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

Lower Serpentine hydrological studies

Land development, drainage and climate scenario report

Securing Western Australia's water future

Water*Science*
technical series

Report no. WST 48
August 2015

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August 2015

ISSN 1836-2877 (online)

ISBN 978-1-921992-88-9 (online)

Acknowledgements

The Department of Water would like to thank the following people for their contribution to this publication: the Water Resource Assessment Branch for report review; Dale Sanderson from the Department of Planning for provision of development area data and report review; Krish Seewraj from the South West Region for assistance with drainage scenario implementation; Paola Duarte and Melinda Burton from the Urban Water Branch for assisting with project management and scenario development.

Reference details

The recommended reference for this publication is:

Marillier, B, Hall, J & Kretschmer, P 2015, *Lower Serpentine hydrological studies – land development, drainage and climate scenario report,* Water Science Technical Series, report no. 48 Department of Water, Western Australia.

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Cover photograph: Aerial view of an urban development near Byford, looking west, Ben Marillier, 2011

Disclaimer

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Summary

The *Lower Serpentine hydrological studies* is a series of three reports describing the development of a surface and groundwater model to simulate drainage, climate and land development scenarios at a regional scale. This report discusses the scenario modelling and results in the context of existing undeveloped urban and industrial zoned land, as well as industrial investigation areas.

The scenarios which were implemented in the Lower Serpentine regional model included:

- **Future climate scenarios** based on Intergovernmental Panel on Climate Change (IPCC) emissions scenarios, including changes in precipitation, evaporation and sea-level-rise. The scenarios were selected to provide results for a *reasonable* range of future climates, and to include historical wet periods. The following scenarios were implemented:
  - Future wet climate: –5.0% change in mean annual rainfall relative to the World Meteorological Organisation (WMO) climate baseline period 1961–90 (Institute of Numerical Mathematics (INMCM), Russian Academy of Science, Russia, B1 scenario).
  - Future medium climate: –9.8% change in mean annual rainfall relative to the WMO climate baseline period 1961–90 (NASA Goddard Institute for Space Studies (NASA/GISS), USA, B1 scenario).
  - Future dry climate: –19.1% change in mean annual rainfall relative to the WMO climate baseline period 1961–90 (Geophysical Fluid Dynamics Laboratory, National Oceanic and Atmospheric Administration, USA, A2 Scenario).
  - Future medium with two wet years: the future medium climate with the years 2044 and 2045 replaced with observed rainfall from 1963 and 1964 – both high rainfall years in excess of 1000 mm.
  - Historical wet: 5.2% increase in mean annual rainfall using the historical climate sequence from 1945 to 1974.

  The climate scenarios represent the 10th, 50th and 90th percentile changes in average annual rainfall assessed from 52 combinations of general circulation model and emissions scenario. The sea-level-rise scenario of 0.9 m by the year 2110 was based on the state planning policy document called Position Statement – State Planning Policy No. 2.6 State Coastal Planning Policy Schedule 1 Sea-level-rise.

- **Development scenarios** based on mapping from the Metropolitan region scheme (MRS), Peel region scheme (PRS) and the Economic employment and lands strategy (EELS), provided by the Department of Planning. The development areas modelled included 'Industrial Investigation' areas from the EELS, and existing undeveloped urban, urban deferred and industrial areas from the region schemes.

- **Subsurface drainage scenarios** in areas of shallow groundwater at different levels including the pre-development average annual maximum groundwater level (AAMaxGL), average annual minimum groundwater level (AAMinGL), and AAMinGL plus 0.5 m, with fill where required for each scenario. The subsurface drainage scenarios aim to capture a *representative* range of drainage levels.

Fifteen scenarios were modelled, including the base-case (current conditions) scenario. The scenarios included various combinations of climate, development and drainage. For each scenario results are reported spatially (groundwater levels and inundation) and quantitatively (water balances and discharge).

