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

Looking after all our water needs

East Wanneroo integrated groundwater-lake flow modelling:

Predictive scenario modelling to support the Gnangara Sustainability Strategy

Hydrogeological record series

Report no. HG35
August 2009

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Summary

This study has used a local-scale numerical model of the east Wanneroo area to investigate the potential influences of land-use change and water management practices on water levels in Lake Mariginiup, Lake Jandabup and the Superficial aquifer.

A suite of seven predictive modelling scenarios have been run from 2001 to 2031 to assess the effects of artificial lake supplementation, pine clearing, urbanisation and directed urban drainage. These scenarios assume that the climate remains as per 1997 to 2006 (730 mm of rainfall per year).

This scenario modelling will inform the Gnangara Sustainability Strategy, a cross-government initiative to develop an action plan for the sustainable use of the Gnangara Mound's water resources.

The modelling suggests that the current regime of augmentation at Lake Jandabup increases the lake's seasonal minimum water level by 0.5 m. Urbanisation in line with the Western Australian Planning Commission's east Wanneroo land-use concept (WAPC 2007) could increase seasonal maximum water levels in Lake Mariginiup by 0.4 m and Lake Jandabup by 0.7 m. Pine clearing has the potential to increase seasonal maximum water levels in Lake Mariginiup by 0.2 m and Lake Jandabup by 0.7 m. Re-establishment of banksia woodlands in areas where pines have been cleared reduces these gains by 0.1 m in Lake Mariginiup and 0.3 m in Lake Jandabup. Redirection and injection of urban stormwater from roads into an infiltration swale up-gradient of Lake Mariginiup could increase spring peak water levels by 0.1 m above the increases under a conventional diffuse recharge regime.

Minimal increases in summer water levels in Lake Mariginiup (0.2 m) are predicted under the urbanisation with pine-clearing scenario. However, this may be enough to reduce oxidation of acid sulfate soils if the lake-bed sediments remain saturated. Summer minimum water levels in Lake Jandabup increase as a result of land-use change to the extent that artificial supplementation may be offset and no longer required.

By 2031 water levels in the Superficial aquifer are predicted to increase by up to 4.0 m if the full range of land-use changes including urbanisation and pine clearing are implemented. Under the pine clearing only and urbanisation only scenarios, watertable increases of up to 3.3 m and 2.7 m respectively would occur. These water-level increases are not evenly distributed across the model domain, with the largest increases to the south and south-east of Lake Jandabup.

This study has demonstrated that local-scale modelling specifically incorporating groundwater-lake interactions can be a useful tool to assess land and water management options. Further scenario modelling should be undertaken using this local-scale model to assess the impacts of private abstraction and climate on water levels in lakes Mariginiup and Jandabup.

1 Introduction

Groundwater management decisions in the Perth region are often informed by outputs from the Perth Regional Aquifer Modelling System (PRAMS) (Davidson & Yu 2008). Regional-scale modelling of the Gnangara Mound using PRAMS suggests that land-use change, including pine clearing and urbanisation, can alter water levels in the Superficial aquifer (Vogwill et al. 2008).

However, the PRAMS model cannot accommodate groundwater-lake interactions and is not able to simulate lake water levels. To overcome these limitations, a local-scale numerical model of the Superficial aquifer in the east Wanneroo area was built to predict lake stage and groundwater levels (Figure 1).

Current land use in the model domain is predominantly horticulture and state forest with some urban and industrial zones (Figure 2).

We have run seven predictive modelling scenarios to assess the effects of various land and water management regimes on water levels in lakes Mariginiup and Jandabup and groundwater levels in the Superficial aquifer. Four management issues were considered:

- artificial lake supplementation
- pine clearing
- urbanisation
- directed urban drainage.

This scenario modelling will inform the Gnangara Sustainability Strategy (GSS). The GSS is a multi-agency project working towards sustainable integrated land and water management on the Gnangara Mound. The Department of Water is the lead agency for the GSS.

The Gnangara Mound is a significant source of water for the City of Perth and supplies around 60 per cent of the Water Corporation's integrated water supply system. The model domain includes public drinking water source protection areas and Water Corporation production wells (Figure 3).

Groundwater levels on the Gnangara Mound have been declining since the 1970s, in part due to declining rainfall (Yesertener 2005). Global climate models predict that this drying trend will continue across south-western Western Australia (IPCC 2007).

The Gnangara Mound supports numerous lakes and wetlands that provide habitat for wading birds, aquatic fauna and fringing vegetation (Davidson 1995; Froend et al. 2004). Water levels in these lakes are declining, thus threatening the ecosystems they support.

The Department of Water has an obligation to ensure Ministerial Criteria water levels (based on ecological water requirements) are met so that the ecological values of these systems are maintained. These water levels are measured at staff gauges in lakes Mariginiup and Jandabup and also at bores adjacent to the lakes (Figure 4). Current Ministerial Criteria are mostly based on static water levels and do not account for long-term climatic change. The department is working towards updating this management framework to a new one based on eco-hydrological states, which will more accurately reflect climate-driven changes in these systems.

The lowering of water levels can also expose organic sediments that acidify when they dry out (McHugh & Bourke 2007). These materials are known as acid sulfate soils. Oxidation of acid sulfate soils has already caused the acidification of Lake Gnangara (pH<4 since 1978), which is unlikely to recover (WAWA 1995). Lakes Jandabup and Mariginiup are at risk of acidification (Froend et al. 2004). To mitigate the acidification risk at Lake Jandabup, the Water Corporation supplements the lake with water from the Leederville aquifer during the dry summer months. This is not an ideal solution because it is costly and depletes the water resources of the source aquifer.

Perth’s population is projected to more than double by 2056 (ABS 2008) and development will continue to occur along the city’s north-west corridor. In 2007 the Western Australian Planning Commission published a report outlining its concept for future land use in the east Wanneroo area (WAPC 2007), which includes a shift away from groundwater-intensive horticulture towards increased urbanisation. This shift could raise water levels in the Superficial aquifer because abstraction would decrease and recharge would increase. To enhance these benefits, the water captured on impermeable surfaces in the urban area could be directed towards the lakes; either through pipes directly into the lake or infiltrated into the Superficial aquifer diffusely across the lake capture zone. Treating this intercepted water as a resource would not only enable developers to fulfil their obligations for on-site water retention, but also help maintain water levels in the lake and thus reduce the acidification risk.

Much of the state forest in the model domain is pine plantation managed by the Forest Products Commission. Research has shown that pines may not just reduce recharge to the Superficial aquifer through evapotranspiration, but could actually result in a net flux of water away from the watertable to the atmosphere (Silberstein 2007). As such, pine clearing has the potential to significantly increase recharge to the Superficial aquifer.

This modelling study will assess the potential impacts of land-use change in the east Wanneroo area on water levels in the Superficial aquifer and lakes Mariginiup and Jandabup. Its local-scale modelling will supplement previous regional-scale studies to inform the management of water and land resources in a context of competing demand from communities and the environment.

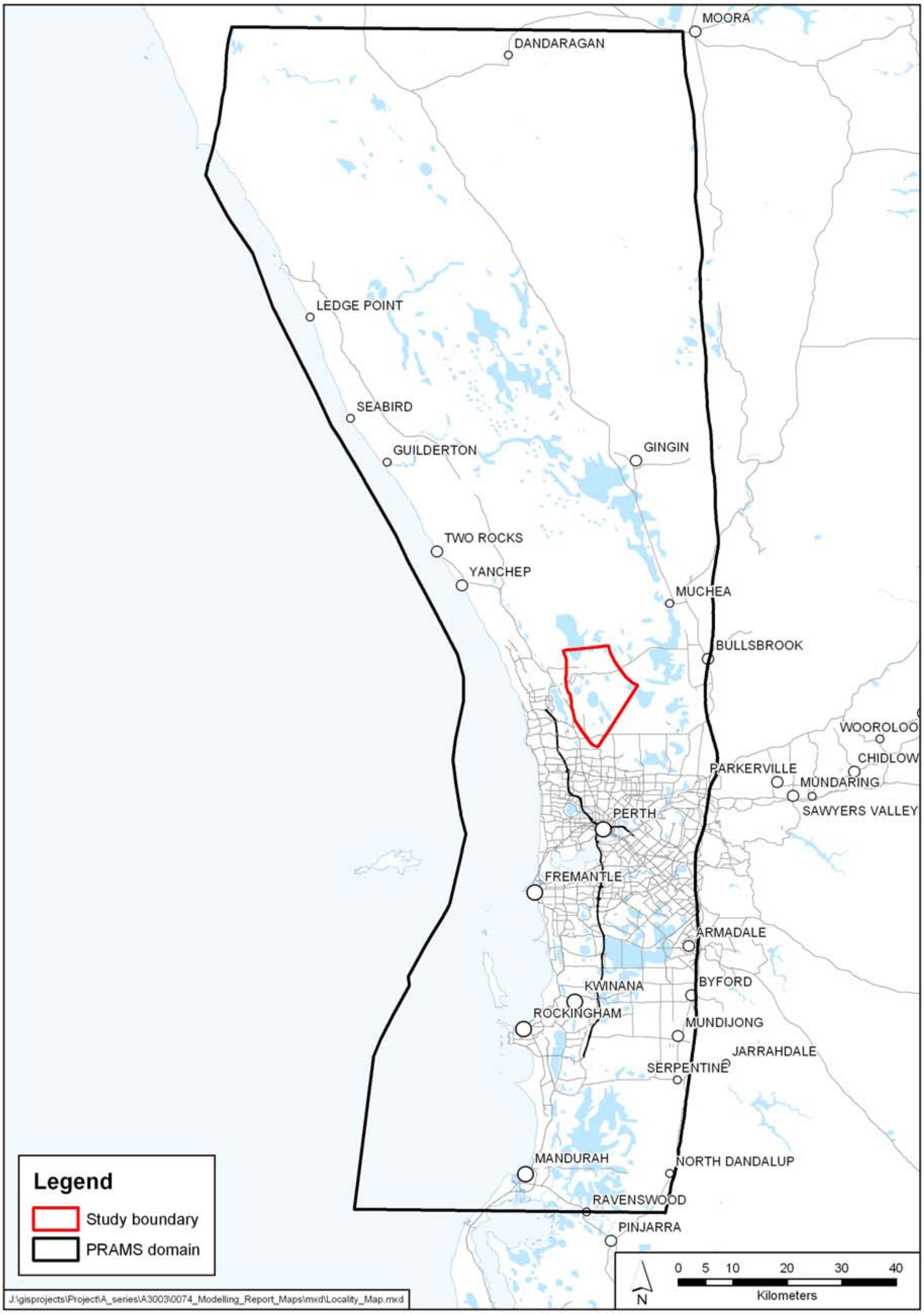

Figure 1: Locality map

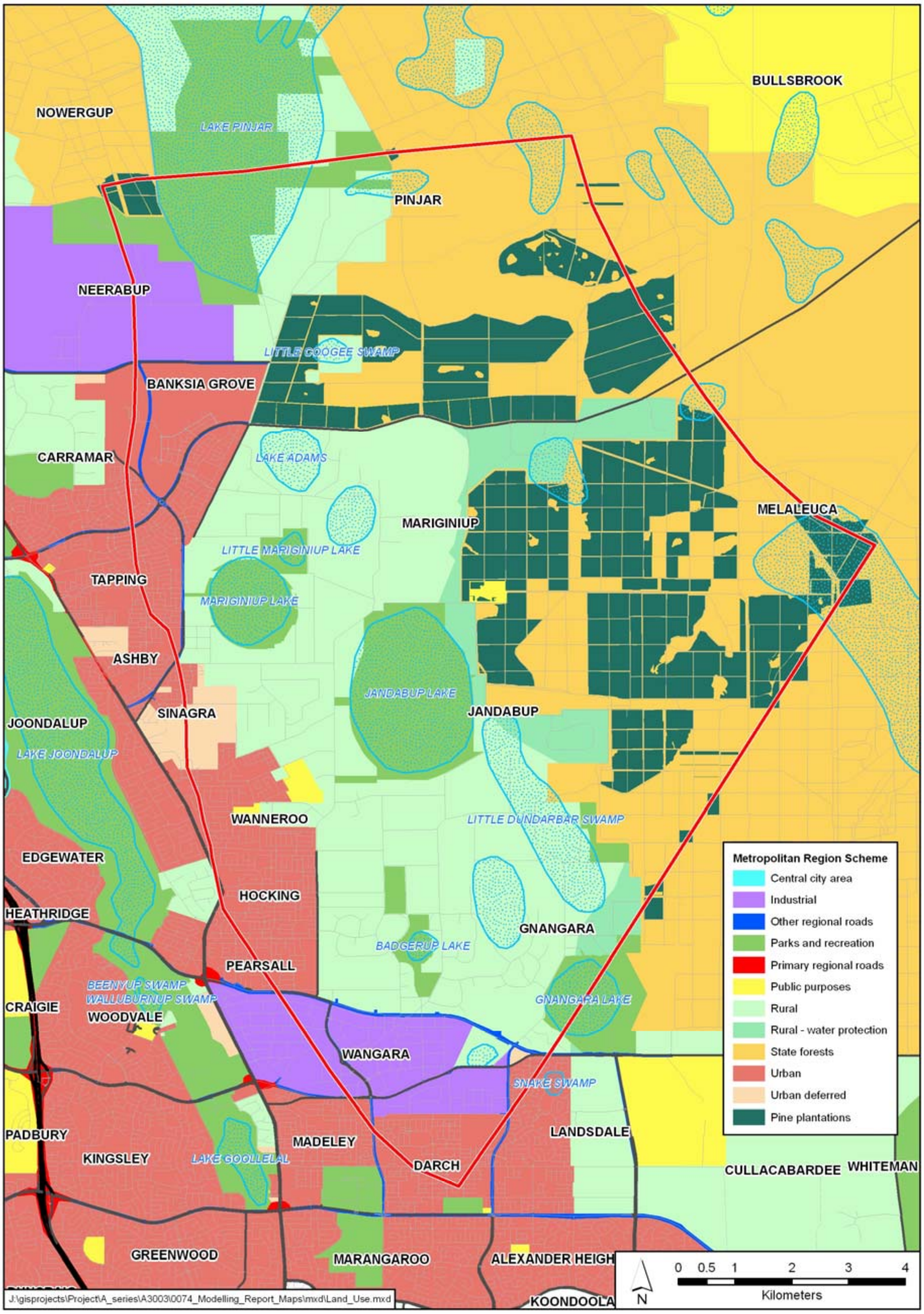

Figure 2: Land-use map

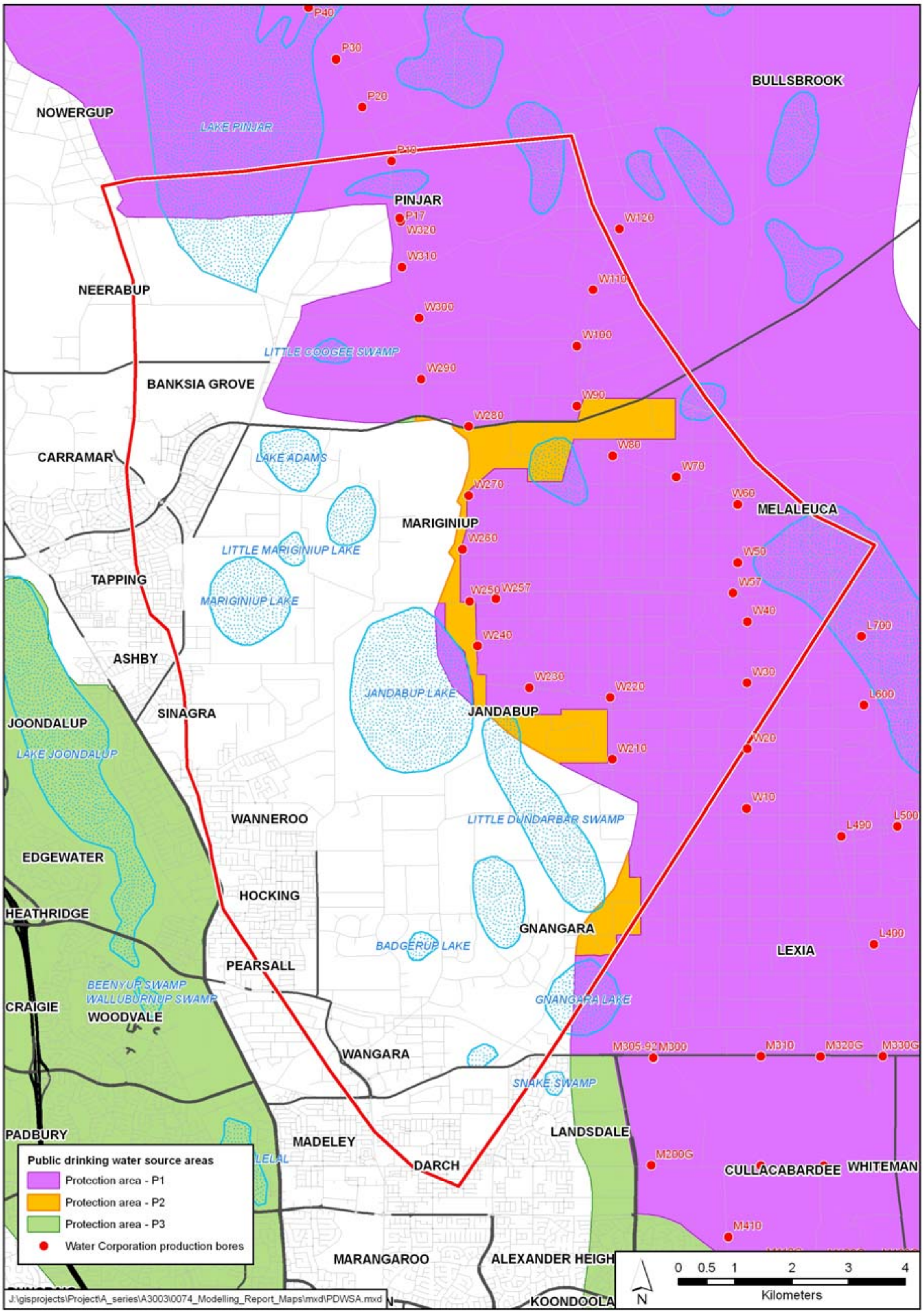

Figure 3: Public drinking water source protection areas and Water Corporation production wells in the Superficial aquifer

