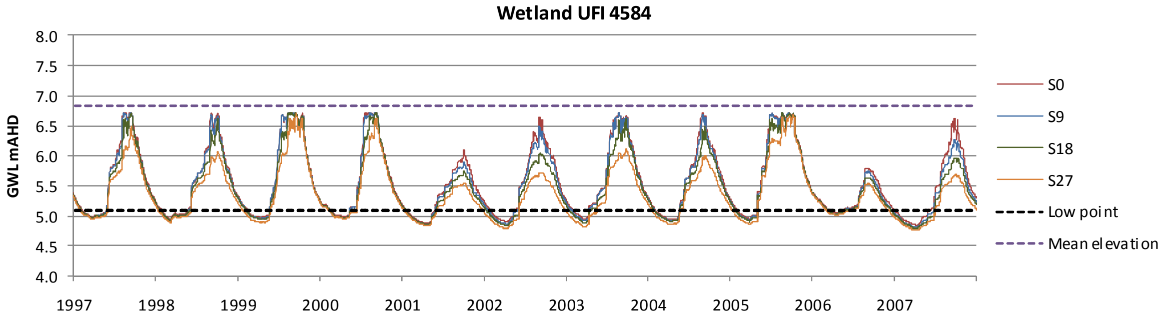


Figure 8.13Conservation category wetland water levels under climate scenarios



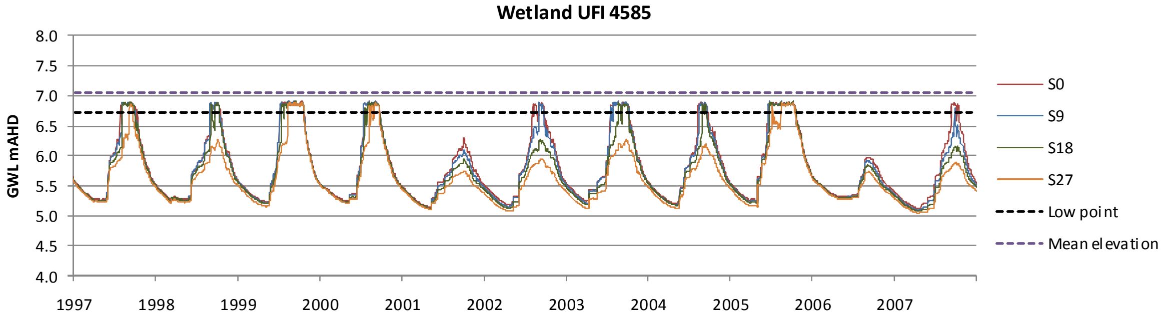


Figure 8.13continued

8.3 Drainage and land development scenarios

Industrial land use and CGL (S1)

This scenario was developed to understand the effect of the proposed Nambeelup industrial estate on the hydrology in the Nambeelup area. Supporting data for this scenario was provided by JDA, who are developing the drainage and water management strategy for the estate.

The planned development has will influence surface and groundwater flows as a result of increased impervious surface, the introduction of subsurface drainage, changes in land use and therefore vegetative cover, and changes in topography related to the cut and fill process. These effects were accounted for in the scenario modelling as outlined below.

Changes in recharge for industrial areas

For MIKE SHE modelling purposes, JDA provided post-development land-use inputs including initial estimates of district and local open space areas, which are appropriate for water balance estimates. This mapping was used to update the land use within the model, as shown in Figure 8.14. A new land-use category 'Industrial' was added, with the leaf area index set to 0.1 and the root depth set to 100 mm, which results in a gross recharge rate averaging 60% of rainfall. This is consistent with recharge rates of between 60 and 70% which were estimated for industrial areas on a regional scale by Xu et al. (2009) using the vertical flux model. The regional scale estimation was an average of recharge from the combination of industrial lots, roads and POS/infiltration sumps/drainage areas. Application of this recharge rate to Nambeelup industrial areas assumes that soak wells or infiltration systems are installed on lots across the development with significant capacity.

Note: the post-development land use input used for the MIKE SHE modelling include estimated indicative drainage areas at boundaries of landholdings. This dataset was developed by JDA and is only suitable for MIKE SHE modelling purposes, and should not be used for local structure planning purposes.

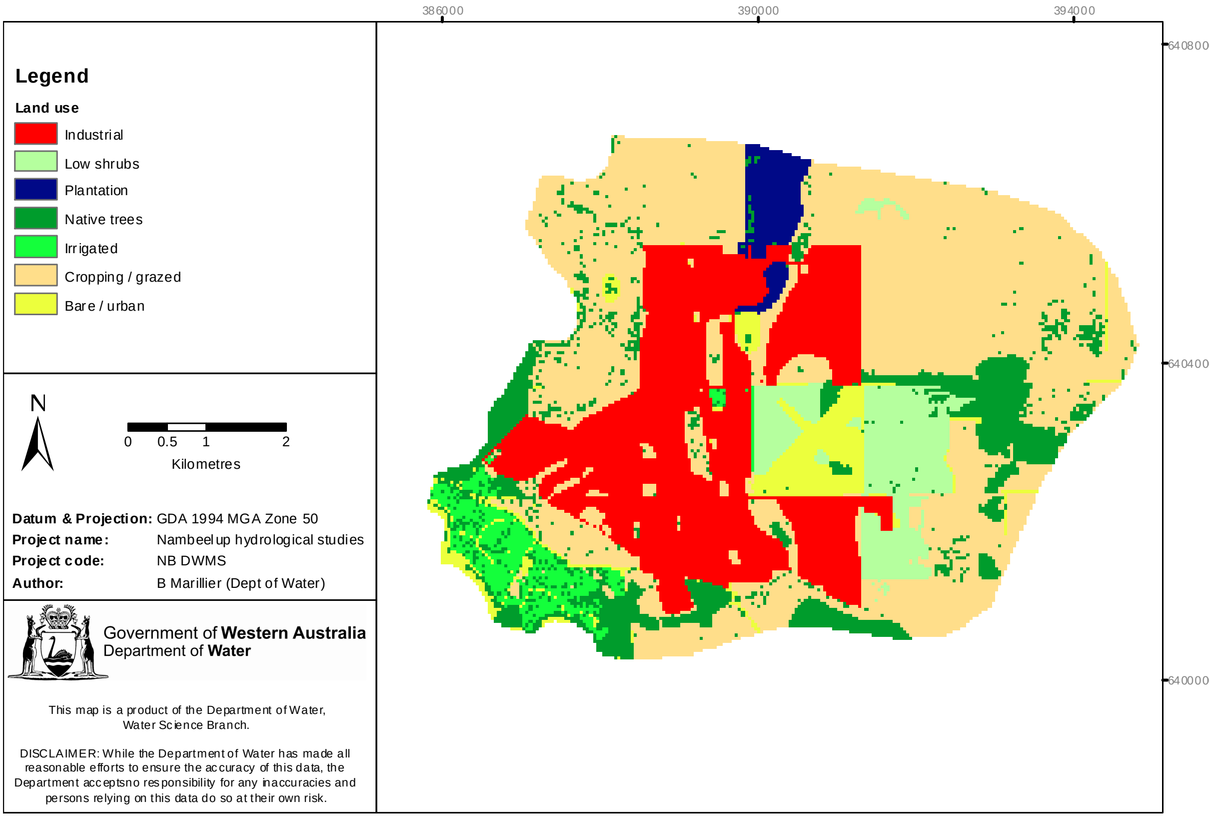


Figure 8.14 Post-development industrial land use within the Nambeelup industrial estate

Subsurface drainage and the controlled groundwater level

A groundwater level within the development area will be controlled using a network of subsurface drainage. JDA provided two datasets which define the extent and level of the planned CGL for the industrial estate, as shown in Figure 8.15.

The subsurface drainage was represented within the numerical model using the saturated zone drainage module within MIKE SHE. Initially, the contour information was interpolated into a surface defining the level of subsurface drainage, at the same resolution as the Nambeelup model grid. Within the model, groundwater which reaches a level at or above the level of the subsurface drainage will be removed from the model at a rate defined by a time constant, which was set to 0.001 /s in this case. This results in a CGL across the area of the model in which subsurface drainage has been defined, and also enables the volume of water drained to be estimated.

In development of the CGL surface, several iterations of the model were simulated to ensure that wetland water levels would not be adversely affected by the additional drainage within the estate.

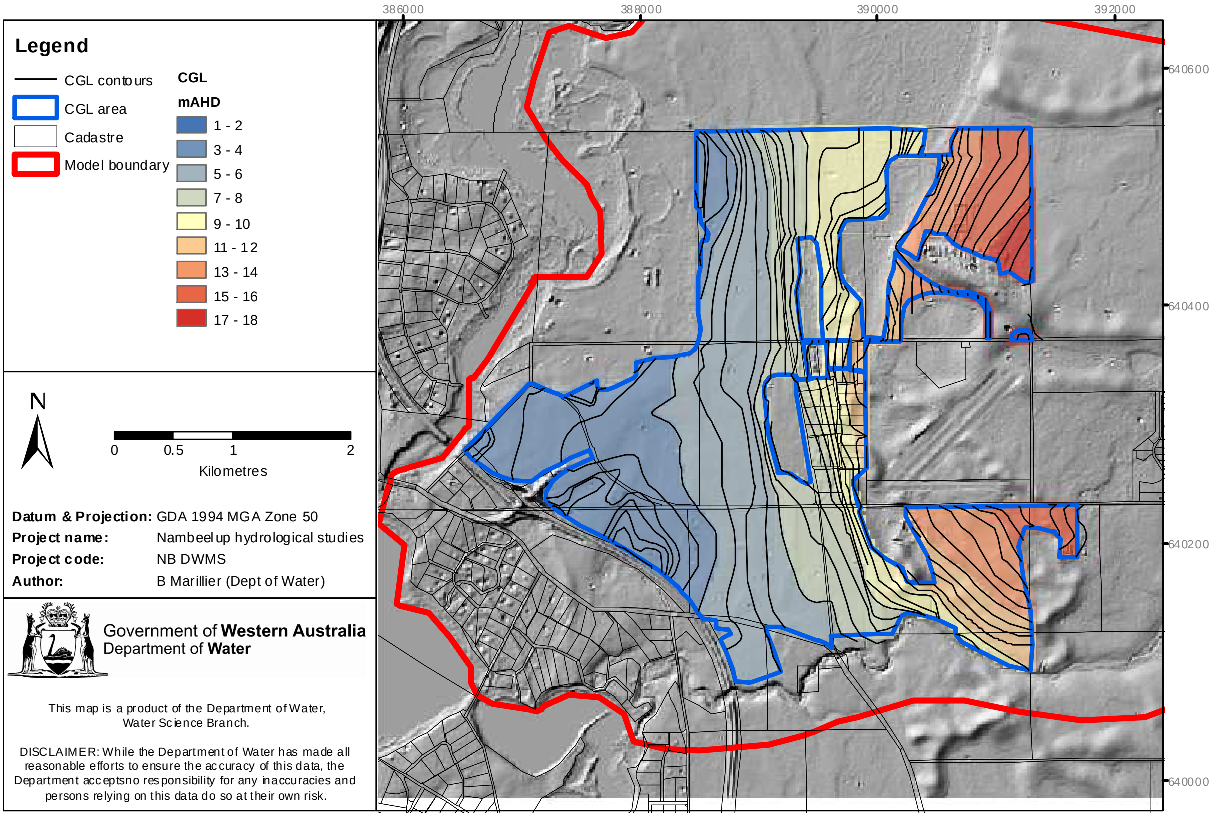


Figure 8.15 Controlled groundwater level within the Nambeelup industrial estate

Post-development cut and fill within the Nambeelup industrial estate

For MIKE SHE modelling purposes, fill surface for industrial land-use areas was based on a minimum of 1 m separation to the controlled groundwater surface. This modified topographic surface was implemented within the model. This represents the most likely post-development surface. For areas within the defined CGL area, the topographic surface was set to the CGL level plus 1 m. For all other areas within the model, the topography remained unchanged. The post-development topographic surface is shown in Figure 8.16 with the change in elevation relative to the pre-development surface shown in the inset map.

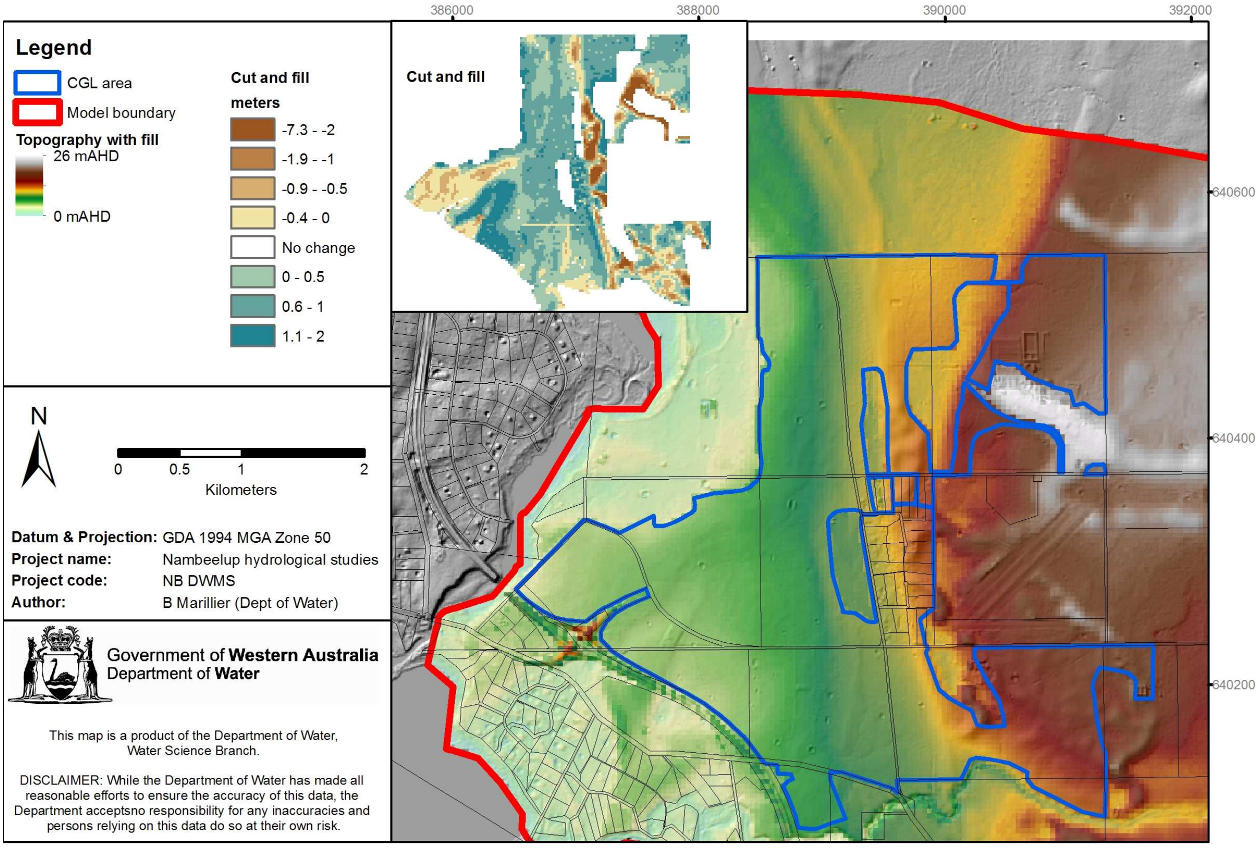


Figure 8.16 Topographic surface with post-development cut and fill

Results for industrial land use and CGL scenario (S1)

S1: Post-development groundwater levels

The post-development depth to AAMaxGL is shown in Figure 8.17 and demonstrates that the average annual winter maximum groundwater levels are at 1 m depth across the development area. The change in the AAMaxGL groundwater level relative to the base case scenario is shown in Figure 8.18. Across the development area, winter groundwater levels are limited to the CGL defined in the model. Hence, where the CGL is above or below the base case AAMaxGL, the post-development AAMaxGL will vary by the same amount.

As a result of the increased recharge under the industrial land use, there is some increase in water level in the wetlands surrounding the planned industrial estate. However, the increase is generally less than 5 cm.

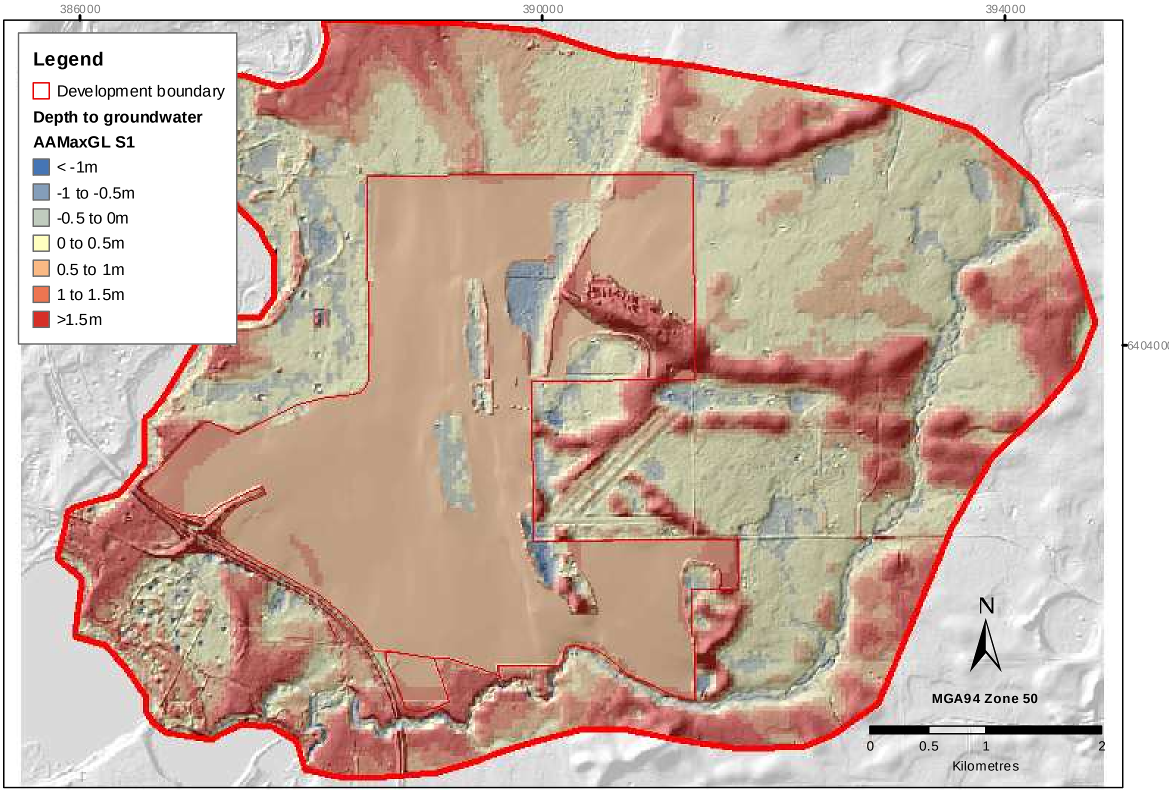


Figure 8.17S1 depth to groundwater based on AAMaxGL

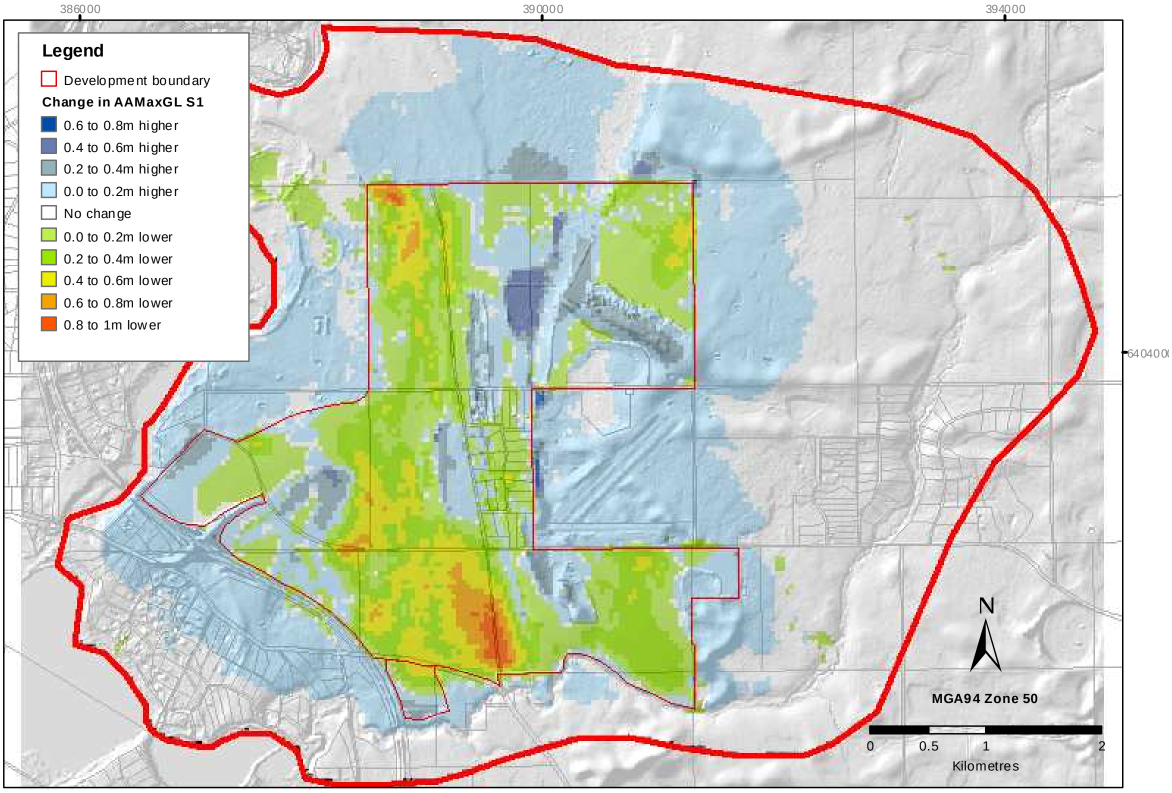


Figure 8.18S1: Change in AAMaxGL relative to the base case scenario

S1: Post-development areas of inundation

Introduction of the CGL and increased recharge results in a slightly higher AAMaxGL to the west of the development area. However, this does not significantly influence the area or depth of inundation in the area of land between the development area and the Serpentine River, as shown in Figure 8.19. Over much of this area the depth of inundation is less than 1 cm, i.e. it is groundwater just at the surface.

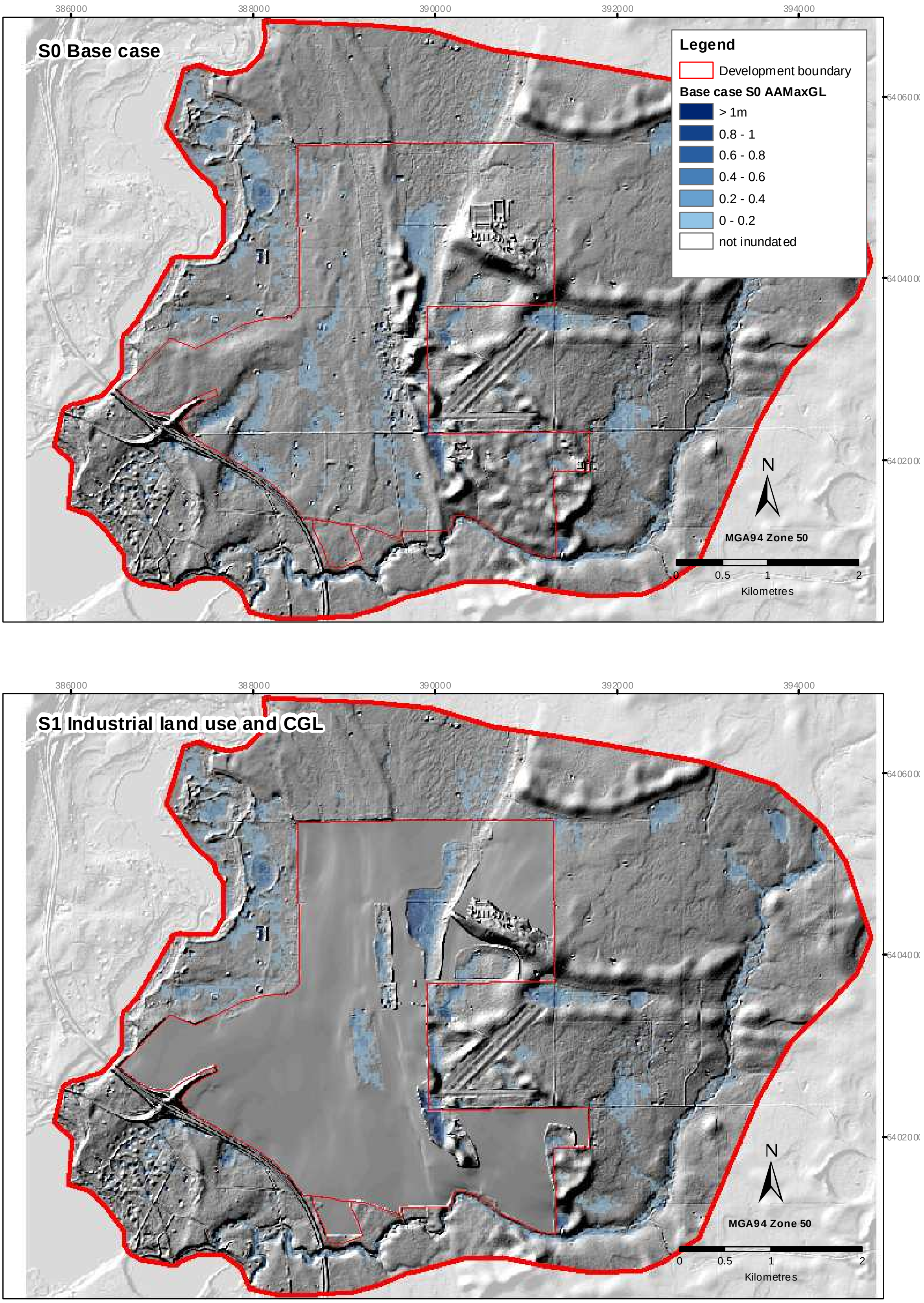


Figure 8.19 Comparison of inundation between S0 and S1 at AAMaxGL

S1: Post-development wetland water levels

Figure 8.20 shows time series of water levels for six wetlands within the study area. It is clear that water levels are unchanged for wetland UFI 5032 and 5033. The airport wetlands UFI 4835N and 4835S show an increase in both maximum water levels and minimum water levels. Wetland UFIs 4584 and 4585 also show an increase in maximum and minimum water levels, and the development results in seasonal inundation that was not present in the base case scenario, due to the raised elevation of the surrounding development area. For the other wetlands the graphs illustrate that periods of winter inundation and summer drying are consistent between the base case and development scenarios. The reason for the higher levels is twofold. Firstly, the CGL for the areas surrounding the wetlands is slightly higher than the base case maximum groundwater levels. Secondly, the reduced evapotranspiration and increase in recharge from the industrial estate means that the groundwater reaches the CGL in the surrounding areas in most winters.