The climate scenarios predicted the following changes relative to the base-case for AAMaxGL, AAMinGL and discharge from the Serpentine River:

- **Future dry climate S1:** –0.82 m AAMaxGL, –0.64 m AAMinGL, –47.5 GL/yr flow
- **Future medium climate S4:** –0.49 m AAMaxGL, –0.41 m AAMinGL, –26.0 GL/yr flow
- **Future wet climate S9:** –0.26 m AAMaxGL, –0.28 m AAMinGL, –8.7 GL/yr flow
- **Historical wet climate S13:** +0.28 m AAMaxGL, +0.04 m AAMinGL, +51.2 GL/yr flow

Gross recharge to the Superficial Aquifer was predicted to average 198 GL/yr for the base-case scenario (34% of rainfall), 138 GL/yr for the future dry climate (28% of rainfall) and 190 GL/yr for the future wet climate (33% of rainfall). Average annual discharge from the Serpentine River was predicted to average 96.7 GL/yr for the base-case scenario, 49.3 GL/yr for the future dry scenario, and 88.0 GL/yr for the future wet scenario.

All climate scenarios were assessed for impact on waterlogging (inundation from groundwater) extent and depth. The base-case scenario showed that around 18% of the study area is prone to waterlogging in winter; in particular, low-lying areas on the eastern margin of the coastal plain, and around Birrega Main Drain, Peel Main Drain and the Serpentine River. The future dry climate scenario predicted a shrinking of inundated area to 14%, and the historical wet scenario showed a greater area of inundation of 23% of the study area. In the future dry climate scenario the number and extent of wetlands within the study area, particularly within the Spearwood Dunes and on the Jandakot Mound, are significantly reduced. The future medium with two wet years scenario (S12) shows that the maximum groundwater level is responsive to the wet years, even after an extended period of lower rainfall. This indicates that areas historically at risk of inundation from groundwater will remain so, even after an extended period of a relatively dry climate.

The 0.9 m sea-level-rise scenario showed that groundwater levels along the coastal fringe would be affected up to 2 km inland, with the Rockingham Peninsula and Becher Point showing the greatest increases. The only development affected was the Kwinana industrial area, however, a clearance to groundwater of greater than 2 m was maintained in the sea-level-rise scenario within the affected area. Water levels along the lower reaches of the Serpentine River were elevated, but did not affect any planned or existing development areas.

Development scenarios were modelled for 19 subareas within the study area. Subsurface drainage was modelled within a subset of these development areas where shallow groundwater was present. The volumes of subsurface drainage water predicted by the model varied between 0 ML/yr for developments with significant depth to groundwater and 4 GL/yr for the Baldivis Industrial development with drains set at the lowest level (AAMinGL) with the wet scenario. Drainage volumes increased as the subsurface drainage depth increased, and decreased with lower rainfall. For all of the development areas within the region, with drains set at AAMaxGL, the total drainage volume predicted was between 7 GL/yr for the dry scenario and 12 GL/yr for the wet scenario.

The drainage volumes presented in the report do not necessarily represent the total volume of water draining from the development area; rather, they represent the volume of water which must be managed within the development footprint. Local differences in drainage design will influence the volume of overland flow, recharge and subsurface drainage within the developments and, therefore, the results presented here should be considered indicative only.

Abstraction from domestic garden bores within the development areas was modelled for all new urban areas. Abstraction was modelled at a rate of 400 kL/yr, assuming a lot size of 400 m^2 covering 60% of the 50.6 km^2 urban residential development area, and a bore installation rate of 11% (around one in ten houses). This resulted in an additional 3.4 GL/yr of unlicensed abstraction from the Superficial Aquifer across the study area. Scenario modelling showed that the additional abstraction reduced the volume of subsurface drainage water from the development areas. There is a high degree of uncertainty associated with the garden bore abstraction scenario. This is due to uncertainties in model inputs and site characteristics which could inhibit the use of garden bores in reality. So results from this scenario should be considered indicative only. Actual abstraction rates will vary according to local aquifer transmissivity and individual usage patterns.