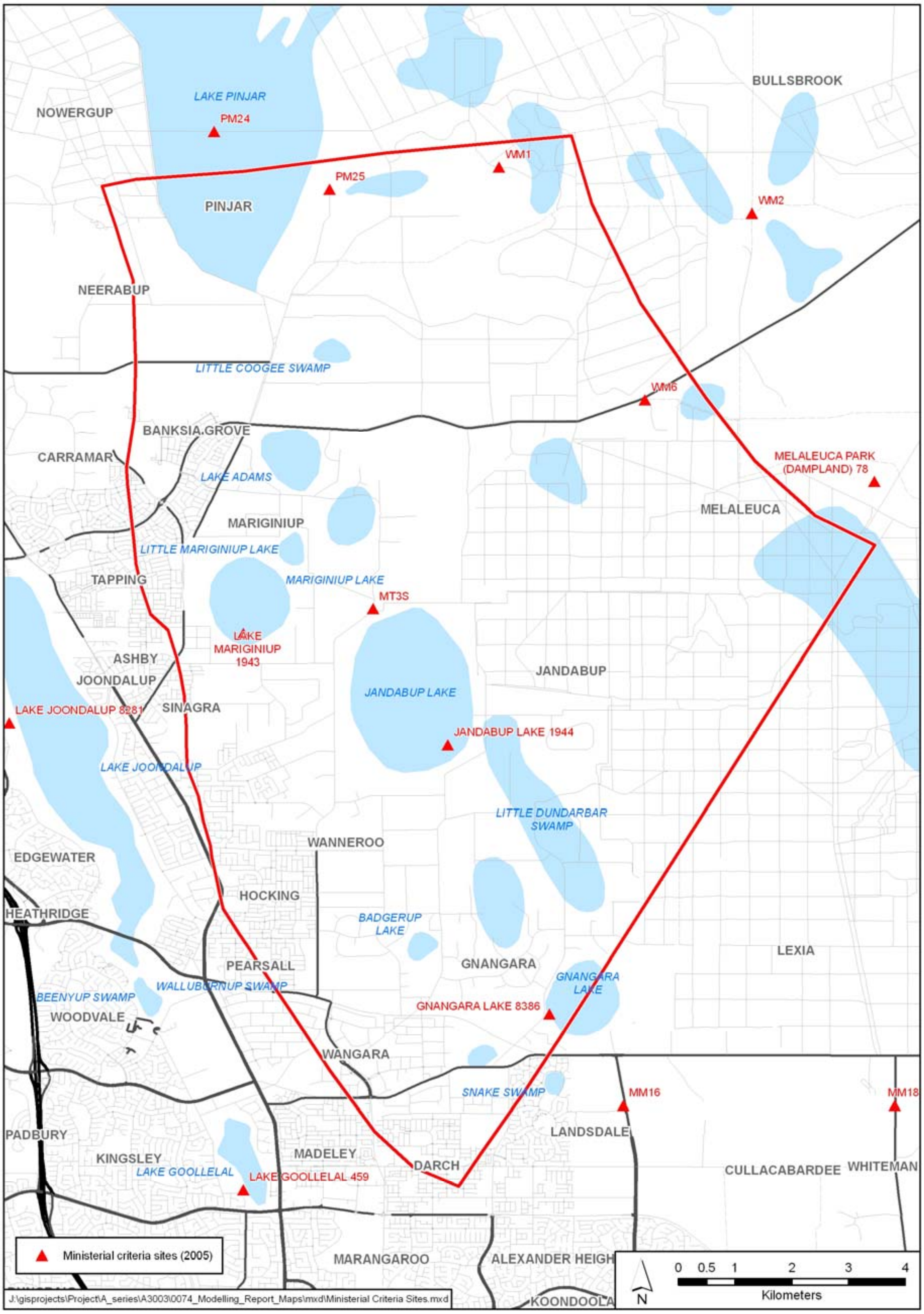

Figure 4: Ministerial Criteria sites at lakes Mariginiup and Jandabup. Site MT3S (Bore 5086) is used to report modelling results

2 Model construction

2.1 Hydrogeological conceptualisation

The Gnangara Mound dominates the regional groundwater-flow regime in the study area. Flow through the model domain is from the north-east to the south-west, with a hydraulic gradient of approximately 20 m along a north-east to south-west transect (Figure 5).

The superficial formations in the area are predominantly sands and silty sands of the Spearwood and Bassendean sand units and are up to 60 m thick. The superficial formations form the unconfined Superficial aquifer, which is underlain by the Leederville and Mirrabooka aquifers. Leakage is downward from the Superficial aquifer to the Leederville aquifer in the north of the model domain, as well as to the Mirrabooka aquifer in the east, with upward leakage from the Mirrabooka to the Superficial aquifer in the south-west of the model domain.

Lakes Mariginiup and Jandabup are through-flow lakes that sit on the superficial formations of the Swan coastal plain (Hall 1983; Allen 1979). Water levels in the lakes vary seasonally in response to groundwater levels. Other lakes in the model area (e.g. lakes Gnangara, Pinjar and Adams) are also expressions of the watertable but do not hold significant surface-water bodies and have not been explicitly included in the model as lakes.

2.2 The calibrated model (2001–06)

RPS Environmental built the numerical model using GMS as a pre- and post-processor for MODFLOW 2000. A brief summary of the model's construction is provided here. For more details about the model's construction, sensitivity and uncertainty analysis, please refer to RPS (2009a).

Model design

Boundaries are specified head at 60 m in the north-east, specified head at 36 m in the west, with no-flow boundaries in the north and south-east (Figure 6). A finite difference grid was constructed within these boundaries using the conceptual model approach in GMS. Grid cell size ranges from 50 m adjacent to the lakes up to 250 m at the boundaries.

The Superficial aquifer was discretised into seven horizontal layers (Figure 7). Leakage between the Superficial aquifer and the underlying formations occurs through the bottom of Layer 7. The layers in the model do not represent lithological units.

Leakage between the Superficial aquifer and the underlying units is included as described above, based on Davidson (1995), the most up-to-date reference at the time the model was constructed. These flux estimates have since been updated, suggesting that leakage within the model domain is only downward, with no upward flow from the Mirrabooka aquifer (Davidson & Yu 2008). However, upward leakage is only 4 per cent of the total leakage in the model and is unlikely to significantly affect water balances in the model.

Groundwater/surface-water interaction

Groundwater/surface-water interactions are simulated using the MODFLOW Lakes Package (Meritt & Konikow 2000). The Lakes Package calculates flow between a lake and the adjacent aquifer based on water levels and lake-bed conductance. Lake cells are defined in the model grid as being able to dry and re-wet over time. When the lake is dry (the lake stage is below the lake bed) these cells become inactive. As water levels rise above the bottom of the lake bed, these cells are reactivated. While the lake cells are active, the water balance is calculated from precipitation, evaporation and runoff.

Calibration

- The model was calibrated over the period 1 October 2001 to 1 October 2006.
- Hydraulic conductivities in the model range from 10 to 13 m/day for Spearwood Sand and from 15 to 18 m/day for Bassendean Sand.
- Observation bore data was from the Department of Water's WIN database.
- Private abstraction rates were based on 80 per cent of licensed allocations to private users, as recorded in the Department of Water's WRL database in October 2007. Annual allocations were distributed to monthly volumes concentrated over the dry summer months.
- Groundwater abstraction by the Water Corporation for public water supply was measured in monthly volumes from the Department of Water's database.
- All abstraction and observation wells are located in Layer 7, irrespective of the actual screened interval. Because all of the model's layers are hydraulically connected, the vertical location of the well screens is unlikely to be significant.
- Lake Jandabup augmentation was based on measured values from 2001 to 2006 (on average ~0.7 GL each summer),
- Rainfall data was from the Bureau of Meteorology's Wanneroo station (9105).
- Evapotranspiration data was from the Bureau of Meteorology's Perth Airport station (9021), with values in the model set at 75 per cent of pan evaporation, with an extinction depth of 3 m. The evapotranspiration coverage in the model applies these rates to the areas of lakes Mariginiup, Jandabup, Pinjar and Gnangara.
- Recharge from rainfall was distributed by land use according to Figure 8.
- Specific yield of 0.28; vertical anisotropy of 3; lake-leakance of 1 and 0.1.

This model yielded a root mean square residual head difference of 0.9 m or 4 per cent of the measured change in hydraulic head across the domain (RPS 2009a).

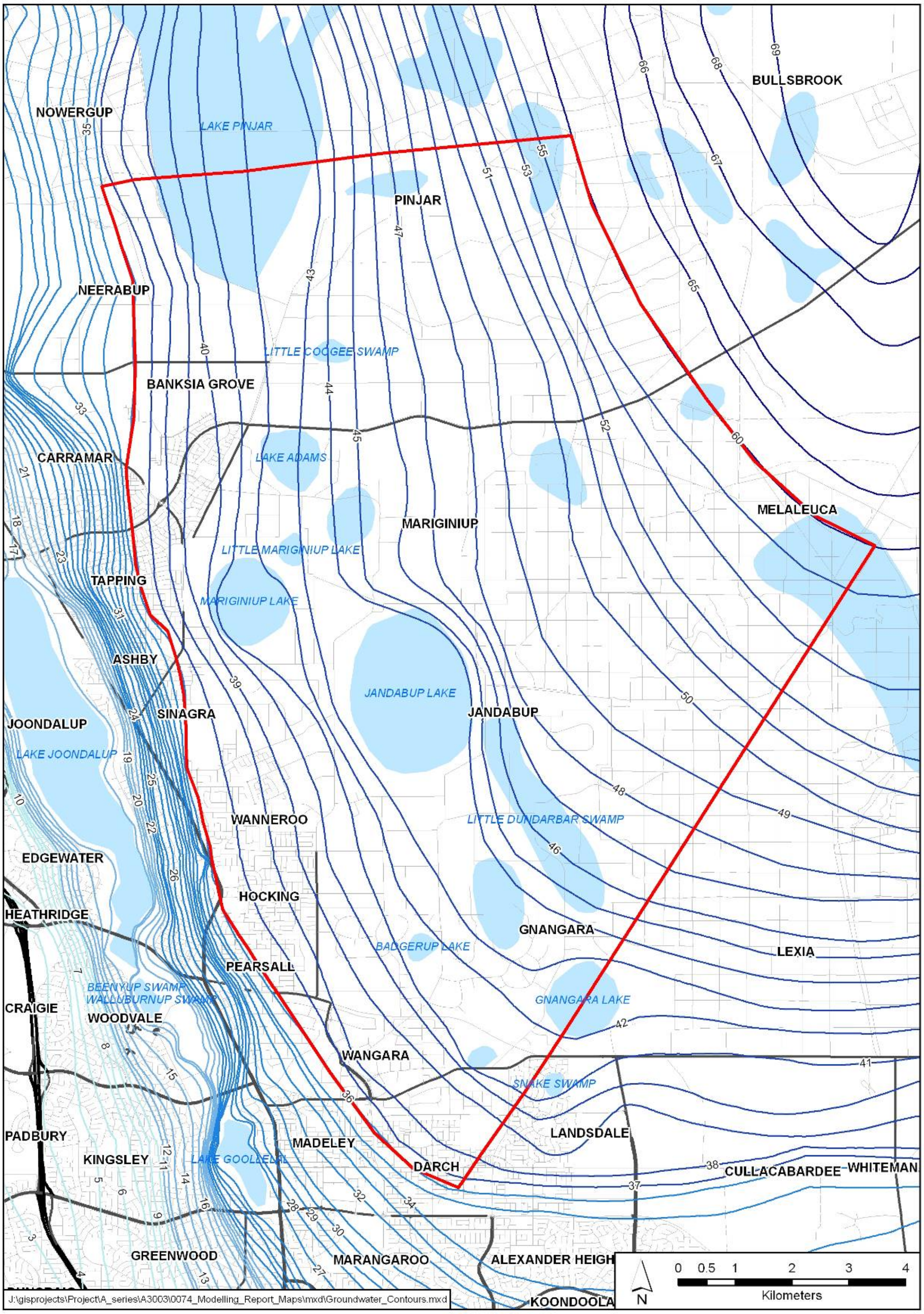

Figure 5: Groundwater contours, historical minimum (m AHD)