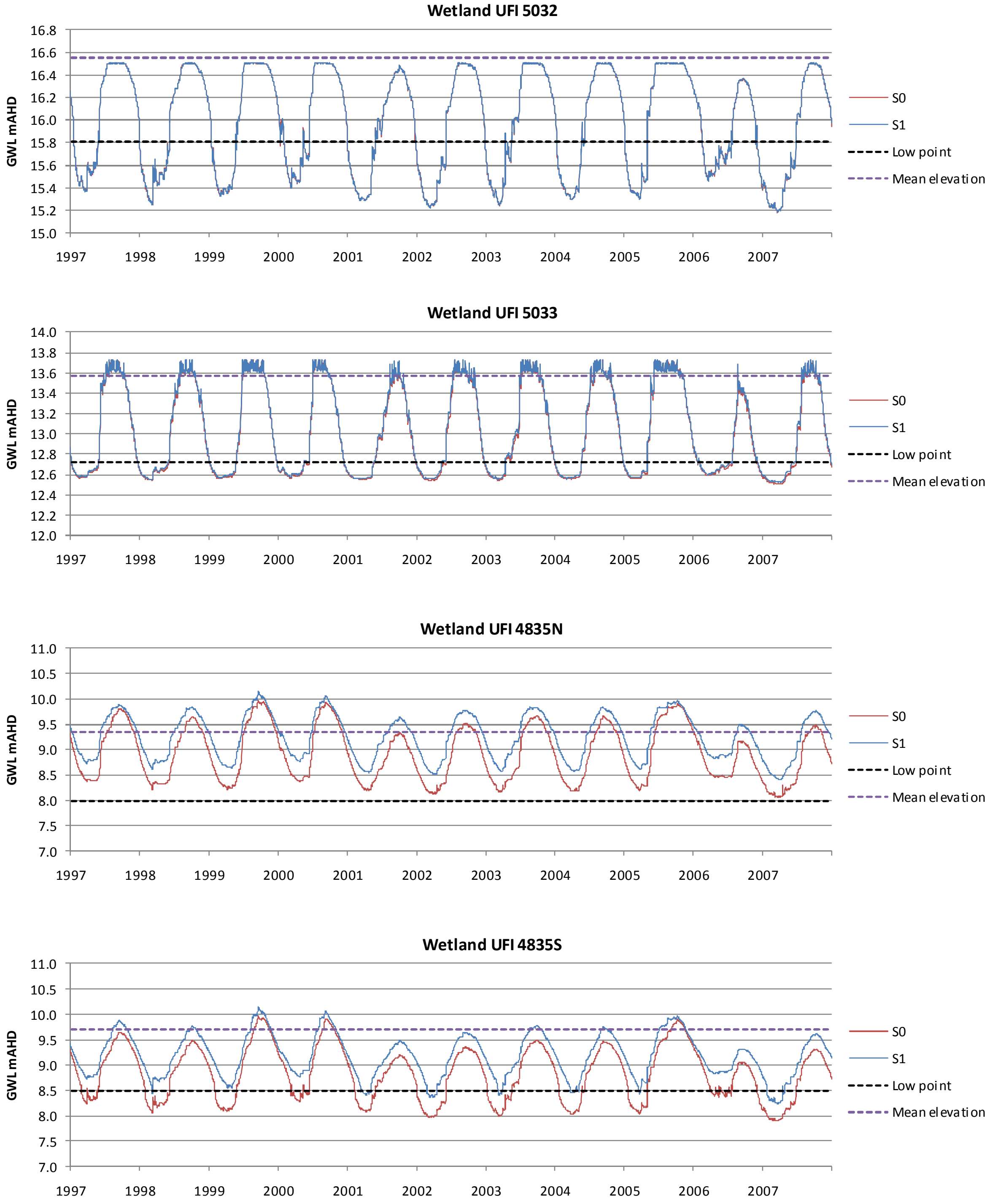


Figure 8.20 Comparison of conservation category wetland water levels for scenarios S0 and S1

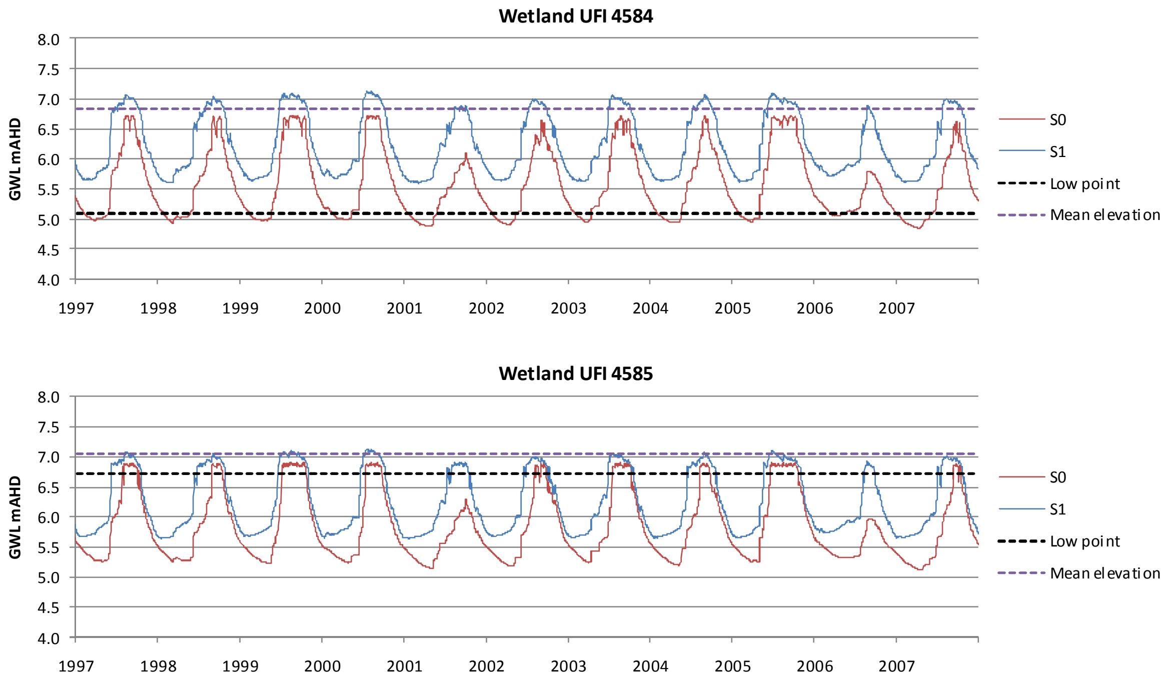
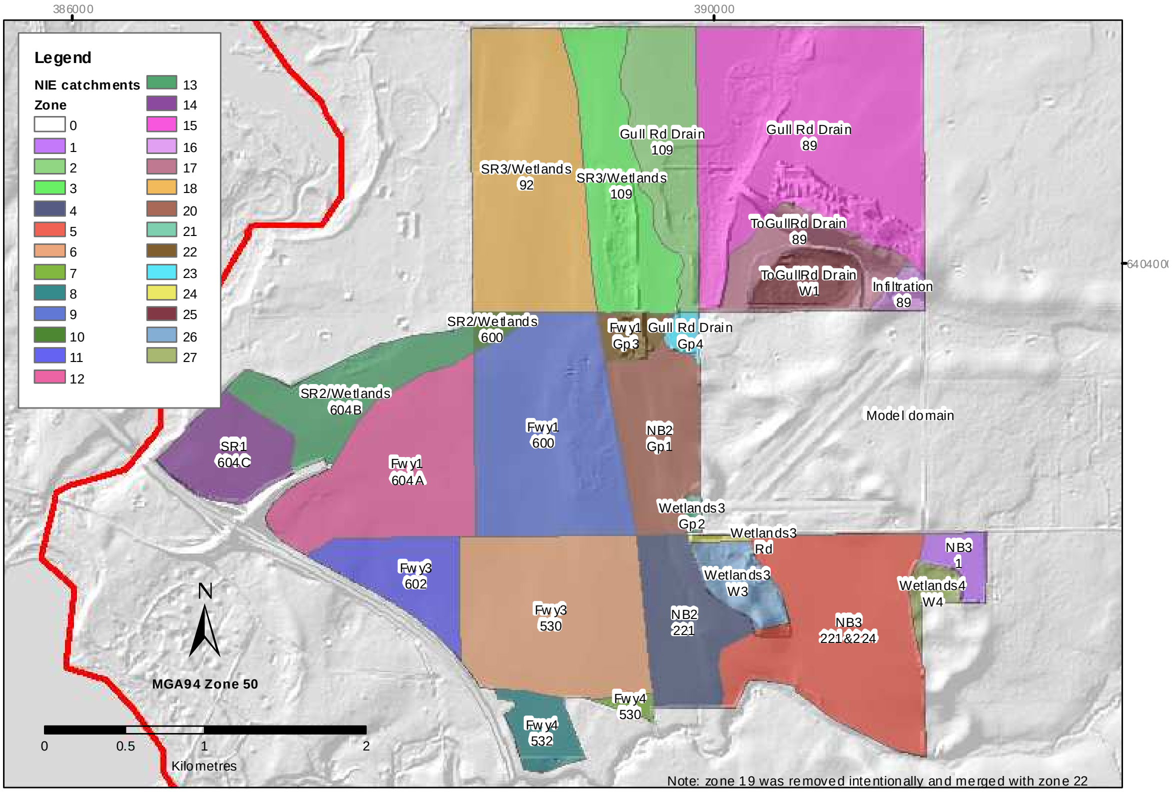


Figure 8.20continued

S1: Subsurface drainage volumes by development subcatchment

The MIKE SHE water balance tool was used to determine subsurface drainage volumes for each of the subcatchments and lots shown in Figure 8.21 and Table 8.1. These subcatchments were provided by JDA and represent distinct drainage area and lot combinations.



Note: zone 19 was removed intentionally and merged with zone 22

Figure 8.21 Subcatchments in the Nambeelup industrial estate

Table 8.1 Subsurface drainage volumes by subcatchment & lot (S1)

Zone	Area (km^2)	Lot	Catchment	Average annual (mm)	Average annual (GL)
Zone9	1.18	600	Fwy1	424	0.50
Zone12	0.96	604A	Fwy1	374	0.36
Zone22	0.11	Gp3	Fwy1	336	0.04
Zone6	1.12	530	Fwy3	422	0.47
Zone11	0.37	602	Fwy3	274	0.10
Zone7	0.04	530	Fwy4	171	0.01
Zone8	0.18	532	Fwy4	148	0.03
Zone2	0.58	109	Gull Rd Drain	142	0.08
Zone15	1.91	89	Gull Rd Drain	164	0.31
Zone23	0.05	Gp4	Gull Rd Drain	597	0.03
Zone16	0.07	89	Infiltration	55	0.00
Zone0	29.57	na	Model domain	na	na
Zone4	0.50	221	NB2	552	0.27
Zone20	0.54	Gp1	NB2	423	0.23
Zone1	0.12	1	NB3	26	0.00
Zone5	1.19	221&224	NB3	203	0.24
Zone14	0.38	604C	SR1	108	0.04
Zone10	0.05	600	SR2/Wetlands	308	0.02
Zone13	0.51	604B	SR2/Wetlands	162	0.08
Zone3	0.71	109	SR3/Wetlands	221	0.16
Zone18	1.22	92	SR3/Wetlands	440	0.54
Zone17	0.33	89	ToGullRd Drain	59	0.02
Zone25	0.22	W1	ToGullRd Drain	1	0.00
Zone21	0.02	Gp2	Wetlands3	90	0.00
Zone24	0.02	Rd	Wetlands3	140	0.00
Zone26	0.19	W3	Wetlands3	43	0.01
Zone27	0.09	W4	Wetlands4	8	0.00
Totals	42.22				3.54

Continued…

Industrial land use, CGL and drainage water (S2)

Scenario S2 was developed to assess the effect of subsurface drainage water on inundation of downstream wetlands and properties. For most of the catchment area of the Nambeelup industrial estate, existing drainage infrastructure is available to convey subsurface drainage water to the Nambeelup Brook. However, there is no existing drainage option for catchments SR2 and SR3, shown in Figure 8.21. One option for managing this drainage water is storage and infiltration in the wetlands to the west of the development area adjacent to the Serpentine River (wetland UFIs 15377 and 4287). However, this additional drainage water has the potential to increase the area of winter inundation for properties downstream of the development.

In order to simulate the influence of drainage water on inundation, the Nambeelup model was configured to apply the drainage water derived from catchment SR2 to wetland UFI 4287, and from catchment SR3 to wetland UFI 15377. The MIKE SHE water balance tool was used to extract a daily time series of subsurface drainage water from Scenario S1 for the two subcatchments (summarised in Figure 8.22). This volume of water was then applied to the wetland areas shown in Figure 8.23. The modelled (S1) average annual discharge from catchment SR2 is 0.1 GL and from SR3 is 0.7 GL.

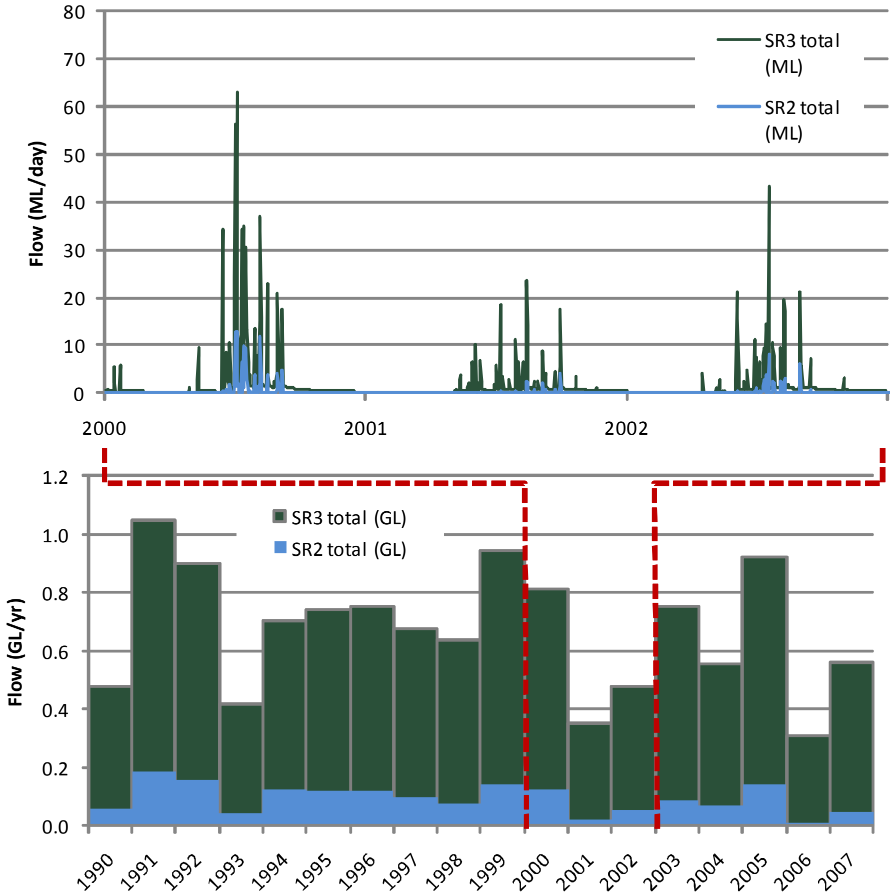


Figure 8.22 Time series of subsurface drainage from catchments SR2 and SR3

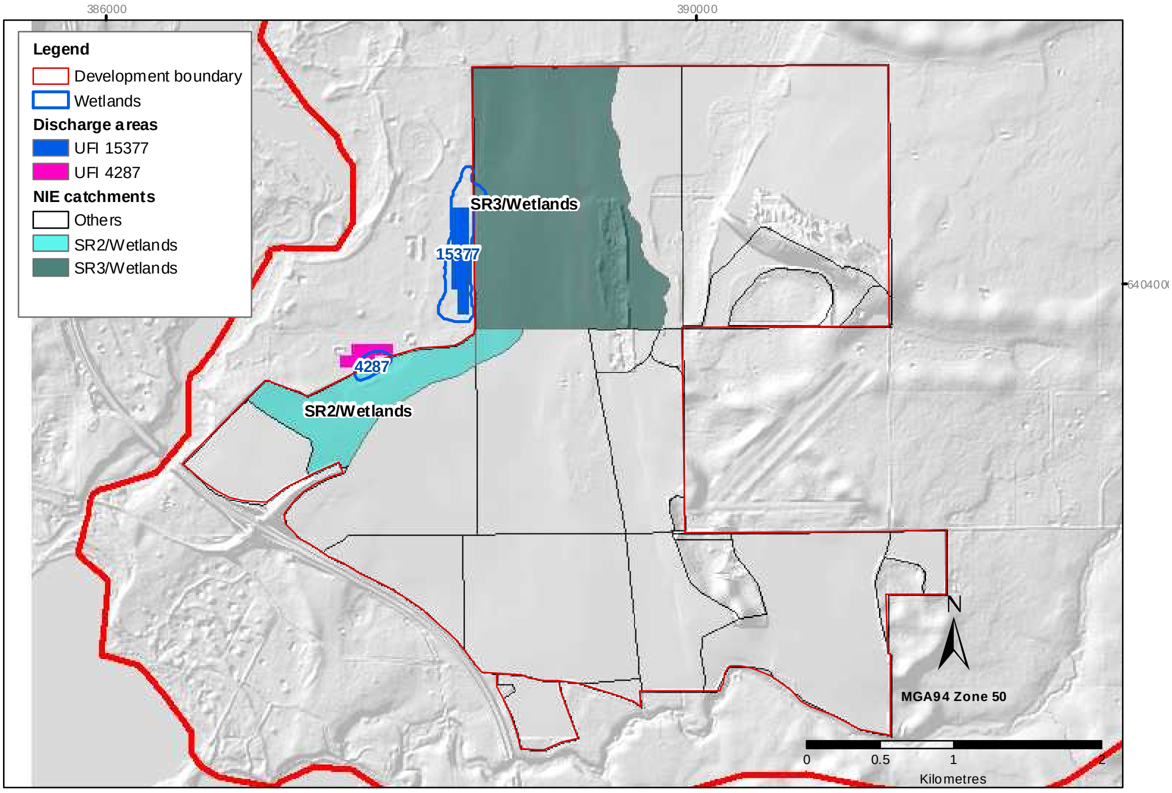


Figure 8.23 Catchments and wetlands receiving water in scenario S2

Results for industrial land use, CGL and drainage water scenario (S2)

S2: Post-development groundwater levels and inundation

Routing of drainage water to the wetlands increases the AAMaxGL water levels in the area to the west of the industrial estate by up to 40 cm as shown in plan view in Figure 8.24 and cross-sectional view in Figure 8.25. The higher winter water level results in increased inundation when compared to the base case scenario, as shown in Figure 8.26.

The results clearly indicate that if the subsurface drainage water derived from catchments SR2 and SR3 is routed to wetland UFIs 4287 and 15377, groundwater levels and the extent of inundation will increase within the vicinity of the wetlands. Thus property owners in Lot 93 would be adversely affected by this management option.

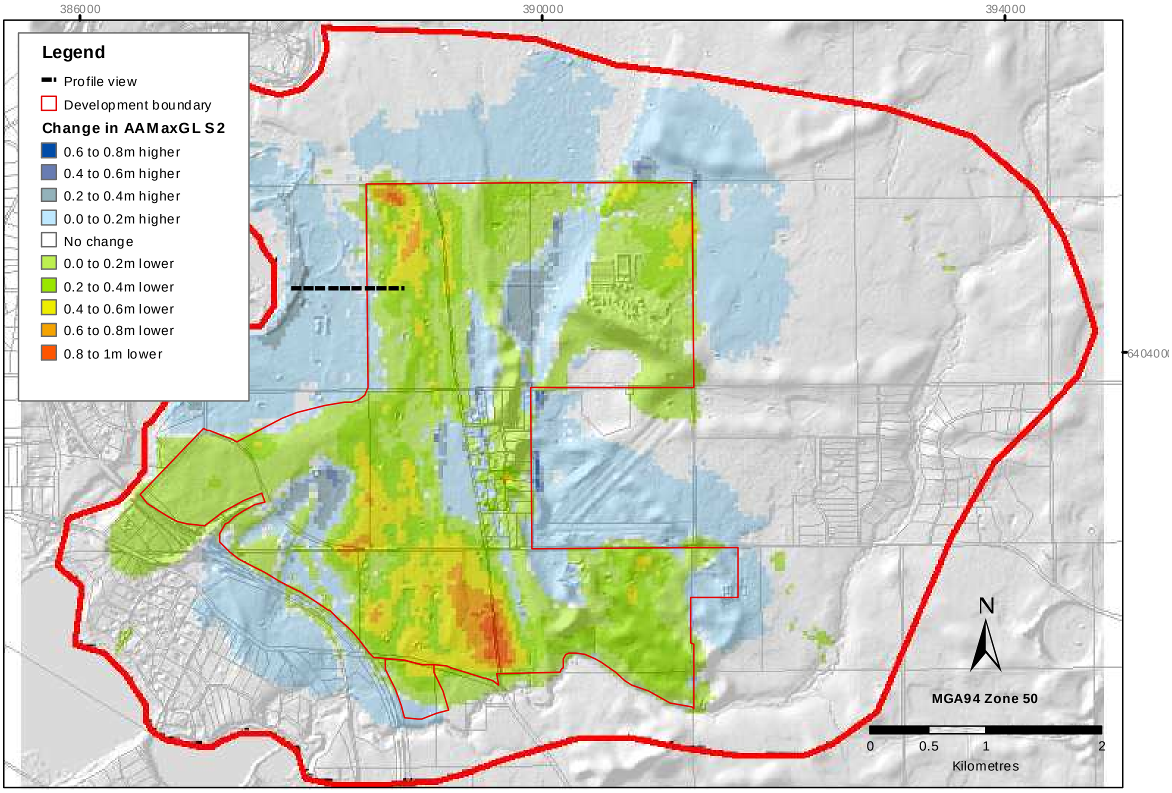


Figure 8.24S2: Change in AAMaxGL relative to the base case scenario

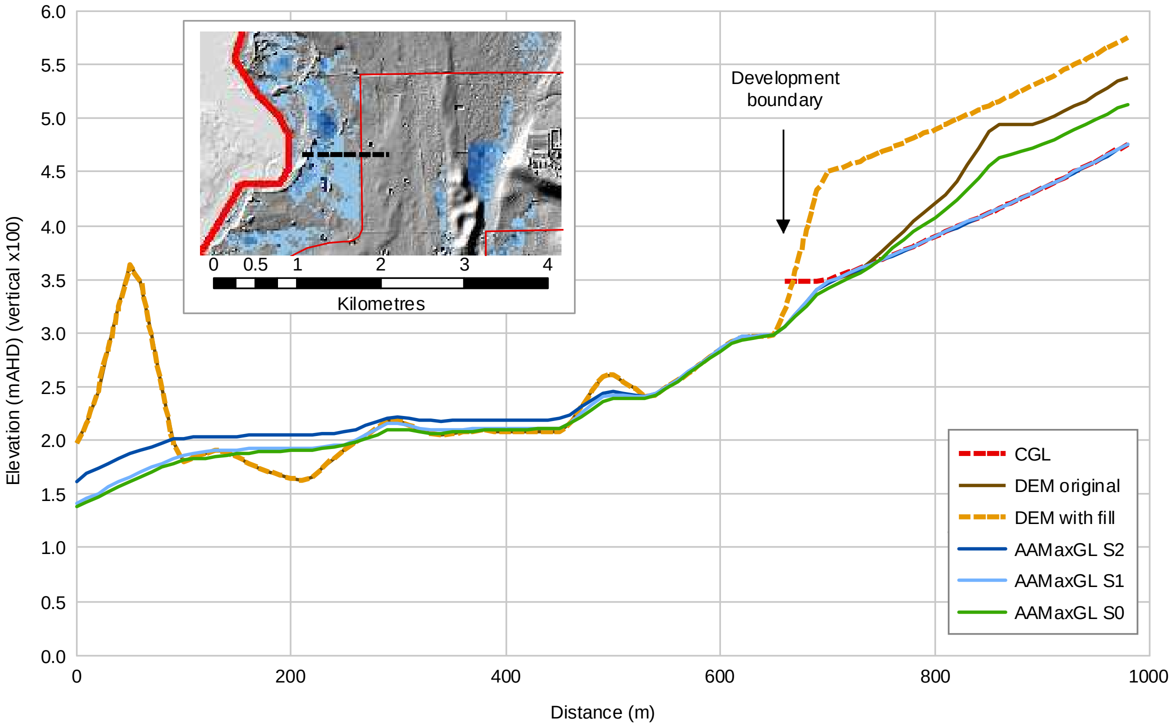


Figure 8.25 Cross-sectional view of AAMaxGL for S0, S1 and S2

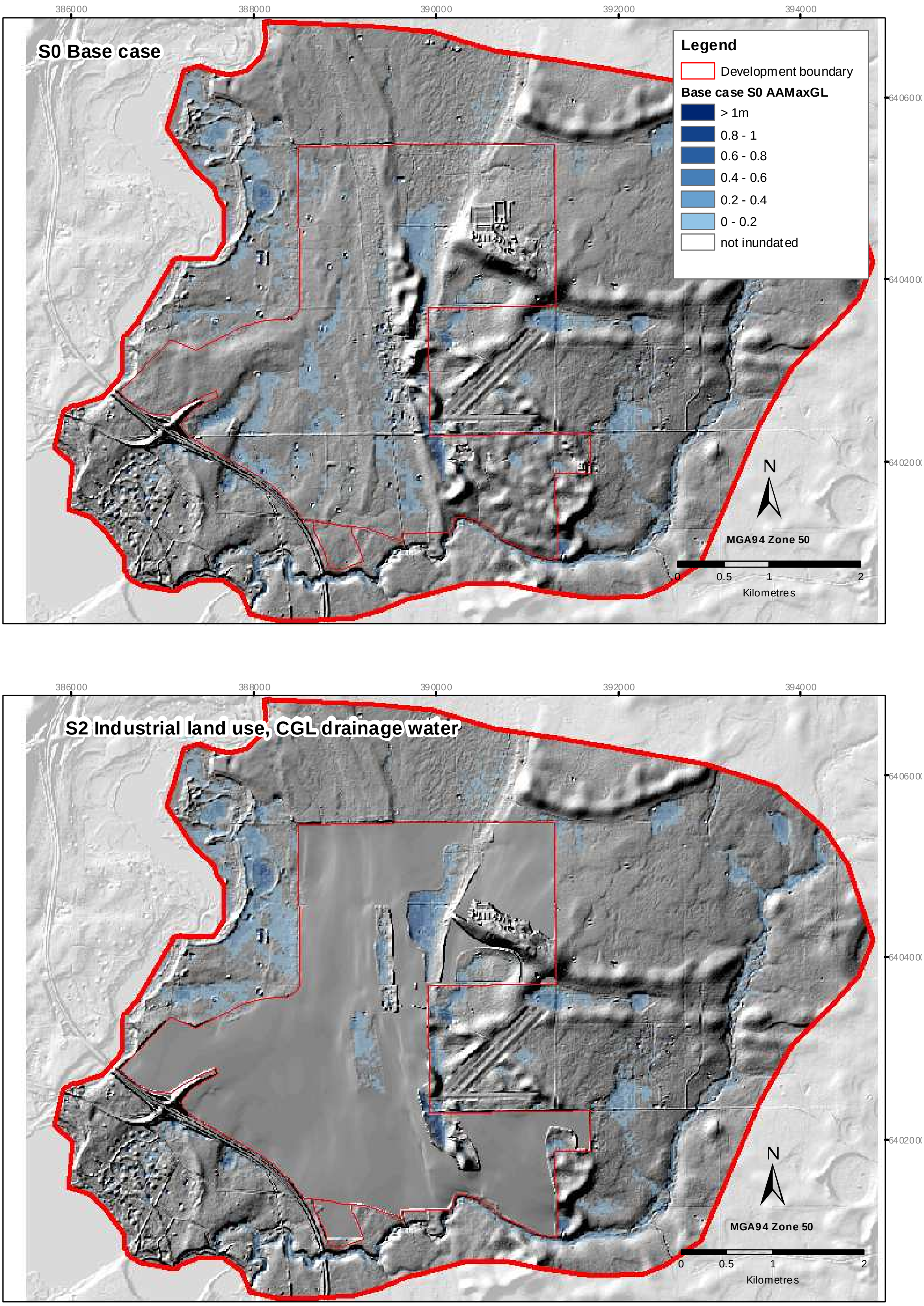


Figure 8.26 Comparison of inundation between S0 and S2 at AAMaxGL

Industrial land use, CGL and future dry climate (S3)

This scenario is a combination of the future land use and CGL scenario S1 and the dry climate scenario S27. It represents a possible future state in which the Nambeelup area experiences a drier climate under the post-development conditions. The primary aim of this scenario was to assess the potential effect on wetland water levels resulting from increased drainage and a dry climate. The land-use, topography and drainage inputs to the model are identical to those used in S0, and the boundary conditions, rainfall, and evapotranspiration datasets are identical to those used in S27.

Results for industrial land use, CGL and future dry climate scenario (S3)

The change in AAMaxGL of S3 relative to S0 is shown in Figure 8.27 below. The results are similar to S27 outside the development area. However, the introduced fill and increased recharge resulting from development acts to increase the AAMaxGL in some areas within and adjacent to the development boundary, and over a more extensive area, the increased recharge helps to reduce the effect of the reduced rainfall. By way of comparison, the average AAMaxGL across the model area is 9.27 m AHD under S27, and 9.39 m AHD under S3.

S3: Post-development groundwater levels

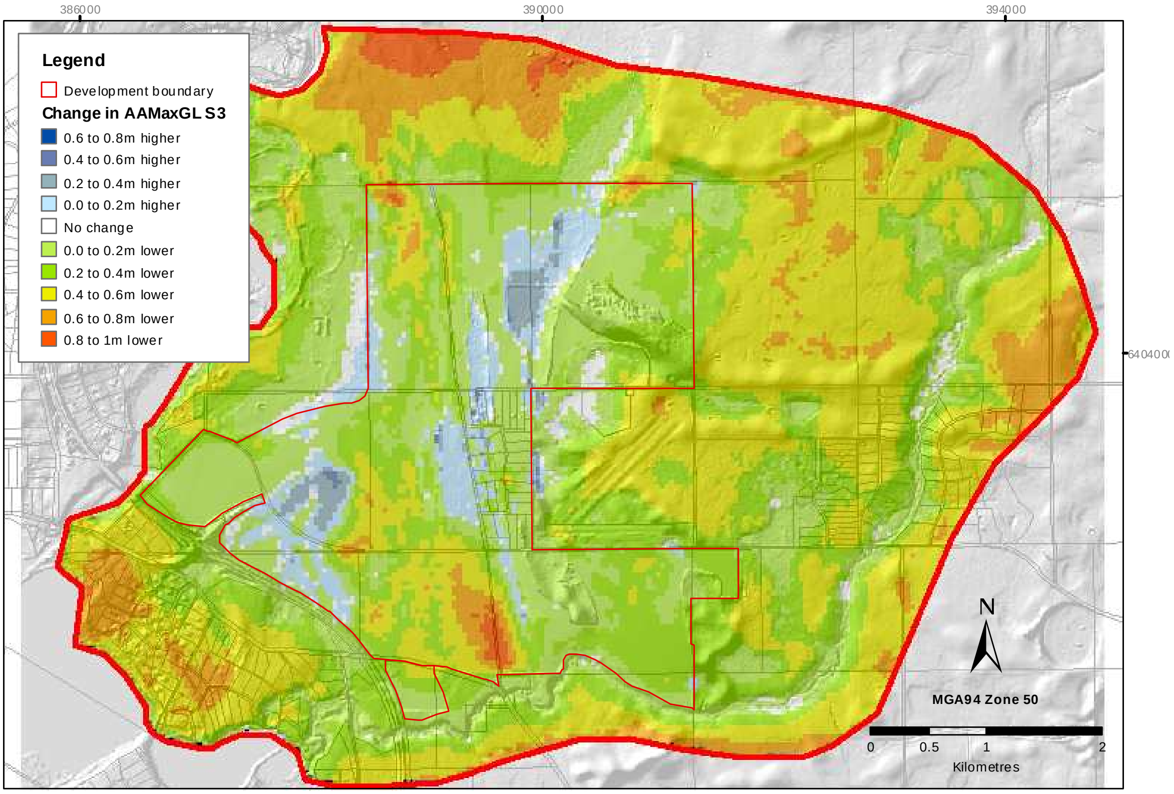


Figure 8.27S3: Change in AAMaxGL relative to the base case scenario

S3: Wetland water levels

Results from the wetland analysis for S3 (Figure 8.28) show that for the airport wetlands UFIs 4835N and 4835S, the increased recharge resulting from the industrial land use acts to offset the effect of reduced rainfall on groundwater levels. It is important to note that this result is in part due to selection of a CGL which does not lower the maximum groundwater level in these wetlands, and allows the groundwater level to reach pre-development maximum levels. The minimum water level in the airport wetlands is higher than for the base case S0 scenario as a result of reduced vegetation rooting depth in the surrounding industrial land use. Wetlands which are located at a distance from the development show a reduction in water level which is comparable to that predicted by the future dry climate scenario S27. Wetland UFIs 4584 and 4585 show higher water levels than both S27 and S0 as a result of the increased recharge in the industrial area. Summary results for all wetlands are shown in Appendix B.