1 Introduction

The Department of Planning is currently undertaking a strategic environmental assessment for the Perth metropolitan area to guide urban and industrial development within the region. The Serpentine hydrological studies provide pre-development and post-development surface water and groundwater information within part of the assessment area to assist in the land development process. Post-development scenario modelling was based on existing but undeveloped zoned urban and industrial land identified in the MRS and PRS, and industrial land identified for investigation in the EELS. This study supports the water planning process within the Serpentine area, and development of a drainage and water management plan (DWMP) which will address the following aspects of the total water cycle in more detail:

- significant environmental assets – including meeting their water requirements and managing the potential impacts of development
- water demand – including supply options, opportunities for conservation and demand management measures, as well as wastewater management
- surface runoff – including both peak event (flood) management and water sensitive urban design principles to be applied to frequent events
- groundwater – including the impact of urbanisation, variation in climate, installation of drainage to manage groundwater levels, possible effects on the environment and the potential to use groundwater as a resource
- water quality management – including source control of pollution, acid sulfate soil management, control of contaminated discharges from industrial areas and management of nutrient exports from surface runoff and groundwater through structural measures.

To support the DWMPs planned for the Lower Serpentine region, the Department of Water's Urban Water Management Branch instigated the following projects:

- a floodplain strategy for Birrega and Oaklands drains, Peel Main Drain, and north-east Baldivis including inundation and local catchment stormwater modelling
- hydrological studies to determine pre-development groundwater levels, water balance modelling, climate impacts, extent of current waterlogged areas and impact of development
- preparation of the Birrega and Oaklands drains DWMP
- planning for future DWMPs for the Lower Serpentine area.

The Department of Water's Water Science Branch was commissioned to deliver the 'hydrological studies' and the floodplain modelling projects. The area specified for the hydrological studies, referred to as the 'modelling boundary', comprises the Lower Serpentine regional model domain shown in Figure 1-1.