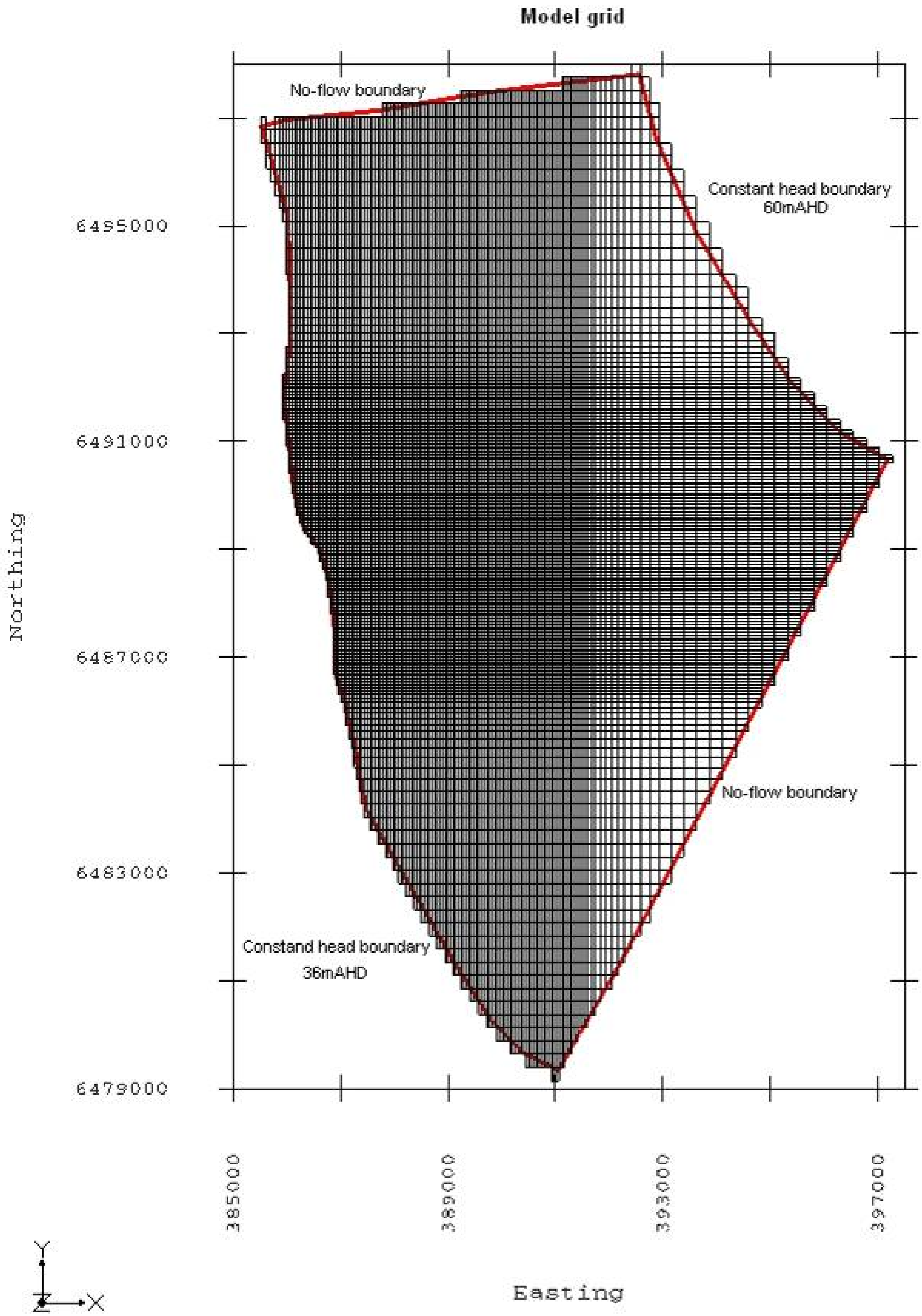

Figure 6: Map of model grid and boundaries

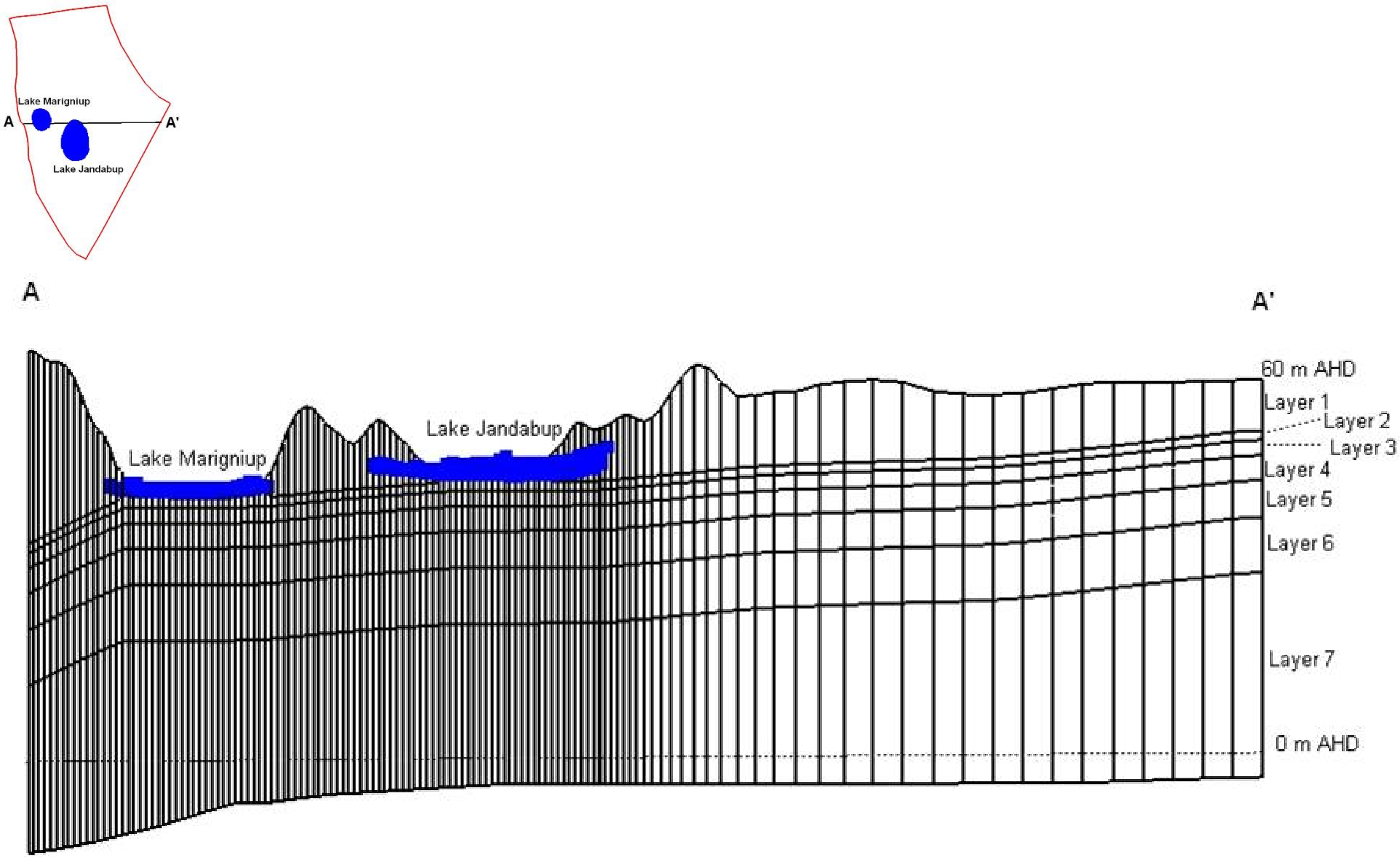

Figure 7: Cross-section of model domain showing layers and the lakes coverage

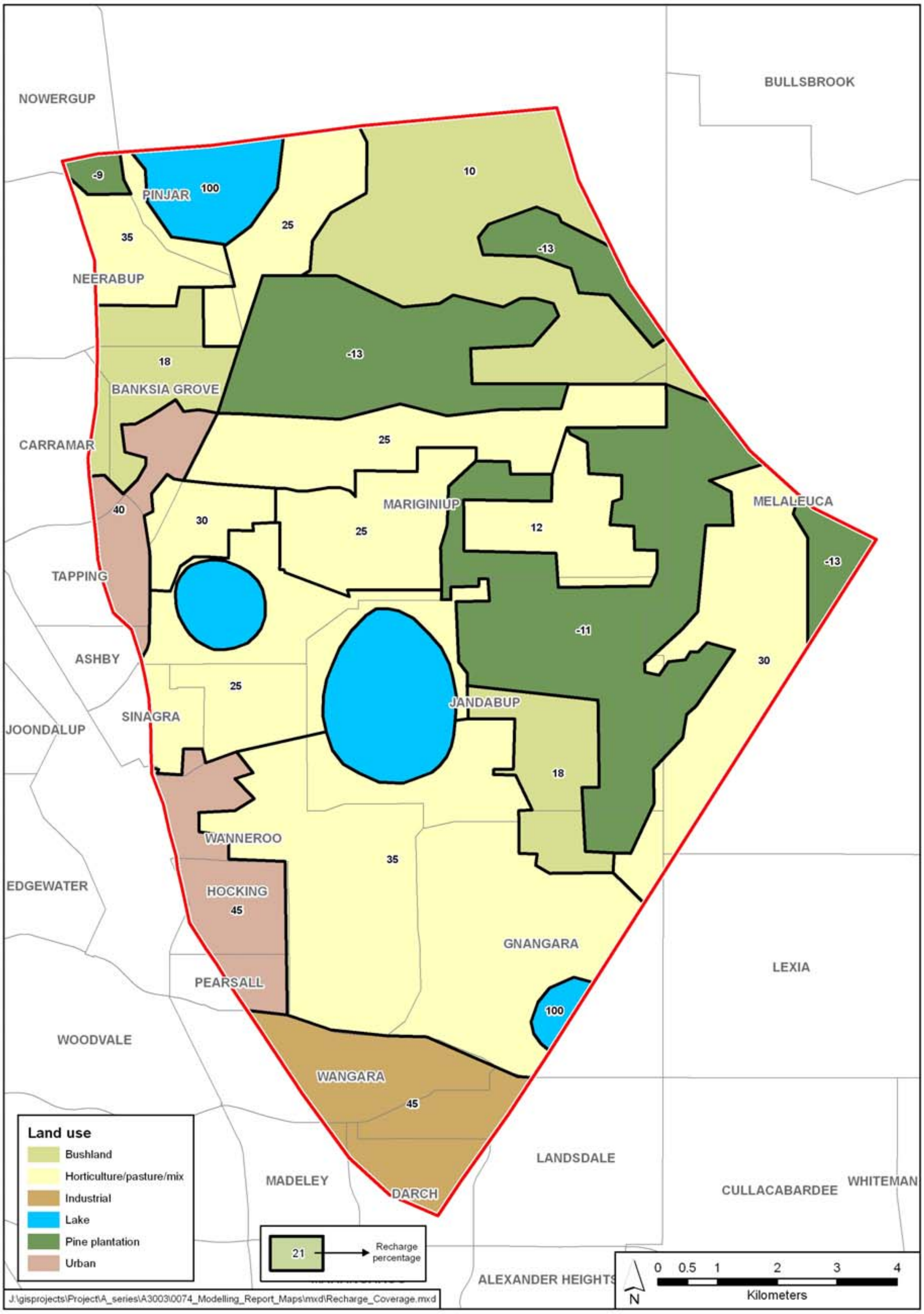

Figure 8: Map of calibrated recharge coverage showing land use and per cent of rainfall recharged to the aquifer

3 Predictive scenarios

3.1 Scenario development

A suite of seven scenarios was conceived to capture the range of land-use options being considered by the Gnangara Sustainability Strategy.

- Scenario 1 is the basecase, simulating the extension of current management practices into the future. This provides a reference point for understanding the effects of land and water management regimes simulated in the other six scenarios.
- Scenario 2 simulates water levels if artificial supplementation of Lake Jandabup ceases.
- Scenario 3 simulates water levels when pine plantations are cleared and replaced with pasture/grassland.
- Scenario 4 simulates water levels when pine plantations are cleared and banksia woodland is established.
- Scenario 5 simulates urbanisation in line with current plans and policies.
- Scenario 6 simulates the full range of land-use change by combining the urbanisation of Scenario 5 with the pine clearing of Scenario 3.
- Scenario 7 provides a variation on Scenario 6 by simulating water captured from urban roads being recharged directly into the lakes, given full land-use change.

A simulated rainfall sequence generated by the Water Corporation to approximate the Perth climate from 1997 to 2006 (730 mm per year) was used in all future scenario runs. This represents a drier climate than the long-term average for Wanneroo (820 mm per year). This synthetic rainfall sequence was used instead of measured rainfall data to be consistent with modelling scenarios run using PRAMS. The impacts of possible future climate regimes were not modelled in this study. In addition, the possible effects of groundwater abstraction by the Water Corporation were not considered.

Land-use change was simulated through the recharge coefficient applied to the rainfall sequence. Annual recharge rates were applied to the monthly rainfall data to produce a step-wise function of monthly recharge in each polygon. The recharge coverage used in the calibrated model was refined to accommodate land-use changes on smaller spatial scales than the calibrated model, as required for the scenario runs. Three sources were used to determine the future land use (and therefore rainfall recharge) for each polygon:

- the Wanneroo future land-use concept outlined in WAPC (2007)
- Cedar Woods' development schedule for the Mariginiup precinct
- the Forest Products Commission's pine-harvesting schedule.

Values of recharge coefficients are outlined in Table 1. These values were chosen to be consistent with the published literature (e.g. Appleyard 1995; Davidson 1995; Silberstein et al. 2004, 2007), regional-scale modelling (PRAMS) and the calibrated local-area model (2001–05). When significant variation in recharge coefficients was encountered in these three sources, preference was given to values that were consistent with the calibrated model period. This was to ensure consistency in recharge coefficients for each land-use category between the calibrated model and the predictive scenarios. The change in recharge coefficient was applied in full as of January 1 in the year of the scheduled land-use change.

Table 1: Annual rainfall recharge coefficients

Land use	Literature	Calibrated model	Predictive scenarios
Urban	37 to 60%	40 to 45%	40%
Industrial	60 to 70%	40 to 45%	40%
Banksia woodland	10 to 38%	10 to 18%	18%
Market garden	36 to 40%	25 to 35%	25 to 35%
Pasture	<36 to 60%	25 to 35%	35%
Pine plantation	-13 to15%	-13 to -9%	-13 to -9%

Groundwater abstraction is also changed in areas that are urbanised, with the allocation from the calibrated model replaced with abstraction rates based on previous studies of domestic water consumption in Western Australia (Water Corporation 2003; ABS 2003).

Grid and aquifer properties remained the same as the calibrated model for all scenarios. Full details of each scenario are provided in Section 3.2 and summarised in Table 2.

Table 2: Scenario matrix

Lake Mariginiup local-area model scenario matrix

		Modelling components												
		Climate	**Abstraction**			**Land use**					**Drainage/supplementation**			
			Water Corp.	Private		Pine clearing			Urban growth		Jandabup augmentation		Urban drainage	
	Scenario	1997–06 (730 mm/yr)	2001–06 volumes	80% of licensed allocation	Reduced (WC 2003; ABS 2003)	Current pine distribution	Clearing as per FPC plans (grassland)	Clearing as per FPC plans (banksia)	Current urban distribution	East Wanneroo plan plus Cedar Woods	2001–06 volumes	No augment-ation from 2010	Conven-tional diffuse	Directed to lake
1	**Basecase** (current management)	X	X	X		X			X		X		X	
2	**No Jandabup augmentation**	X	X	X		X			X			X	X	
3	**Pine clearing**	X	X	X			X		X		X		X	
4	**Post-pine banksia**	X	X	X				X	X		X		X	
5	**Urbanisation**	X	X		X	X				X	X		X	
6	**Urbanisation plus pine clearing**	X	X		X		X			X	X		X	
7	**Directed recharge**	X	X		X		X			X	X			X

3.2 Predictive scenario description

Scenario 1: Basecase

This scenario simulates the continuation of current water and land management regimes and provides a baseline for interpreting the other six scenarios. Recharge coefficients remain the same as the calibrated period 2001–06 (see Figure 8).

Rainfall and evaporation data have been updated to include measured data up to and including December 2008. A synthetic 12-month sequence for each parameter provided by the Water Corporation is used to represent the actual climate of 1997–2006 (730mm/yr), looped between January 2009 and December 2030.

Groundwater abstraction for both public and private use is the five-year 2001–06 dataset repeated until 2030.

Augmentation of water levels in Lake Jandabup was included in this scenario in line with current management practices; that is, ~1 GL/yr delivered to the lake between November and May. Total volumes for each summer were interpolated between the start and end dates for pumping, as recorded by the Department of Water.

Scenario 2: No Jandabup augmentation

This scenario simulates water levels in the absence of artificial water-level maintenance of Lake Jandabup. The augmentation component was removed from the Lakes Package after the supplementation of the 2008–09 summer was complete; the scenario was then run to 2030.

Scenario 3: Pine clearing

This scenario models the effects of pine-plantation clearing. Projected dates for pine clearing in areas within the model domain were provided by the Forest Products Commission in line with its pine-harvesting schedule (current as at August 2008). Where there were multiple dates within a model polygon, a median value was used as the date of pine clearing for the scenario run (Figure 9). Pine clearing was implemented as of 1 January of the relevant year. A 35 per cent recharge coefficient was applied to the rainfall sequence after pine clearing to simulate grassland/pasture. Land uses other than pine plantation remain as they are in the calibtrated model.

Scenario 4: Post-pine banksia

This scenario simulates pine clearing followed by the re-establishment of banksia woodland. All model components are the same as the pine-clearing scenario, except that an 18 per cent recharge coefficient is applied to the rainfall sequence after pine clearing. This percentage of rainfall recharge has been used previously for medium-density banksia in regional groundwater modelling using PRAMS (Silberstein 2004). The growth or burning of the banksia are not taken into account: the recharge rate is changed to 18 per cent as of the date of pine clearing and remains constant until the end of the model run.

Scenario 5: Urbanisation

This scenario models water-level changes associated with urban development under conventional water management practices. Two data sources were incorporated into the recharge coverage: WAPC's land-use concept (2007) and Cedar Woods' local-scale development plan for the area around Lake Mariginiup (Zagwocki pers. comm.).

Areas changing to urban land use were set to 35 per cent rainfall recharge on 1 January of the year they were scheduled for development (Figure 9). Dates were available for the Cedar Woods development area, with initiation of new allotments every five years. For areas of the model planned to be urbanised outside the Cedar Woods development area (as indicated in WAPC 2007), it was assumed that a similar staged approach would be used at five-yearly intervals, starting with the lots closest to the Cedar Woods development area.

In areas that shifted from horticulture to urban land use, the private abstraction as included in the basecase was removed and a new coverage was applied to simulate groundwater use in these areas. Abstraction rates in these newly urbanised areas were based on estimations from the Water Corporation (2003) and the Australian Bureau of Statistics (2003).

Scenario 6: Urbanisation plus pine clearing

This scenario incorporates the land-use changes of both the urbanisation and pine-clearing scenarios. In areas where pines are cleared, the recharge rate is converted to that of pasture at 35 per cent rainfall recharge as per Scenario 3. The WAPC and Cedar Woods land-use plans are incorporated as per Scenario 5.

Scenario 7: Directed recharge

The directed recharge scenario simulates the collection of water from roads in the urbanised area and direction of this water into an infiltration swale directly up-gradient (50 m east) of Lake Mariginiup. It is assumed that 30 per cent of the urban development will be roads and that 80 per cent of rainfall running off these roads will be directed to the infiltration swale. All other facets of the model are the same as Scenario 6.

The interception and redirection of runoff from the urban area would presumably reduce the amount of recharge. However, it is difficult to estimate how much the recharge should be reduced and so rainfall recharge in urbanised areas is still applied as 35 per cent of rainfall. Not including a reduction in rainfall recharge may elevate the predicted groundwater levels in the urban area, but is unlikely to significantly affect the predicted water levels in Lake Mariginiup.