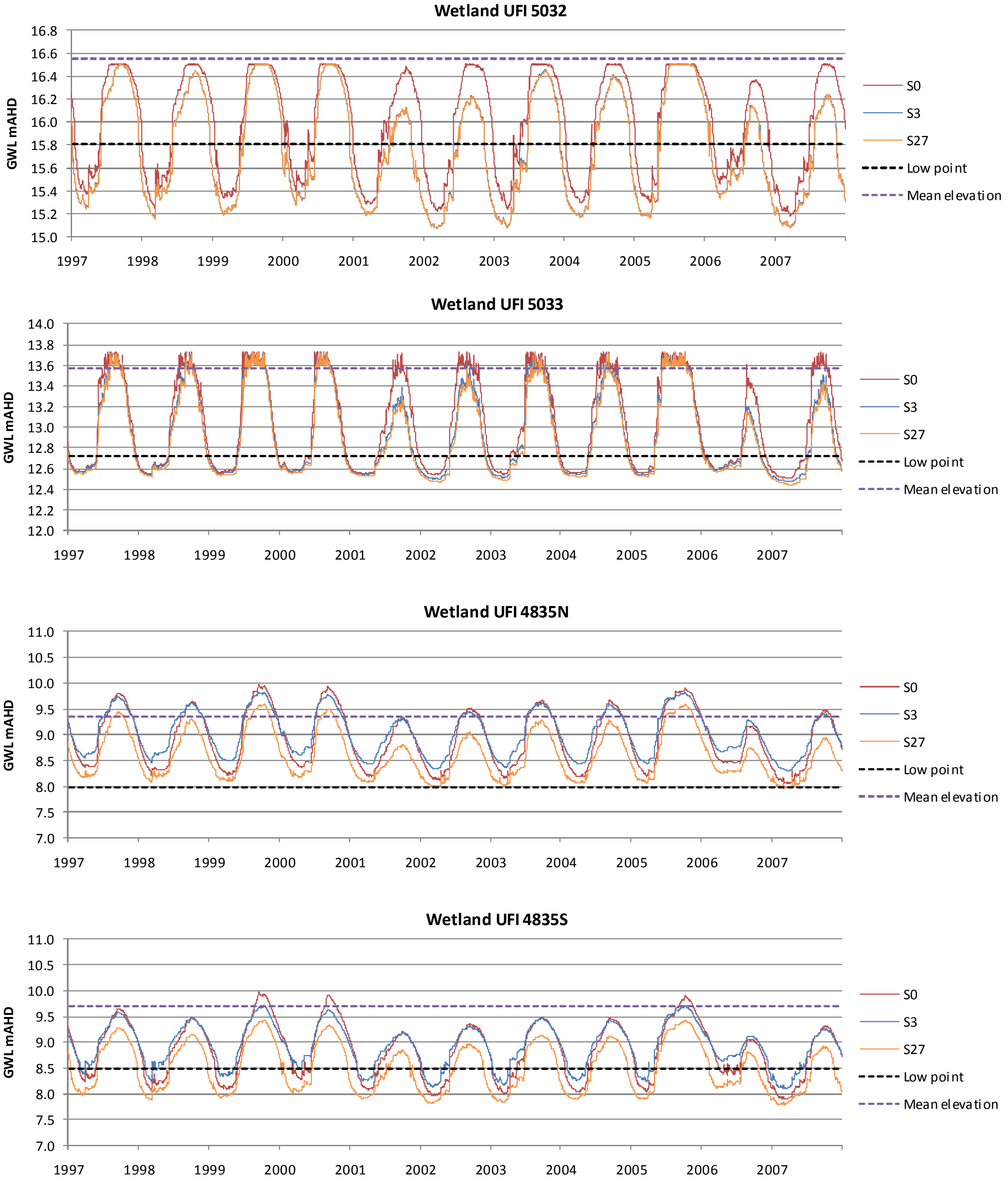
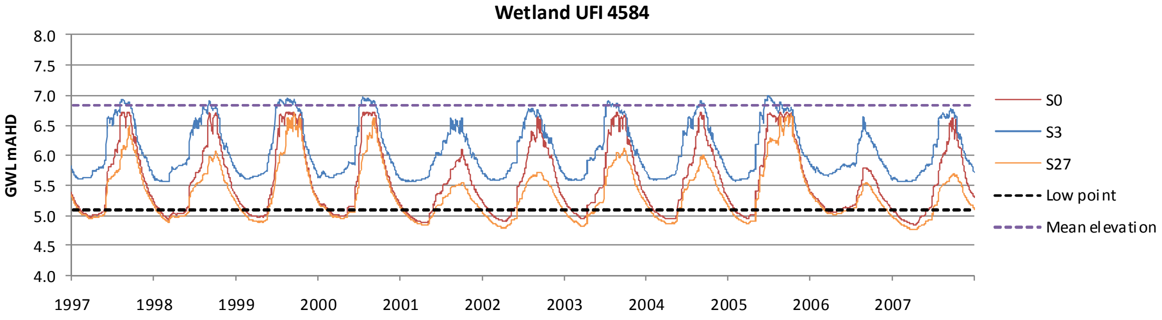


Figure 8.28 Comparison of conservation category wetland water levels for scenarios S0, S3 and S27



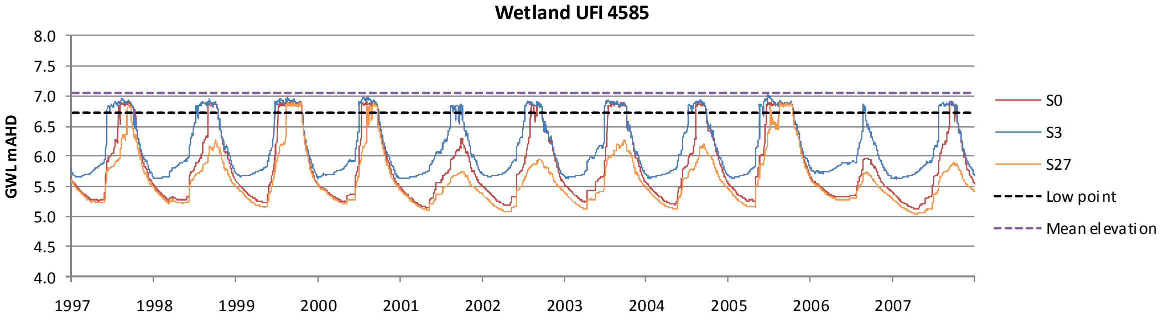


Figure 8.28continued

S3: Subsurface drainage volumes by development subcatchment

For scenario S3 the MIKE SHE water balance tool was used to determine subsurface drainage volumes for each of the subcatchments and lots shown in Figure 8.21 and Table 8.2. These subcatchments were provided by JDA and represent distinct drainage area and lot combinations. The estimated drainage volumes from scenario S1 and S3 indicate the upper and lower limits respectively, for drainage water that may be available for a managed aquifer recharge scheme. Scenario S3 shows that a total of 2.11 GL/yr of water would be produced by the subsurface drainage network, which is 43% less than scenario S1. Based on scenario analysis, the likely range in the average annual volume of subsurface drainage water available is between 2.11 and 3.54 GL/yr. Scenario S4 is discussed in the following section, and drainage results for this scenario are included in Table 8.2. The lower recharge associated with S4 results in less subsurface drainage water.

Table 8.2 Subsurface drainage volumes by subcatchment and lot (S1, S3, S4 comparison)

Zone	Area (km2)	Lot	Catchment	S1 Average annual (mm)	S1 Average annual (GL)	S3 Average annual (mm)	S3 Average annual (GL)	S4 Average annual (mm)	S4 Average annual (GL)
Zone22	0.11	Gp3	Fwy1	336	0.03	111	0.01	151	0.01
Zone12	0.96	604A	Fwy1	374	0.36	250	0.24	238	0.23
Zone9	1.18	600	Fwy1	424	0.50	306	0.36	268	0.32
Zone11	0.37	602	Fwy3	274	0.10	174	0.06	186	0.07
Zone6	1.12	530	Fwy3	422	0.47	296	0.33	264	0.30
Zone7	0.04	530	Fwy4	171	0.01	60	0.00	99	0.00
Zone8	0.18	532	Fwy4	148	0.03	57	0.01	80	0.01
Zone23	0.05	Gp4	Gull Rd Drain	597	0.03	127	0.01	450	0.02
Zone2	0.58	109	Gull Rd Drain	142	0.08	37	0.02	64	0.04
Zone15	1.91	89	Gull Rd Drain	164	0.31	63	0.12	91	0.17
Zone16	0.07	89	Infiltration	55	0.00	1	0.00	30	0.00
Zone0	29.57	na	Model domain	na	na	na	na	na	na
Zone4	0.50	221	NB2	552	0.27	388	0.19	322	0.16
Zone20	0.54	Gp1	NB2	423	0.23	267	0.14	268	0.14
Zone1	0.12	1	NB3	26	0.00	2	0.00	12	0.00
Zone5	1.19	221&224	NB3	203	0.24	77	0.09	111	0.13
Zone14	0.38	604C	SR1	108	0.04	23	0.01	45	0.02
Zone10	0.05	600	SR2/Wetlands	308	0.02	178	0.01	173	0.01
Zone13	0.51	604B	SR2/Wetlands	162	0.08	65	0.03	88	0.05
Zone3	0.71	109	SR3/Wetlands	221	0.16	104	0.07	121	0.09
Zone18	1.22	92	SR3/Wetlands	440	0.54	309	0.38	264	0.32
Zone25	0.22	W1	ToGullRd Drain	1	0.00	0	0.00	0	0.00
Zone17	0.33	89	ToGullRd Drain	59	0.02	6	0.00	21	0.01
Zone24	0.02	Rd	Wetlands3	140	0.00	4	0.00	93	0.00
Zone21	0.02	Gp2	Wetlands3	90	0.00	4	0.00	64	0.00
Zone26	0.19	W3	Wetlands3	43	0.01	1	0.00	28	0.01
Zone27	0.09	W4	Wetlands4	8	0.00	0	0.00	4	0.00
Totals	42.22				3.54		2.11		2.11

Industrial land use, CGL, and moderate recharge (S4)

The presence of shallow groundwater in the proposed Nambeelup industrial area was highlighted by JDA as a potential limiting factor in the infiltration capacity of soak wells or infiltration basins to adequately infiltrate the volumes of runoff generated by increased impervious surface. The assumption used in scenarios S1, S2 and S3 was that by infiltrating runoff within the estate, recharge would be increased. As shown in S1, the increase in recharge resulted in substantial requirements for subsurface drainage infrastructure, with an average annual discharge of 3.54 GL of drainage water modelled.

JDA requested that an alternative scenario be modelled (S4) where only smaller rainfall events are infiltrated via in-lot soak wells. Based on the rainfall record used to model the area, JDA and the Water Science Branch determined that infiltrating daily rainfall events of around 4 mm or less would result in an average gross recharge rate of 41% which is less of an increase relative to the pre-development water balance. The MIKE SHE model was configured to give an average annual gross recharge of 41% within the development area for scenario S4.

This recharge rate would require that the soak wells would infiltrate, over one year, the product of the impervious area of the development (10.5 km^2), and the average annual sum of daily rainfall up to 4 mm (331 mm/yr). This totals 3.5 GL/yr of recharge across the development area, with an additional 0.6 GL/yr estimated to recharge in public open space areas. This is a rough estimate only as actual recharge is likely to depend on the intensity, frequency and duration of the rainfall events, with some losses due to evaporation.

The presence of fill and free draining soils are expected to substantially reduce evaporation directly from the groundwater, and therefore, groundwater levels are still likely to reach the controlled groundwater level in most years, hence maintaining the wetland levels, and still resulting in some discharge from subsurface drainage. The S4 scenario was modelled to assess the response of wetland water levels and required drainage volume to the reduced recharge.

Because less water is assumed to be infiltrated within-lot for this scenario, more direct runoff must be managed within the development area. This groundwater model is not designed to assess the increase in surface runoff expected from development. However, accounting for the direct runoff and its treatment is an important consideration at the DWMS and LWMS (local water management strategy) stage. Requirements for the capture and treatment of the 1-year 1-hour event should be considered in the context of the Department of Water’s priorities for better urban water management (WAPC 2008).

Results for industrial land use, CGL and moderate recharge scenario (S4)

Figure 8.29 illustrates the change in AAMaxGL for S4 relative to S0. The results are similar to those from the higher recharge scenario S1, with parts of the development area lower, and the AAMaxGL maintained around the wetlands. Figure 8.30 shows wetland water level results for six significant wetlands, and illustrates that wetland water levels are maintained post-development. However, the reduced recharge results in slightly lower levels relative to the higher recharge scenario (S1).

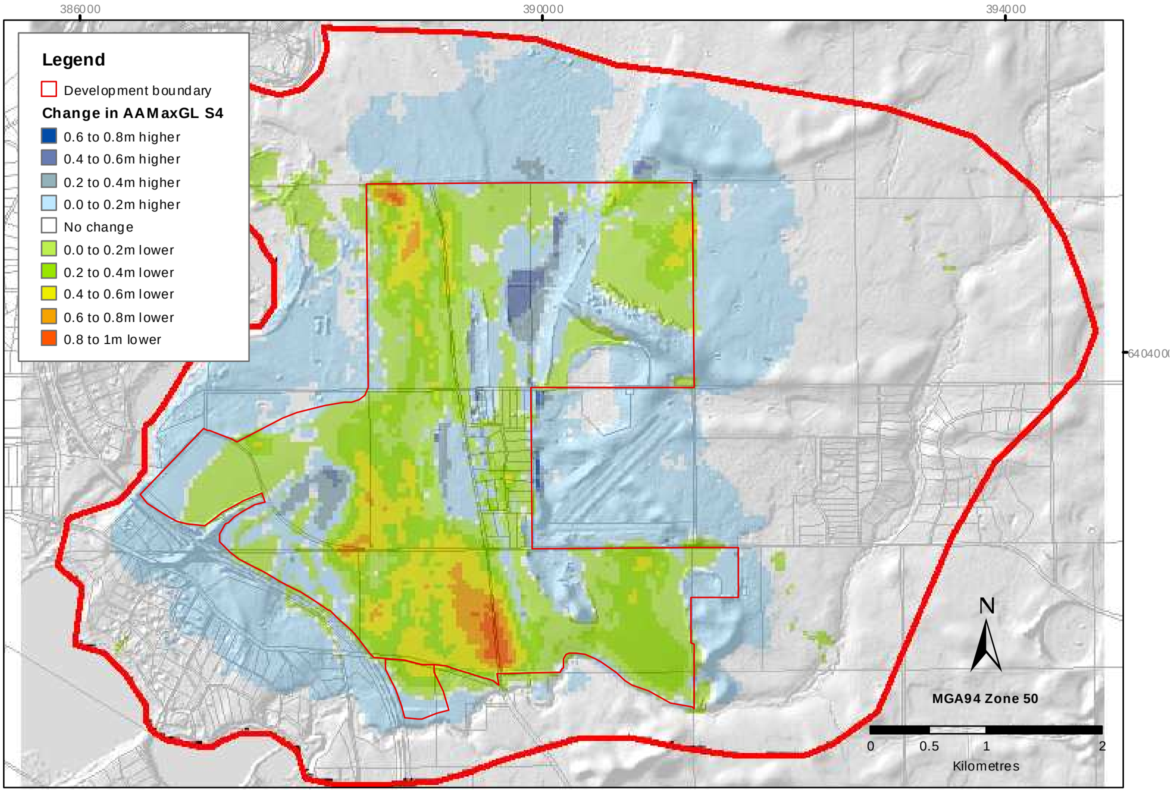


Figure 8.29S4: Change in AAMaxGL relative to the base case scenario

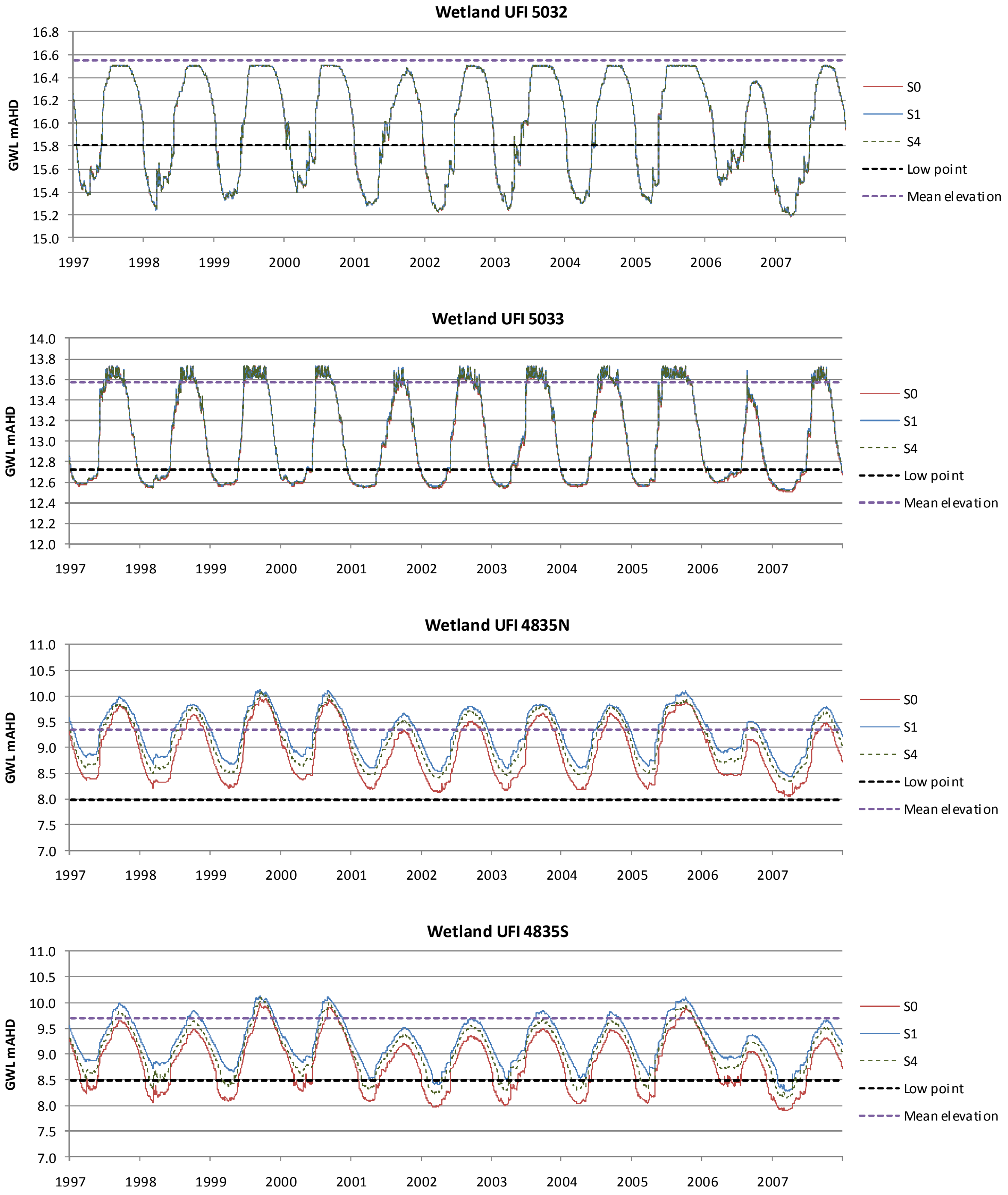
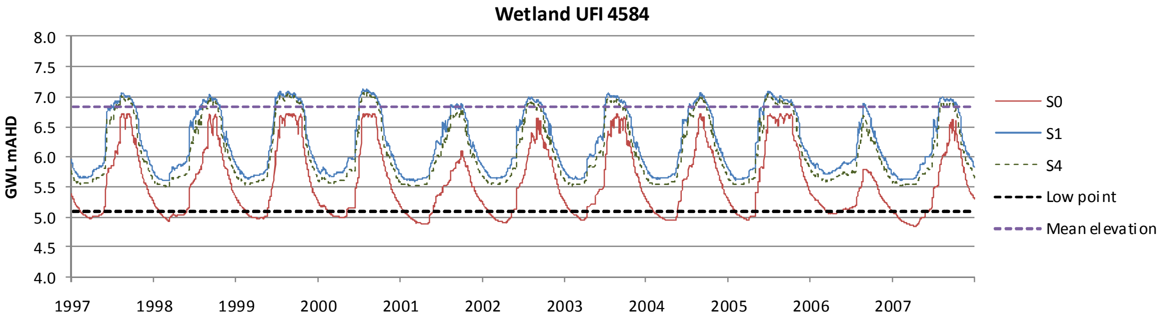


Figure 8.30 Comparison of conservation category wetland water levels for scenarios S0, S1 and S4



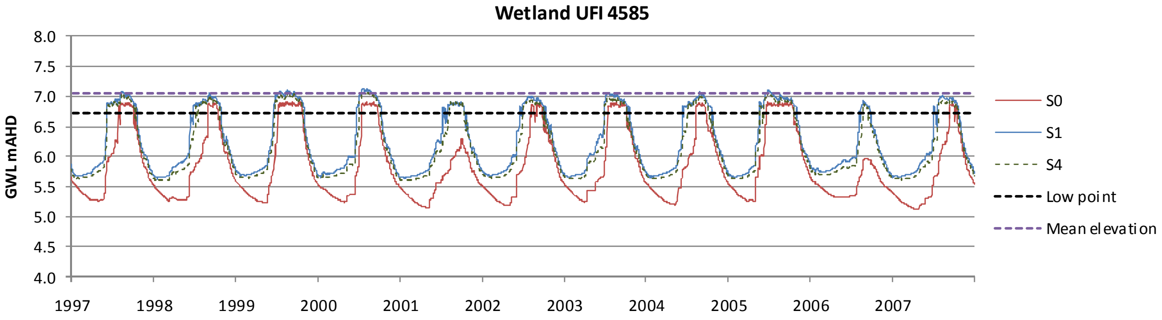


Figure 8.30continued

8.4 Pre- and post-development water balance

Pre- and post-development water balances illustrate the change in hydrology and hydrogeology resulting from development. Table 8.3 shows the Superficial Aquifer water balance for the development area for scenarios S0 (base case), S1 (industrial land use, fill and CGL), S3 (industrial land use, fill, CGL and a dry climate), and S4 (industrial land use, fill, CGL and moderate recharge). Figure 8.31 illustrates losses from the Superficial Aquifer for scenarios S0, S1, S3, and S4. As the change in storage is minimal, the sum of the aquifer losses approximates total recharge to the aquifer.

Table 8.3 Comparative development area water balances for scenarios S0, S1, S3 and S4

Development area water balance				
	S0 **GL/yr**	**S1** **GL/yr**	**S3** **GL/yr**	**S4** **GL/yr**
Gross recharge	3.7	5.7	4.2	4.3
Horizontal flow in	0.6	0.5	0.4	0.5
Recharge from river	0.0	0.0	0.0	0.0
Evapotranspiration from groundwater	3.0	1.0	0.9	1.2
Horizontal flow out	1.0	1.4	1.4	1.2
Baseflow to rivers and drains	0.15	0.15	0.13	0.13
Subsurface drainage	0.0	3.5	2.1	2.1
Abstraction	0.1	0.1	0.1	0.1

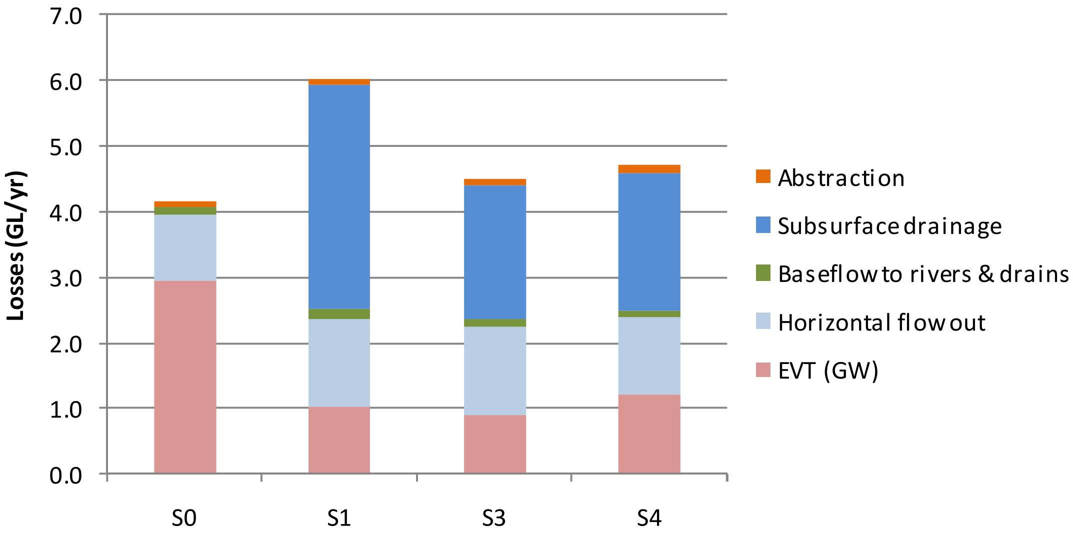


Figure 8.31 Comparison of aquifer losses for scenarios S0, S1, S3 and S4

For the base case scenario S0, the main loss from the aquifer is from evapotranspiration. Figure 8.31 shows that for scenario S1 recharge is increased, and evapotranspiration is decreased. The additional water generated is lost from the aquifer via the subsurface drainage system. For scenario S3, the increase in recharge resulting from development is offset by the reduced rainfall simulated for a dry climate. Evapotranspiration from groundwater is reduced under the scenario S3, with the additional water lost through subsurface drainage. For scenario S4, the gross recharge is slightly higher than the base case scenario, but is substantially less than scenario S1. Evapotranspiration from groundwater is reduced with a corresponding increase in aquifer losses due to subsurface drainage.

Baseflow to rivers and drains, and horizontal groundwater flow from the development area are relatively unchanged for the post-development scenarios S1 and S3. However, It is important to note that the additional subsurface drainage water generated within the development area is likely to influence off-site hydrology, depending on how it is managed. Surface runoff will need to be detained and treated up to the 1-year 1-hour event, and discharge from the site must be conveyed without increasing the risk of flood or inundation.

Volumes of ‘additional discharge water’

The volume of ‘additional discharge water’ refers to the mean annual additional discharge from the site, in the form of surface flows, which did not occur in the pre-development scenario. The additional discharge water is a result of reduced evapotranspiration from groundwater, altered depth to groundwater via use of fill, less evapotranspiration from the surface and unsaturated soil profile, and changes from pervious areas to impervious areas. The MIKE SHE water balance tool can be used to approximate the volume of water, by examining the results of the pre- and post-development scenarios, to examine changes in the hydrological regime.

Table 8.4 shows the surface water discharges from the industrial estate for the pre- and post-development conditions. These include the baseflow to rivers and drains (groundwater discharge to waterways), overland flow to rivers or the boundary and subsurface drainage. Note that runoff from impervious surfaces which is not infiltrated within lot **is not** included in the MIKE SHE water balance. For the post-development scenarios there will be an increase in overland flow resulting from events which are not infiltrated. This volume of water was not accounted for, and is highlighted as '+OL imp.' (plus overland impervious) in Table 8.4.

For scenarios S1 and S4, average annual gross recharge was calculated as 55% (5.7 GL) and 41% (4.3 GL) respectively (based on model results).

Table 8.4 Pre- and post-development surface water discharged from the Nambeelup industrial estate

Nambeelup industrial estate surface water discharge (1978 to 2007)

	S0 **GL/yr**	**S1** **GL/yr**	**S3** **GL/yr**	**S4** **GL/yr**
Overland flow to rivers and drains	0.6	0.0	0.0	0.0
Overland flow to boundary	0.2	0.1	0.0	0.1
Overland (impervious)*	na	+OL imp.	+OL imp.	+OL imp.
Baseflow to rivers and drains	0.15	0.15	0.13	0.13
Subsurface drainage	0.0	3.5	2.1	2.1
Total	0.9	3.8	2.2	2.3
'Additional discharge water'	0.0	2.8	1.3	1.4

** This flux is not accounted for in the MIKE SHE water balance.*

'+OL imp.' – plus overland impervious

In all of the scenarios run, the development of the Nambeelup industrial estate results in an increase in surface water discharge through increased recharge and reduced evapotranspiration from groundwater requiring subsurface drainage. In the case of S1, where a greater volume of rainfall is infiltrated, it was estimated that an average of 3.5 GL/yr of subsurface drainage water would result from the development, with some additional increase in overland flow likely. The drier climate for S3 results in substantially less subsurface drainage water due to reduced recharge. For the S4 scenario, the lower recharge rates (compared to S1) result in 2.1 GL/yr of subsurface drainage water. However, the estimate of overland flow from impervious surfaces would increase as a result of lower on-site infiltration. In terms of 'additional discharge water', S1 and S4 are likely to be similar once the overland flow component from the development is appropriately accounted for. Given the size of the development, average rainfall and extent of impervious surface, the overland flow generated is likely to be in the order of 1 to 3 GL/yr, depending on the drainage infrastructure which is constructed on site.

The estimates of discharge presented here should be refined as necessary at the local water management strategy planning phase, and are intended as indicative values at the development scale. The total volume of water generated within the Nambeelup industrial estate will depend on local drainage design (e.g. evaporative losses from compensation basins and swales).

9 Conclusions

The results of the Nambeelup groundwater model scenarios have highlighted the importance of considering all aspects of the hydrological cycle for development in areas constrained by shallow ground watertables. Base case modelling results show that sections of the planned Nambeelup industrial estate are subject to extensive waterlogging and inundation in most winters. Shallow groundwater supports 29 “resource enhancement” and “conservation category” wetlands, which are surface expressions of superficial groundwater. Hence, development of the industrial estate presents a challenge, as it is necessary to limit inundation within the development itself, manage drainage water to prevent off-site effects, and prevent alteration to the hydrological regime of the wetlands that would reduce ecosystem function. The combined influence of climate change and development must also be considered.