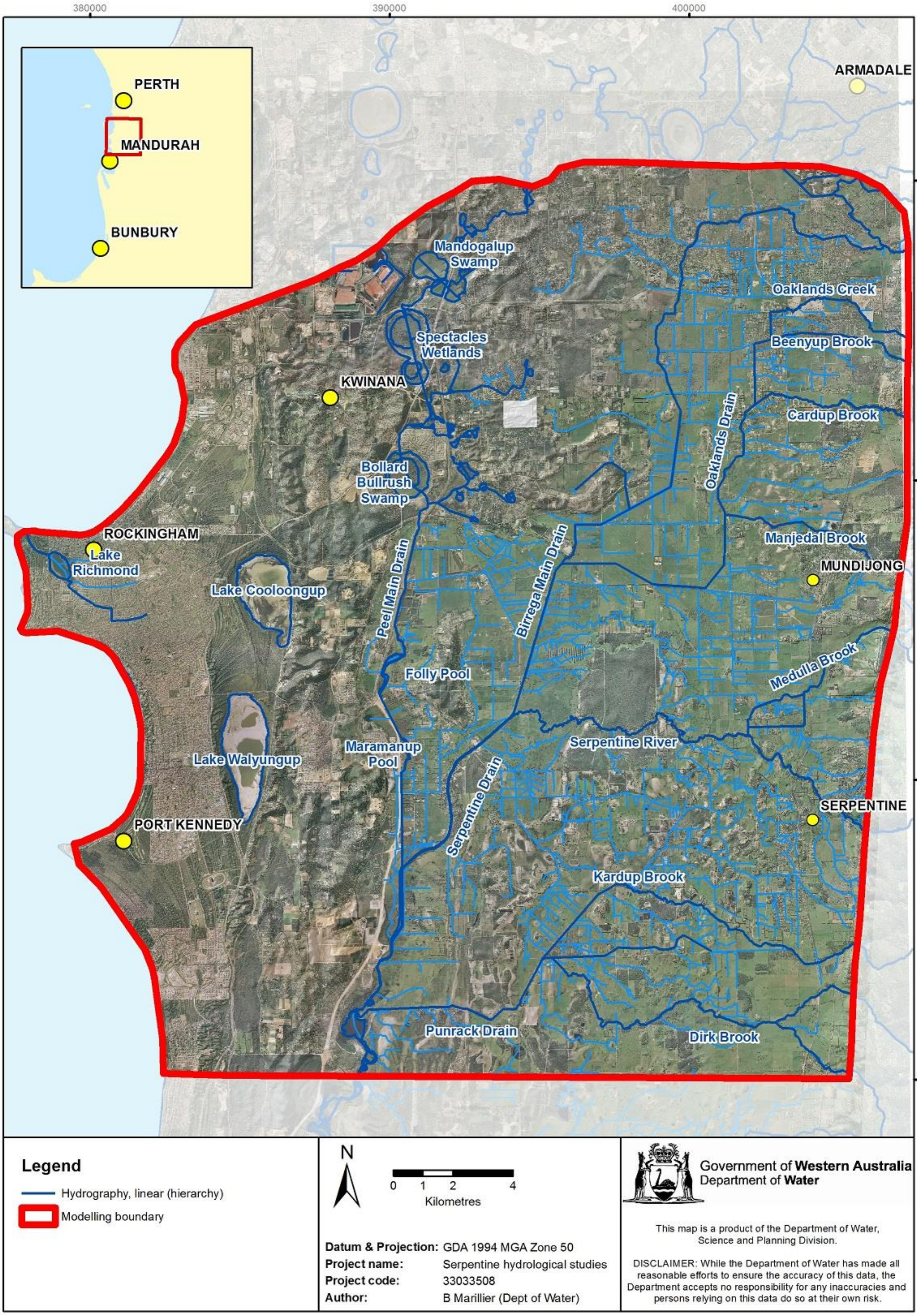


Figure 1-1 Modelling boundary for the Serpentine region

1.1 Project objective

The purpose of the *Lower Serpentine hydrological studies* is to develop and calibrate a regional-scale integrated surface water and groundwater model capable of simulating climate, drainage and land use scenarios.

The project's primary objectives are to deliver the following products:

- a calibrated regional-scale surface water and groundwater model
- climate, drainage and land use scenario modelling results
- maps and ESRI shapefiles associated with the model and scenario results.

The project requires the modelling results to ascertain the following:

- maximum, 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 waterways and wetlands
- re-use opportunities such as community bores and surface detention
- likely areas of waterlogging
- flows in rivers, drains and tributaries
- flood, wet, dry, average year and climate change impacts.

1.2 Scope of work

The scope of the *Lower Serpentine hydrological studies* was divided into three phases: this report addresses the third and final phase. Each phase was associated with significant project milestones and was accompanied by a scientific report. The three phases were as follows:

1. Develop a conceptual model of groundwater and surface water within the Serpentine study area, which:
    a) reviews the literature covering previous work in the area
    b) outlines the study area
    c) describes the local hydrology and climate
    d) develops a geological model of the study area
    e) defines the aquifer systems and major hydrogeological processes, including relevant aquifer parameters
    f) provides a numerical steady-state water balance that includes all major groundwater and surface water processes and the interaction between them.

The report associated with this phase – *Lower Serpentine hydrological studies: conceptual model report* (Marillier et al. 2012a) – is available from the Department of Water's website.

2. Construct and calibrate a transient regional groundwater model covering the Lower Serpentine area. This involves the simulation of surface water in relevant waterways and groundwater flow in each aquifer, the calculation of flows and water budgets for each of the aquifers, and the determination of groundwater-level contours.