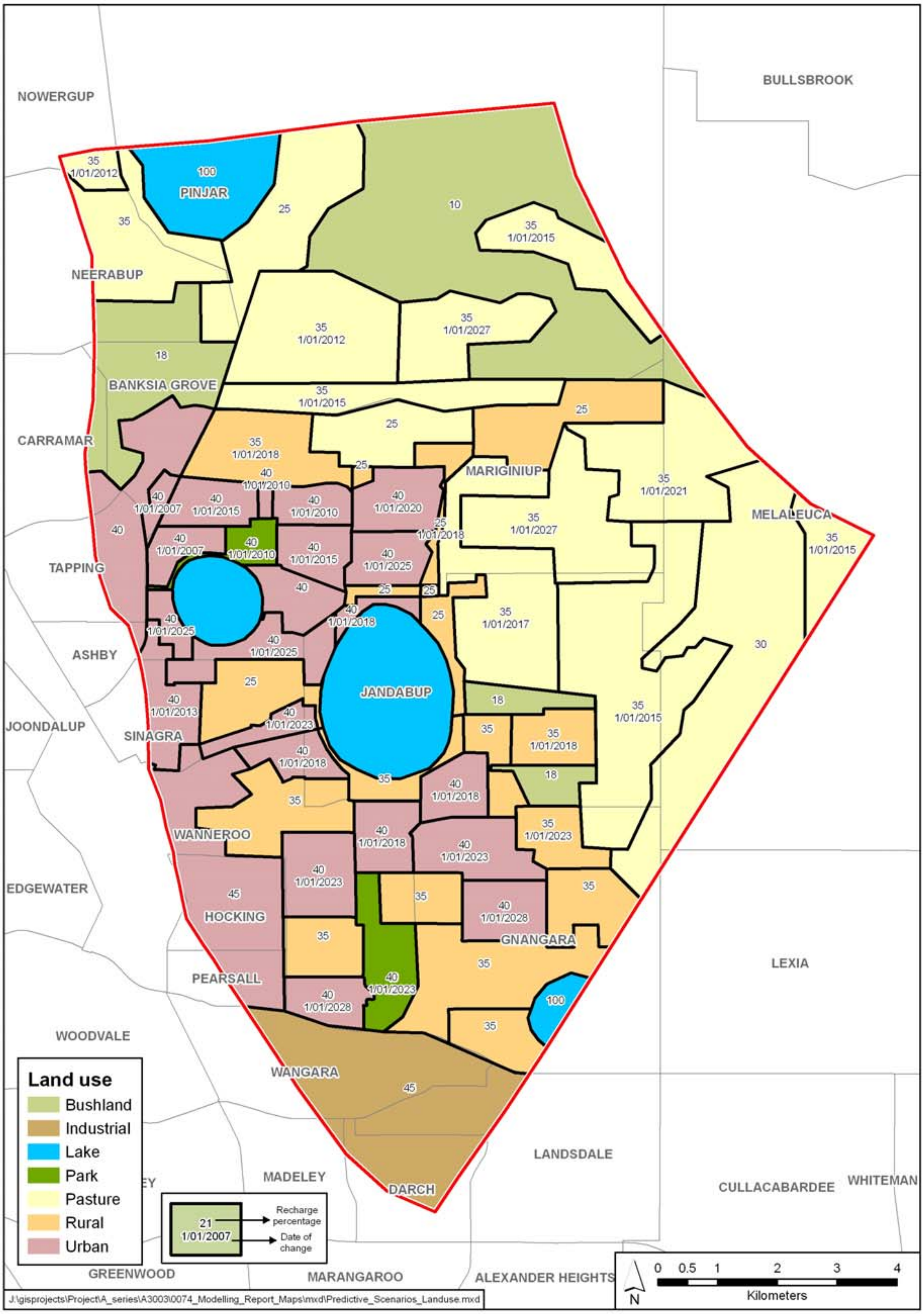

Figure 9: Recharge rates and date of change for predictive scenario recharge coverages

4 Predictive scenario results

Scenario results are presented as:

- time-series of lake-stage data
- time-series of observation-well data
- a map of groundwater levels simulated by the basecase
- maps of groundwater-level change between each scenario and the basecase.

Time-series of groundwater levels in Bore 5086 (WIN ID) (see site MT3S on Figure 4) are presented for all scenarios. This bore was selected because it was well calibrated over the 2001–06 period and was located in the centre of the model domain (and thus was not subject to boundary effects) between lakes Mariginiup and Jandabup.

Contour plots for the basecase are simulated groundwater levels in m AHD. For all other scenarios the contour maps show the change in hydraulic head (the difference between the basecase and that scenario). In these maps, positive values represent an increase in groundwater levels above the basecase, and negative values a decrease relative to the basecase. A map of the hydraulic head difference between Scenario 7 (directed recharge) and Scenario 6 (conventional urbanisation) is also presented.

All of the groundwater-level contour maps are based on the hydraulic head as predicted in Layer 3 on 1 April 2030. This layer represents the top-most layer of the model that does not contain 'lake' cells and reflects the predicted height of the watertable. Layers 1 and 2 were not considered suitable for mapping as the cells assigned to the Lakes Package can be inactivated, resulting in 'holes' in the dataset. Furthermore, because all the layers are hydraulically connected, the predicted heads at each time-step do not vary significantly between layers.

4.1 Scenario 1: Basecase

Water-level predictions under the basecase scenario do not represent expected actual water levels, but provide a reference point for comparison with other scenario predictions. This follows from the recommendations of RPS (2009) based on model calibration, sensitivity and uncertainty analysis.

Lake Mariginiup water-level trends show steady seasonal variation from 2009 under the basecase scenario. Water levels peak at 41.5 m AHD in October of each year, which is consistent with the water-level maxima observed in 2008. The lake is predicted to be dry (≤41.1 m AHD) for approximately four months between January and May each year. The discrepancy between the observed and simulated minimum water levels is because the bottom of the staff gauge is at 41.3 m AHD, 0.2 m above the absolute minimum of the lake bed (Figure 10).

Lake Jandabup experiences a slight declining trend over the simulation period. Water-level maxima are 45.0 m AHD, with minima of 44.5 m AHD at the end of the simulation. The inter-annual variation is a result of artificial supplementation, with different volumes applied each year as per the 2001–06 supplementation regime (Figure 11).

The groundwater gradient remains east to west across the model domain, with the fixed head boundaries constraining the flow field. The influence of Water Corporation production wells is evident with some of the groundwater contours indicating draw-down caused by well abstraction (figures 12 and 13).

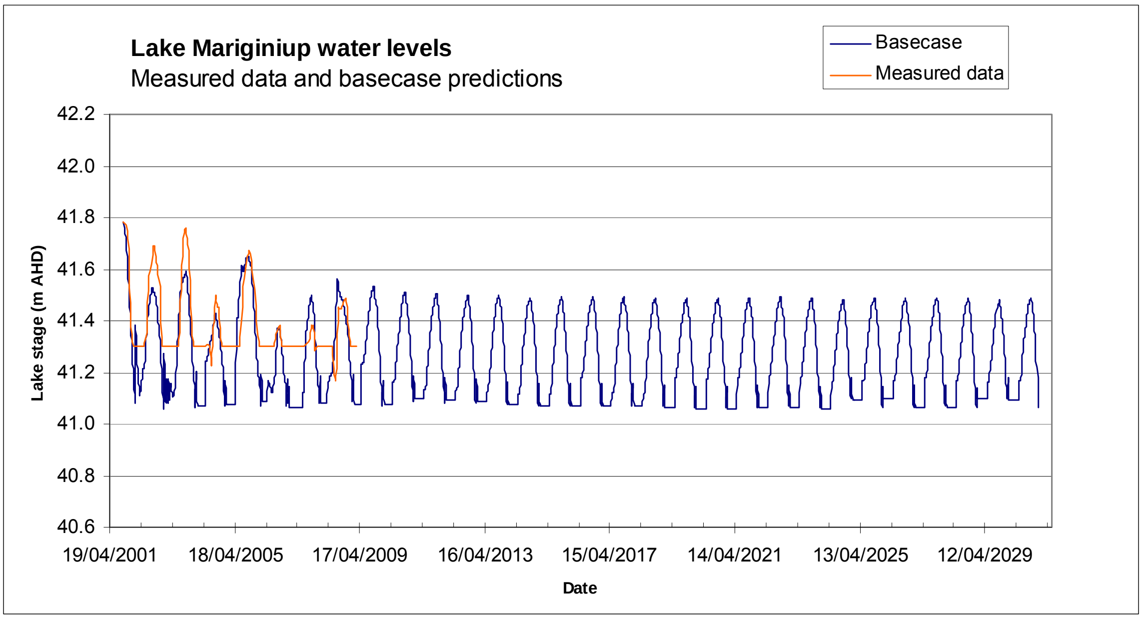

Figure 10: Basecase scenario: predicted water levels in Lake Mariginiup

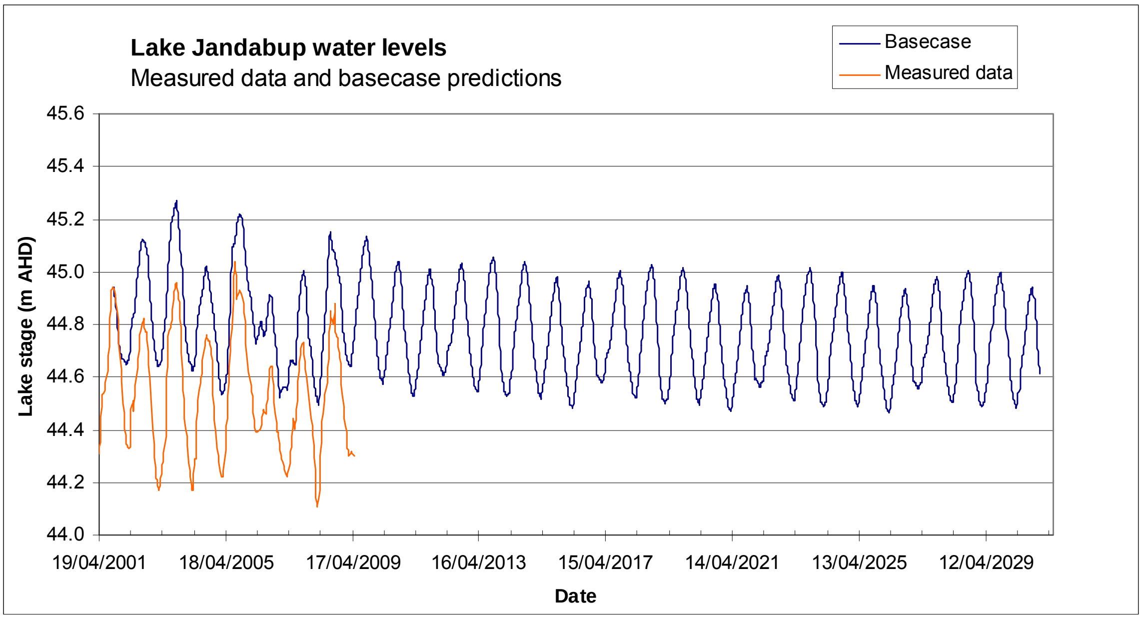

Figure 11: Basecase scenario: predicted water levels in Lake Jandabup

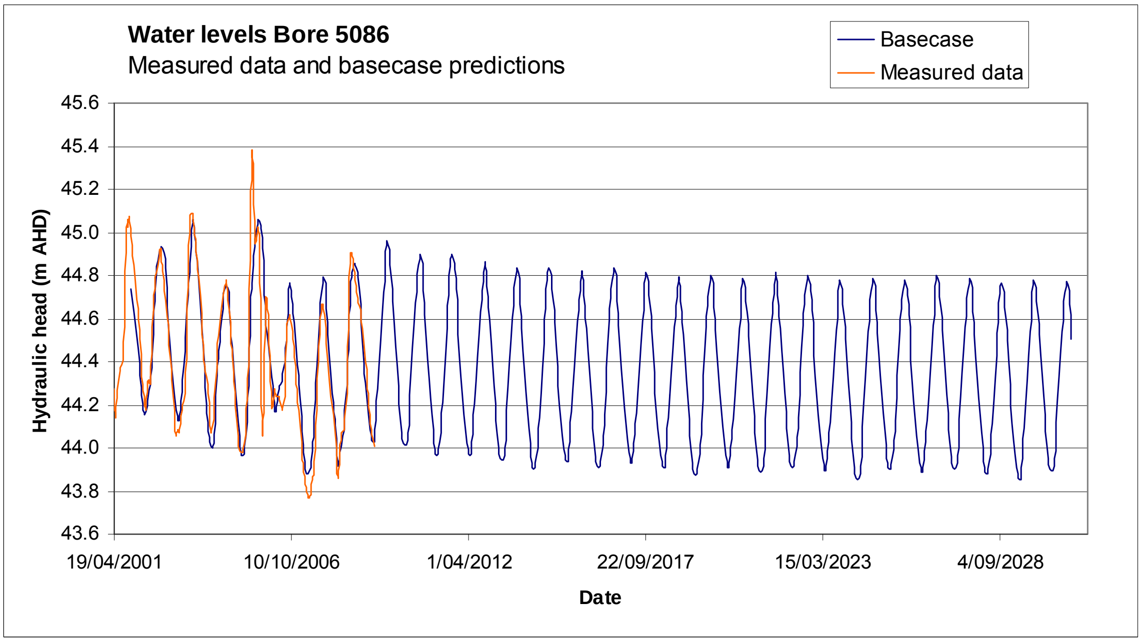

Figure 12: Basecase scenario: predicted water levels in Bore 5086

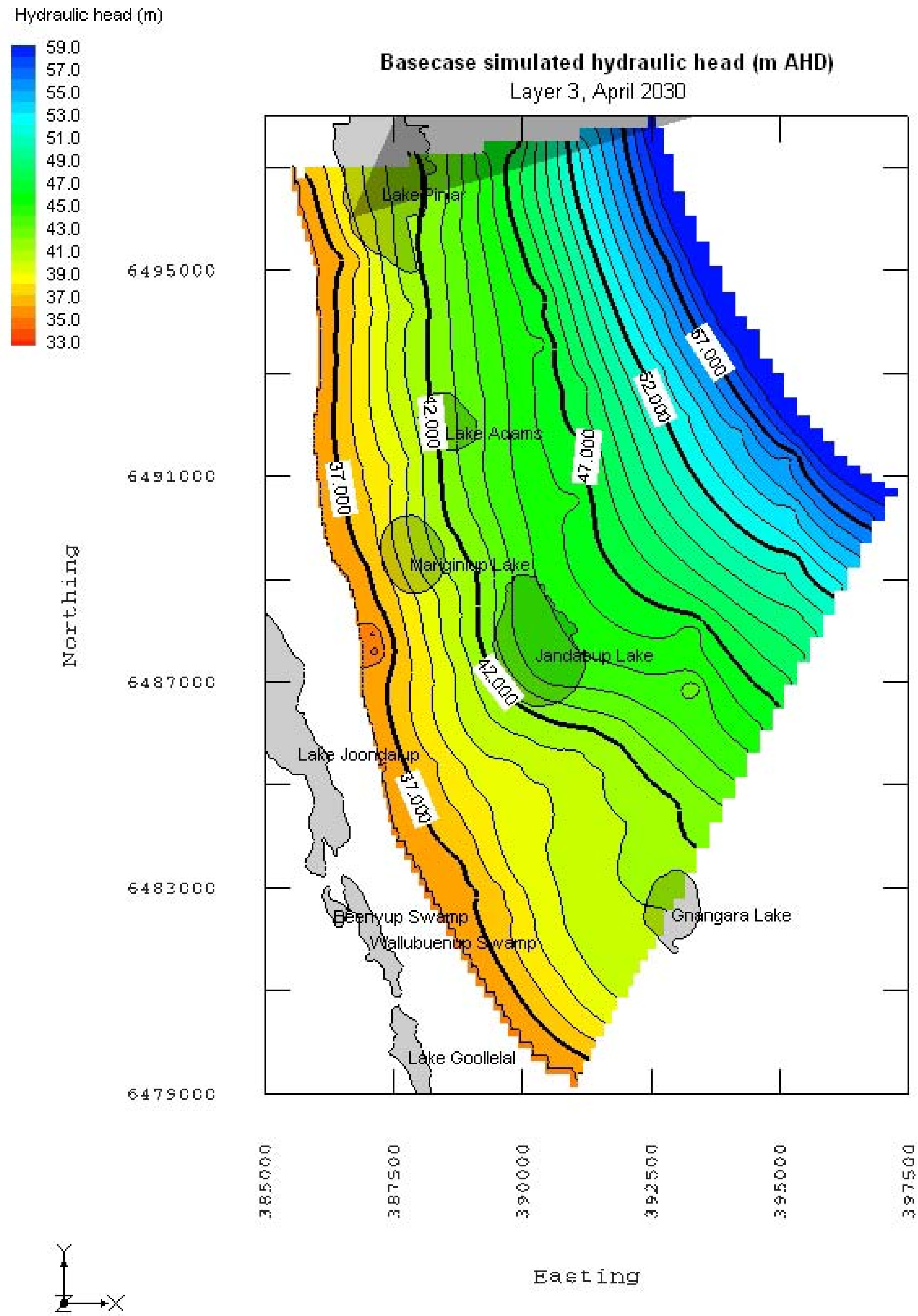

Figure 13: Basecase scenario: predicted hydraulic head contours in Layer 3, April 2030 (m AHD, 1 m intervals)

4.2 Scenario 2: No Jandabup augmentation

In this scenario artificial supplementation of Lake Jandabup has been removed from the Lakes Package as of 2010. Mariginiup water levels remain unchanged from the basecase (Figure 14). Jandabup water levels decrease after augmentation ceases, with water-level maxima declining by 0.3 m and minima by 0.5 m (Figure 15). As such, the amplitude of seasonal variation in lake water levels increases by 0.2 m. Groundwater levels decline by up to 0.8 m directly beneath and to the south-west of the lake without augmentation (Figure 17). Groundwater levels in Bore 5086 are predicted to decrease by 0.1 m relative to the basecase (Figure 16).