The scenarios which were simulated with the Nambeelup model assessed the proposed Nambeelup industrial estate in the context of the inherent landscape constraints. The main conclusions drawn from the scenarios are discussed below:

- The Base Case scenario S0 water balance for the development area indicated gross recharge was 35% of average rainfall and net recharge (gross recharge less evapotranspiration from groundwater) was 9% of average rainfall for the 1978 to 2007 simulation period. The major fluxes from the development area water balance are the rainfall and total evapotranspiration. Total Evapotranspiration was 88.3 % of rainfall, of which 29 % was directly from the groundwater and the remainder from the unsaturated soils. Modelled overland outflows to rivers, drains and boundaries plus baseflow to rivers/drains totalled an average of 9.1 % of annual rainfall for the 1978 to 2007 period. The remainder 2.6 % of annual rainfall is translated to either additional horizontal aquifer outflow (1.7%) or abstraction (0.9%).
- The climate scenarios S9, S18 and S27 demonstrate that there is a large range of potential groundwater levels based on predicted future drier climates with no land use change. The driest climate scenario S27 shows a reduction in average annual maximum groundwater level of up to 1 m in places, whereas the wettest scenario S9 shows minor reduction in groundwater levels relative to current conditions. Maximum groundwater levels associated with inundated areas, including wetlands, show less response to climate change in comparison to areas with greater depth to groundwater.
- Scenario S1 – industrial land use and controlled groundwater level – showed that the proposed modifications to the surface topography, land use, and drainage within the Nambeelup industrial estate were unlikely to lower wetland water levels, and would not result in an increase in inundation off-site (note that S1 does not consider where additional drainage water is discharged). The land-use change with use of fill resulted in less evapotranspiration losses from groundwater and was shown to increase net recharge, such that the average annual maximum groundwater level is comparable to the defined controlled groundwater level. This means that the watertable reaches the controlled groundwater level every winter. The introduction of subsurface drainage and gross recharge from industrial area of 60% generates an average of 3.5 GL/yr of water which must be managed. The main source of the additional drainage water is from reduced evapotranspiration (and therefore increased recharge and runoff) within the industrial land use.
- Scenario S2 – industrial land use, controlled groundwater level, and drainage to wetlands under current climate rainfall – showed that routing of subsurface drainage water from part of the Nambeelup industrial estate at quantities as per scenario S1 to

two wetland locations would result in an increase in winter inundation over Lot 93, which is located outside the development area.

- Scenario S3 – industrial land use, controlled groundwater level, and dry climate – showed that development of the Nambeelup industrial estate is likely to assist in maintaining water levels in important wetlands under a drier climate. In particular, the Airport wetland UFIs 4835S and 4835N show a decline in winter water level under a dry climate with no development, but show almost no change when modelled with post-development conditions and a dry climate. The model demonstrates that the increased recharge under the industrial land use acts to offset decreased recharge from reduced rainfall – provided that an appropriate controlled groundwater level is set in the development area adjacent to the wetlands.
- Scenario S4 – industrial land use, CGL, and moderate recharge – showed that wetland water levels could be adequately maintained with an average gross recharge rate of 41% within the development area, based on appropriately sized in-lot soak wells. The model estimated that subsurface drainage water would average 2.1 GL/yr post-development. Where reduced capacity for infiltration in the lots occurs, the resultant increase in overland flow of the 1yr 1hr portion to the POS from the development area would need to be treated (e.g. via bio-filtration with underlying subsoils).

Based on the scenarios modelled, the planned Nambeelup industrial estate will not substantially change the hydrological regime of the wetlands considered, but may result in an increase in both maximum and minimum water levels, and the length of time of inundation in winter. This is most evident where modelled CGL inverts were set at the maximum groundwater level, or natural surface around wetland UFIs 4584 and 4585, which led to increased wetland levels. This is in contrast to areas where the CGL was revised to be set at AAMaxGL surrounding other wetland buffers, which resulted in maintaining the wetland hydrological AAMaxGLs. Wetland hydrological regimes are affected by the location and level of CGLs adjacent to the wetland buffer, and the gross recharge from lots. Changes to the hydrological regime were comparatively less with the lower gross recharge rate modelled in S4. It should be noted that changes in groundwater quality resulting from the estate were not considered.

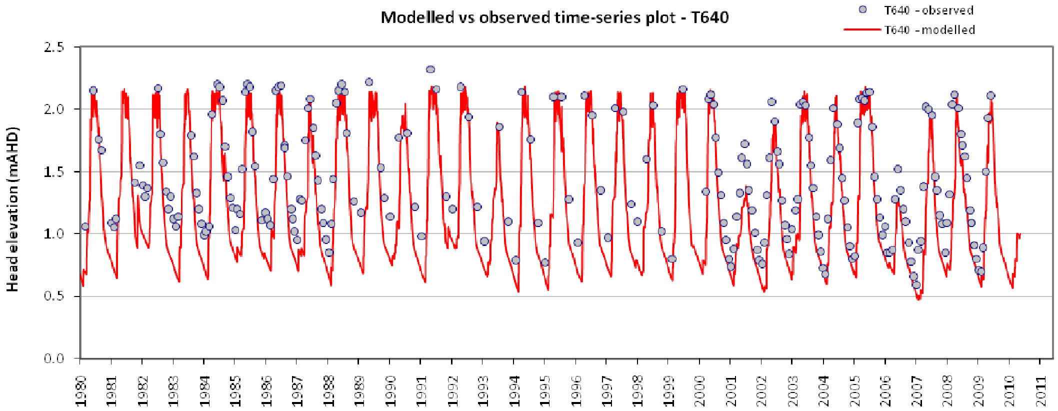
The Nambeelup industrial estate is unlikely to increase inundation in down-gradient properties provided the estimated 3.5 GL/yr of subsurface drainage water is adequately managed. In particular, the 0.8 GL/yr which is estimated to come from catchments SR2 and SR3 (based on a 60% gross recharge rate) will require a drainage pathway from the western edge of the development such as Gull Rd drain), as routing this water to wetlands in Lot 93 and 604 will result in inundation of these properties under continued existing climate conditions. Overland flow which is not infiltrated within the estate may result in increased total discharge from the development area, and disposal options for this water should be considered in more detailed planning at the local water management strategy stage.

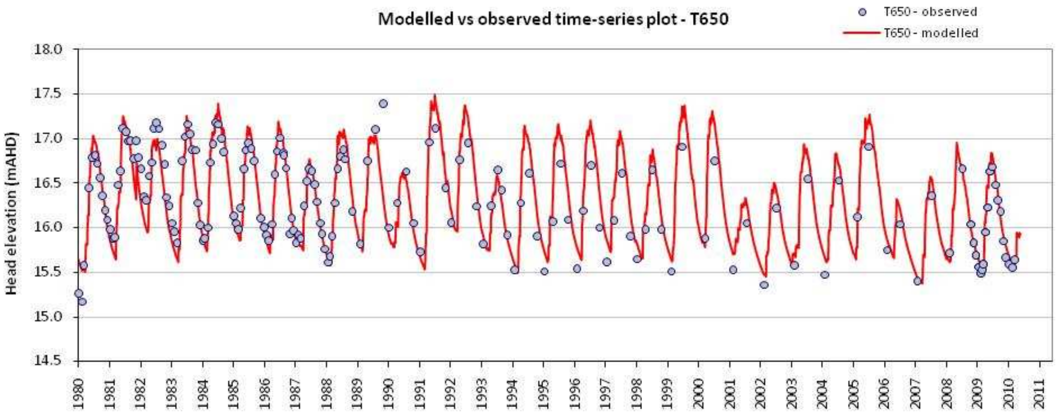
Appendices

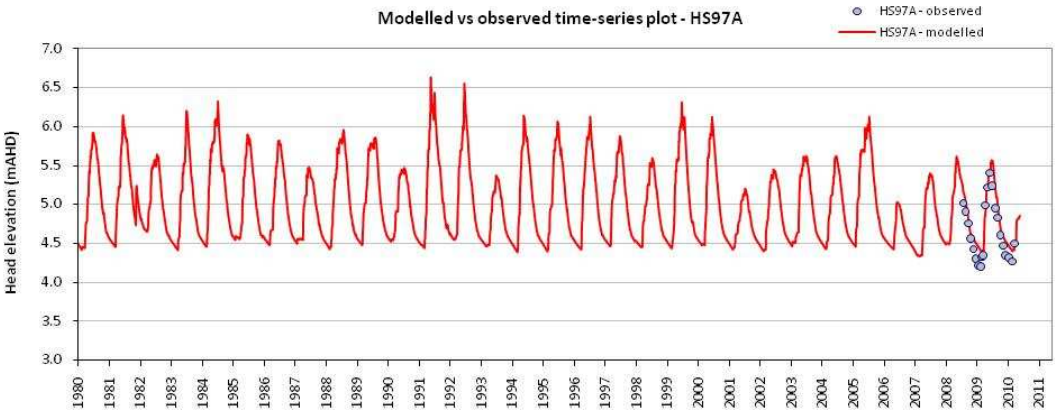
Appendix A – Modelled and observed groundwater heads and wetland levels

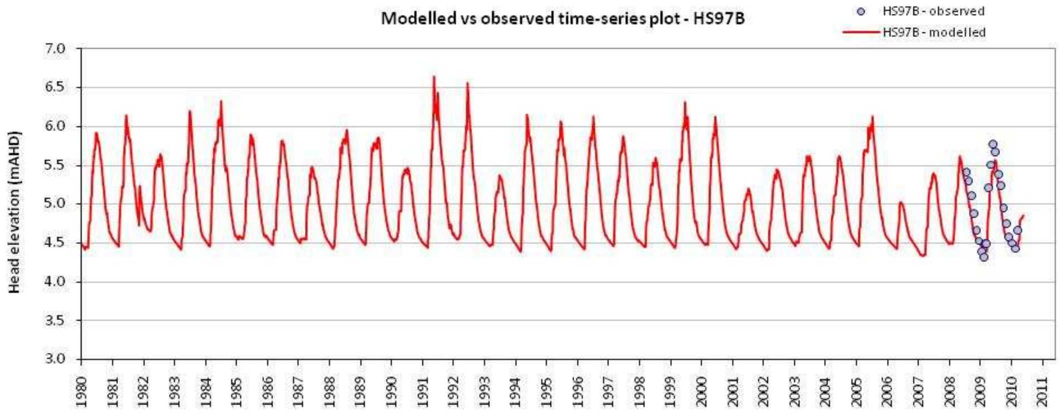
These graphs show how the modelled heads compared to the observed heads for the full period of calibration, as described in Section 6.3. The scenario modelled was the base case, S0 – current conditions.

Department of Water bores





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HS97B - observed
HS97B - modelled
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6.0
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4.5
4.0
3.5
3.0
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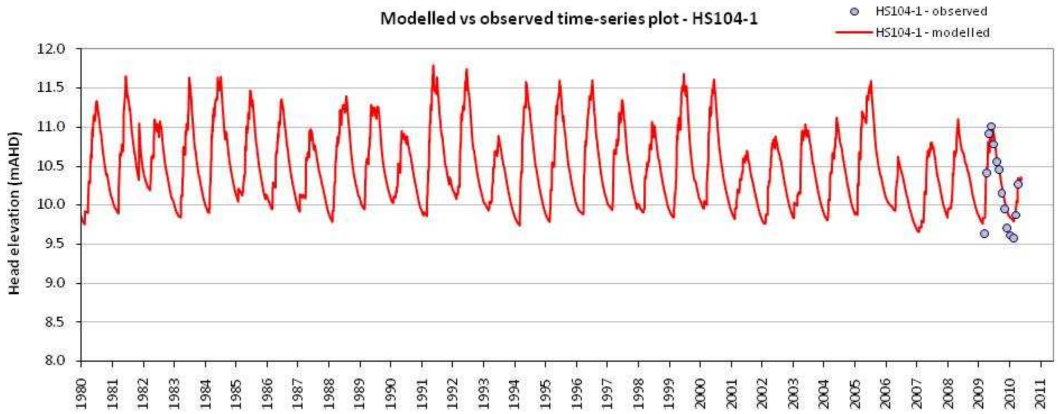
Modelled vs observed time-series plot - HS104-1
HS104-1 - observed
HS104-1 - modelled
Head elevation (mAHD)
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11.0
10.5
10.0
9.5
9.0
8.5
8.0
1980
1981
1982
1983
1984
1985
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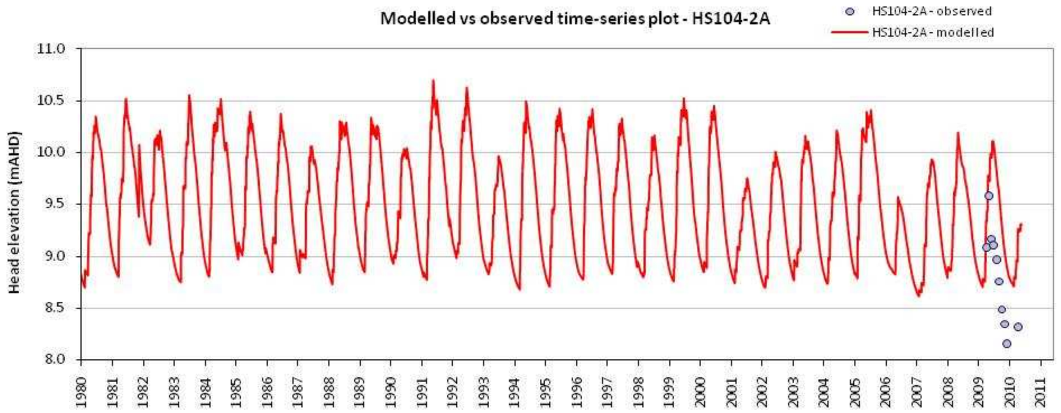
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HS104-2A - observed
HS104-2A - modelled
Head elevation (mAHD)
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10.0
9.5
9.0
8.5
8.0
1980
1981
1982
1983
1984
1985
1986
1987
1988
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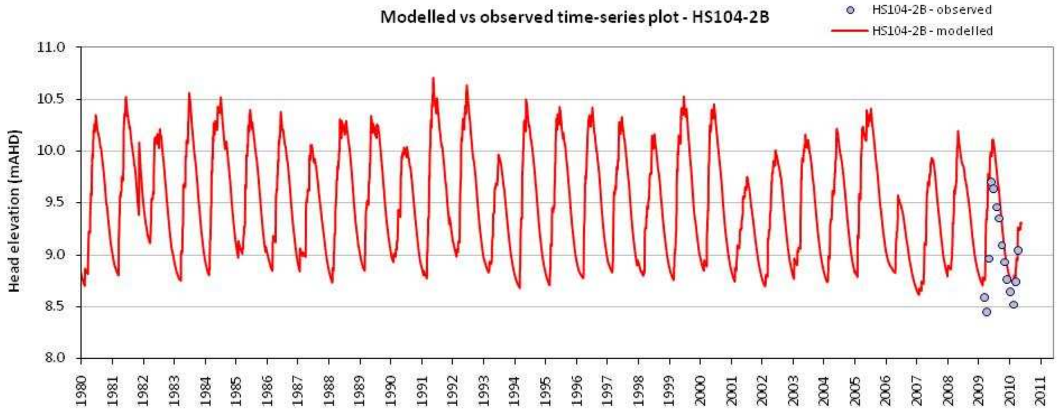
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HS104-2B - modelled
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9.0
8.5
8.0
1980
1981
1982
1983
1984
1985
1986
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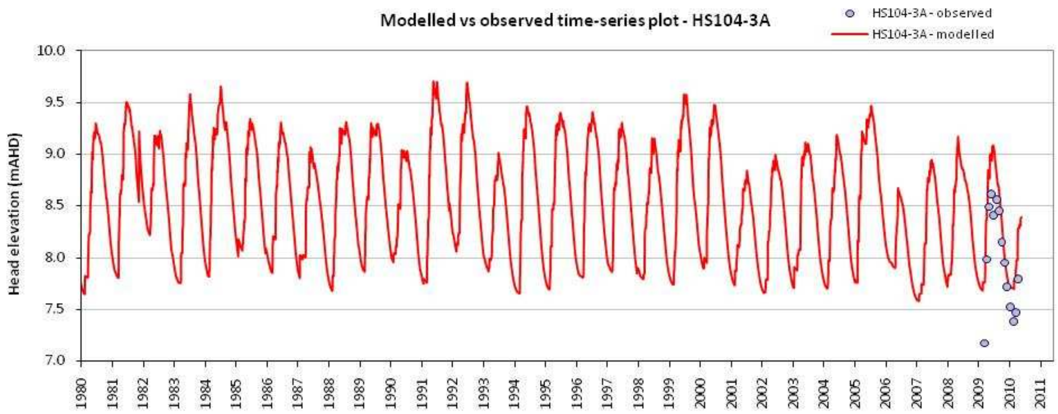
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HS104-3A - modelled
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9.5
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8.5
8.0
7.5
7.0
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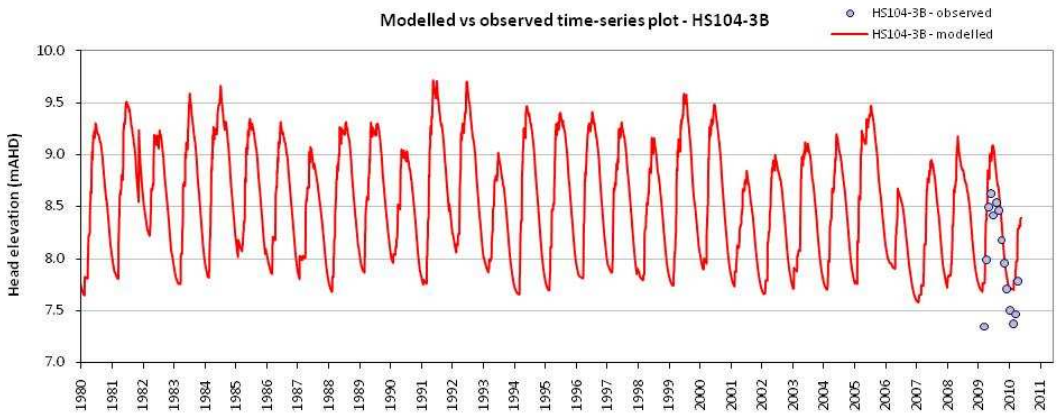
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HS104-3B - modelled
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7.5
7.0
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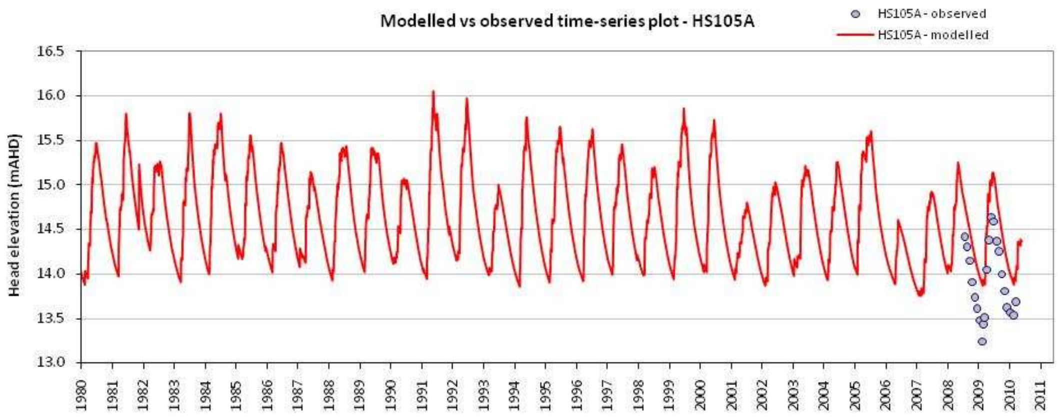
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HS105A - modelled
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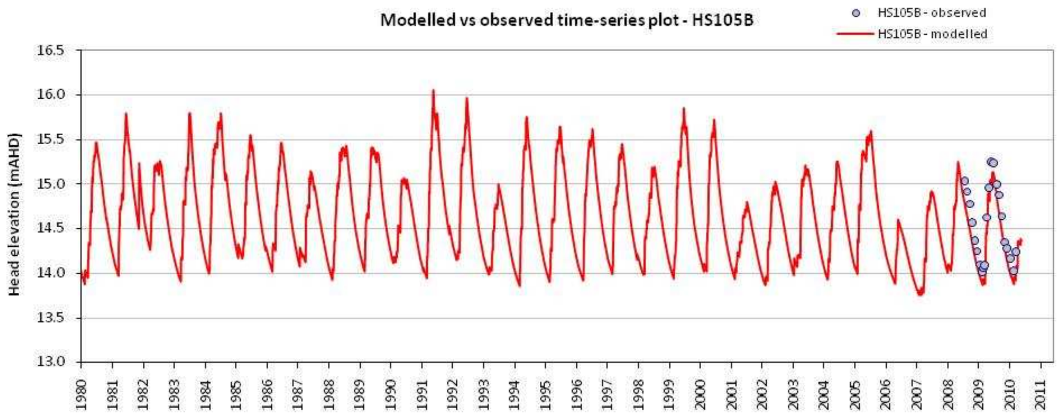
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HS105B - modelled
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13.5
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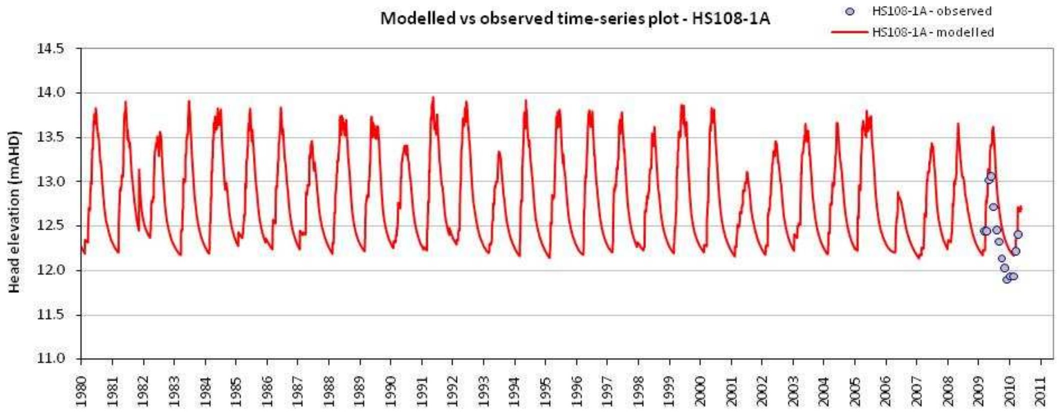
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011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HS108-1A - modelled
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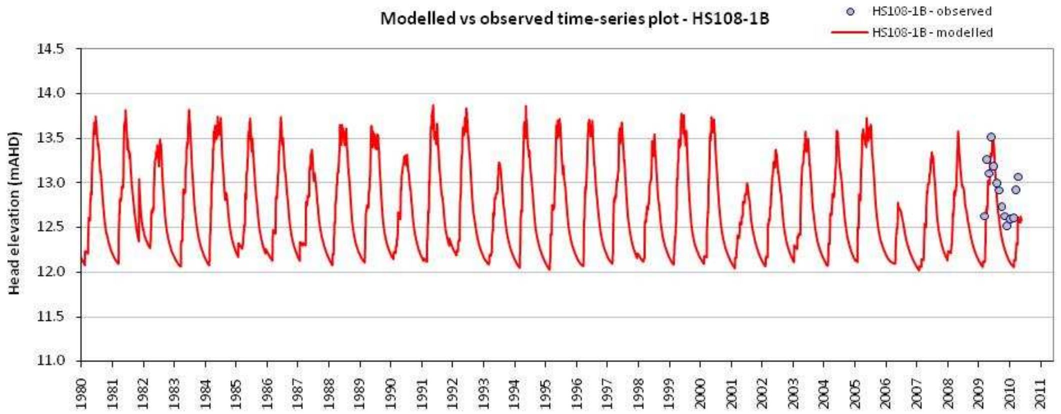
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HS108-1B - modelled
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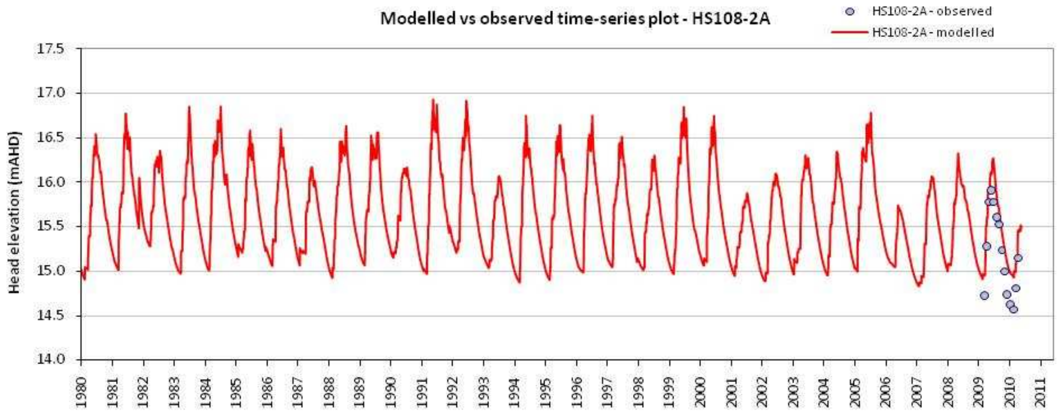
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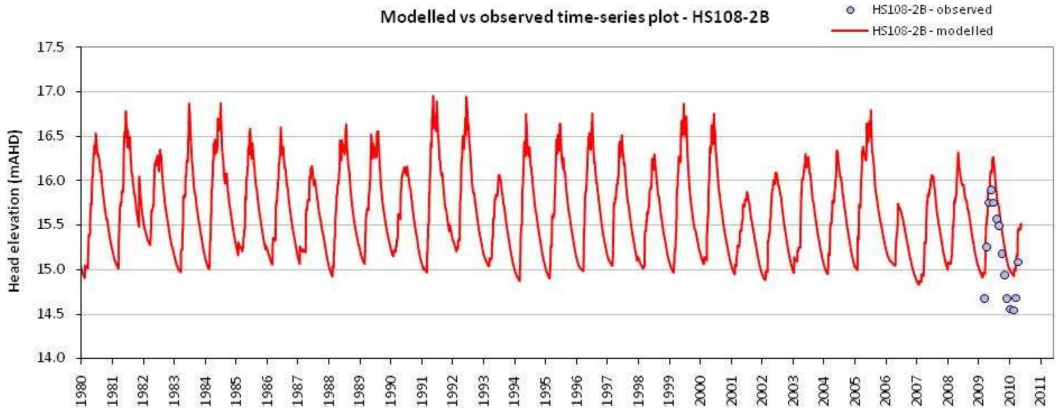
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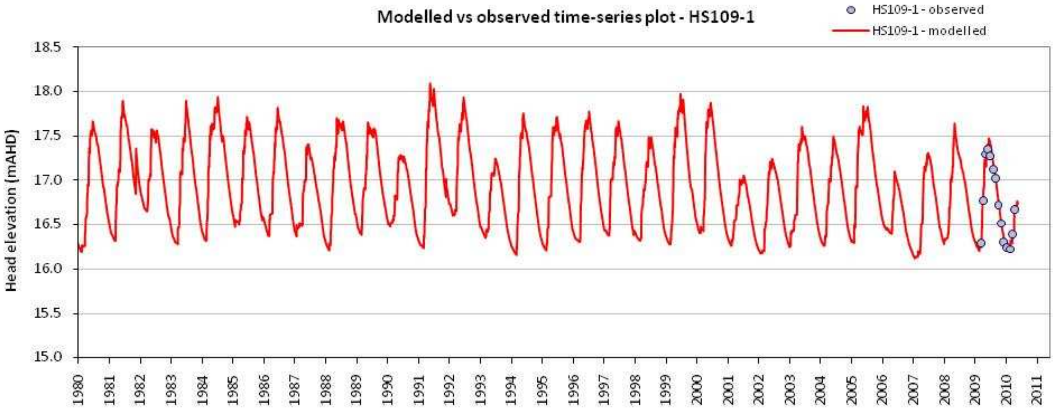
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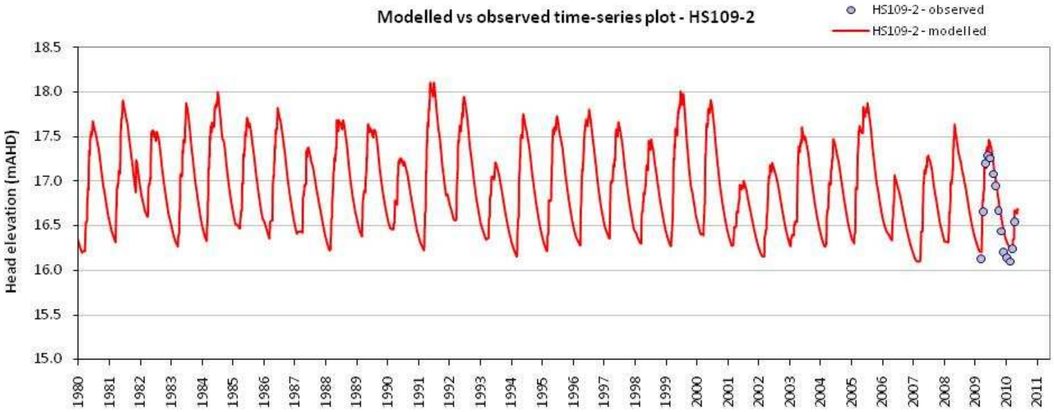
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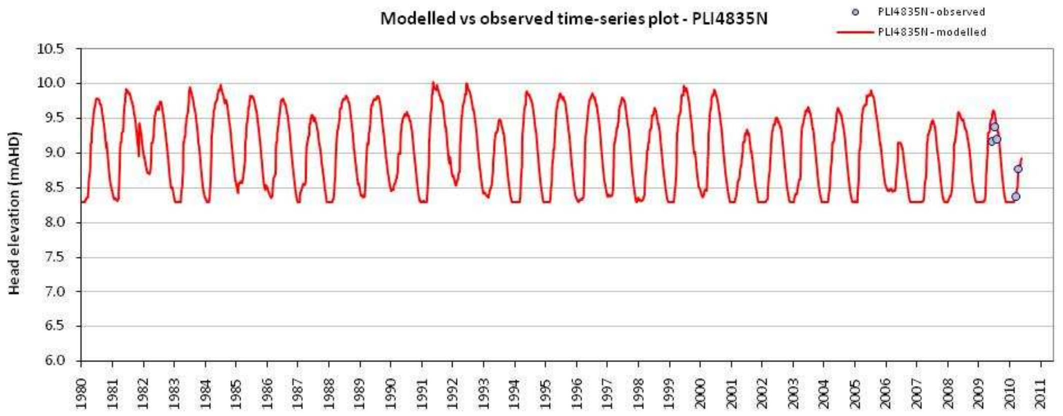
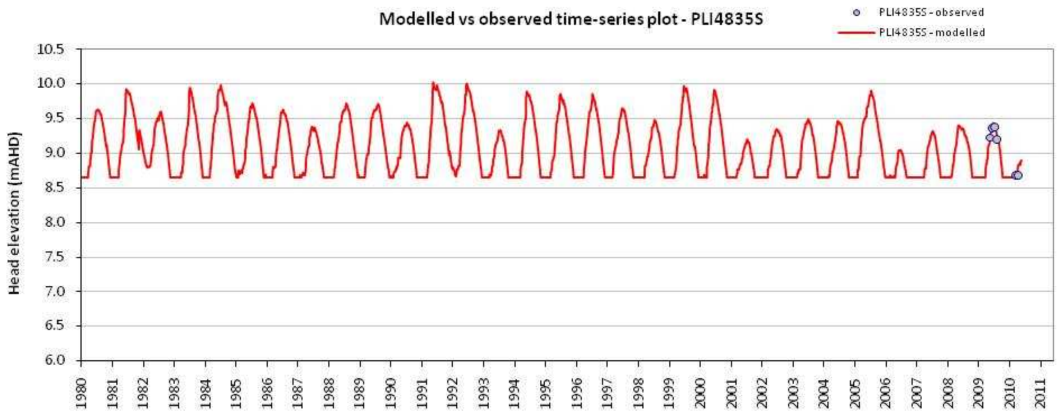
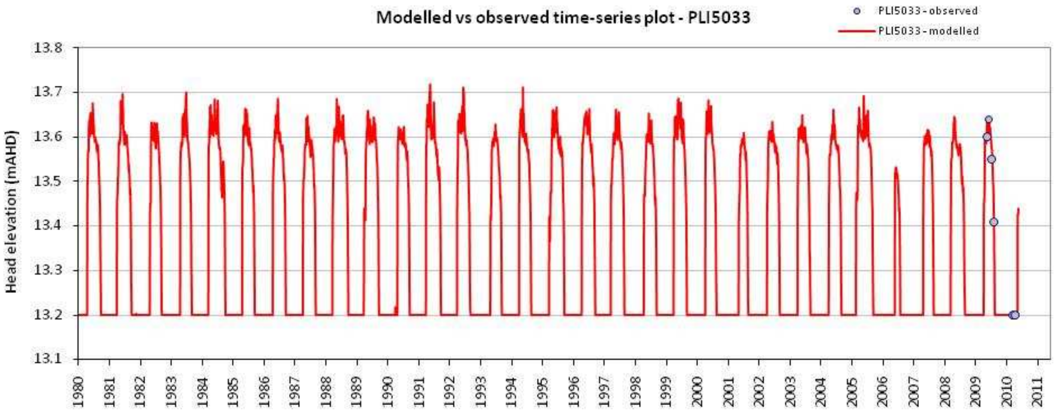
Department of Water gauge boards