   Model construction was based on the conceptual model described in phase 1. The model had an appropriate level of detail for capturing major surface water and groundwater processes at the regional scale. The model was calibrated according to the criteria set by the *Murray Darling Basin Commission guidelines for groundwater flow modelling* (Middlemis 2000). Results of the calibration, validation and sensitivity analysis were reported as a component of this phase.

   A detailed description of model construction and calibration is available from the Department of Water website in the report *Lower Serpentine hydrological studies: model construction and calibration report* (Marillier et al. 2012b).

3. A suite of scenarios were modelled to calculate the change to water balance and groundwater levels under various land use and climate scenarios. The Department of Water's Urban Water Management Branch selected scenarios for the Water Science Branch to model. The scenarios included:

   a. **Land development scenarios:** These were based on information published by the Department of Planning including the Metropolitan region scheme, Peel region scheme and Economic and employment lands strategy.

   b. **Drainage scenarios:** Subsurface drainage was modelled at a range of depths to simulate the effect on the Superficial Aquifer and estimate drainage volumes. Drainage was set at AAMinGL, AAMinGL + 0.5 m and AAMaxGL to provide a plausible range of drainage scenarios associated with development.

   c. **Climate scenarios:** A range of future climate scenarios was simulated to account for various possibilities in changing rainfall and evapotranspiration. These were based on Intergovernmental Panel on Climate Change (IPCC) projections and included projected changes in rainfall and evapotranspiration. Results from global circulation models were used to generate scenario inputs. A historical wet period was also simulated.

The results of climate scenario modelling are reported spatially (groundwater contours) and quantitatively (through water balance results). The influence of scenario modelling on areas of inundation, volumes of drainage water, and groundwater levels are presented and discussed in this report.

2 Lower Serpentine regional model scenarios: background and implementation

2.1 Land development scenarios

Background

Initially it was intended that this groundwater study incorporate land development scenarios based on the areas identified in the draft South metropolitan and Peel structure plan (SMPSS). Due to the Department of Planning's ongoing strategic environmental assessment, release of the SMPSS was delayed until proposed future development areas could be confirmed. Therefore this study only includes modelling for existing but undeveloped zoned urban and industrial land identified in the Metropolitan region scheme (MRS) and Peel region scheme (PRS), and industrial land identified for investigation in the Economic and employment lands strategy (EELS).

All 'Industrial Investigation' areas which were identified in the EELS and located within the study area were included in scenario modelling. Note that the areas identified in the EELS have not been rezoned, and are still subject to the outcomes of the strategic environmental assessment. So no assumptions should be made regarding potential development in these areas.

The areas zoned 'Urban' and 'Urban Deferred' in the MRS and PRS were used to identify potential urban development in scenario modelling. Areas zoned 'Industrial' and those classified for industrial investigation in the EELS were defined as industrial development in the scenario modelling. The total development footprint is 73.5 km^2 for both urban and industrial land uses. The Department of Water has grouped the development areas into 19 subareas for the purposes of reporting at the development scale (Figure 2-1).

Domestic bores are used extensively on the Swan Coastal Plain to water gardens and lawns. Bores used to supply water for stock and domestic purposes and which abstract less than 1500 kL/yr do not require a groundwater licence. Table 2-1 shows indicative water use from domestic bores for urban and rural residential properties of different sizes (DoW 2009). There is considerable variability in groundwater use depending on the individual property. The Department of Water does not recommend development of garden bores in unsuitable areas as outlined in Operational policy 5.17: Metropolitan domestic garden bores (DoW 2011).

Table 2-1 Indicative water use from domestic bores

Property size (m^2)	Indicative groundwater use (kL/yr)	Average bore installation rate (% of lots)
Less than 500	400	5
500 – 999	800	30
1000 – 5000 (0.5 ha)	1000	50
Greater than 5000 (0.5 ha)	1500	80

In 2009 the Department of Water estimated that there were 167 000 garden bores in the Perth metropolitan area, with an estimated average use of 440 kL of water a year (DoW 2011).