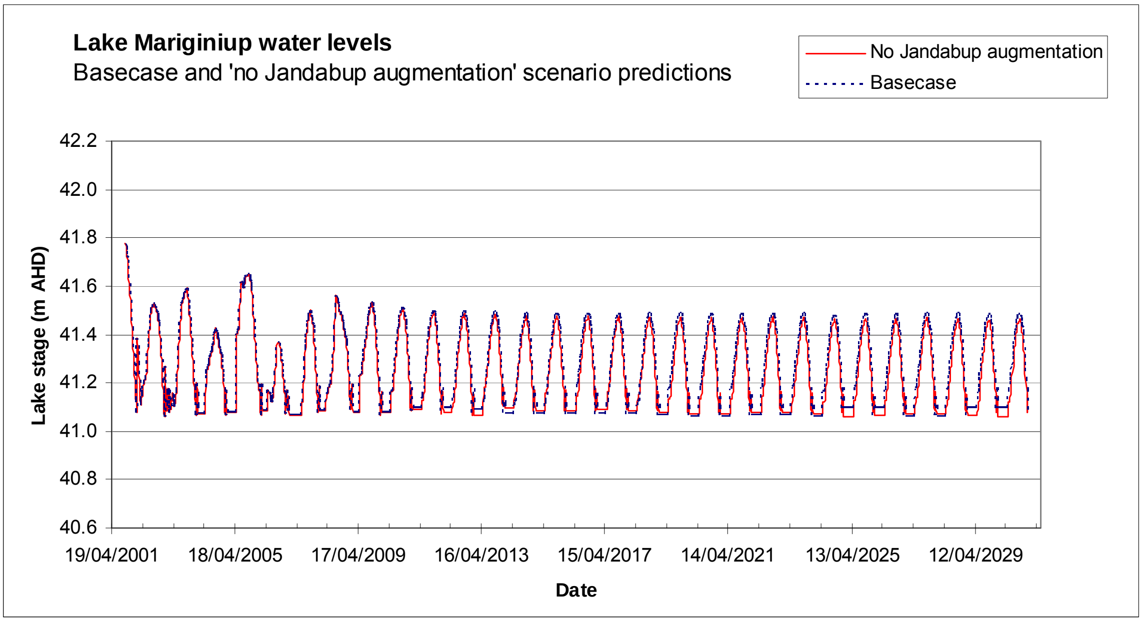

Figure 14: Scenario 2: predicted water levels in Lake Mariginiup

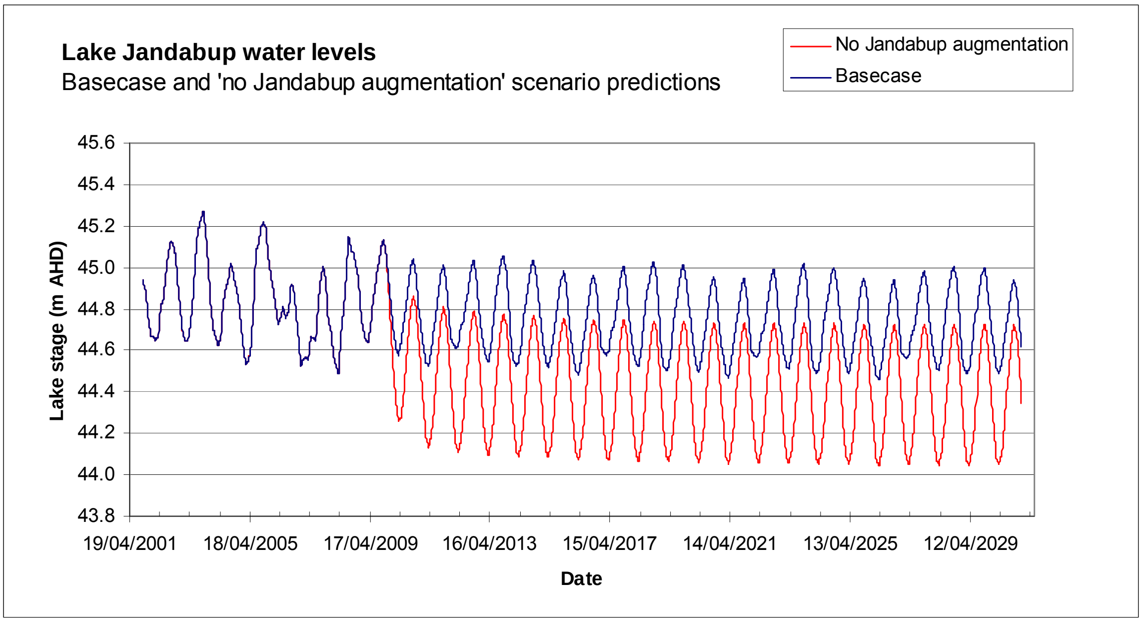

Figure 15: Scenario 2: predicted water levels in Lake Jandabup

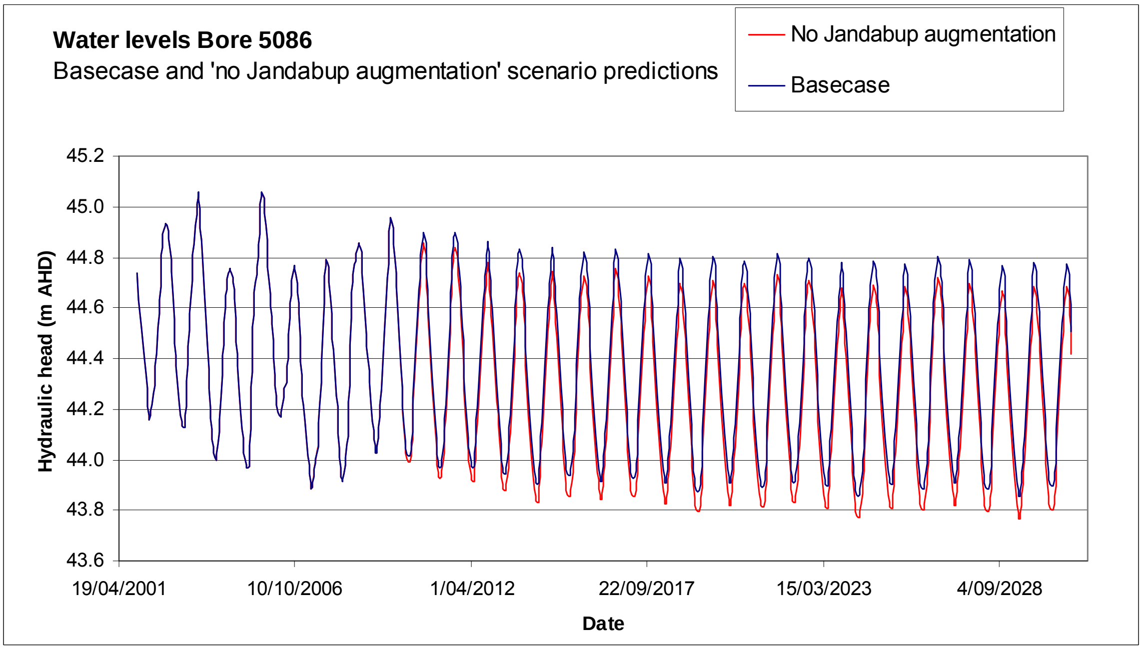

Figure 16: Scenario 2: predicted water levels in Bore 5086

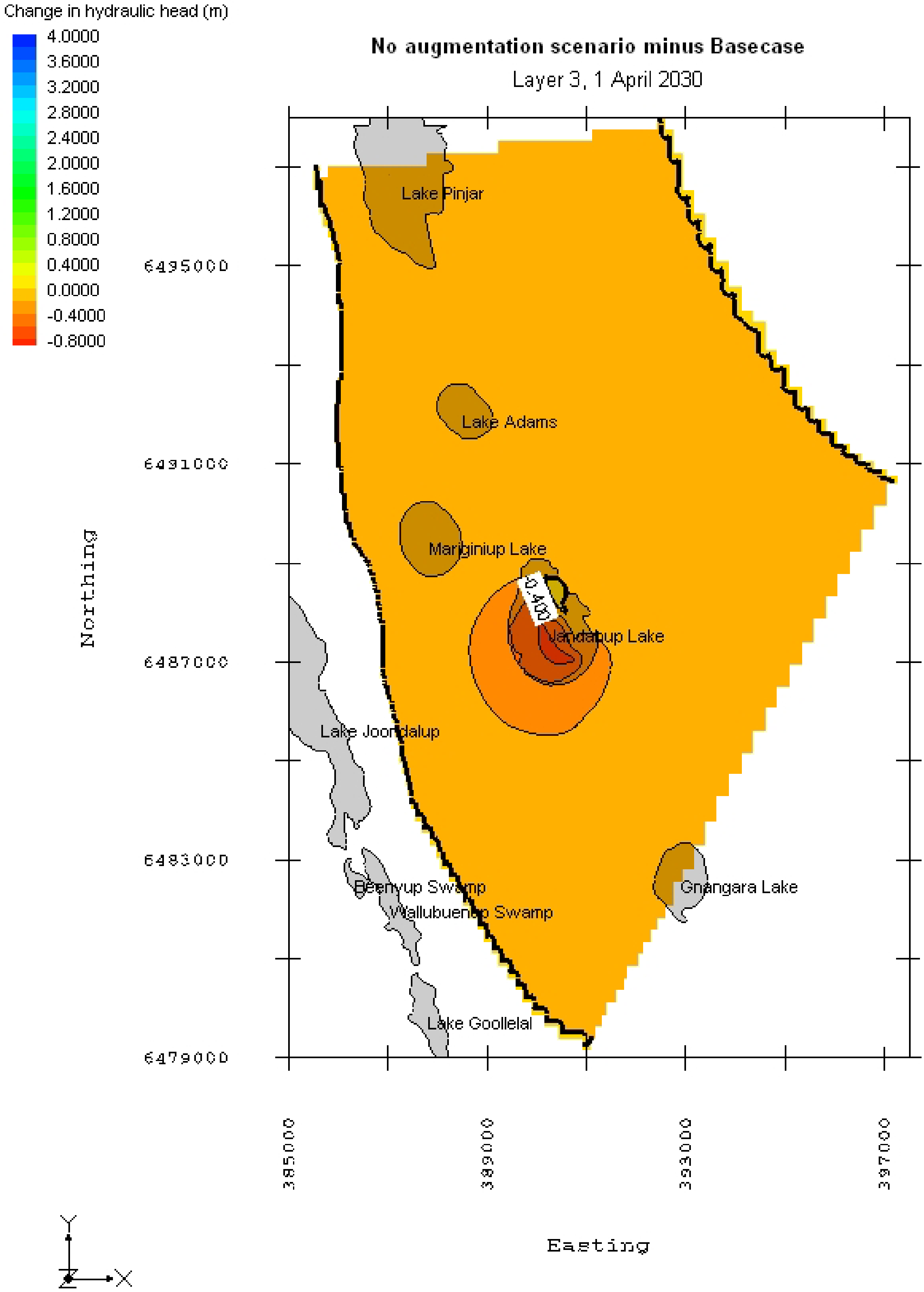

Figure 17: Scenario 2: change in hydraulic head relative to the basecase, Layer 3, April 2030 (contoured at 0.2 m intervals)

4.3 Scenarios 3 and 4: Pine clearing and post-pine banksia

These scenarios simulate the possible impact of pine-plantation clearing on water levels. The pine-clearing scenario assumes there will not be any active revegetation and the land will remain as pasture with 35 per cent rainfall recharge. The post-pine banksia scenario simulates the re-establishment of banksia on land where pines have been cleared, with 18 per cent rainfall recharge.

Water levels in Lake Jandabup are more influenced by the pine clearing than Lake Mariginiup due to proximity and flow directions (figures 18 and 19).

When pasture remains after pine clearing, the maximum and minimum water levels at Lake Jandabup are increased approximately 0.7 and 0.6 m respectively. Water-level minima at Lake Mariginiup remain unchanged with the lake bed dry over summer, while maximum water levels are increased by 0.2 m relative to the basecase. Oscillations in predicted water levels after summer are possibly associated with the re-wetting process in the simulation (RPS 2009a).

With the establishment of banksia woodland, seasonal maximum water levels at Lake Jandabup increased by 0.4 m and Lake Mariginiup by 0.1 m (figures 18 and 19). Summer minima at Lake Jandabup are increased by 0.3 m.

Increases in groundwater levels of up to 3.3 m are predicted directly beneath and down-gradient of the cleared pines where the plantation is replaced by pasture (Figure 21). The establishment of banksia woodland reduces the increase to 2.1 m (Figure 22). Water levels in Bore 5086 increased by 1.0 m under pasture and 0.7 m under banksia (Figure 20) relative to the basecase at the end of the simulation.