Modelled vs observed time-series plot - PLI5033
PLI5033 - observed
PLI5033 - modelled
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13.6
13.5
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13.3
13.2
13.1
1980
1981
1982
1983
1984
1985
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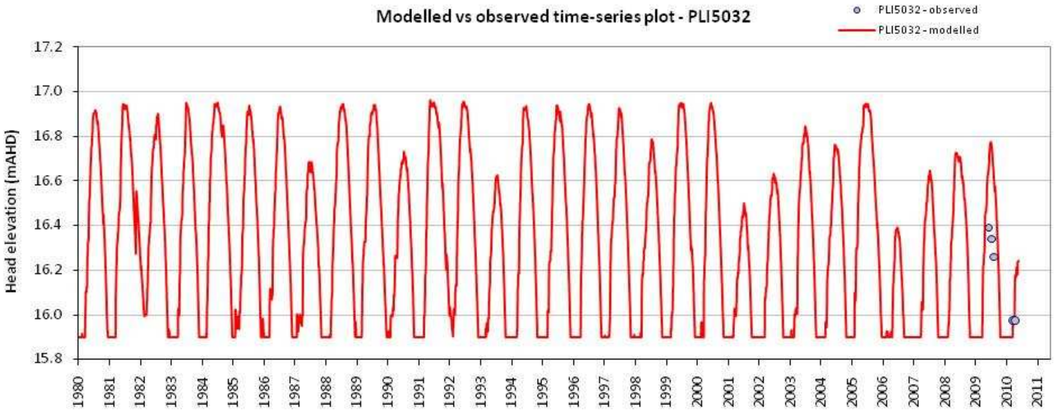
Modelled vs observed time-series plot - PLI5032
PLI5032 - observed
PLI5032 - modelled
Head elevation (mAHD)
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17.0
16.8
16.6
16.4
16.2
16.0
15.8
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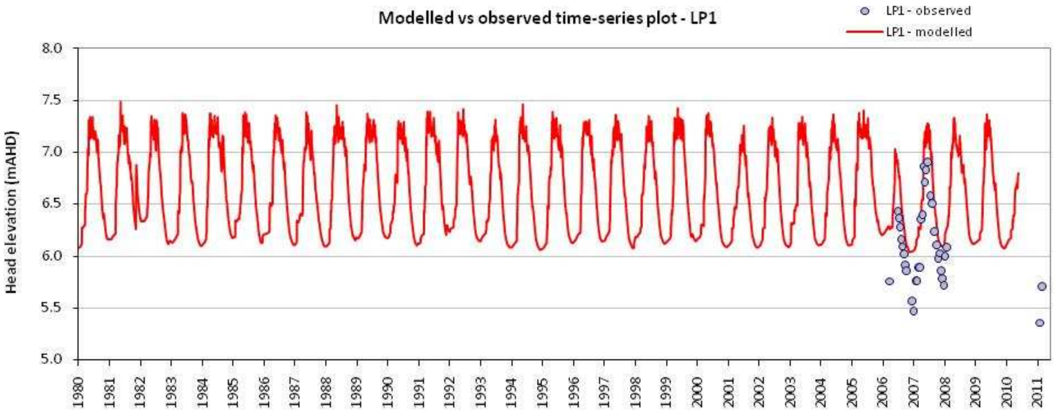
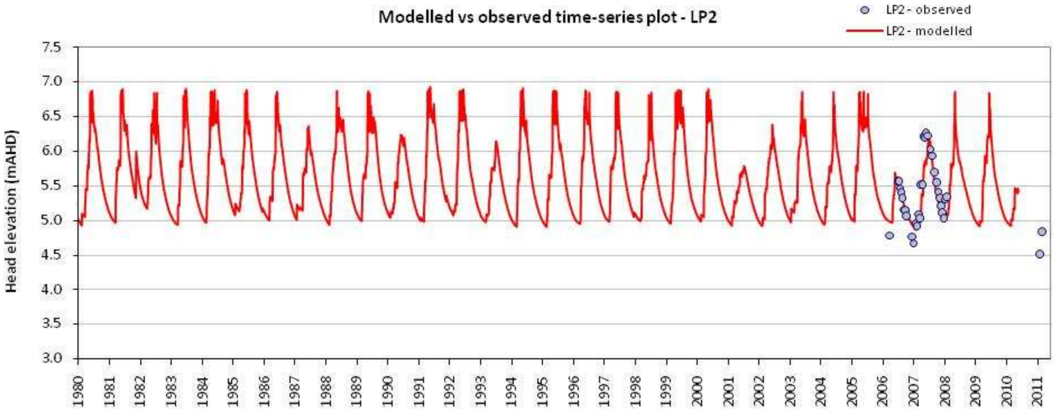
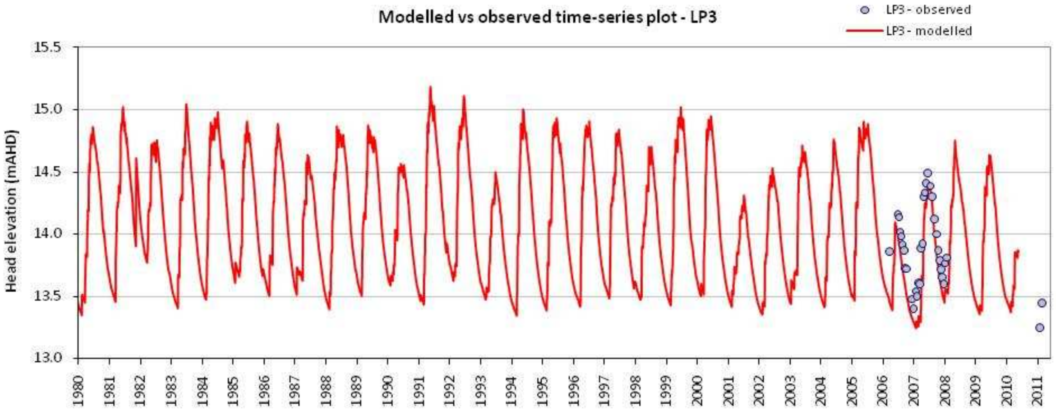
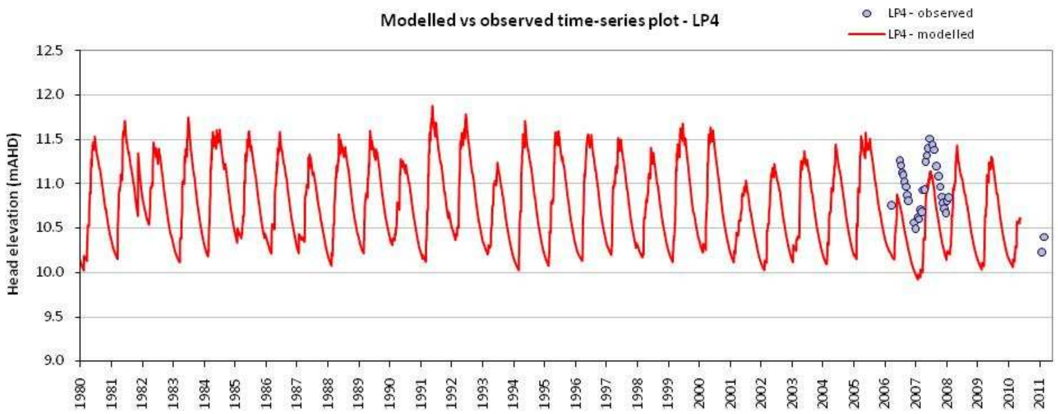
Consultant bores