Model implementation of development scenarios

Recharge and land use

Urban residential and industrial development within the Lower Serpentine area was modelled by altering the land use properties for the proposed development areas. Model parameters associated with recharge under different land uses include vegetation root depth (RD) and leaf area index (LAI). Xu et al. (2009) describe recharge rates under a variety of land uses calculated to support development of the Perth Regional Aquifer Modelling System (PRAMS). In urban residential areas, groundwater recharge was estimated as 50% of rainfall, and in urban commercial or industrial areas the recharge estimate was 63%. Recharge estimates were based on a Bassendean Sand soil type with a deep water table.

For the development scenarios, the LAI and RD were adjusted within the model for the ‘industrial development’ and ‘urban development’ land classes to obtain an appropriate recharge rate (Table 2-2). The parameters were derived within the model assuming a Bassendean Sand soil type, free-draining soils, and rainfall for the period 1975–2010. Note that within the full numerical model recharge rates will vary depending on depth to watertable, landscape position, drainage and rainfall.

Table 2-2 Recharge rates and parameters for development areas

Development type	LAI (m^2/m^2)	RD (mm)	Modelled recharge (%)*
Industrial development	0.5	250	63
Urban development	1.0	1200	50

**Recharge modelled from 1975 to 2010*

Domestic garden bores

The presence of domestic garden bores was implemented in the Mike SHE model by adding abstraction bores within the 'urban development' land use. An average lot size of 400 m^2 was used to determine the abstraction volume and number of bores to include in the model. This is the average residential lot size required to achieve the WAPC's objective of 15 dwellings per urban zoned hectare. A study into the incidence of bores in the Perth metropolitan area (Research Solutions 2009) reported installation rates at a more detailed scale than the Department of Water's policy document (DoW 2009), and 400 m^2 corresponded to a rate of 11% (see Table 2-3 below). This rate was used in the modelling scenario.

Table 2-3 Percentage of properties watering gardens with bore water for different lot sizes (Research Solutions 2009)

Property size (m^2)	**0–400**	**401–600**	**601–700**	**701–800**	**>800**	**All**
Percentage of properties watering gardens with bore water	11%	18%	26%	39%	47%	30%

The following technique was used to determine the abstraction volumes for domestic bores:

- The total area of the 'urban development' land use was calculated (50.6 km^2): 60% of this was assumed to be residential lots (30.4 km^2) based on estimates provided by the Department of Planning.
- The area available for residential land was divided into 400 m^2 lots, assuming a bore installation rate of 11%. Abstraction was assumed to be 400 kL/yr for each bore based on Table 2-1. This equates to a total abstraction volume of 3.4 GL/yr across the entire modelling area due to new garden bores.
- The total abstraction rate was evenly distributed across grid cells within the urban development areas, assuming a constant abstraction rate between October and May. Abstraction was from the first computational layer, which corresponds to the Superficial Aquifer.

It was assumed that no unlicensed bores would be installed within planned industrial areas.