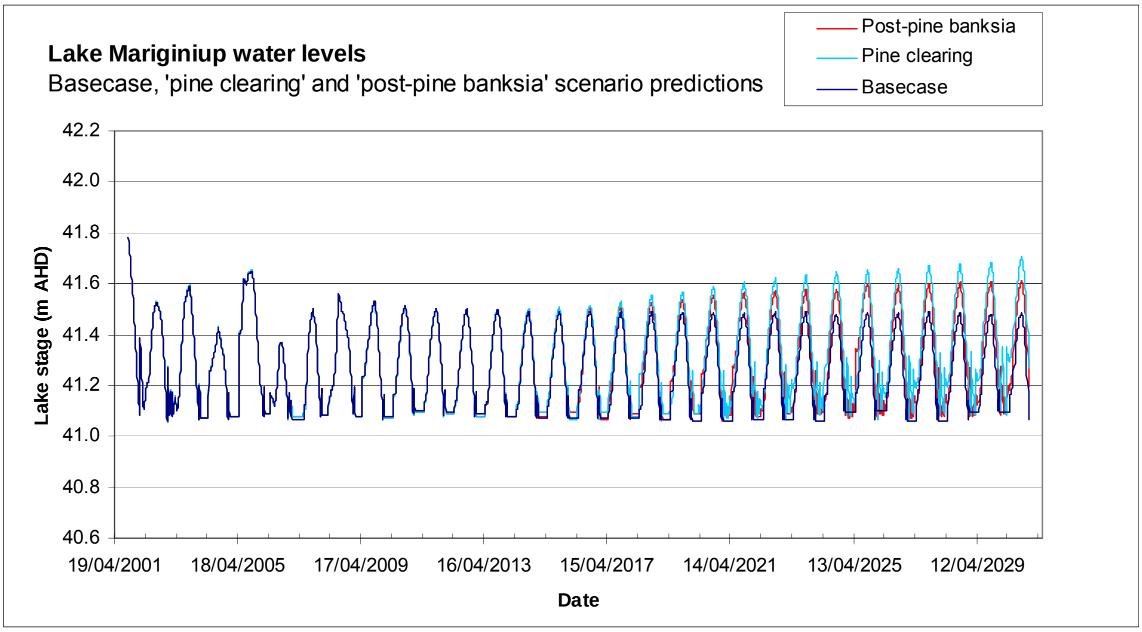

Figure 18: Scenarios 3 and 4: predicted water levels in Lake Mariginiup

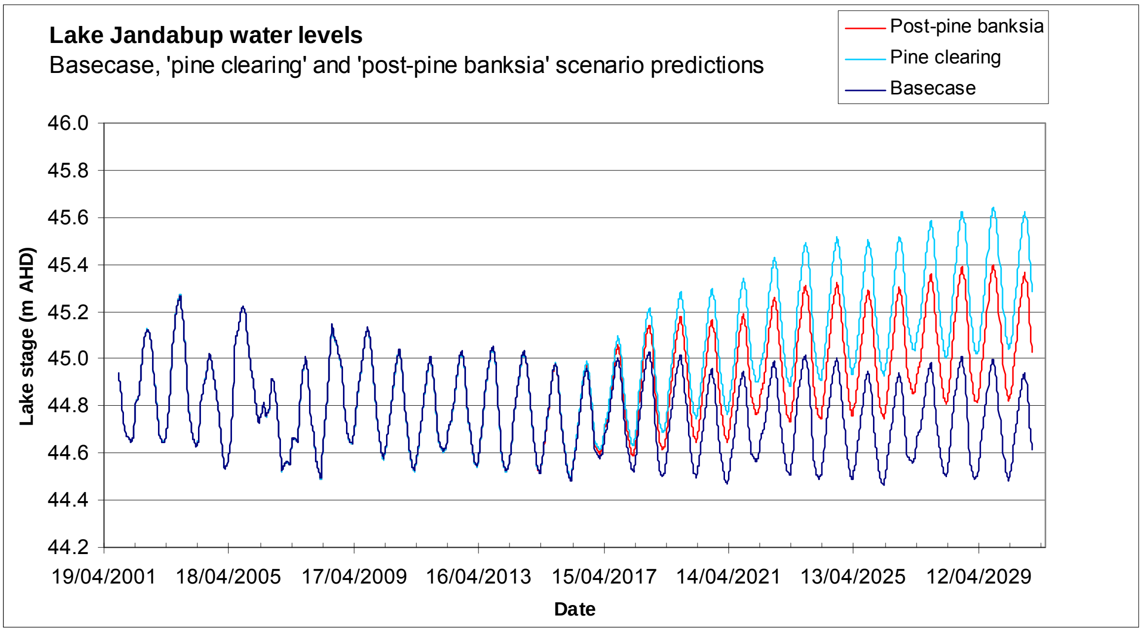

Figure 19: Scenarios 3 and 4: predicted water levels in Lake Jandabup

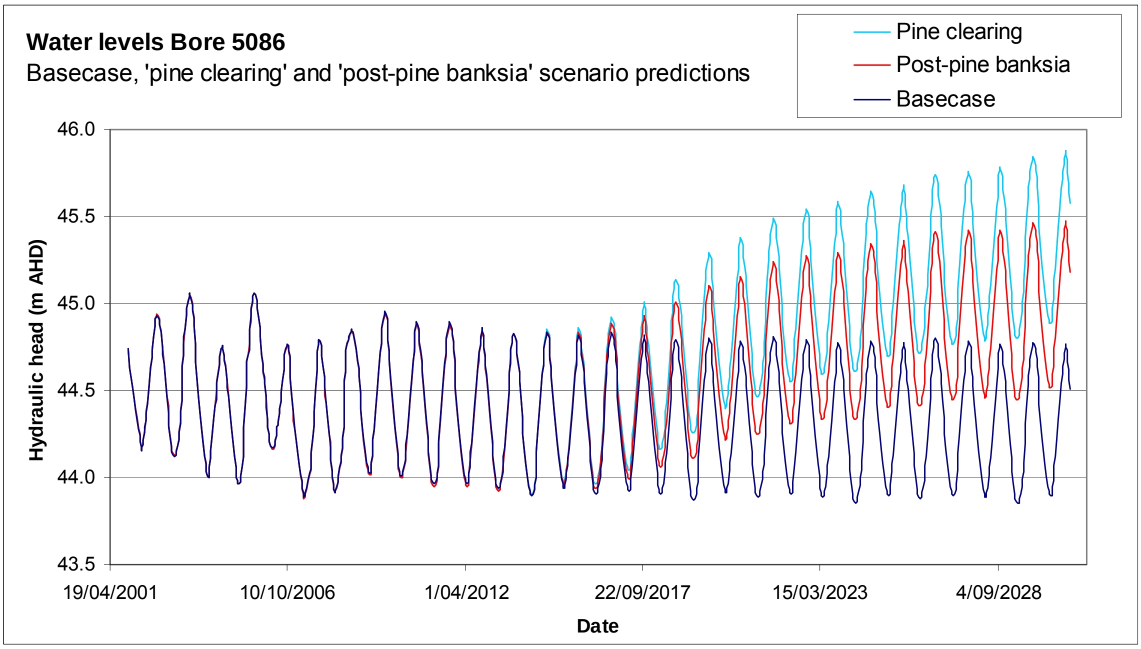

Figure 20: Scenarios 3 and 4: predicted water levels in Bore 5086

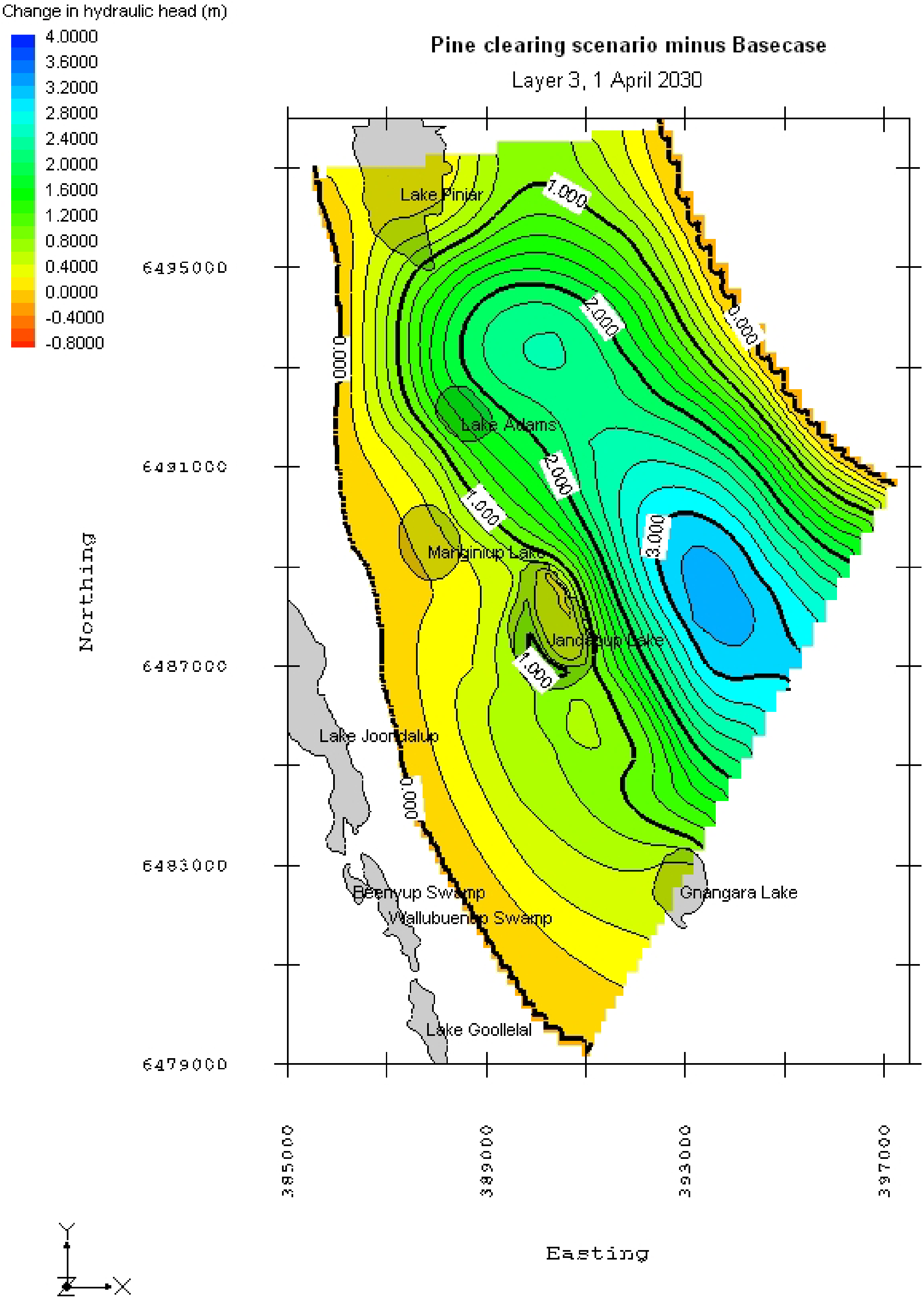

Figure 21: Scenario 3: change in hydraulic head relative to basecase, Layer 3, April 2030

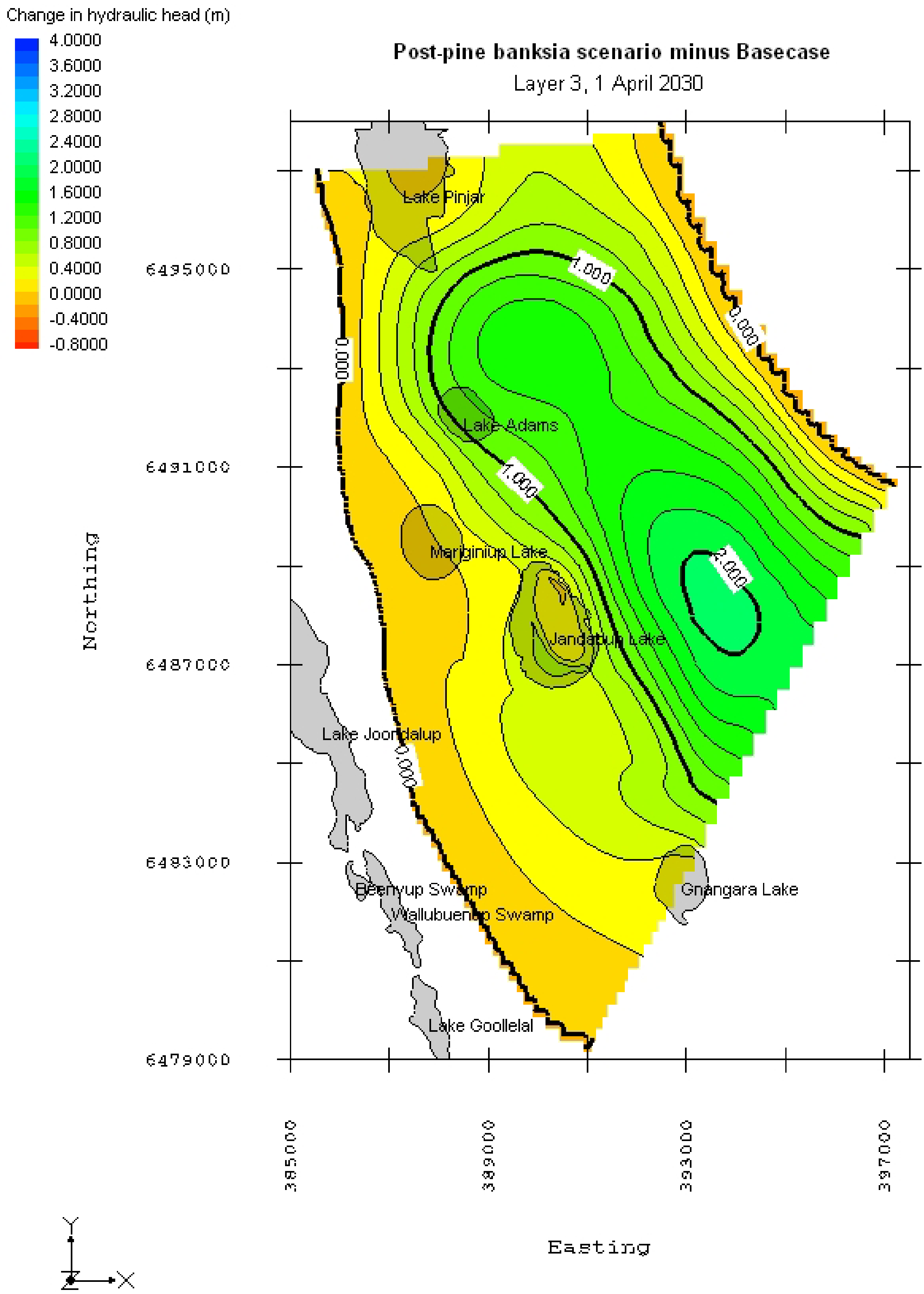

Figure 22: Scenario 4: change in hydraulic head relative to basecase, Layer 3, April 2030

4.4 Scenarios 5 and 6: Urbanisation and urbanisation plus pine clearing

The urbanisation scenario for Lake Mariginiup suggests an increase in seasonal maxima (up to 0.4 m) as well as seasonal minima (by 0.1 m) relative to the basecase (Figure 23). Maximum water levels in Lake Jandabup increase by 0.7 m and minima by 0.6 m relative to the basecase (Figure 24).

When urbanisation is combined with pine clearing the model suggests Lake Mariginiup would maintain surface water during summer from 2026. However, the predicted water levels are only at the height of the bottom of the staff gauge (41.3 m AHD). Under this scenario maximum water levels in Lake Mariginiup increase by 0.6 m relative to the basecase, while the minima remain the same. As a result, the amplitude of seasonal fluctuation in water levels almost doubles.

In both scenarios 5 and 6 the increases in maximum water levels in Lake Jandabup start later than those of Lake Mariginiup because of the dates of pine clearing and urbanisation in the area. However, the magnitude of the increase is larger, with maximum water levels up to 1.4 m higher than the basecase. Minimum water levels in Lake Jandabup are increased by 1.2 m, and so the amplitude of seasonal water-level fluctuation in Lake Jandabup increases by 0.2 m.

Groundwater levels increase by up to 2.7 m under urbanisation, with the biggest increase south of Lake Jandabup (Figure 26). When pine clearing is also included the same area experiences an increase of 3.9 m relative to the basecase, with the highest increases east of Lake Jandabup (4.0 m) where pines have been cleared (Figure 27). Seasonal maximum water levels in Bore 5086 increase by 1.2 m in the urbanisation scenario and 1.9 m when pine clearing is also included (Figure 25).