Modelled vs observed time-series plot - LP4
LP4 - observed
LP4 - modelled
Head elevation (mAHD)
12.5
12.0
11.5
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9.5
9.0
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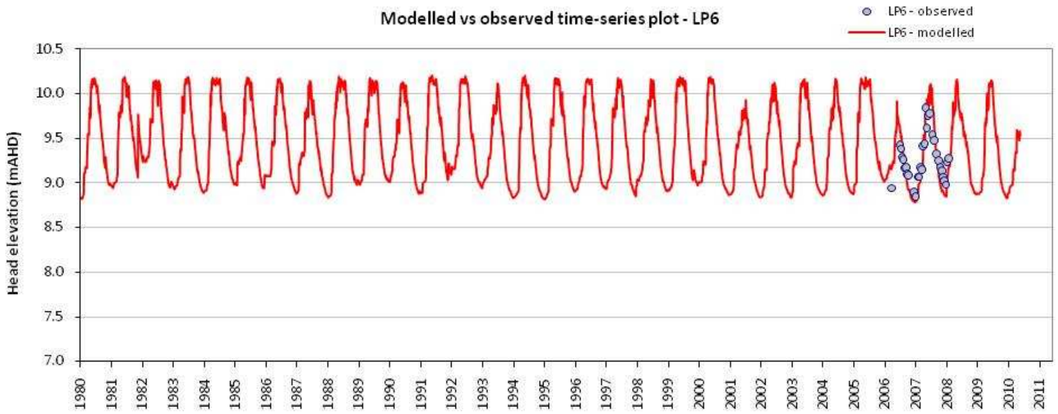
Modelled vs observed time-series plot - LP6
LP6 - observed
LP6 - modelled
Head elevation (mAHD)
10.5
10.0
9.5
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8.0
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7.0
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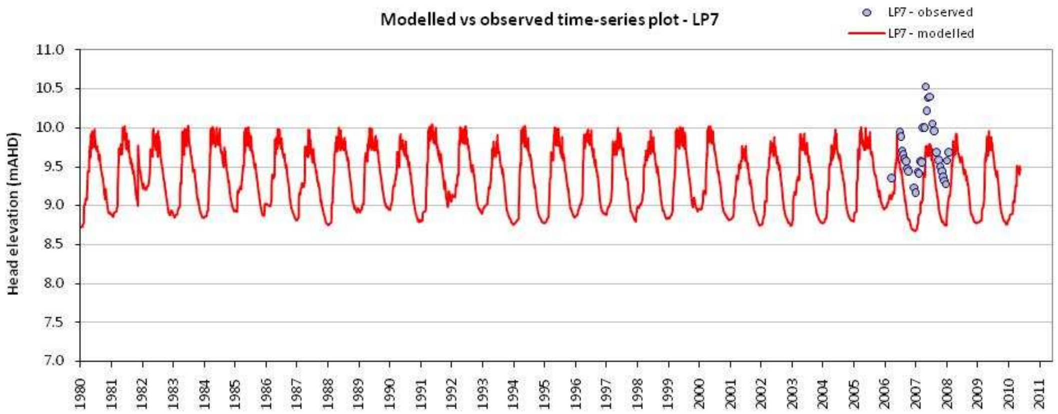
Modelled vs observed time-series plot - LP7
LP7 - observed
LP7 - modelled
Head elevation (mAHD)
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10.0
9.5
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7.5
7.0
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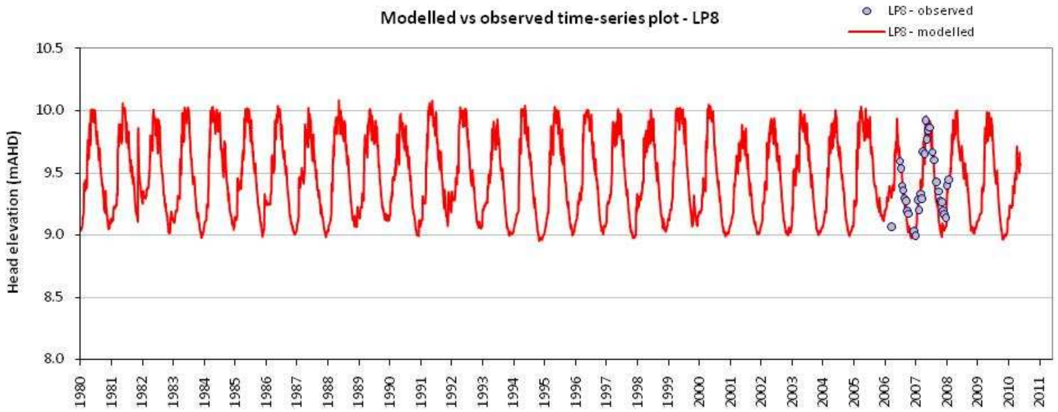
Modelled vs observed time-series plot - LP8
LP8 - observed
LP8 - modelled
Head elevation (mAHD)
10.5
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9.0
8.5
8.0
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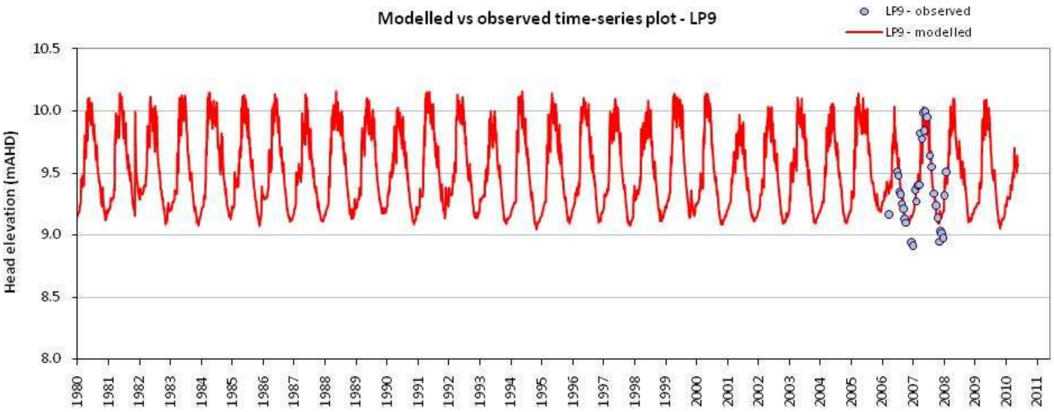
Modelled vs observed time-series plot - LP9
LP9 - observed
LP9 - modelled
Head elevation (mAHD)
10.5
10.0
9.5
9.0
8.5
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1980
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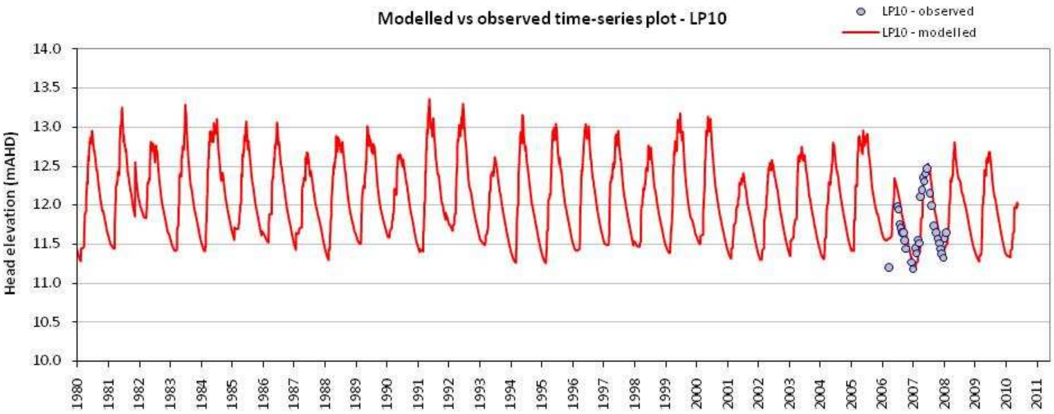
Modelled vs observed time-series plot - LP10
LP10 - observed
LP10 - modelled
Head elevation (mAHD)
14.0
13.5
13.0
12.5
12.0
11.5
11.0
10.5
10.0
1980
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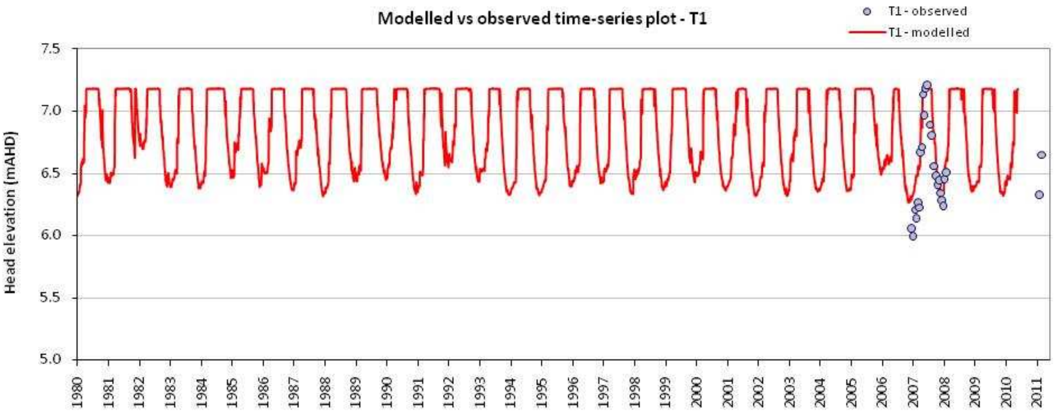
Modelled vs observed time-series plot - T1
T1 - observed
T1 - modelled
Head elevation (mAHD)
7.5
7.0
6.5
6.0
5.5
5.0
1980
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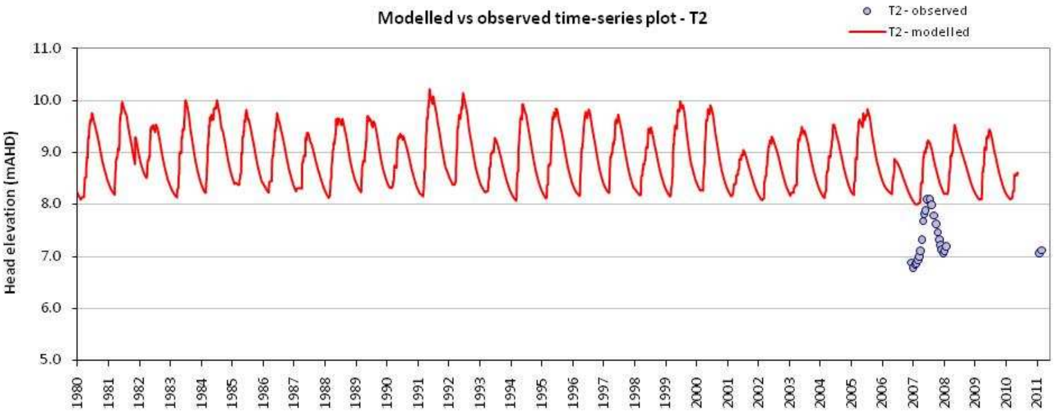
Modelled vs observed time-series plot - T2
T2 - observed
T2 - modelled
Head elevation (mAHD)
11.0
10.0
9.0
8.0
7.0
6.0
5.0
1980
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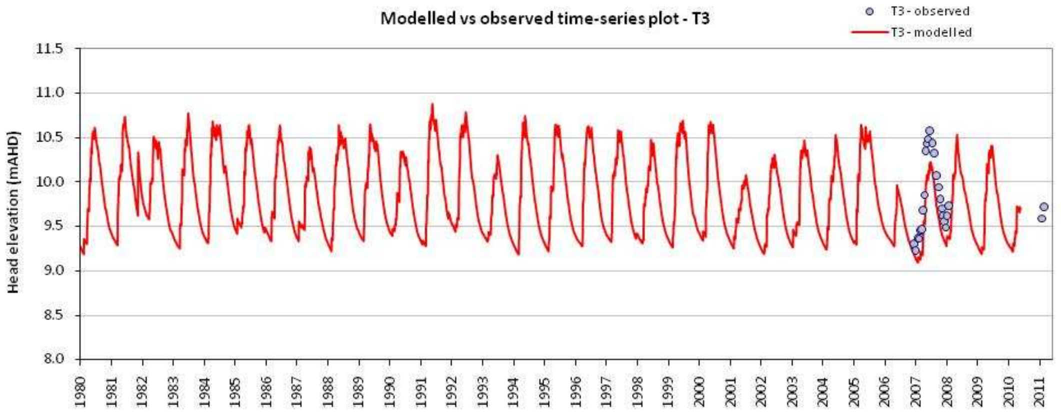
Modelled vs observed time-series plot - T3
T3 - observed
T3 - modelled
Head elevation (mAHD)
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
1980
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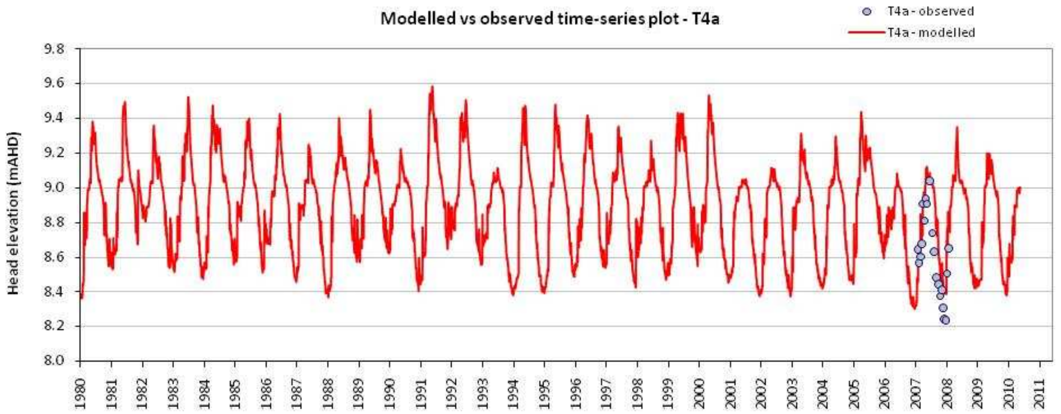
Modelled vs observed time-series plot - T4a
T4a - observed
T4a - modelled
Head elevation (mAHD)
9.8
9.6
9.4
9.2
9.0
8.8
8.6
8.4
8.2
8.0
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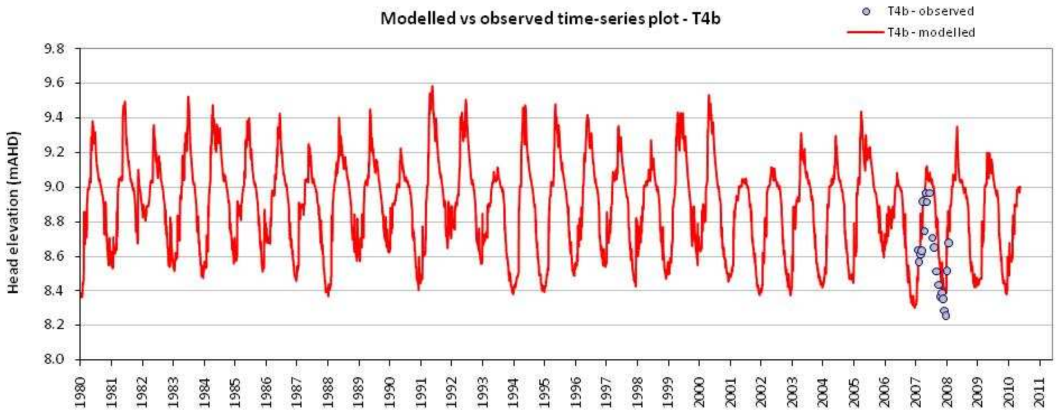
Modelled vs observed time-series plot - T4b
T4b - observed
T4b - modelled
Head elevation (mAHD)
9.8
9.6
9.4
9.2
9.0
8.8
8.6
8.4
8.2
8.0
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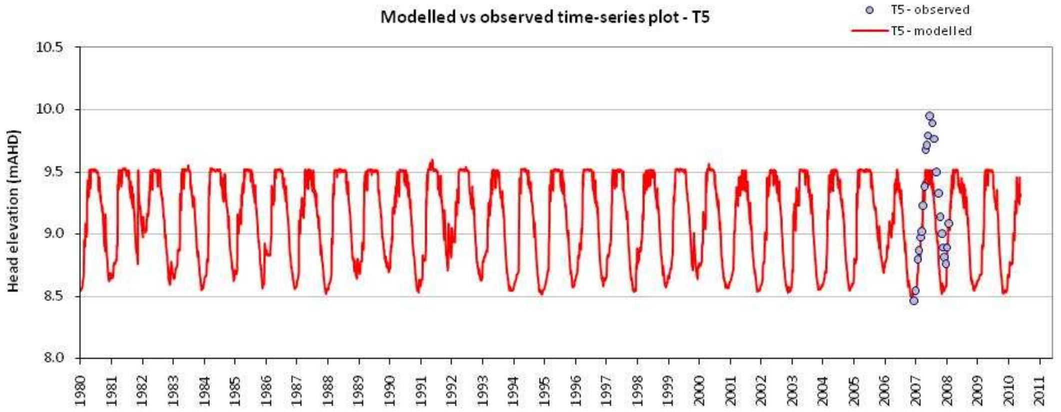
Modelled vs observed time-series plot - T5
T5 - observed
T5 - modelled
Head elevation (mAHD)
10.5
10.0
9.5
9.0
8.5
8.0
1980
1981
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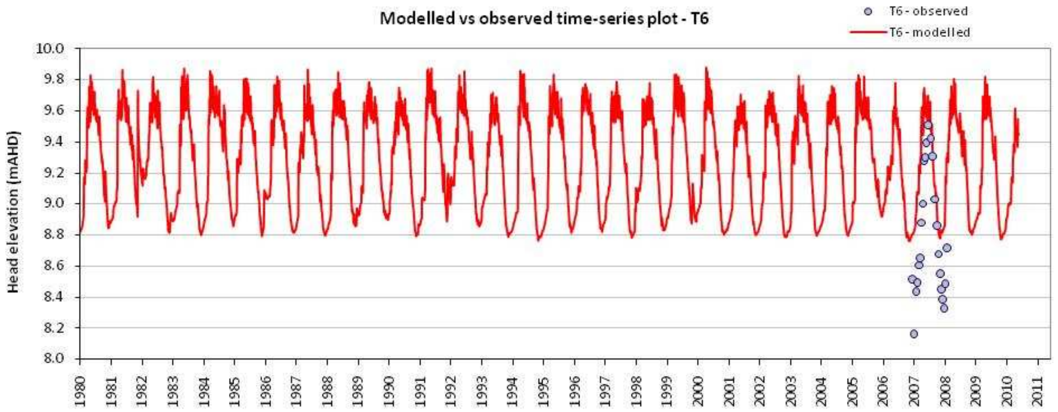
Modelled vs observed time-series plot - T6
T6 - observed
T6 - modelled
Head elevation (mAHD)
10.0
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9.6
9.4
9.2
9.0
8.8
8.6
8.4
8.2
8.0
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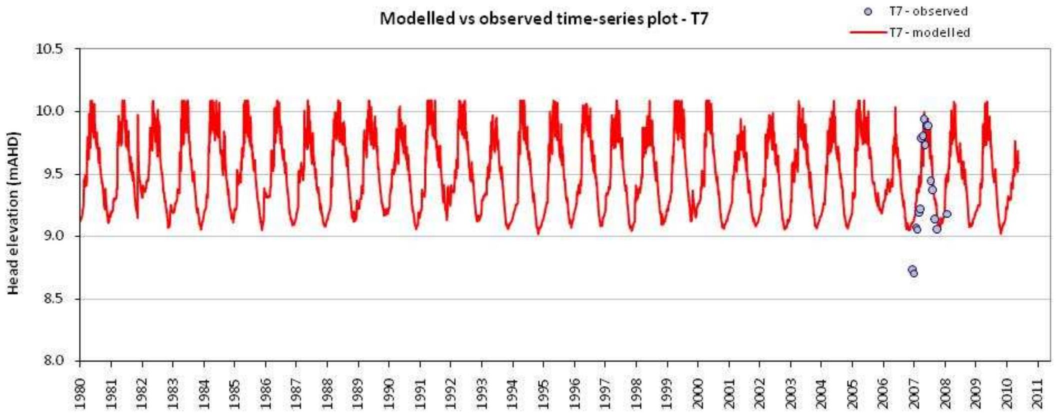
Modelled vs observed time-series plot - T7
T7 - observed
T7 - modelled
Head elevation (mAHD)
10.5
10.0
9.5
9.0
8.5
8.0
1980
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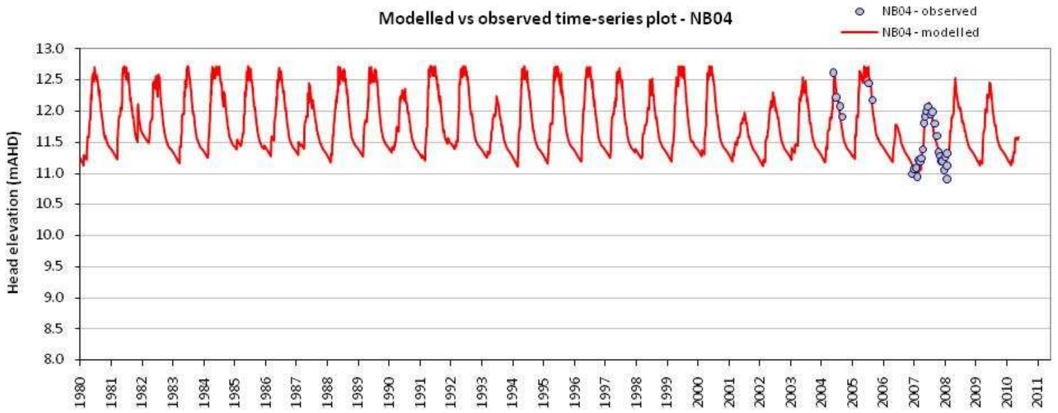
Modelled vs observed time-series plot - NB04
NB04 - observed
NB04 - modelled
Head elevation (mAHD)
13.0
12.5
12.0
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
1980
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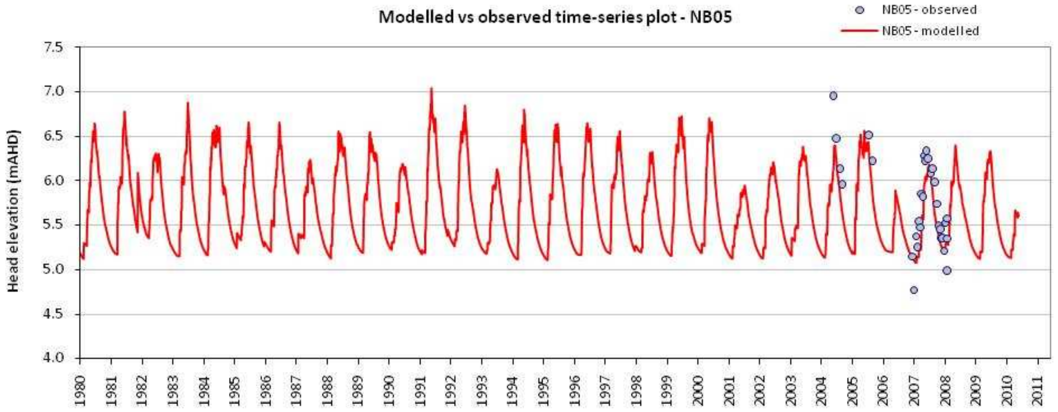
Modelled vs observed time-series plot - NB05
NB05 - observed
NB05 - modelled
Head elevation (mAHD)
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
1980
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1982
1983
1984
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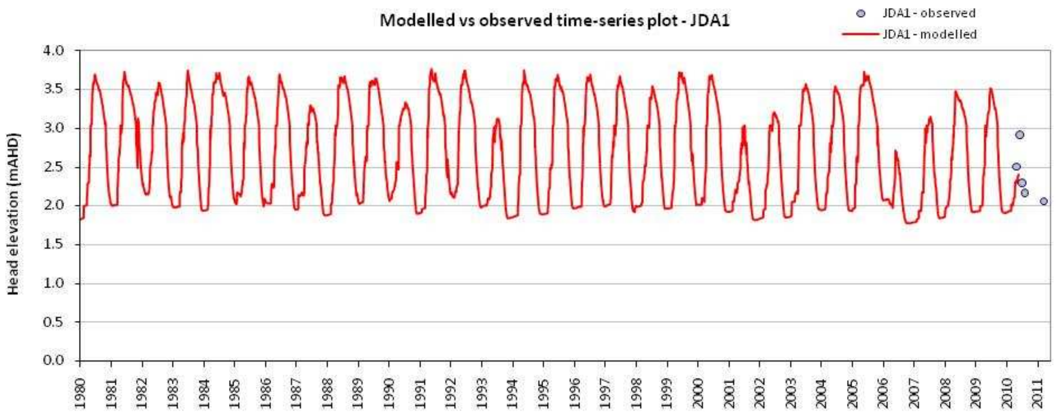
Modelled vs observed time-series plot - JDA1
JDA1 - observed
JDA1 - modelled
Head elevation (mAHD)
4.0
3.5
3.0
2.5
2.0
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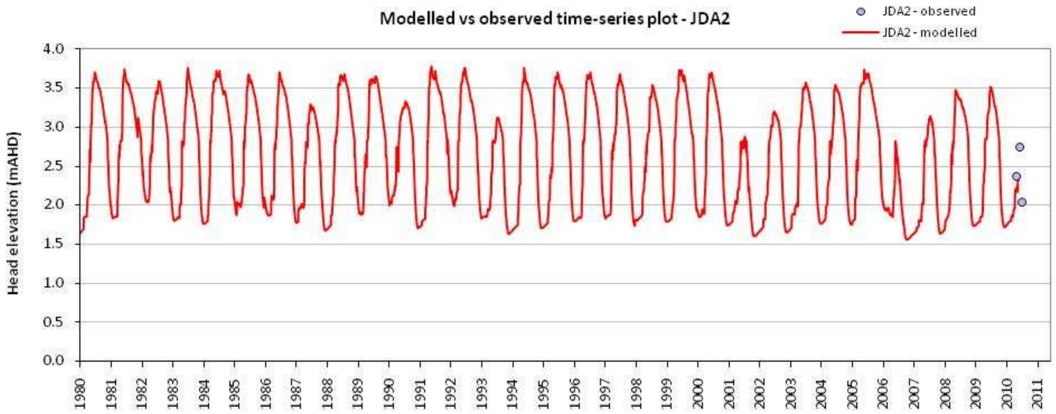
Modelled vs observed time-series plot - JDA2
JDA2 - observed
JDA2 - modelled
Head elevation (mAHD)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
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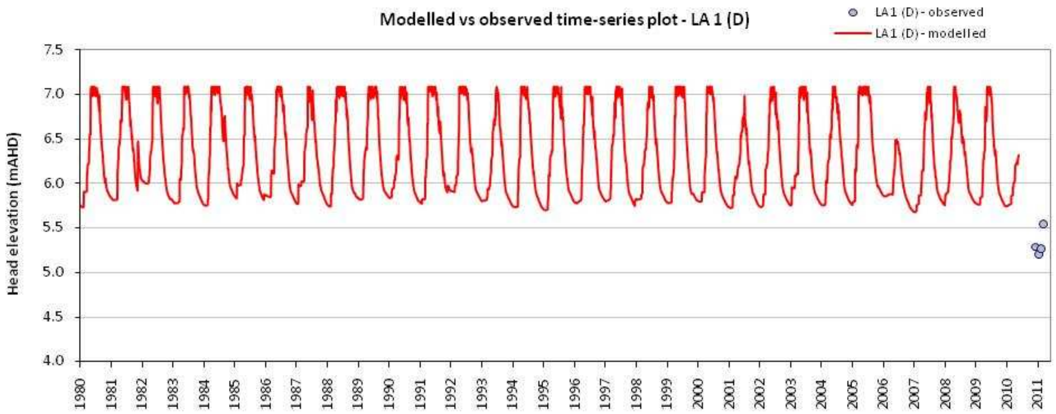
Modelled vs observed time-series plot - LA 1 (D)
LA 1 (D) - observed
LA 1 (D) - modelled
Head elevation (mAHD)
7.5
7.0
6.5
6.0
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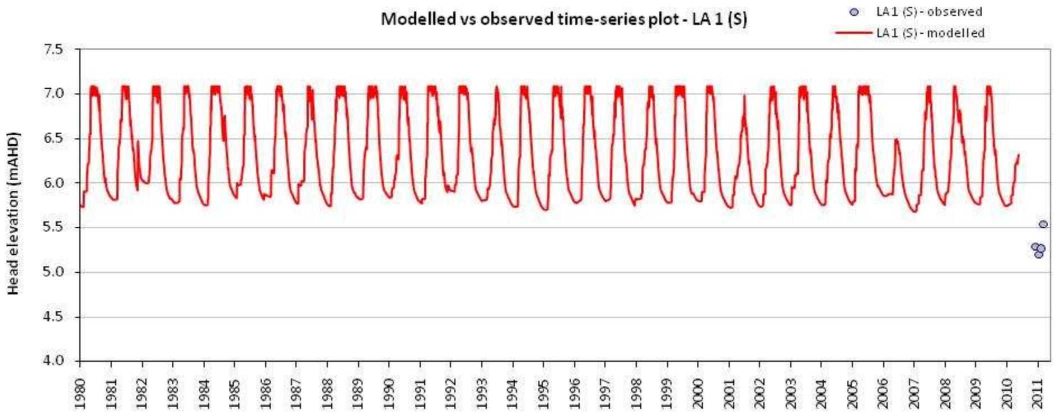
Modelled vs observed time-series plot - LA 1 (S)
LA 1 (S) - observed
LA 1 (S) - modelled
Head elevation (mAHD)
7.5
7.0
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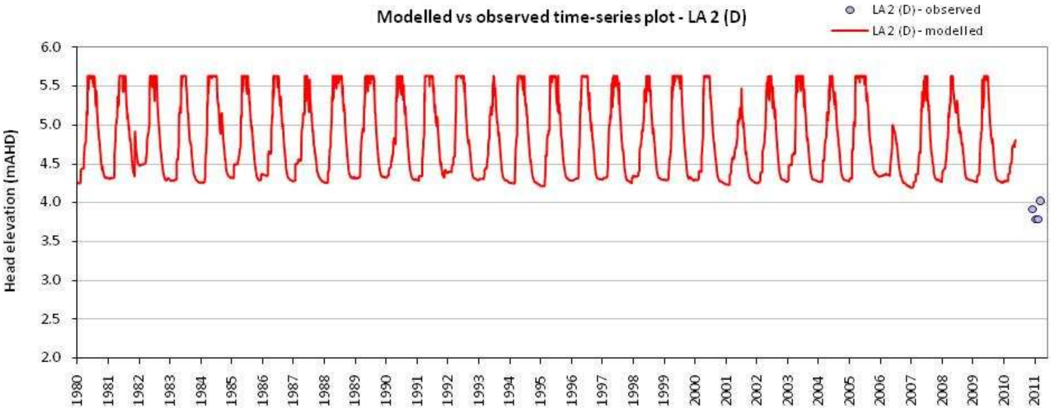
Modelled vs observed time-series plot - LA 2 (D)
LA 2 (D) - observed
LA 2 (D) - modelled
Head elevation (mAHD)
6.0
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5.0
4.5
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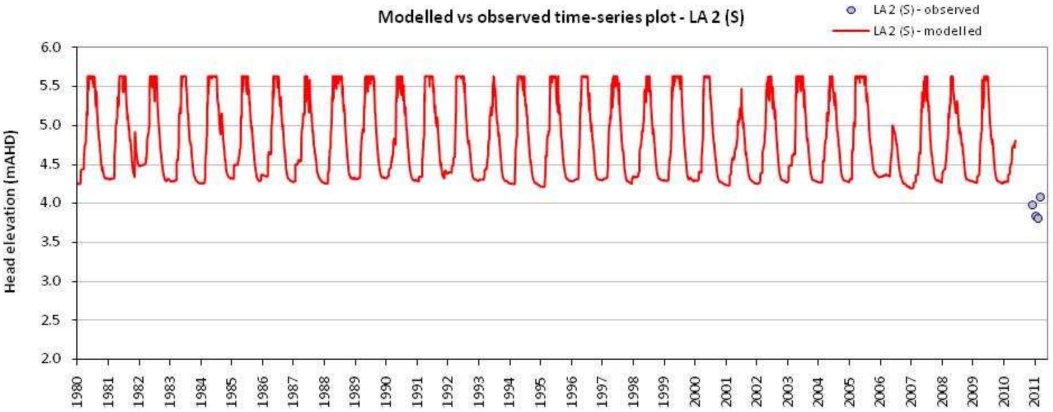
Modelled vs observed time-series plot - LA 2 (S)
LA 2 (S) - observed
LA 2 (S) - modelled
Head elevation (mAHD)
6.0
5.5
5.0
4.5
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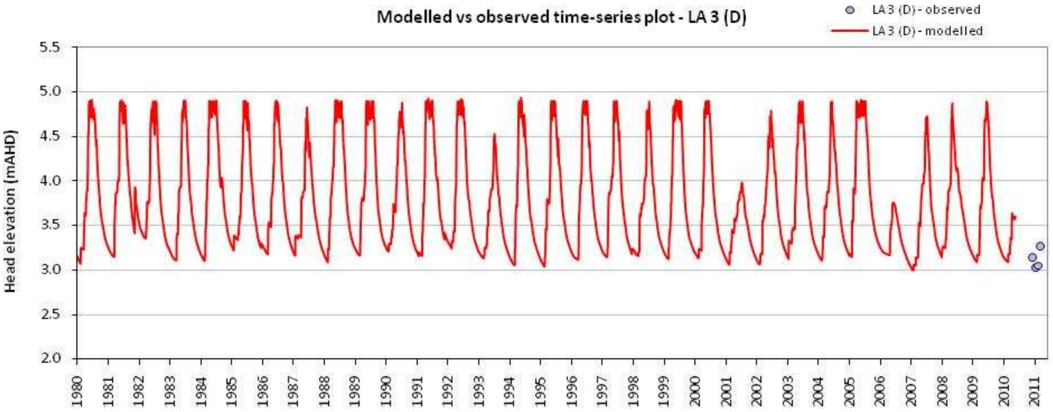
Modelled vs observed time-series plot - LA 3 (D)
LA 3 (D) - observed
LA 3 (D) - modelled
Head elevation (mAHD)
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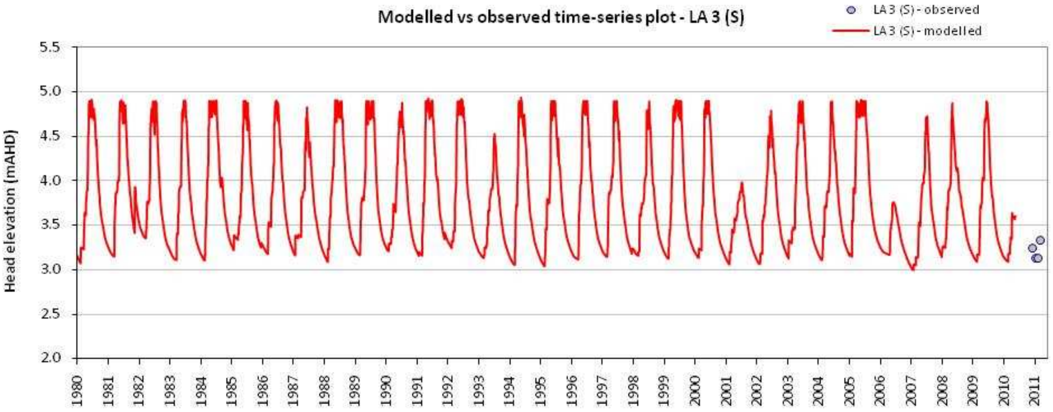
Modelled vs observed time-series plot - LA 3 (S)
LA 3 (S) - observed
LA 3 (S) - modelled
Head elevation (mAHD)
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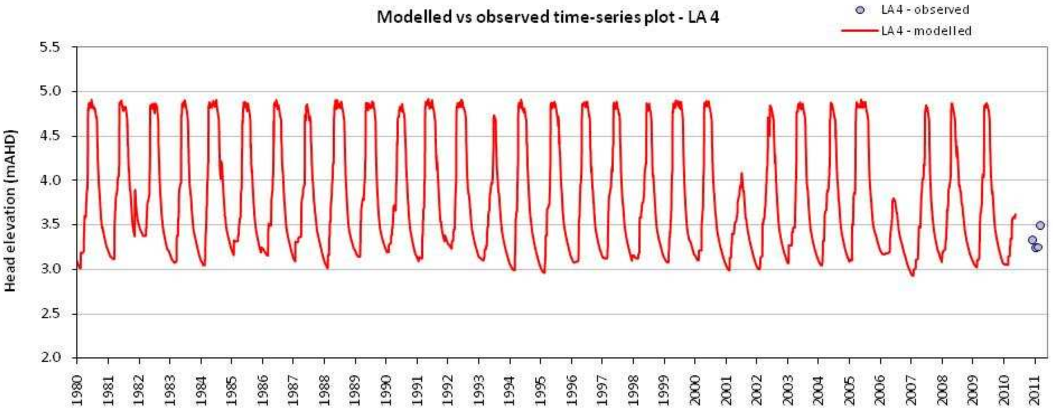
Modelled vs observed time-series plot - LA 4
LA 4 - observed
LA 4 - modelled
Head elevation (mAHD)
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2.5
2.0
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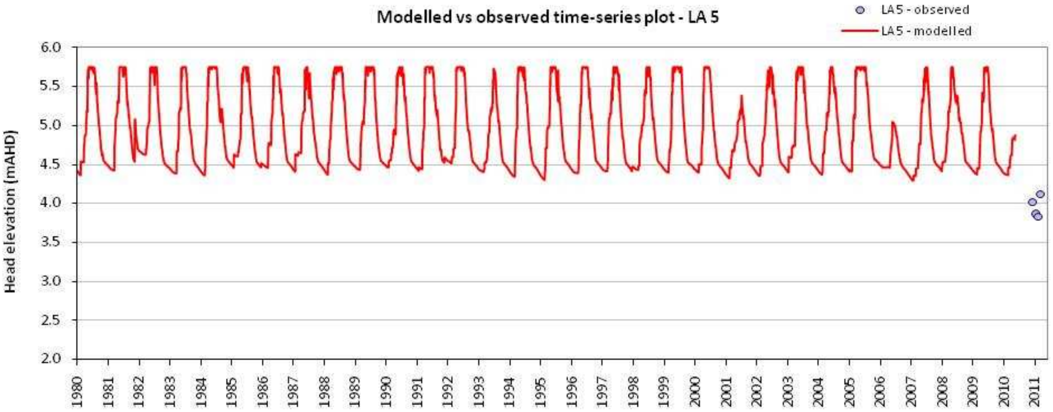
Modelled vs observed time-series plot - LA 5
LA 5 - observed
LA 5 - modelled
Head elevation (mAHD)
6.0
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4.0
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3.0
2.5
2.0
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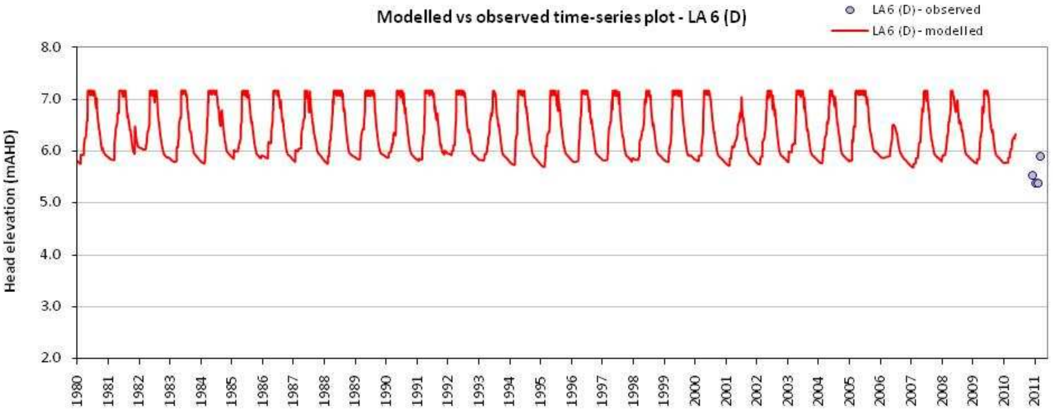
Modelled vs observed time-series plot - LA 6 (D)
LA 6 (D) - observed
LA 6 (D) - modelled
Head elevation (mAHD)
8.0
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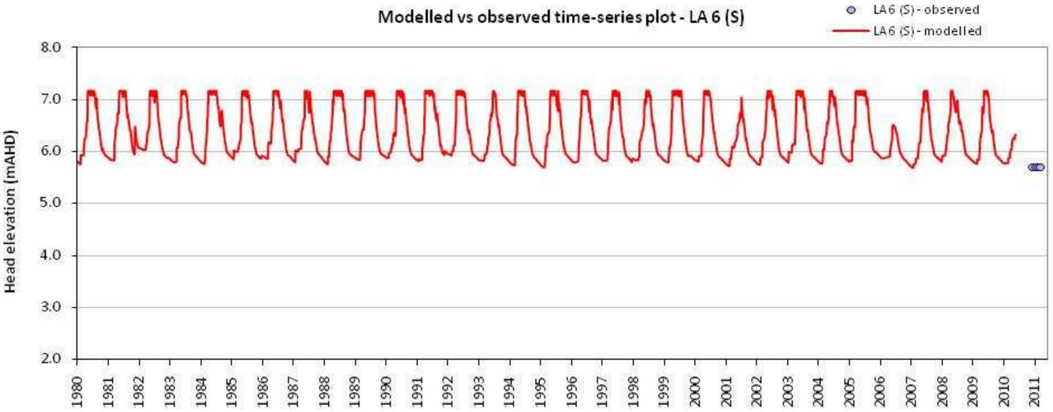
Modelled vs observed time-series plot - LA 6 (S)
LA 6 (S) - observed
LA 6 (S) - modelled
Head elevation (mAHD)
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3.0
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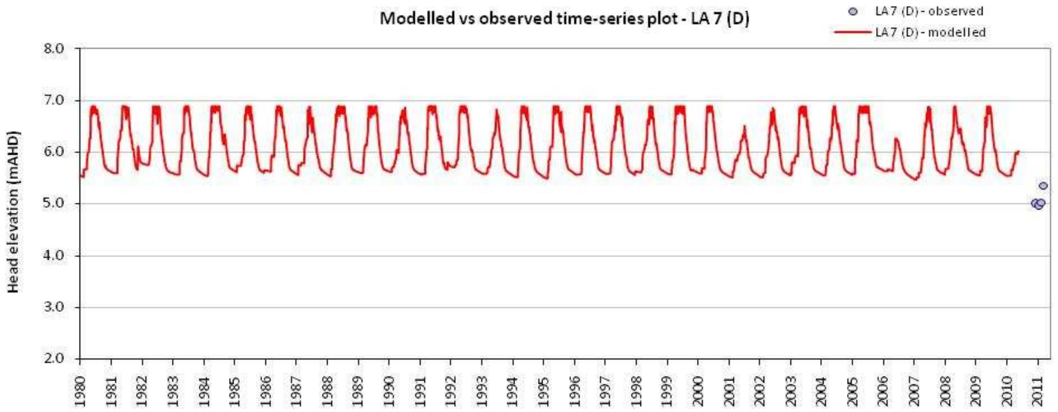
Modelled vs observed time-series plot - LA 7 (D)
LA7 (D) - observed
LA7 (D) - modelled
Head elevation (mAHD)
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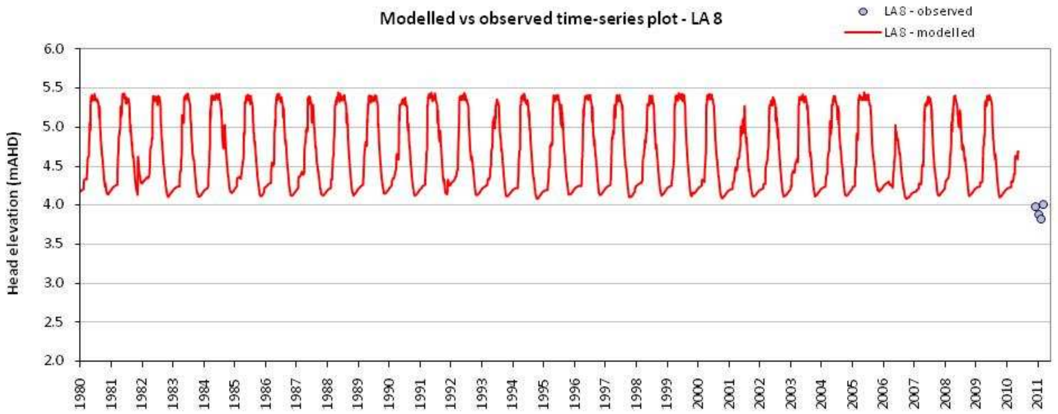
Modelled vs observed time-series plot - LA 8
LA8 - observed
LA8 - modelled
Head elevation (mAHD)
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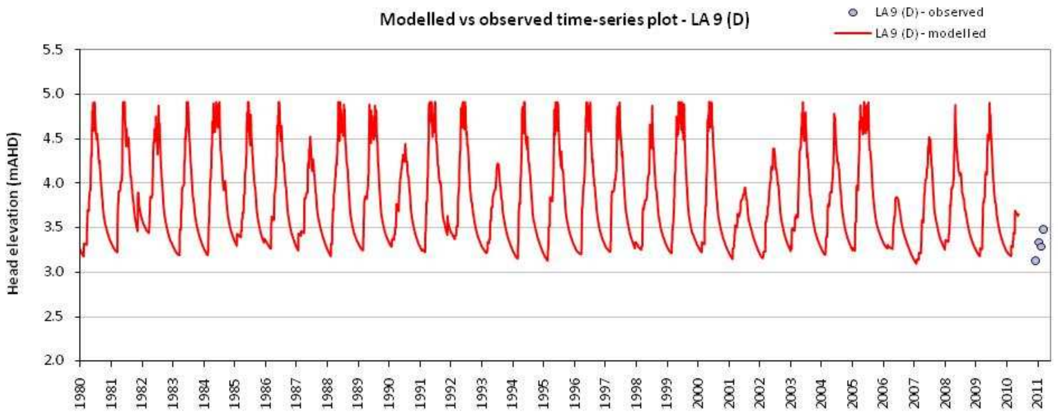
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LA9 (D) - modelled
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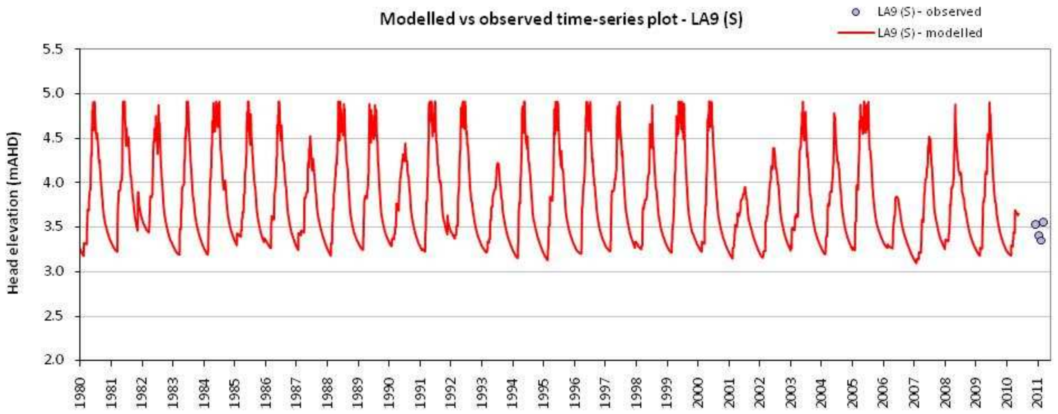
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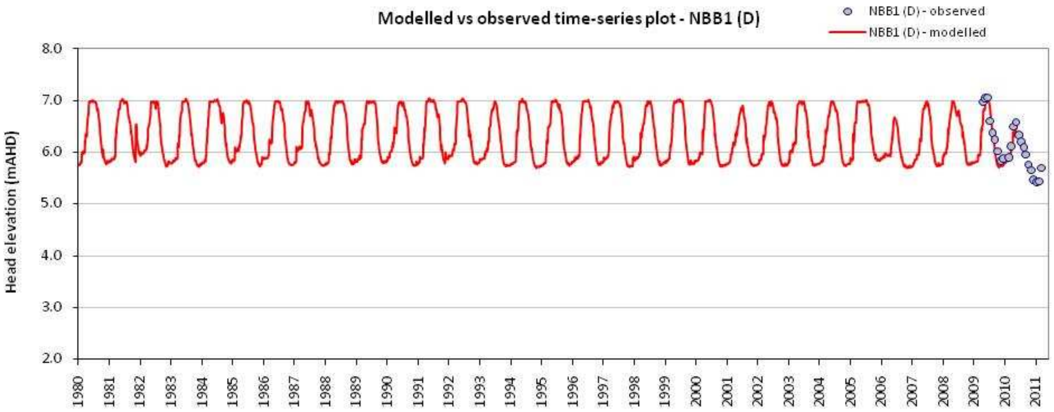
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NBB1 (D) - modelled
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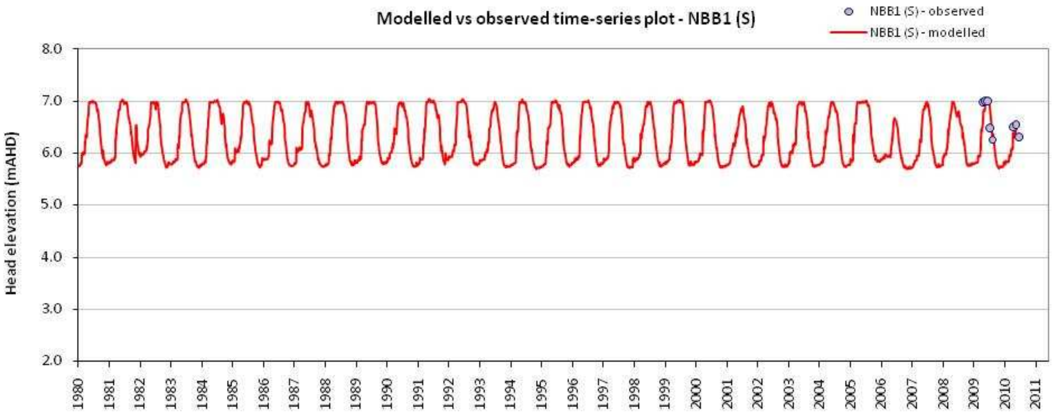
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NBB1 (S) - modelled
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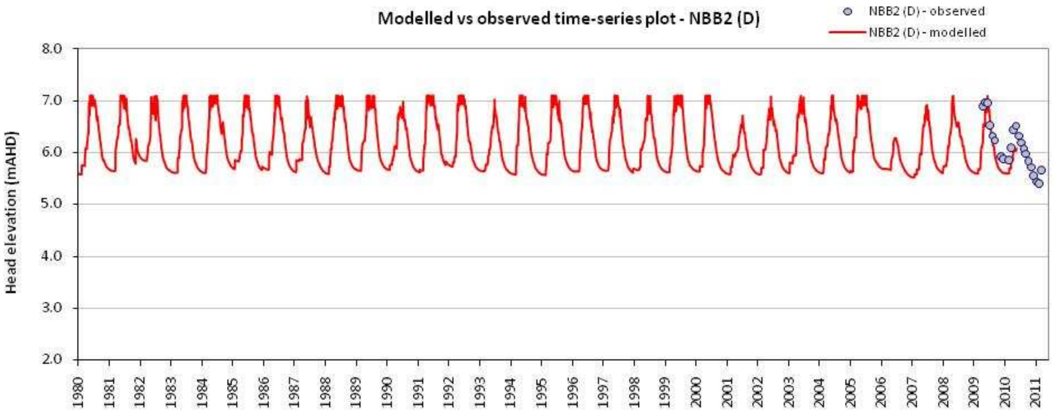
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NBB2 (D) - modelled
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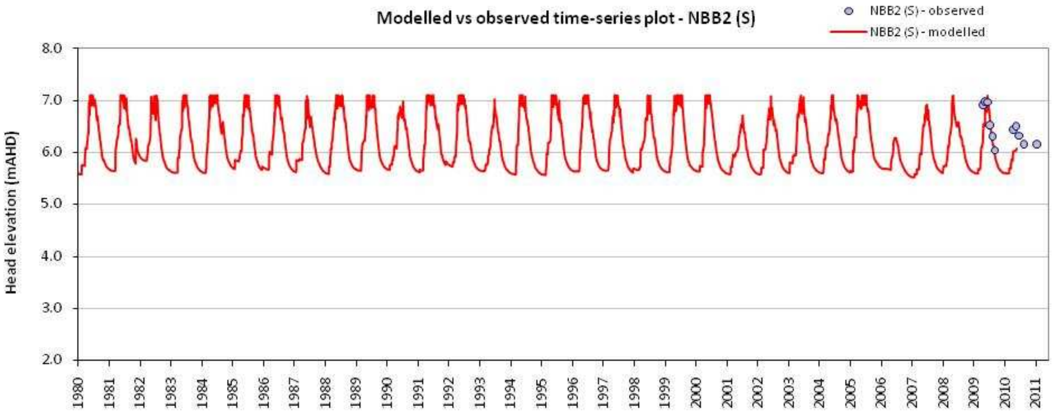
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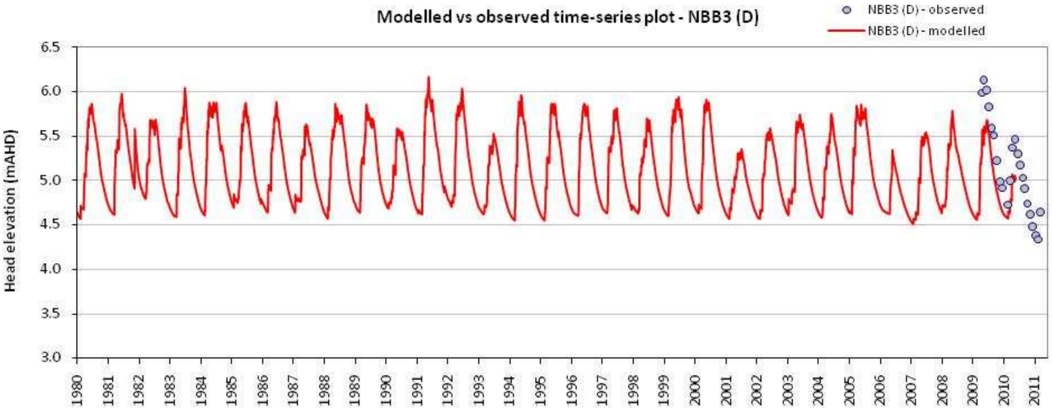
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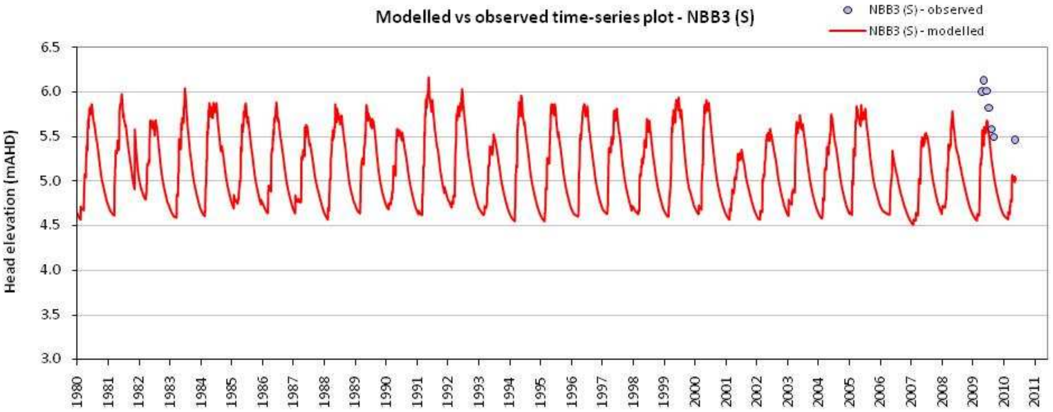
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NBB3 (S) - modelled
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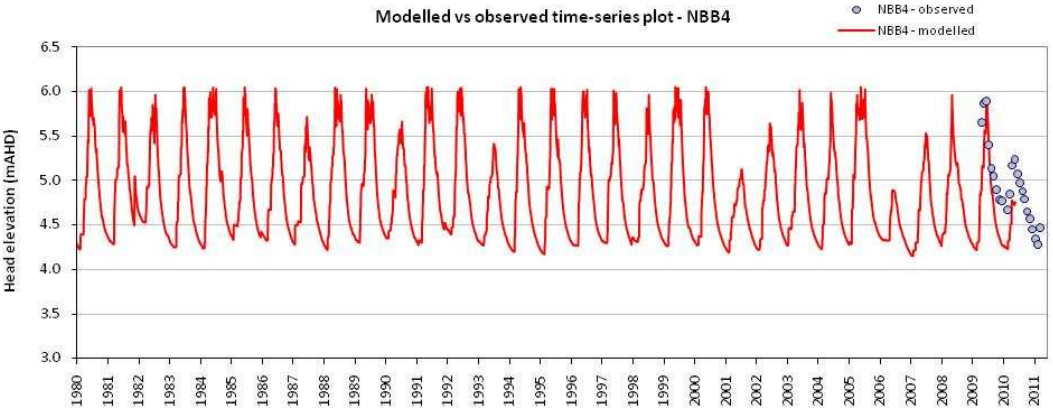
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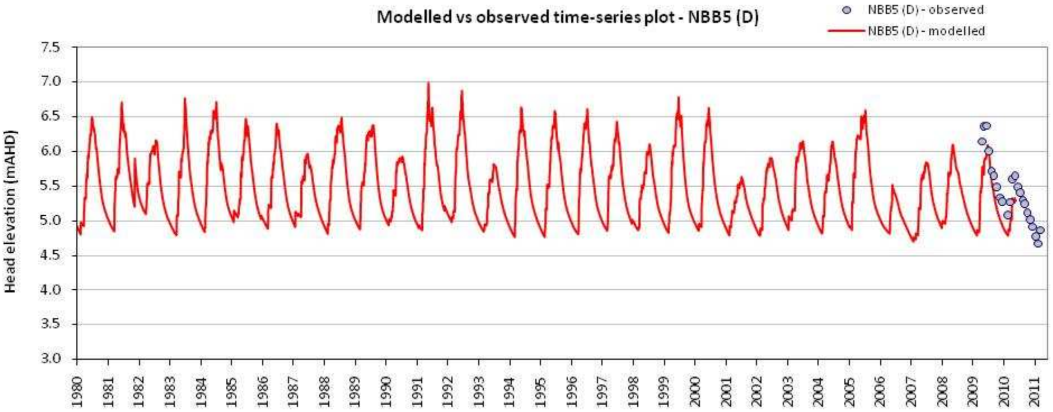
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NBB5 (D) - modelled
Head elevation (mAHD)
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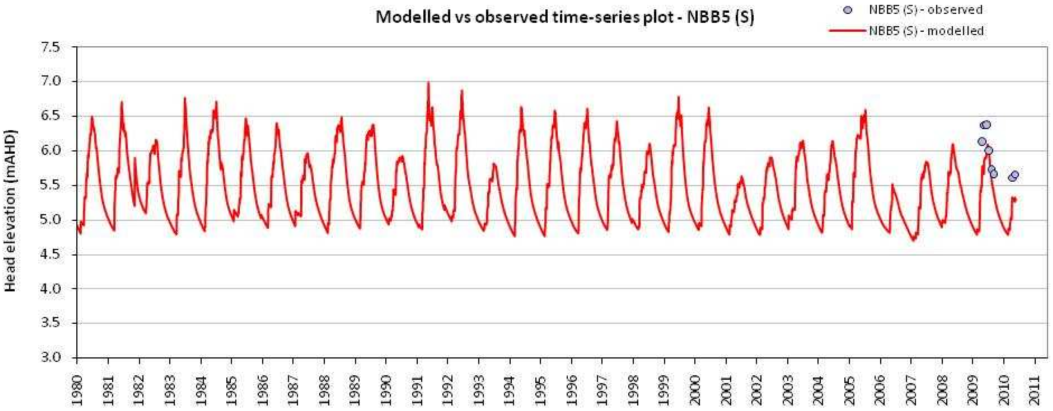
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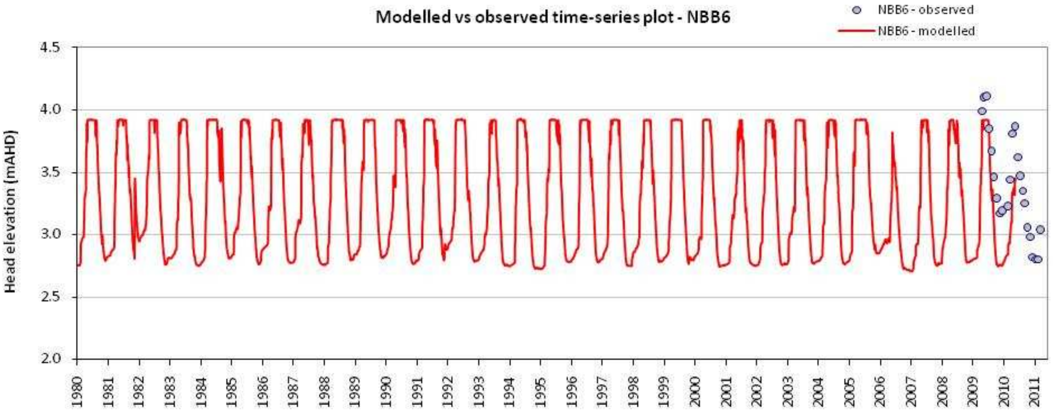
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NBB6 - modelled
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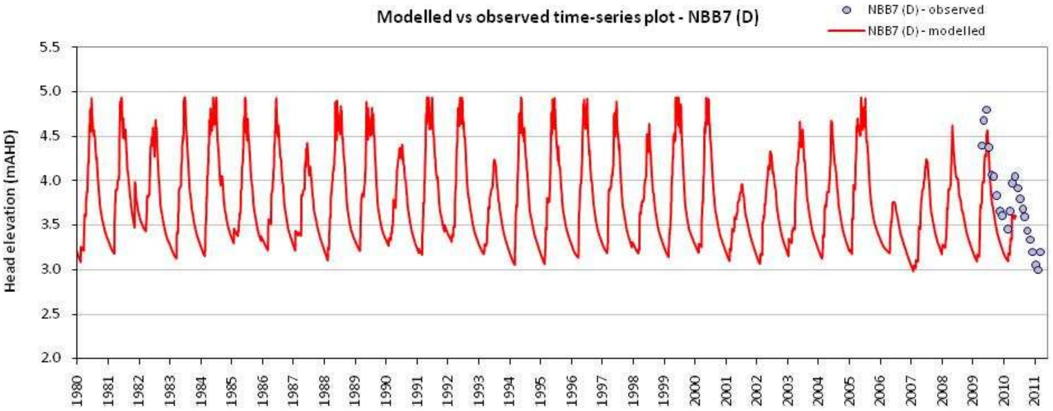
Modelled vs observed time-series plot - NBB7 (D)
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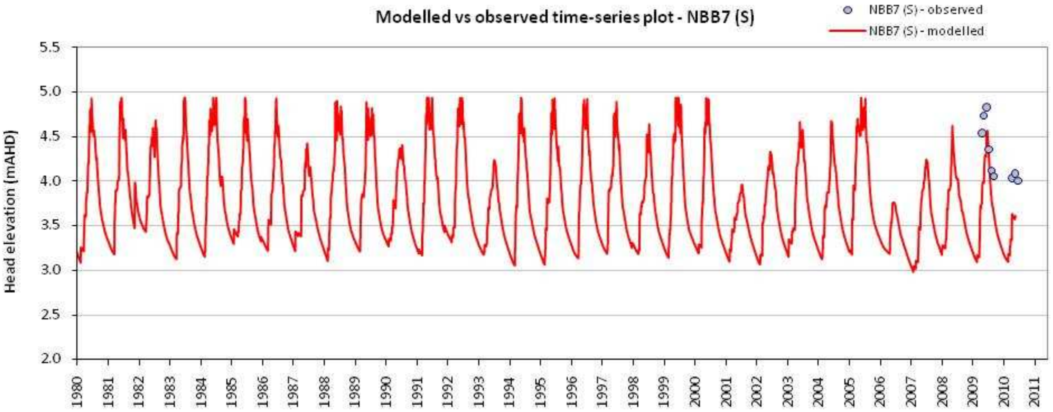
Modelled vs observed time-series plot - NBB7 (S)
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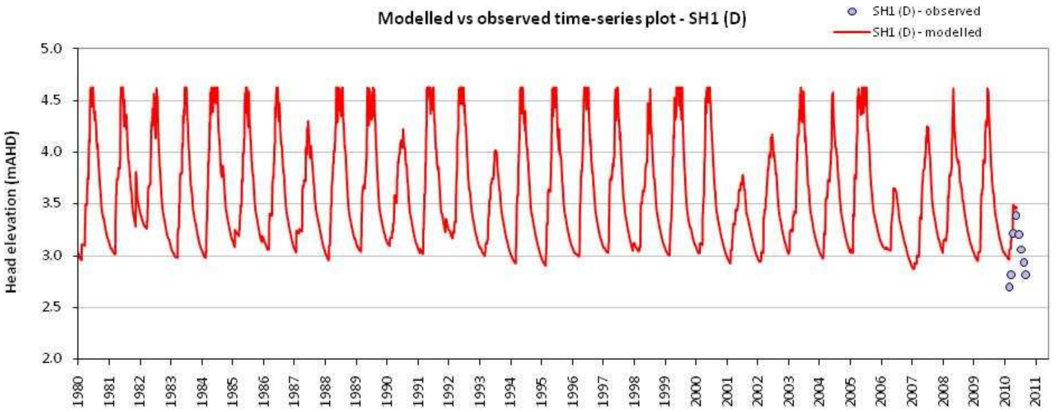
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SH1 (D) - modelled
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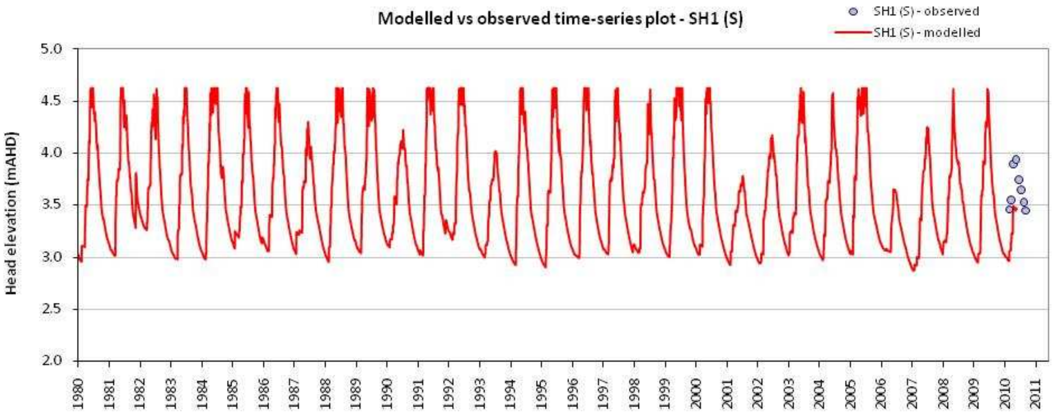
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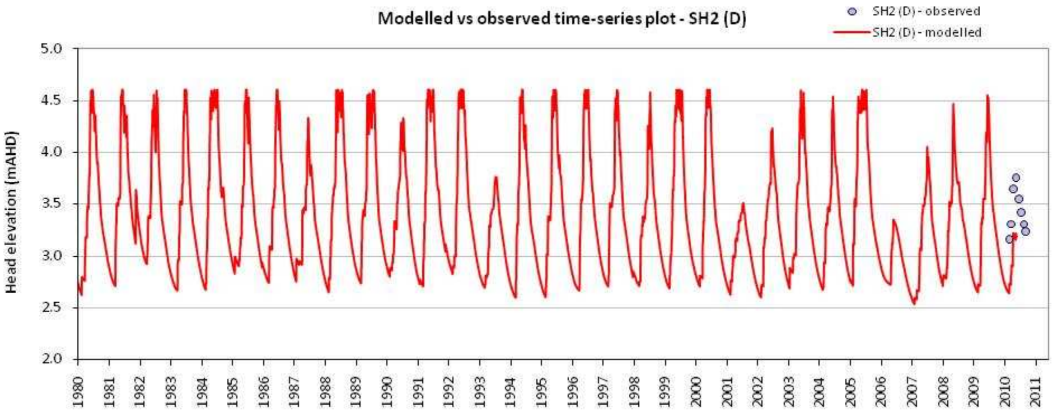
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SH2 (D) - modelled
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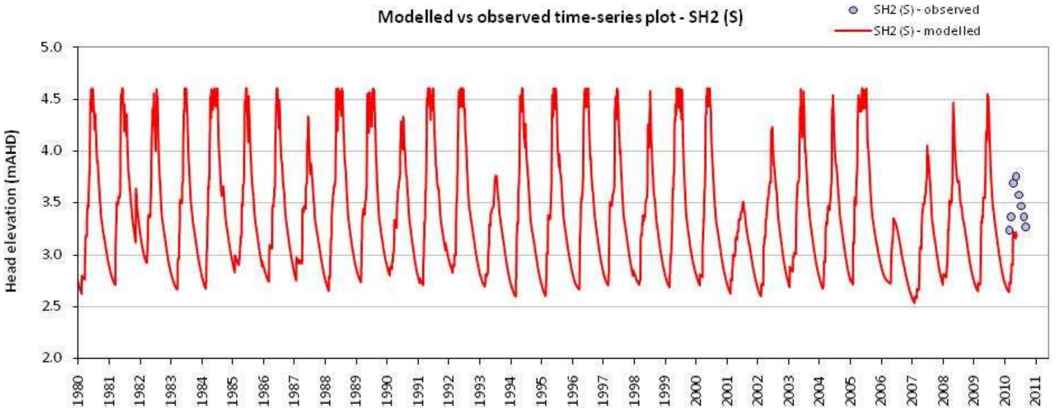
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SH2 (S) - modelled
Head elevation (mAHD)
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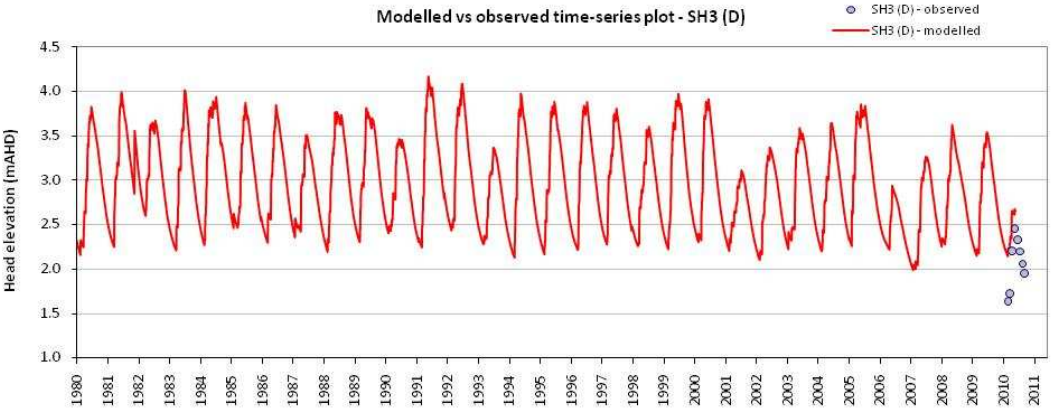
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SH3 (D) - modelled
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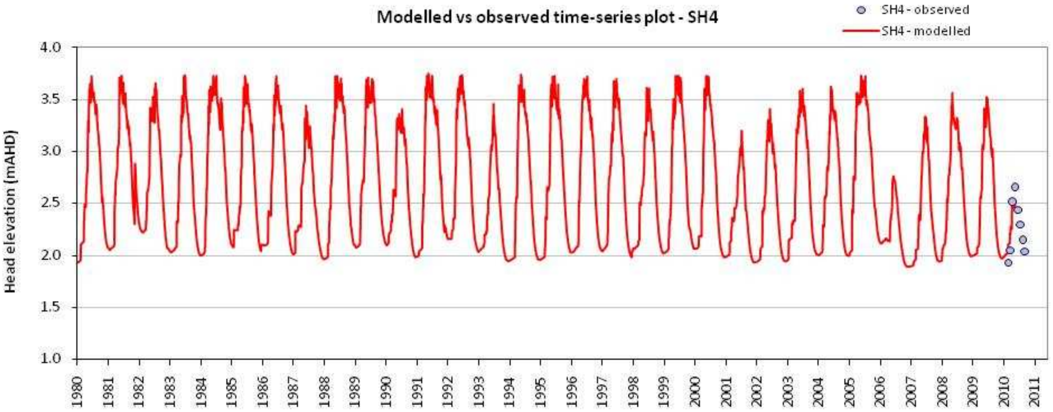
Modelled vs observed time-series plot - SH4
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SH4 - modelled
Head elevation (mAHD)
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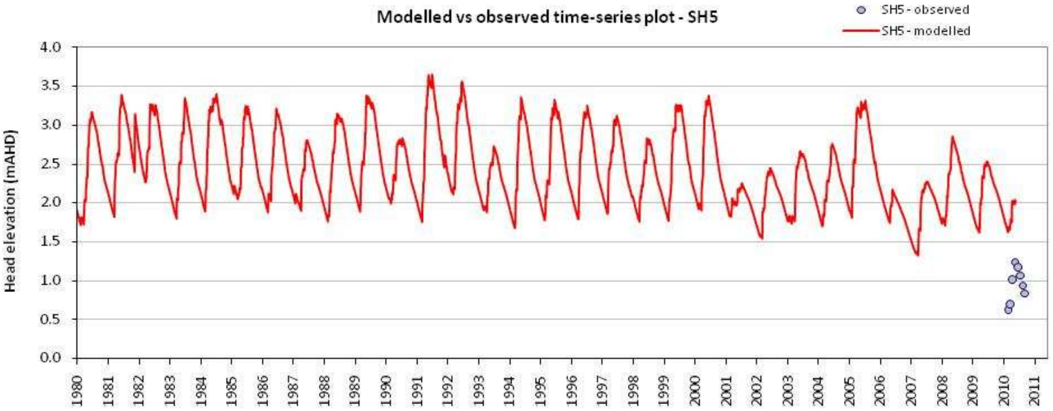
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SH5 - observed
SH5 - modelled
Head elevation (mAHD)
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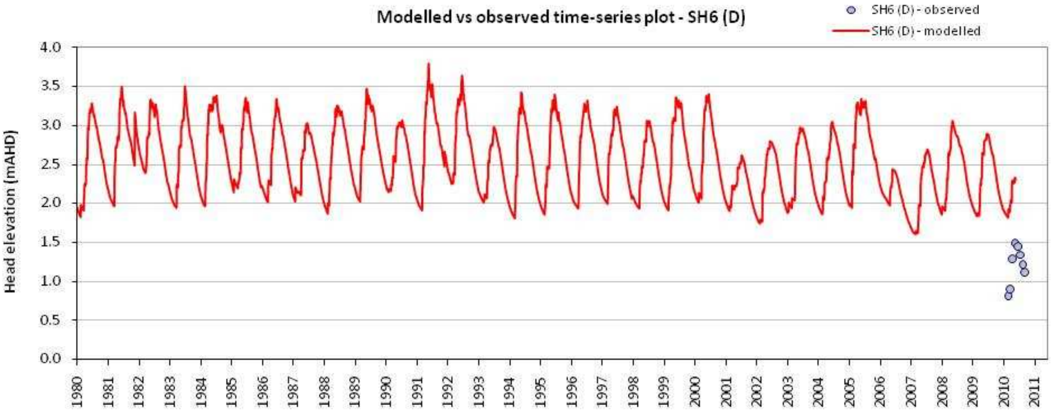
Modelled vs observed time-series plot - SH6 (D)
SH6 (D) - observed
SH6 (D) - modelled
Head elevation (mAHD)
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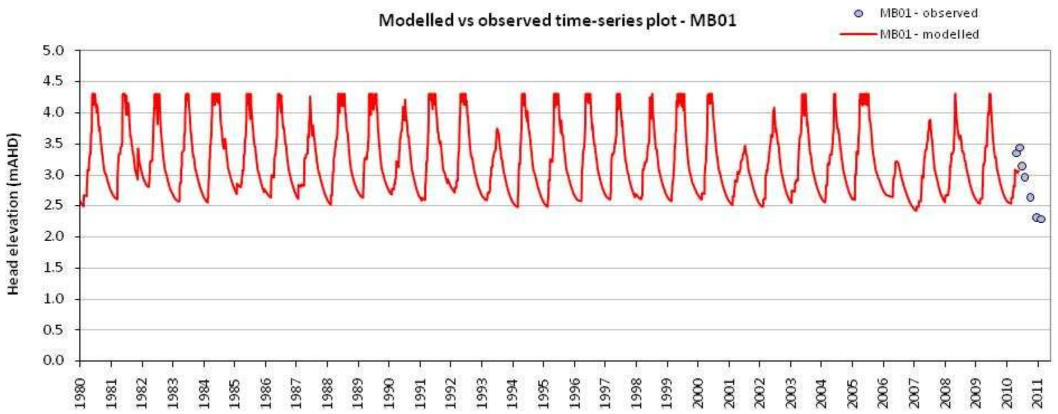
Modelled vs observed time-series plot - MB01
MB01 - observed
MB01 - modelled
Head elevation (mAHD)
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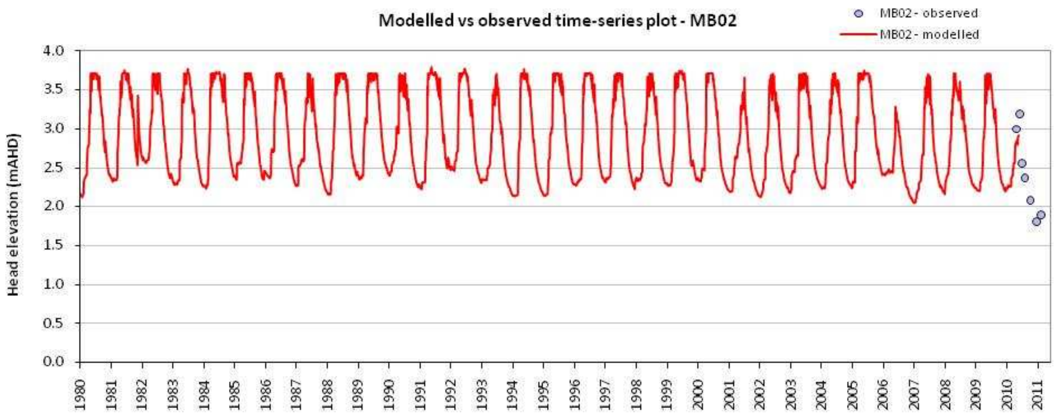
Modelled vs observed time-series plot - MB02
MB02 - observed
MB02 - modelled
Head elevation (mAHD)
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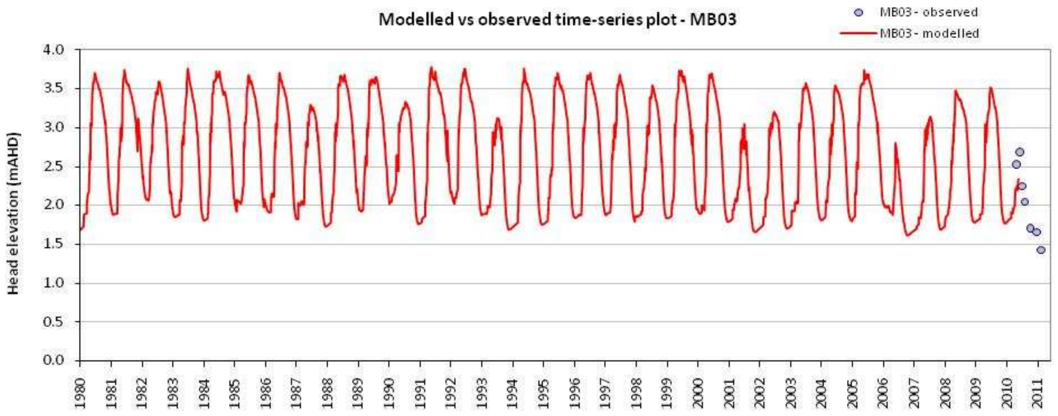
Modelled vs observed time-series plot - MB03
MB03 - observed
MB03 - modelled
Head elevation (mAHD)
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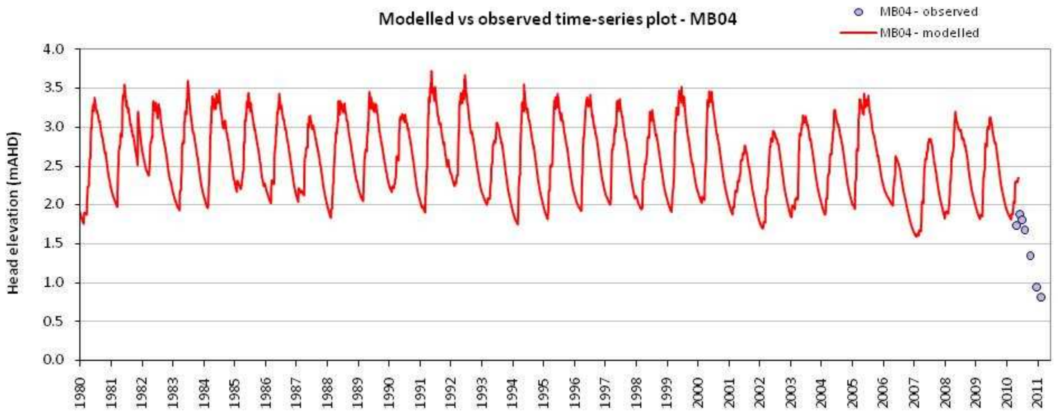
Modelled vs observed time-series plot - MB04
MB04 - observed
MB04 - modelled
Head elevation (mAHD)
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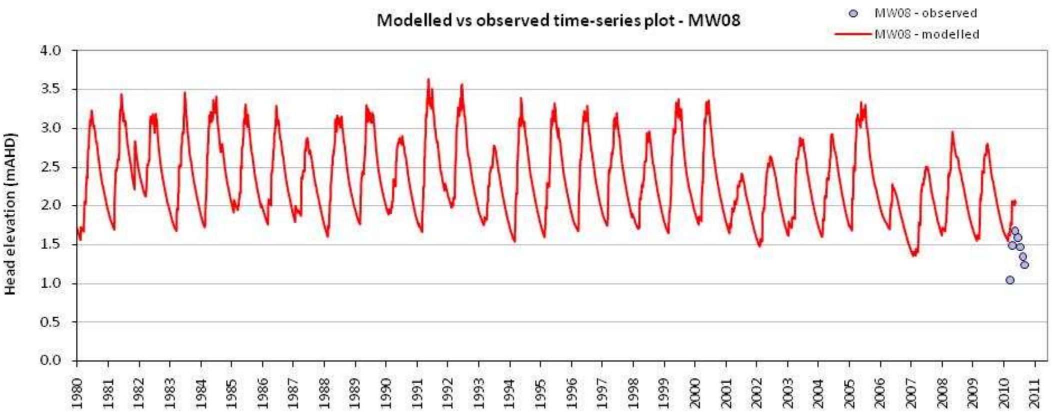
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MW08 - observed
MW08 - modelled
Head elevation (mAHD)
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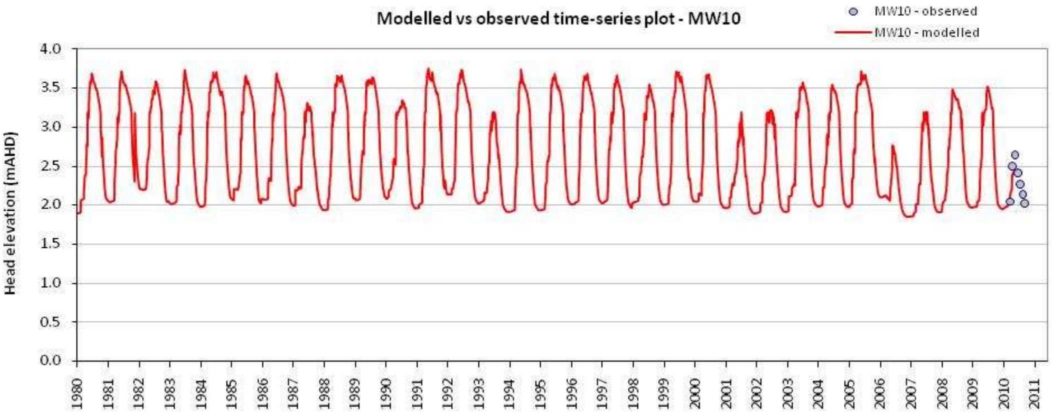
Modelled vs observed time-series plot - MW10
MW10 - observed
MW10 - modelled
Head elevation (mAHD)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1980
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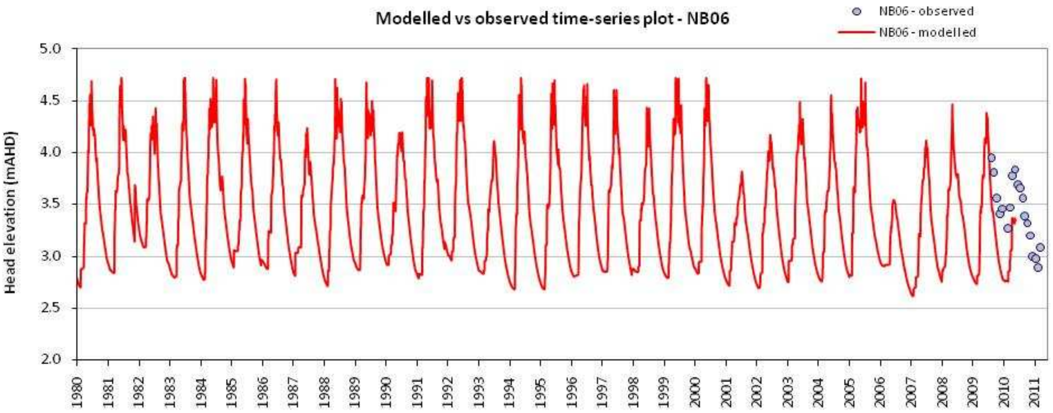
Modelled vs observed time-series plot - NB06
NB06 - observed
NB06 - modelled
Head elevation (mAHD)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1980
1981
1982
1983
1984
1985
1986
1987
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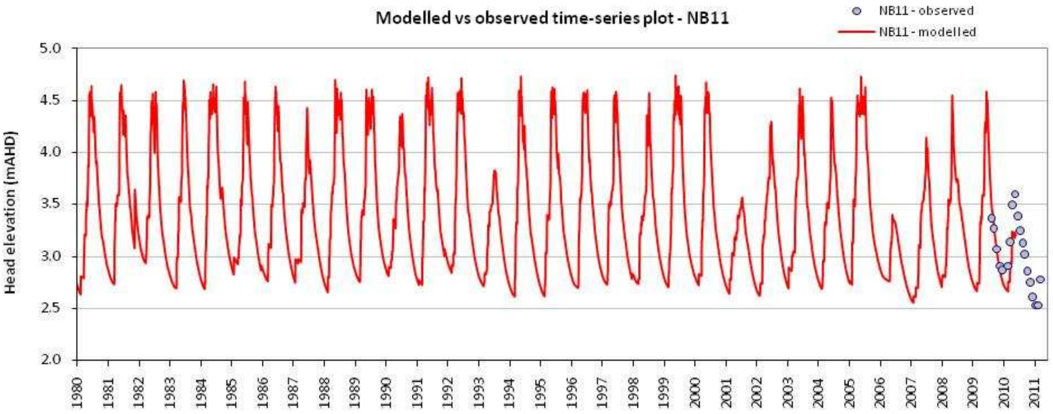
2010
2011