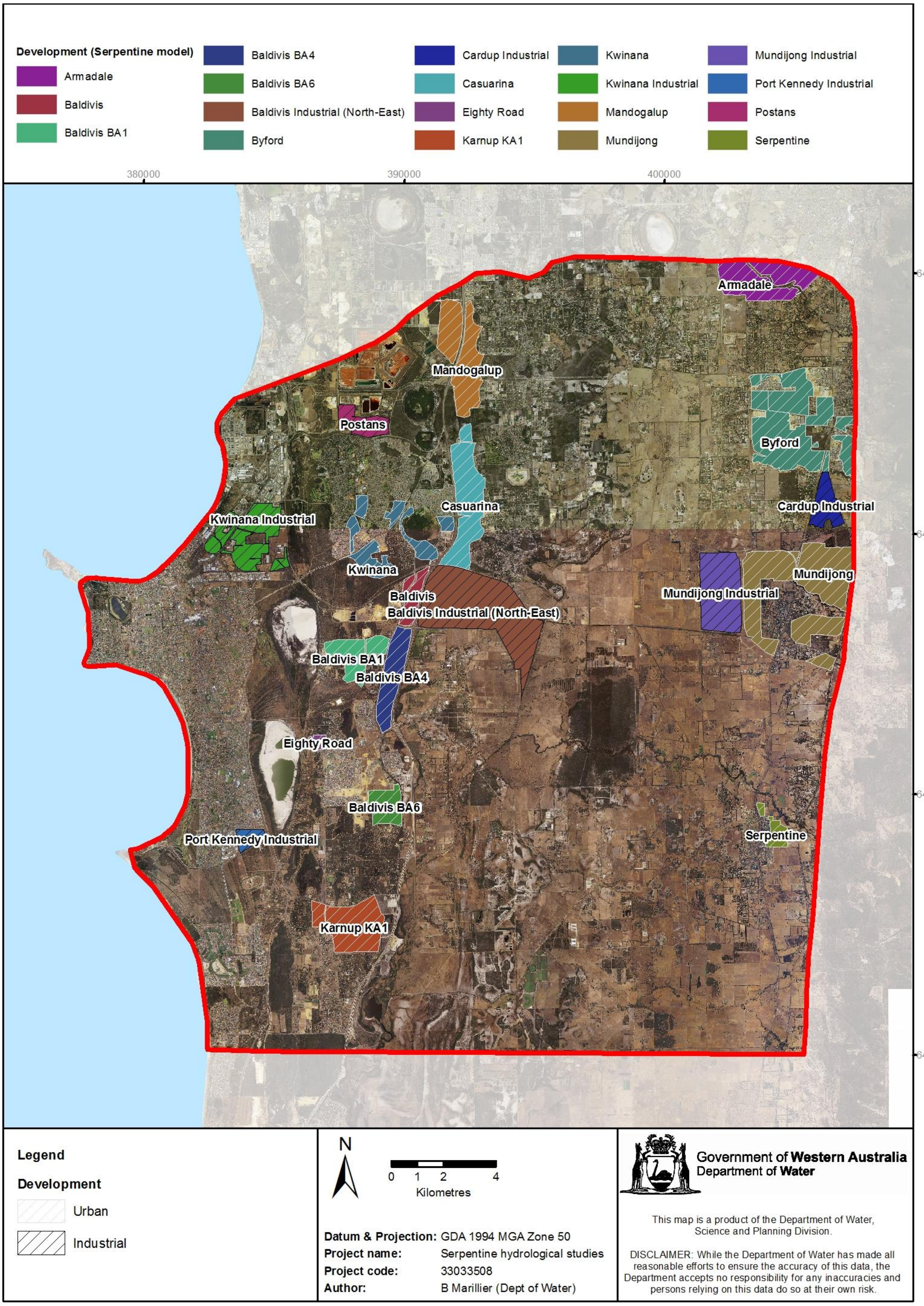


Figure 2-1 Development sub-areas for the Lower Serpentine region

Drainage

To protect infrastructure and assets from flooding and groundwater inundation, sufficient clearance from groundwater levels must be provided and maintained by groundwater drainage, earthworks, foundation design or a combination of these methods. Design of a groundwater drainage system should take into account the requirement for infrastructure and urban amenity to be protected from seasonal inundation, and the potential impact on the aquifer system, groundwater-dependent ecosystems and waterbodies. Design should ensure free-draining outlets from the drainage system, and consider the potential for capture and reuse of water; for example, by integrating drainage infrastructure with managed aquifer recharge (MAR) schemes.

To explore the effects of drainage infrastructure on regional groundwater, several drainage scenarios were modelled. Note that the drainage scenarios described here **are not prescriptive of drainage design requirements or controlled groundwater levels**. Rather the drainage scenarios are designed to give an **indicative range of groundwater levels and volumes of drainage water that result from representative subsurface drainage levels at regional scale**. Drainage requirements for individual developments will be site specific, and as such, appropriate controlled groundwater levels will vary depending on local conditions. Proponents should refer to the *Guidelines for assessing the need for and setting controlled groundwater levels* (DoW 2012) for requirements related to subsurface drainage design.