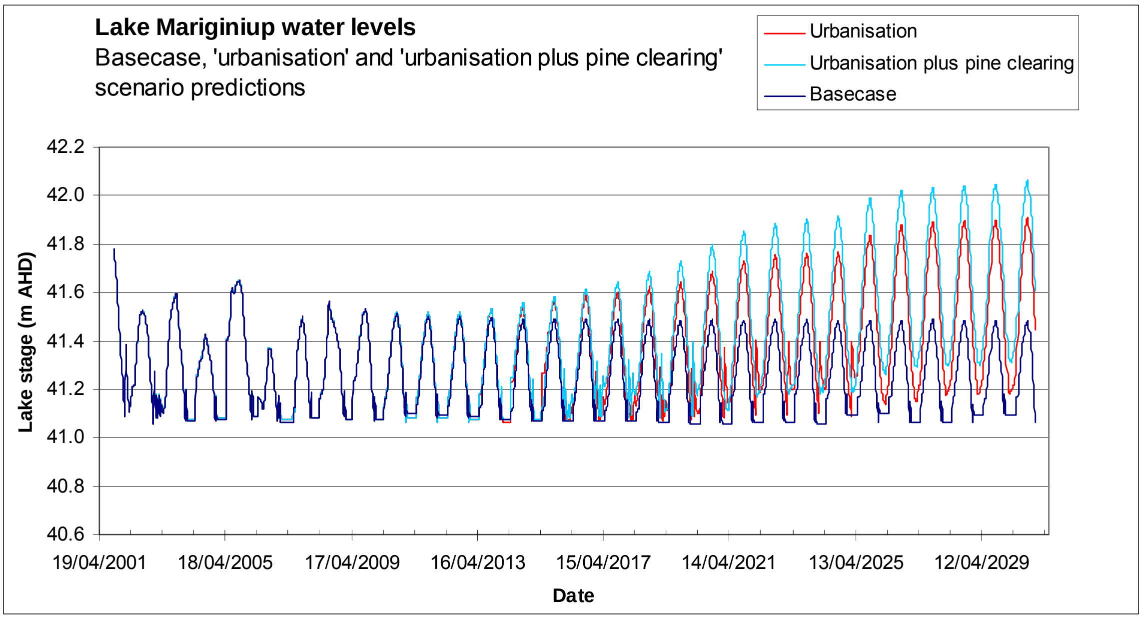

Figure 23: Scenarios 5 and 6: predicted water levels in Lake Mariginiup

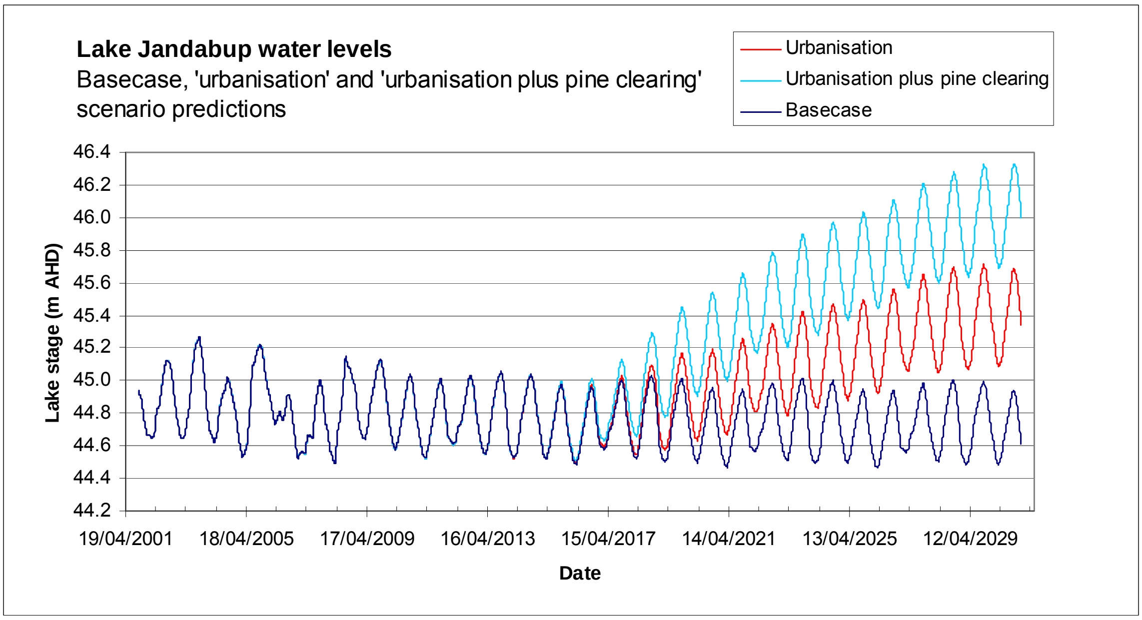

Figure 24: Scenarios 5 and 6: predicted water levels in Lake Jandabup

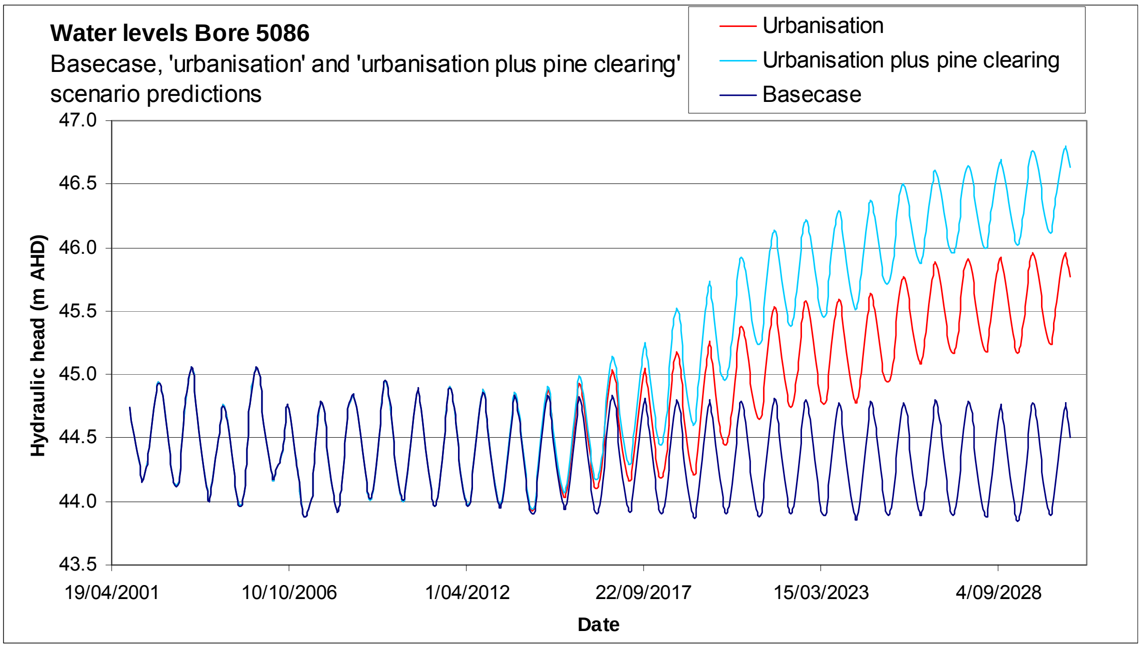

Figure 25: Scenarios 5 and 6: predicted water levels in Bore 5086

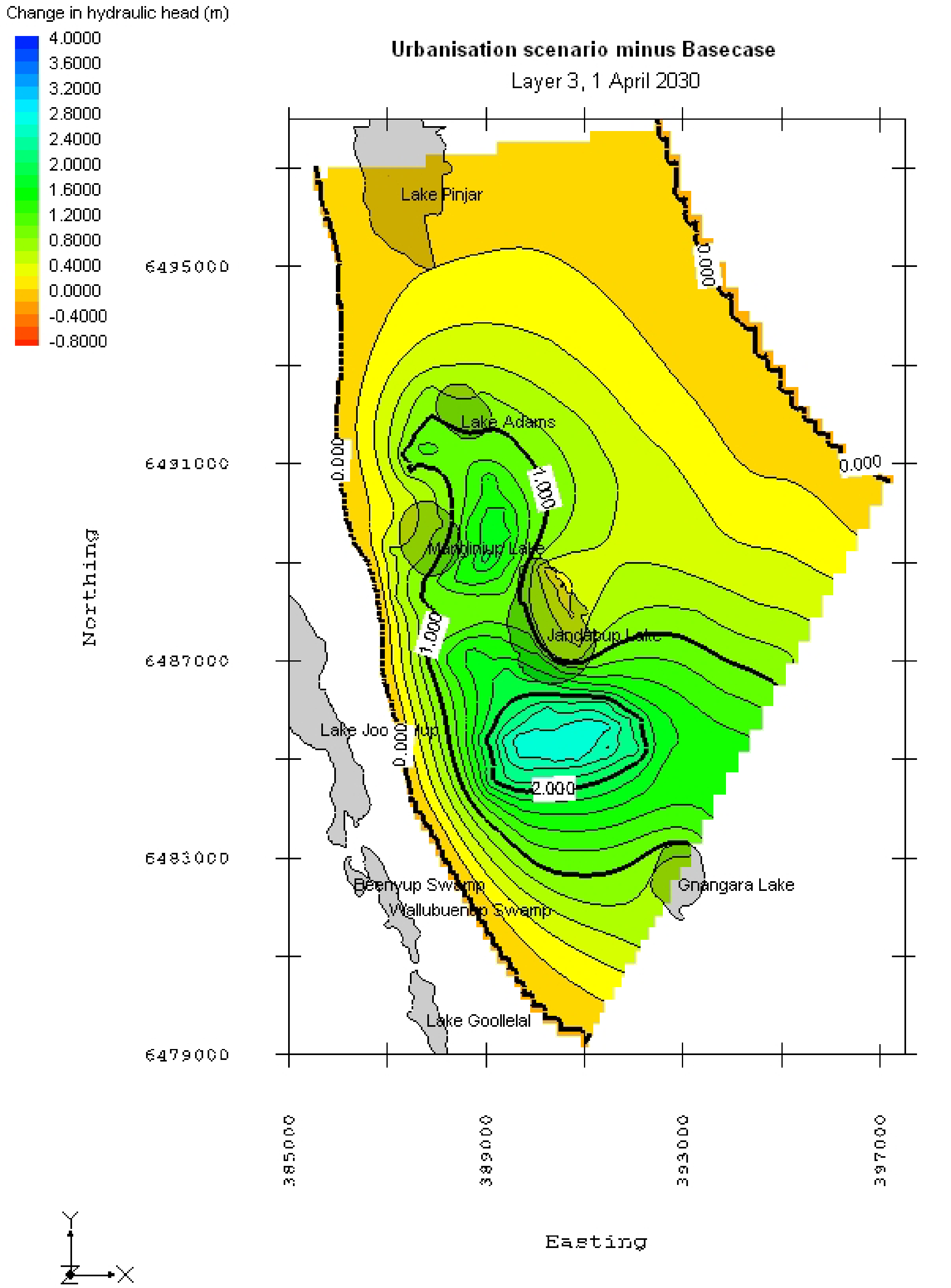

Figure 26: Scenario 5: change in hydraulic head relative to basecase, Layer 3, April 2030

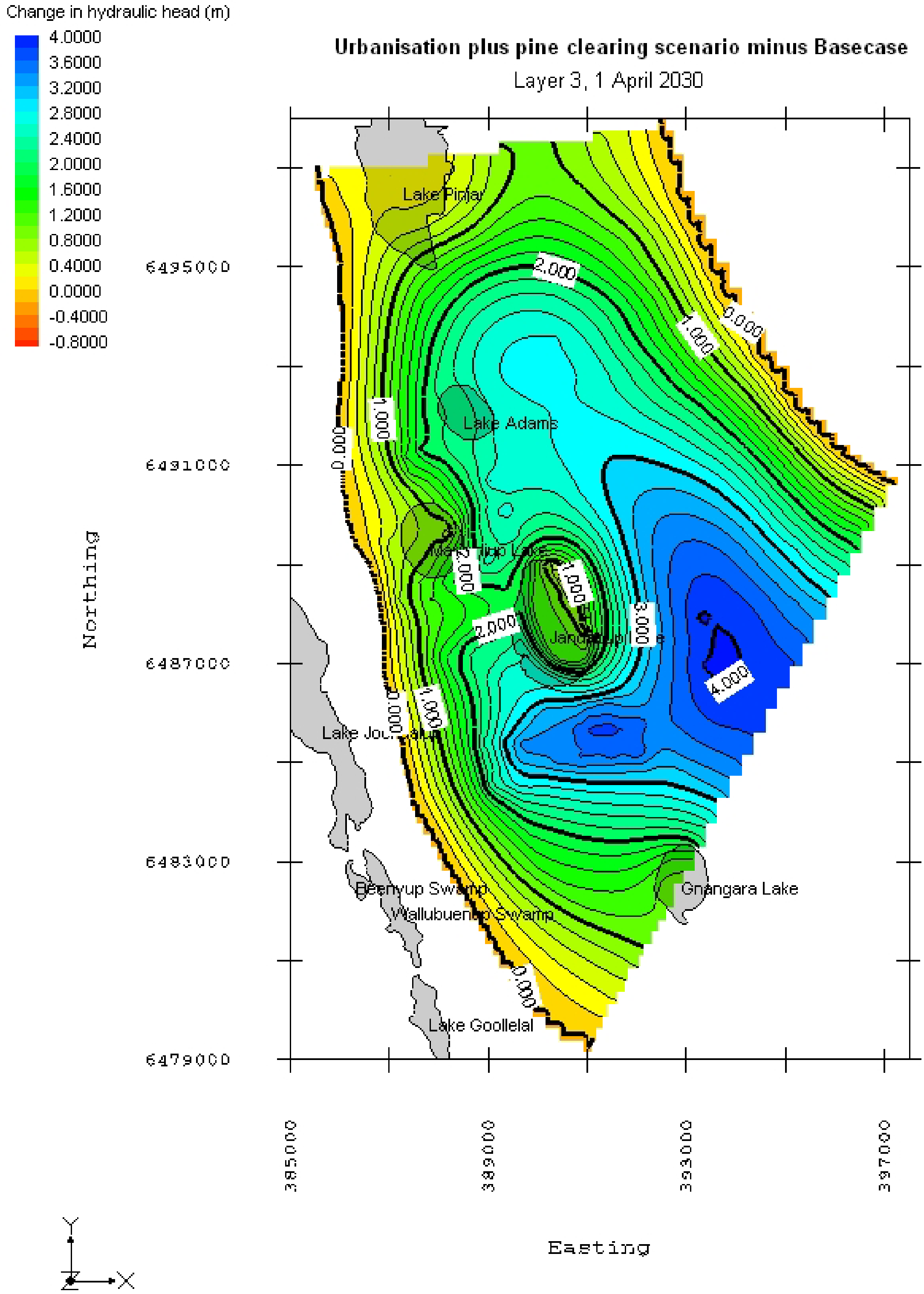

Figure 27: Scenario 6: change in hydraulic head relative to basecase, Layer 3, April 2030

4.5 Scenario 7: Directed recharge

This scenario is based on Scenario 6 (urbanisation plus pine clearing) with the addition of directed urban runoff. Water is captured from road surfaces in the urban area and injected into an infiltration swale 50 m up-gradient (east) of Lake Mariginiup.

Spring peak water levels in Lake Mariginiup are 0.1 m higher than those predicted under conventional urban water management in Scenario 6 (Figure 28).

Water levels in Lake Jandabup and Bore 5086 remain unchanged from Scenario 6 (figures 29 and 30). Groundwater contours are also not significantly different to Scenario 6 (Figure 31). Hydraulic head directly under the infiltration swale is 0.1 m higher than Scenario 6, while all other areas have changed by less than 0.1 m.