Modelled vs observed time-series plot - NB11
NB11 - observed
NB11 - modelled
Head elevation (mAHD)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
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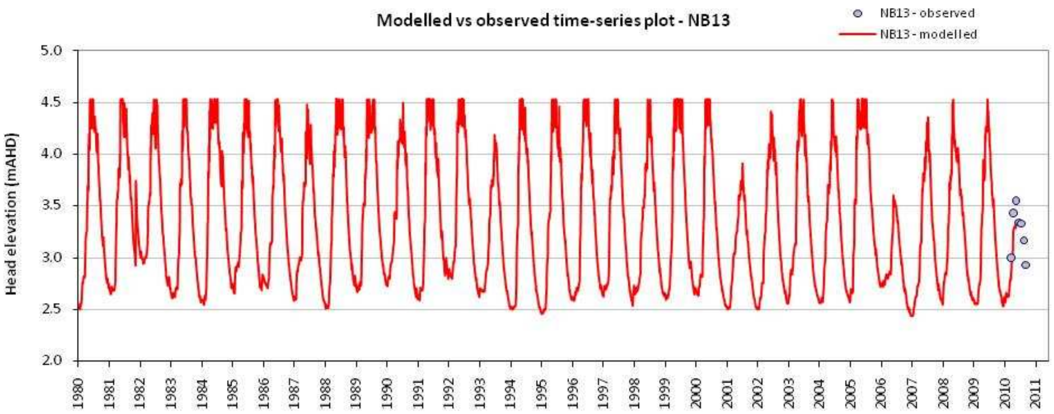
2009
2010
2011