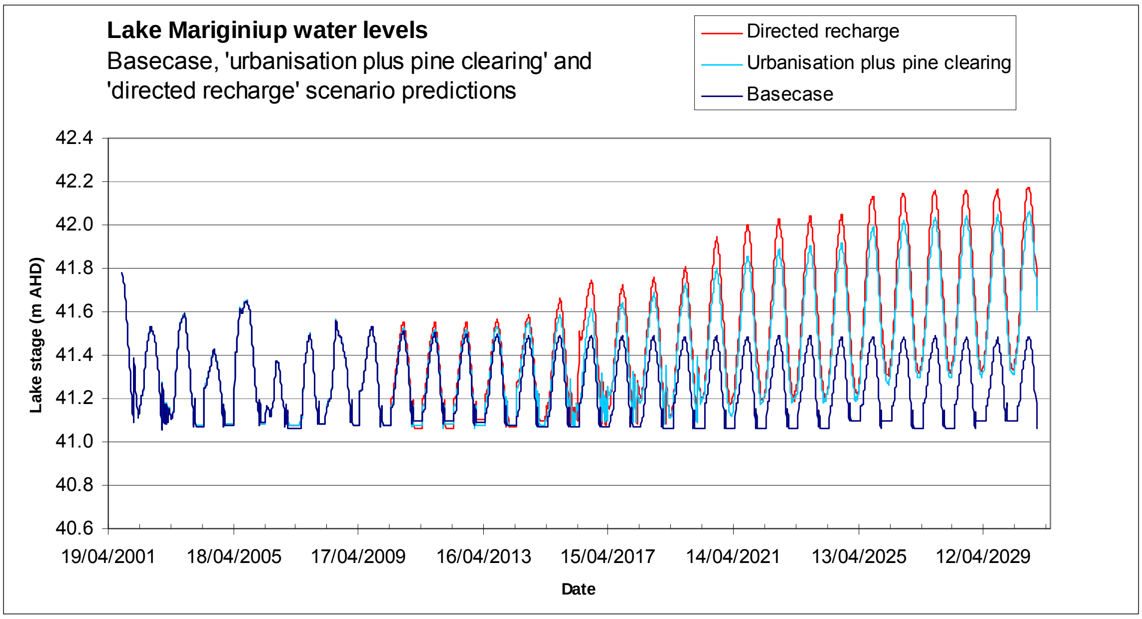

Figure 28: Scenario 7: predicted water levels in Lake Mariginiup

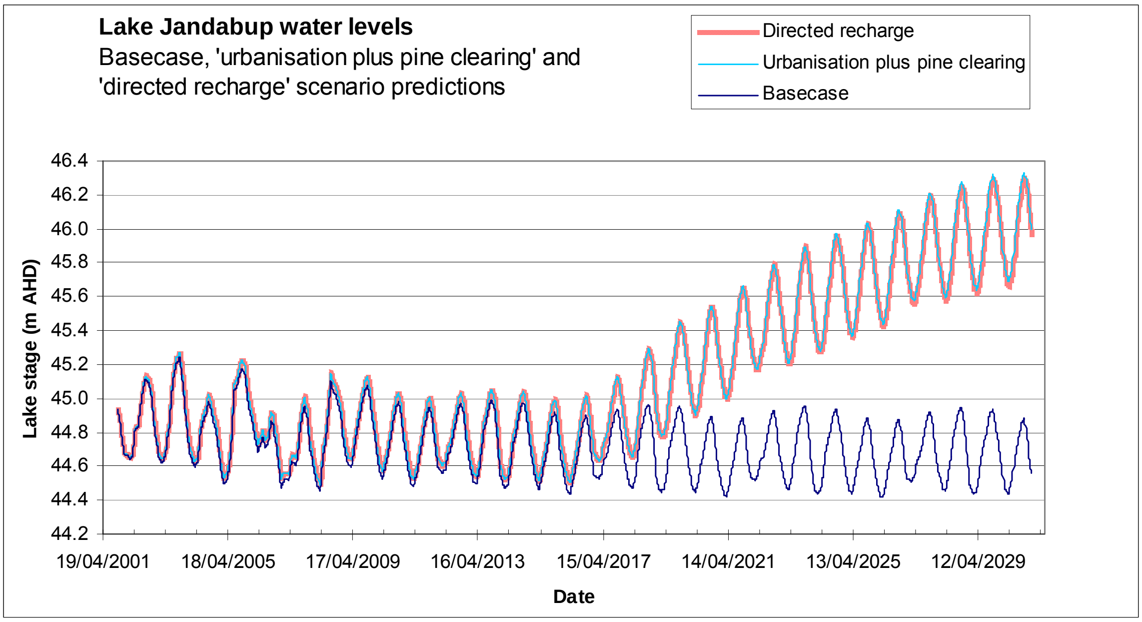

Figure 29: Scenario 7: predicted water levels in Lake Jandabup

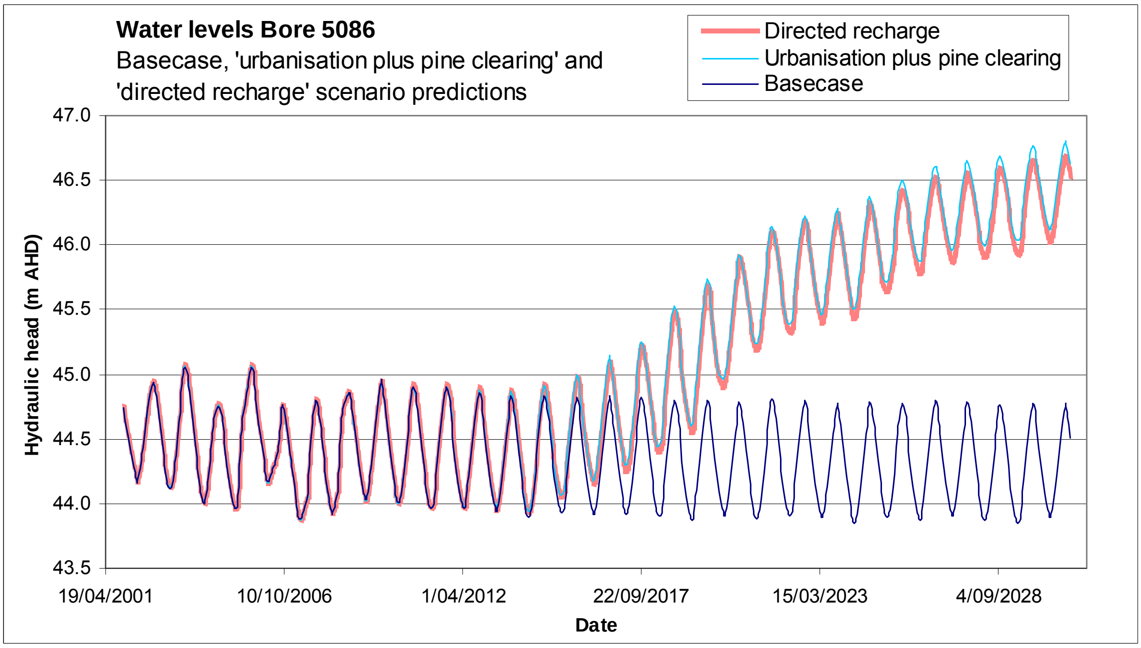

Figure 30: Scenario 7: predicted water levels in Bore 5086

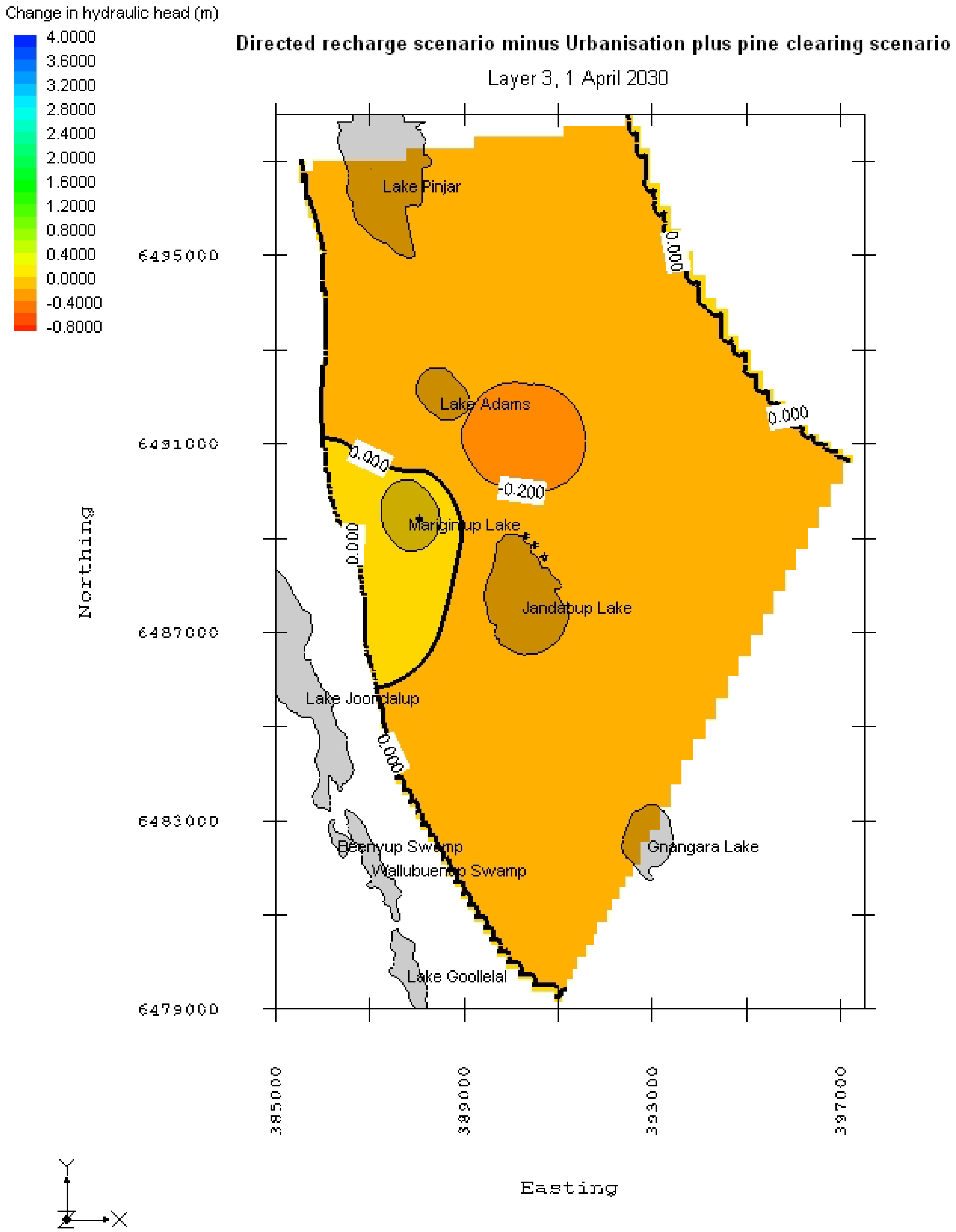

Figure 31: Scenario 7: change in hydraulic head relative to Scenario 6, Layer 3, April 2030

5 Interpretation of scenario predictions

5.1 Uncertainty in recharge coefficients

The water-level changes simulated in these scenario runs are heavily dependent on the coefficients of rainfall recharge assigned to reflect land-use change. As described in Section 3.1, a range of values have been reported in the literature. The values applied in these scenarios are on the conservative end and were chosen to be consistent with values used in the calibrated model. The actual percentage of rainfall that is recharged to the aquifer will vary spatially and temporally, even within areas that are classified as having the same land use.

The change in model outputs when different recharge coefficients are applied is demonstrated by the variation between the pine clearing and banksia scenarios. The only difference between these two scenarios is the value of the recharge coefficient applied after pine clearing (35 per cent for Scenario 3; 18 per cent for Scenario 4). The difference in the predicted groundwater-level change relative to the basecase between these scenarios is 1.2 m at the location of maximum groundwater increase (3.3 m with grassland; 2.1 m with banksia). That is, an 18 per cent difference in rainfall recharge resulted in a 1.2 m difference in maximum groundwater-level change relative to the basecase. The difference in predicted lake levels under the pine clearing and banksia scenarios was 0.3 m at Lake Jandabup and 0.1 m at Lake Mariginiup.

The literature suggests that the percentage of rainfall recharge in urbanised areas could vary by up to 20 per cent (Appleyard 1995; Silberstein et al. 2004). This constitutes a significant source of uncertainty within the model simulations in addition to those discussed by RPS (2009a). Running multiple scenarios that encompass the possible range of recharge values would allow for this uncertainty to be more accurately quantified.

If processes at the surface and in the unsaturated zone were specifically included in the model (e.g. WAVES, VFM), then the influence of uncertainty in recharge rates could be reduced. This explicit modelling approach would also increase computational effort and data input requirements.

5.2 Implications for management

This local-area modelling study supports the implementation of land-use change as a tool for managing water levels in the east Wanneroo area. The results suggest that both pine clearing and urbanisation could lead to significant rises in the watertable and lake water levels (Table 4).

Artificial supplementation of Lake Jandabup maintains water levels by up to 0.5 m. This amount is less than the water-level gain predicted at the end of the scenario run under the pine clearing and urbanisation scenarios (Scenarios 3 and 5). As such, this modelling suggests that if either of these land-use changes is implemented, water levels in Lake Jandabup may be sufficient without augmentation in the future.

However, it must be remembered that these modelling scenarios do not account for any decline in rainfall below 1996–2007 levels, which Perth is predicted to experience (IPCC 2007). Regional-scale groundwater models have shown that climate plays a significant role in determining water levels on the Gnangara Mound, and a drier climate could lower the watertable in the east Wanneroo area by up to 2 m (Vogwill et al. 2008). The impact of climate-driven watertable decline on lake water levels is not known and could be a subject of further investigation using this local-area model.

Water levels in Lake Mariginiup are increased more by urbanisation than pine clearing. This is likely due to the spatial distribution of each land-use change, with more urbanisation occurring within the lake's capture zone. With combined urbanisation and pine clearing, spring peak water levels are 0.6 m higher than the basecase. Increased summer minima, while not high enough to be recorded on the staff gauge, would increase sediment saturation and could thereby reduce the oxidation of potential acid sulfate soils (Turvey 2007).

Table 3: Predicted changes in minimum and maximum water levels in lakes Mariginiup and Jandabup

Scenario	Change in water level relative to the basecase (m)			
	Lake Mariginiup		Lake Jandabup	
	Minima	Maxima	Minima	Maxima
1. Basecase	*Datum*	*Datum*	*Datum*	*Datum*
2. No Jandabup augmentation	0	0	-0.5	-0.3
3. Pine clearing	0	0.2	0.6	0.7
4. Post-pine banksia	0	0.1	0.3	0.4
5. Urbanisation	0.1	0.4	0.6	0.7
6. Pine clearing plus urbanisation	0.2	0.6	1.2	1.4
7. Road runoff injected into swale	0.2	0.7	1.2	1.4

Directed recharge of water captured from urban roads in the immediate vicinity of Lake Mariginiup could raise seasonal maximum water levels by 0.1 m above standard water management practices (diffuse infiltration of urban runoff). It would be possible to increase the captured volume by including the roofs of houses as a source, as well as roads. RPS has estimated that the seasonal maximum could increase by an additional 0.1 m under this scenario (Carl Davies, pers. comm.).

The cost-effectiveness of this type of directed stormwater management must be evaluated in the context of possible environmental benefits. The redirection of stormwater away from the source urban area would reduce the recharge to the watertable in that development zone. Therefore, under a directed recharge scenario the increases in lake water levels occur at the expense of watertable rise in the urban area. A directed recharge scheme would also require infrastructure to be installed and maintained over the life of the scheme.

In addition to economic considerations, implementation of such a stormwater redirection scheme outside the lake's immediate catchment would contravene the principles of the *Stormwater management manual for Western Australia* (DOW 2007). This manual promotes the retention of stormwater within the immediate urban catchment so as to preserve the pre-development hydrology and minimise the transport of pollutants.

The Water Corporation has concluded from steady-state modelling that pine clearing is essential to maintain water levels on Gnangara Mound under a drying climate (Xu 2008). The transient scenarios run using this local-scale model of the east Wanneroo area supports this conclusion, demonstrating the positive impact of pine clearing on groundwater and lake water levels.

In addition, the modelling shows that urbanisation in the east Wanneroo area has the potential to increase water levels in the Superficial aquifer by a similar order of magnitude to pine clearing (3.3 m maximum increase under pine clearing with pasture; 2.7 m maximum increase under urbanisation only). This supports the findings of Vogwill et al. (2008) that urbanisation can act as a tool for mitigating groundwater-level declines on the Gnangara Mound. As discussed in Section 5.1, the increases under urbanisation are likely to be conservative, assuming rainfall recharge is towards the lower end of the rates reported in the literature.

Management of private abstraction in newly urbanised areas will ultimately determine the actual gains in rainfall recharge. This study assumes that groundwater usage by homeowners will continue in line with recent trends (Water Corporation 2003; ABS 2003). A shift in policy away from the use of garden bores could lead to increased water levels in addition to those simulated in these scenarios.

Impacts of groundwater abstraction were not assessed in this study. Regional-scale modelling suggests that groundwater abstraction can play a significant role in determining water levels on the Gnangara Mound (Xu 2008; Vogwill et al. 2008). Groundwater is abstracted from the Superficial aquifer in the east Wanneroo area by the Water Corporation for public water supply, and also by private users. Scenario modelling using PRAMS has estimated that reducing private abstraction by 20 per cent could increase watertable levels in the east Wanneroo area by up to 1.5 m (Vogwill et al. 2008). Further modelling should be undertaken using this local-scale model to assess the impacts of groundwater abstraction on lake water levels and the watertable in the east Wanneroo area.

6 Conclusions and recommendations

- Local-scale modelling that explicitly incorporates groundwater/surface-water interactions is a useful tool to evaluate land and water management options.
- Land-use change in the east Wanneroo area is likely to increase water levels in the Superficial aquifer and lakes Mariginiup and Jandabup.
- The maximum water-level increase in the Superficial aquifer under pine clearing is of comparable magnitude to the maximum increase under urbanisation. However, the location of these maximum increases differs according to the distribution of the land-use change.
- Urbanisation or pine clearing could potentially offset the need for artificial supplementation of water levels in Lake Jandabup in the future.
- Summer minimum water levels in Lake Mariginiup are unlikely to increase significantly if both pine clearing and urbanisation are implemented, but the increase may be sufficient to maintain the saturation of sediment and reduce the oxidation of potential acid sulfate soils.
- The implementation of a directed recharge regime could provide small increases lake water levels, but this would occur at the expense of groundwater-level increases. This scenario needs to be further evaluated for cost-effectiveness and environmental significance.
- Further scenario modelling should be carried out using this local-scale model to assess the impacts of public and private abstraction on water levels in the east Wanneroo area.
- Future scenario modelling should report results as ranges of possible water-level change to better communicate the level of uncertainty in the scenario results.

References

ABS – see Australian Bureau of Statistics

Allen, AD 1979, 'The hydrogeology of Lake Jandabup, Swan coastal plain, WA', *Western Australian Geological Survey Annual Report 1979*, pp 32-40.

Appleyard, S 1995, 'The impact of urban development on recharge and groundwater quality in a coastal aquifer near Perth, Western Australia', *Hydrogeology Journal,* 3(2) 65-75.

Australian Bureau of Statistics 2003, *Domestic water use, Western Australia, 2003*, Australian Bureau of Statistics report 4616.5.55.001

Australian Bureau of Statistics 2008, *Population projections Australia*, Australian Bureau of Statistics report 3222.0

Davidson, WA 1995, *Hydrogeology and groundwater resources of the Perth Region, Western Australia*, Western Australian Department of Mines, Perth.

Davidson, WA & Yu, X 2006, *Perth Regional Aquifer Modelling System (PRAMS) hydrogeology and groundwater modelling*, Department of Water, Perth.

Department of Water 2007, *Stormwater management manual for Western Australia*, Department of Water, Perth.

DOW – see Department of Water

Farrington, P & Bartle, GA 1991, 'Recharge beneath a banksia woodland and a *Pinus pinaster* plantation on coastal deep sands in south Western Australia', *Forestry Ecology and Management*, 40, 101-118.

Froend, R, Loomes, R, Horwitz, P, Rogan, R, Lavery, P, How, J, Storey, A, Bamford, M & Metcalf, B 2004, Study of ecological water requirements on the Gnangara and Jandakot mounds under Section 46 of the Environmental Protection Act, Task 1: Identification and re-evaluation of ecological values, report prepared for the Water and Rivers Commission, Perth.

Hall, J 1983, 'The hydrogeology of Lake Mariginiup, Perth, Western Australia', *Geological Survey of Western Australia Professional Papers 1983*, Government Printing Office, Perth.

IPCC – see Intergovernmental Panel on Climate Change

Intergovernmental Panel on Climate Change 2007, *Climate change 2007: The physical science basis*, Contribution of Working Group I to the Fourth Assessment Report of the IPCC, Cambridge University Press.

McDonald & Harbaugh 1988, *A modular three-dimensional finite difference groundwater flow model*, United States of America Department of the Interior, Washington.

Merritt, ML & Konikow, LF 2000, *Documentation of a computer program to simulate lake-aquifer interaction using the MODFLOW groundwater flow model and*

MOC3D solute-transport model, United States Geological Survey Water-Resources Investigations report 00-4167, Tallahassee, Florida.

McHugh, SM & Bourke, SA 2007, *Management area review of shallow groundwater systems on Gnangara and Jandakot mounds*, Hydrogeological record series, report no. HG25, Department of Water, Perth Western Australia.

Middlemis, H, Merrick, N & Ross, J (eds) 2000, *Groundwater flow modelling guideline*, Murray Darling Basin Commission, Australia.

RPS 2009a, *Local area model of groundwater flows and lake interactions: Lakes Mariginiup and Jandabup,* report prepared by RPS for the Department of Water and Cedar Woods Properties Ltd. Western Australia, pp 28.

RPS 2009b, *Local area model of groundwater flows and lake interactions user manual: Lakes Mariginiup and Jandabup*, report prepared by RPS for the Department of Water and Cedar Woods Properties Ltd. Western Australia, pp 18.

Sharma, ML, Barron, RJW & Craig, AB 1988, *Influence of land use on natural groundwater recharge in the unconfined aquifers of the Swan coastal plain, Western Australia,* CSIRO project report, July 1985 to June 1988, Australia.

Sharma, ML, Byrne, JD, Herne, DE & Kin, PG 1991, *Impact of horticulture on water and nutrient fluxes to a sandy aquifer*, CSIRO report 91/33, Australia.

Silberstein, R, Barr, A, Hodgson, G, Pollock, D, Salama, R & Hatton, T 2004, *A vertical flux model for the Perth groundwater region,* CSIRO Western Australia.

Silberstein, R, Walker, S, Hick, W, Higgson, S, Dumbrell, I, Canci, M & Hodgson, G 2007, *Water balance of the pine plantations of the Gnangara Mound*, seminar presented 17 May, 2007, CSIRO Land and Water, Floreat, Western Australia viewed March 2008, <www.clw.csiro.au/division/perth/seminars/2007/documents/Silberstein_May2007.pdf>.

Turvey, C 2007, *An investigation of the relationships between hydrogeology, geochemistry and lake acidification at Lake Mariginiup, Western Australia,* Honours thesis, University of Western Australia, Perth.

Vogwill, RIJ, McHugh, SL, O'Boy, CA & Yu, X 2007, *PRAMS scenario modelling for water management of the Gnangara Groundwater Mound*, Hydrogeological record series, report no. HG21, Department of Water, Perth.

WAPC – see Western Australian Planning Commission

Water Authority of Western Australia 1995, *Report of proposed changes to environmental conditions, Gnangara Mound groundwater resources (Section 46)*, Water Authority of Western Australia, Perth.

Water Corporation 2003, *Domestic water use study in Perth, Western Australia 1998–2001*, Water Corporation, Perth, Western Australia.

WAWA – see Water Authority of Western Australia

Western Australian Planning Commission 2007, *The future of east Wanneroo: Land use and water management in the context of Network City*, Western Australian Planning Commission, Perth.

Xu, C 2008, *Modelling of groundwater levels on the Gnangara Mound*, Water Corporation, Perth.

Yesertener, C 2008, *Assessment of the declining groundwater levels in the Gnangara Groundwater Mound*, Hydrogeological record series, report no. HG14, Department of Water, Perth.

www.water.wa.gov.au