Modelled vs observed time-series plot - NB13
NB13 - observed
NB13 - modelled
Head elevation (mAHD)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1980
1981
1982
1983
1984
1985
1986
1987
1988
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Appendix B – Scenario results for wetland water levels

Wetland elevation			Base case S0	Future wet climate S9		Future medium climate S18		Future dry climate S27		CGL and industrial land use S1		CGL, drainage water and industrial S2		CGL, industrial, dry climate S3		CGL, industrial land use, moderate recharge S4	
Wetland UFI	Lowest mAHD	Average mAHD	AAMinGL mAHD	AAMinGL mAHD	Δm	AAMinGL mAHD	Δm	AAMinGL mAHD	Δm	AAMinGL mAHD	Δm	AAMinGL mAHD	Δm	AAMinGL mAHD	Δm	AAMinGL mAHD	Δm
14652	0.69	1.42	0.12	0.10	-0.02	0.09	-0.03	0.05	-0.07	0.14	0.02	0.18	0.06	0.09	-0.04	0.13	0.01
15377	2.15	3.00	1.17	1.15	-0.02	1.14	-0.03	1.11	-0.06	1.37	0.20	1.36	0.19	1.35	0.18	1.34	0.17
15373	1.36	1.66	0.10	0.08	-0.02	0.06	-0.04	0.01	-0.09	0.13	0.02	0.21	0.11	0.05	-0.05	0.12	0.02
15381	8.19	11.60	7.88	7.86	-0.02	7.85	-0.03	7.80	-0.08	8.17	0.30	8.01	0.14	8.01	0.14	8.08	0.21
15379	5.84	6.33	5.08	5.08	-0.01	5.07	-0.01	5.06	-0.03	Developed		Developed		Developed		Developed	
14592	1.37	1.96	0.06	0.05	-0.01	0.02	-0.04	-0.05	-0.11	0.11	0.05	0.09	0.02	0.02	-0.04	0.09	0.03
4883	15.07	16.93	15.35	15.33	-0.02	15.26	-0.09	15.16	-0.19	15.40	0.05	15.34	-0.01	15.24	-0.10	15.37	0.02
5032	**15.80**	**16.55**	**15.33**	**15.30**	**-0.03**	**15.27**	**-0.06**	**15.20**	**-0.12**	**15.33**	**0.01**	**15.33**	0.00	**15.21**	**-0.12**	**15.33**	**0.01**
14598	1.10	2.03	-0.28	-0.27	0.00	-0.31	-0.03	-0.38	-0.10	-0.25	0.03	-0.27	0.00	-0.33	-0.06	-0.26	0.02
4287	2.25	2.66	1.24	1.22	-0.02	1.21	-0.03	1.16	-0.08	1.36	0.11	1.30	0.06	1.33	0.08	1.33	0.09
13906	10.32	11.53	10.21	10.20	-0.02	10.18	-0.03	10.14	-0.08	10.34	0.13	10.28	0.07	10.27	0.05	10.32	0.11
4584	**5.10**	**6.83**	**4.96**	**4.95**	**-0.02**	**4.94**	**-0.03**	**4.90**	**-0.06**	**5.61**	**0.65**	**5.47**	0.50	**5.59**	**0.63**	**5.54**	**0.57**
4585	**6.71**	**7.06**	**5.24**	**5.22**	**-0.02**	**5.21**	**-0.03**	**5.18**	**-0.06**	**5.66**	**0.42**	**5.60**	0.36	**5.64**	**0.40**	**5.63**	**0.39**
13898	10.33	11.63	9.39	9.38	-0.01	9.36	-0.03	9.33	-0.06	9.67	0.28	9.57	0.18	9.61	0.22	9.63	0.24
5182	13.43	14.48	13.20	13.19	-0.01	13.18	-0.02	13.16	-0.04	13.20	0.00	13.20	0.00	13.16	-0.04	13.20	0.00
15374	7.25	8.24	6.60	6.59	-0.02	6.55	-0.05	6.48	-0.13	7.13	0.53	6.94	0.34	7.04	0.44	7.05	0.44
13305	12.09	15.63	12.59	12.58	0.00	12.58	0.00	12.58	-0.01	12.59	0.00	12.59	0.00	12.58	-0.01	12.59	0.00
15378	12.70	14.39	11.50	11.48	-0.02	11.43	-0.07	11.35	-0.15	11.66	0.16	11.60	0.10	11.56	0.06	11.63	0.13
13892	13.41	14.65	13.61	13.59	-0.02	13.55	-0.06	13.47	-0.13	13.89	0.28	13.81	0.20	13.77	0.17	13.83	0.23
4835N	**7.99**	**9.34**	**8.26**	**8.23**	**-0.03**	**8.18**	**-0.08**	**8.12**	**-0.14**	**8.66**	**0.40**	**8.49**	0.24	**8.50**	**0.25**	**8.55**	**0.29**
5033	**12.72**	**13.57**	**12.56**	**12.55**	**-0.01**	**12.54**	**-0.01**	**12.52**	**-0.04**	**12.57**	**0.01**	**12.56**	0.01	**12.54**	**-0.02**	**12.57**	**0.01**
5129	14.11	14.99	13.05	13.03	-0.01	13.01	-0.04	12.96	-0.08	13.10	0.06	13.08	0.04	13.04	-0.01	13.08	0.04
14438	10.37	11.40	9.71	9.68	-0.02	9.64	-0.07	9.56	-0.15	10.05	0.35	9.84	0.13	9.97	0.26	9.98	0.27
14424	13.27	14.15	12.61	12.59	-0.02	12.55	-0.07	12.46	-0.15	12.85	0.23	12.74	0.13	12.75	0.14	12.79	0.17
5034	13.02	13.43	11.92	11.91	-0.01	11.89	-0.03	11.85	-0.07	11.94	0.02	11.93	0.01	11.87	-0.05	11.93	0.01
5029	12.09	12.71	10.95	10.94	-0.01	10.92	-0.03	10.89	-0.07	10.96	0.01	10.96	0.00	10.90	-0.05	10.96	0.01
5127	12.92	13.75	11.83	11.81	-0.02	11.74	-0.08	11.65	-0.18	11.98	0.16	11.87	0.04	11.86	0.03	11.92	0.09
15236	10.06	11.96	9.12	9.10	-0.02	9.10	-0.02	9.07	-0.05	9.12	0.00	9.12	0.00	9.07	-0.05	9.12	0.00
5128	10.73	11.57	9.91	9.90	-0.01	9.90	-0.01	9.89	-0.03	9.91	0.00	9.91	0.00	9.89	-0.02	9.91	0.00
4835S	**8.49**	**9.69**	**8.12**	**8.08**	**-0.04**	**8.02**	**-0.10**	**7.94**	**-0.18**	**8.56**	**0.44**	**8.33**	0.21	**8.33**	**0.21**	**8.42**	**0.29**

**Significant wetlands highlighted in bold*

Wetland elevation			Base case S0		Future wet climate S9			Future medium climate S18			Future dry climate S27			CGL and industrial land use S1			CGL, drainage water and industrial S2			CGL, industrial, dry climate S3			CGL, industrial land use, moderate recharge S4		
Wetland UFI	Lowest mAHD	Average mAHD	AAMaxGL mAHD	Surface water depth	AAMaxGL mAHD	Δm	Δ depth %	AAMaxGL mAHD	Δm	Δ depth %	AAMaxGL mAHD	Δm	Δ depth %	AAMaxGL mAHD	Δm	Δ depth %	AAMaxGL mAHD	Δm	Δ depth %	AAMaxGL mAHD	Δm	Δ depth %	AAMaxGL mAHD	Δm	Δ depth %
14652	0.69	1.42	1.83	1.14	1.80	-0.02	-2%	1.70	-0.12	-11%	1.52	-0.31	-27%	1.83	0.00	0%	1.94	0.11	10%	1.62	-0.21	-18%	1.81	-0.02	-1%
15377	2.15	3.00	2.50	0.35	2.49	-0.01	-4%	2.46	-0.04	-12%	2.37	-0.13	-37%	2.51	0.01	2%	2.51	0.01	2%	2.50	0.00	-1%	2.51	0.01	2%
15373	1.36	1.66	1.93	0.57	1.90	-0.03	-5%	1.77	-0.15	-27%	1.61	-0.32	-56%	1.94	0.01	2%	2.06	0.13	23%	1.78	-0.14	-25%	1.93	0.00	1%
15381	8.19	11.60	9.31	1.12	9.30	-0.01	-1%	9.27	-0.04	-3%	9.15	-0.16	-14%	9.76	0.45	40%	9.59	0.29	26%	9.51	0.21	18%	9.68	0.37	33%
15379	5.84	6.33	6.22	0.38	6.21	-0.01	-2%	6.18	-0.04	-9%	6.10	-0.12	-31%	Developed			Developed			Developed			Developed		
14592	1.37	1.96	1.95	0.58	1.87	-0.08	-14%	1.69	-0.26	-45%	1.36	-0.58	-100%	2.03	0.08	14%	2.08	0.13	23%	1.65	-0.30	-52%	2.00	0.06	10%
4883	15.07	16.93	16.88	1.81	16.81	-0.07	-4%	16.55	-0.33	-18%	16.21	-0.67	-37%	16.92	0.04	2%	16.87	-0.01	-1%	16.34	-0.54	-30%	16.90	0.01	1%
5032	**15.80**	**16.55**	**16.50**	**0.69**	**16.49**	**0.00**	**-1%**	**16.48**	**-0.02**	**-3%**	**16.43**	**-0.07**	**-10%**	**16.50**	**0.00**	**0%**	**16.50**	**0.00**	**0%**	**16.43**	**-0.07**	**-9%**	**16.50**	**0.00**	**0%**
14598	1.10	2.03	1.34	0.24	1.28	-0.06	-26%	1.00	-0.35	-145%	0.68	-0.67	-278%	1.49	0.14	59%	1.45	0.11	45%	0.84	-0.50	-211%	1.41	0.06	27%
4287	2.25	2.66	2.51	0.25	2.50	0.00	-1%	2.48	-0.03	-11%	2.40	-0.11	-43%	2.51	0.01	2%	2.52	0.01	4%	2.50	0.00	-1%	2.51	0.00	2%
13906	10.32	11.53	11.59	1.27	11.58	-0.01	-1%	11.53	-0.06	-5%	11.42	-0.17	-14%	11.72	0.13	10%	11.71	0.12	9%	11.59	0.00	0%	11.71	0.12	10%
4584	**5.10**	**6.83**	**6.63**	**1.53**	**6.59**	**-0.04**	**-2%**	**6.50**	**-0.13**	**-8%**	**6.31**	**-0.32**	**-21%**	**7.04**	**0.41**	**27%**	**6.97**	**0.35**	**23%**	**6.91**	**0.29**	**19%**	**7.00**	**0.38**	**25%**
4585	**6.71**	**7.06**	**6.83**	**0.11**	**6.81**	**-0.01**	**-13%**	**6.73**	**-0.10**	**-90%**	**6.55**	**-0.28**	**-248%**	**7.05**	**0.23**	**199%**	**7.01**	**0.18**	**159%**	**6.96**	**0.13**	**117%**	**7.03**	**0.20**	**176%**
13898	10.33	11.63	10.38	0.05	10.38	0.00	-9%	10.36	-0.02	-46%	10.30	-0.08	-172%	11.16	0.78	1612%	11.10	0.72	1485%	10.87	0.49	1017%	11.13	0.75	1552%
5182	13.43	14.48	14.42	0.99	14.40	-0.02	-2%	14.34	-0.08	-8%	14.21	-0.21	-22%	14.42	0.00	0%	14.42	0.00	0%	14.21	-0.21	-22%	14.42	0.00	0%
15374	7.25	8.24	7.89	0.64	7.87	-0.03	-4%	7.76	-0.13	-20%	7.50	-0.39	-60%	8.16	0.27	42%	8.09	0.20	30%	8.02	0.13	20%	8.12	0.23	36%
13305	12.09	15.63	13.72	1.63	13.71	-0.01	0%	13.68	-0.04	-2%	13.63	-0.09	-6%	13.71	0.00	0%	13.71	0.00	0%	13.63	-0.09	-5%	13.71	0.00	0%
15378	12.70	14.39	12.95	0.25	12.90	-0.05	-21%	12.67	-0.29	-113%	12.35	-0.60	-237%	13.06	0.11	43%	13.01	0.06	23%	12.62	-0.33	-130%	13.03	0.08	32%
13892	13.41	14.65	14.92	1.51	14.87	-0.05	-3%	14.71	-0.22	-14%	14.49	-0.43	-29%	15.06	0.14	9%	15.02	0.09	6%	14.73	-0.19	-13%	15.03	0.10	7%
4835N	**7.99**	**9.34**	**9.75**	**1.76**	**9.70**	**-0.05**	**-3%**	**9.55**	**-0.19**	**-11%**	**9.37**	**-0.38**	**-22%**	**9.92**	**0.18**	**10%**	**9.85**	**0.10**	**6%**	**9.66**	**-0.08**	**-5%**	**9.87**	**0.13**	**7%**
5033	**12.72**	**13.57**	**13.73**	**1.00**	**13.72**	**0.00**	**0%**	**13.71**	**-0.02**	**-2%**	**13.66**	**-0.07**	**-7%**	**13.73**	**0.00**	**0%**	**13.73**	**0.00**	**0%**	**13.68**	**-0.05**	**-5%**	**13.73**	**0.00**	**0%**
5129	14.11	14.99	14.35	0.24	14.32	-0.03	-11%	14.21	-0.14	-57%	14.04	-0.31	-128%	14.39	0.04	17%	14.37	0.02	9%	14.13	-0.22	-90%	14.37	0.02	9%
14438	10.37	11.40	11.01	0.64	10.95	-0.06	-9%	10.82	-0.19	-30%	10.63	-0.38	-59%	11.13	0.13	20%	11.02	0.01	1%	10.93	-0.08	-13%	11.08	0.07	11%
14424	13.27	14.15	13.93	0.66	13.88	-0.05	-8%	13.74	-0.19	-29%	13.50	-0.43	-65%	14.04	0.11	17%	13.97	0.04	6%	13.79	-0.13	-20%	13.99	0.06	9%
5034	13.02	13.43	13.18	0.16	13.15	-0.03	-16%	13.10	-0.08	-52%	12.95	-0.23	-139%	13.18	0.00	1%	13.18	0.00	0%	12.99	-0.19	-120%	13.18	0.00	1%
5029	12.09	12.71	12.25	0.16	12.22	-0.02	-15%	12.15	-0.10	-63%	11.99	-0.26	-162%	12.25	0.01	3%	12.24	0.00	-2%	12.01	-0.24	-152%	12.25	0.00	-1%
5127	12.92	13.75	13.26	0.34	13.19	-0.07	-20%	12.97	-0.29	-85%	12.68	-0.58	-172%	13.38	0.12	36%	13.29	0.03	9%	12.95	-0.31	-93%	13.32	0.06	17%
15236	10.06	11.96	10.39	0.33	10.39	0.00	-1%	10.38	-0.02	-5%	10.37	-0.03	-8%	10.39	0.00	0%	10.39	0.00	0%	10.37	-0.02	-7%	10.39	0.00	-1%
5128	10.73	11.57	11.15	0.42	11.14	-0.01	-2%	11.11	-0.04	-8%	11.04	-0.11	-26%	11.15	0.00	0%	11.15	0.00	0%	11.06	-0.09	-21%	11.15	0.00	0%
4835S	**8.49**	**9.69**	**9.65**	**1.16**	**9.58**	**-0.07**	**-6%**	**9.41**	**-0.24**	**-21%**	**9.23**	**-0.42**	**-36%**	**9.88**	**0.23**	**20%**	**9.77**	**0.12**	**10%**	**9.53**	**-0.11**	**-10%**	**9.81**	**0.16**	**14%**

**Significant wetlands highlighted in bold*

Shortened forms

AAMaxGL	Average annual maximum groundwater level
AAMinGL	Average annual minimum groundwater level
AHD	Australian height datum
ARI	Average recurrence interval
AveGL	Average groundwater level
CGL	Controlled groundwater level
CR	Coefficient of runoff
DEC	Department of Environment and Conservation
DEM	Digital elevation model
DHI	Danish Hydraulic Institute
DoW	Department of Water
DTGW	Depth to groundwater
DWMS	District water management strategy
ESRI	Environmental Systems Research Institute
EVT	Evapotranspiration
FAO56	Food and Agricultural Organization – Irrigation and Drainage paper 56
GIS	Geographic information system
JDA	Jim Davies and Associates Pty Ltd
LiDAR	Light detection and ranging
LWMS	Local water management strategy
MaxGL	Maximum groundwater level
MinGL	Minimum groundwater level
MSR	Mean sum of residuals
RMS	Root mean square
UFI	Unique feature identifier
Wcfc	Water content at field capacity
Wcs	Water content at saturation
Wcwp	Water content at wilting point
QDERM	Queensland Department of Environment and Resource Management

Glossary

Controlled groundwater levels	A level at which groundwater is artificially maintained through drainage infrastructure
Shapefile	ESRI's proprietary format for storing spatial data
SQUARE	Streamflow quality for rivers and estuaries – a semi-distributed rainfall, runoff and nutrient model
MIKE SHE	An integrated surface and groundwater modelling platform developed by DHI
MIKE 11	A 1D hydraulic model for simulating river flow, stage, water quality and sediment transport, developed by DHI
MIKE Zero	A framework for modelling with the MIKE range of products developed by DHI
SILO data drill	A database of in-filled climatic data within Australia provided by QDERM

References

Deeney, AC 1989, Geology and groundwater resources of the superficial formations between Pinjarra and Bunbury, Perth Basin, Report 26, pp. 31-57, Geological Survey of Western Australia.

Department of Water 2010, *Murray drainage and water management plan*, Department of Water, Perth.

——in press, draft *Groundwater modelling guidelines for urban drainage in areas of high watertable*, Department of Water, Perth.

Groundwater Consulting Services 2007, *Revised average annual maximum groundwater level estimate Nambeelup Lifestyle Estate, Lakes Road, Ravenswood*, Groundwater Consulting Services, Perth.

Hall, J, Kretschmer, P, Quinton, B & Marillier, B 2010a, *Murray hydrological studies: surface water, groundwater and environmental water – conceptual model report*, Water science technical series, report no. 16, Department of Water, Perth.

—— 2010b, *Murray hydrological studies: model construction and calibration report*, Water science technical series, report no. 25, Department of Water, Perth.

——2010c, *Murray hydrological studies: land development, drainage and climate scenario report*, Water science technical series, report no. 26, Department of Water, Perth.

Kelsey, P, Hall, J, Kretschmer, P, Quinton, B & Shakya, S 2010, *Hydrological and nutrient modelling of the Peel–Harvey catchment, Western Australia*, A report to the National Pollutant Inventory, Department of Water, Perth.

Kretschmer, P, Christie, E, Fisher, S, Marillier, B & Reitsema T 2011, *Feasibility of managed aquifer recharge using drainage water*, Water science technical series, report no. 38, Department of Water, Perth.

Middlemis, H 2000 *Murray-Darling Basin Commission groundwater flow modelling guidelines*, Aquaterra Consulting Pty Ltd.

Parsons Brinckerhoff 2002, *Nambeelup groundwater study*, Parsons Brinckerhoff, Western Australia.

—— 2008 *Nambeelup groundwater monitoring*, Parsons Brinkerhoff, Western Australia.

Pennington Scott 2008, Southern Perth Basin Groundwater Bulletin, Department of Water, Western Australia.

RPS-BBG 2006, *Nambeelup hydrogeological investigations*, RPS-BBG, Perth.

Western Australian Planning Commission 2002, *Peel Regional Scheme*, Western Australian Planning Commission, Perth.

——2008, *Better urban water management*, Western Australian Planning Commission, Perth, Western Australia

——in press, *South metropolitan and Peel sub-regional structure plan*, Western Australian Planning Commission, Perth.

Queensland Department of Environment and Resource Management 2011, *DERM enhance meteorological datasets*, <http://www.longpaddock.qld.gov.au>, accessed online October 2011

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Department of Water
168 St Georges Terrace, Perth, Western Australia
PO Box K822 Perth Western Australia 6842
Phone: (08) 6364 7600
Fax: (08) 6364 7601
www.water.wa.gov.au

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