The drainage scenarios implemented with the Lower Serpentine model are based on modelled base-case groundwater levels. The drainage levels considered are the AAMaxGL, and the AAMinGL, and which are statistical representations of 1981–2010 historical groundwater levels. The selection of these levels aimed to delineate the possible range of levels at which subsurface drainage may be installed, with drainage set at AAMaxGL likely to drain less water than drainage set at AAMinGL. The following drainage scenarios were modelled:

- no drainage
- drainage at AAMaxGL with an appropriate level of fill to simulate post-development recharge conditions
- drainage at 0.5 m above AAMinGL with an appropriate level of fill to simulate post-development recharge conditions
- drainage at AAMinGL with an appropriate level of fill to simulate post-development recharge conditions.

Note that fill must be represented in the model by altering the topography to correctly simulate recharge for free-draining soils in developments which contain subsurface drainage. Fill introduced to the model was assumed to have the same hydraulic properties as Bassendean Sand. Soils with lower saturated hydraulic conductivities are likely to result in less recharge.

In development areas with more than 3 m clearance to pre-development maximum groundwater levels, subsurface drainage was not simulated. The 3 m clearance depth was used to estimate areas which would or would not require subsurface drainage at regional scale. Based on trial simulations, it was estimated that simulated groundwater levels would not increase by more than 3 m under the development scenarios, and so a 3 m cut-off level for subsurface drainage was a reasonable assumption for modelling purposes. This clearance level is not departmental policy, as drainage requirements will vary substantially between sites, and is an assumption made for modelling purposes only, as sites with significant depth to water table are unlikely to require subsurface drainage.

Model implementation of drainage scenarios

Drainage was implemented in Mike SHE using the saturated zone drainage option. This module is designed to simulate both surface channels and drains which are too small to be simulated by Mike 11 and subsurface drainage systems. Drain flow is simulated using an empirical formula which uses a time constant (leakage rate) and a drain level (absolute or relative level of drain). Drain levels were defined spatially where development is planned. The saturated zone drainage module is also used for simulation of agricultural drains within the base-case Mike SHE model.

Within Mike SHE there are several options for routing saturated zone drainage. In the case of agricultural surface drains, drainage was routed to the relevant Mike 11 channel within the model (as described in Marillier et al. 2012b). Existing agricultural drains located outside the development areas were left unchanged within the model. For the urban and industrial development areas, drainage was routed directly to a boundary cell unless an existing drain was in place. Where existing drains were in place within the developments, the drainage paths were left unchanged but the drain elevation was set to the relevant level for the scenario (e.g. AAMinGL + 0.5 m). This means that no consideration is given to the availability of free-draining outlets for the subsurface drainage. It is assumed that all water reaching the level of the drainage network can be effectively drained. This enables calculation of the volume of drainage water from each development. Existing surface drainage features remain unchanged and will drain to Mike 11, additional subsurface drainage within the development areas effectively removes water from the model, and does not drain to Mike 11, therefore free-draining outlets are assumed.

The changes to the base-case model for implementation of the drainage scenarios were as follows:

- Base-case MaxGL, AAMaxGL, AAMinGL and AAMinGL + 0.5 m were calculated using model results from the simulation period 1981–2010.
- The MaxGL surface was used to define areas which have greater than 3 m depth to the water table and would not be included in the simulation of subsurface drainage.
- Drainage levels were set at either AAMaxGL, AAMinGL, or AAMinGL + 0.5 m for areas to be included in simulation of subsurface drainage with the development areas.

- The surface topography of the model was modified to ensure that there was at least 1 m of clearance between the subsurface drainage level and the surface level of the model.
- The unsaturated zone soil type was set to Bassendean Sand for the development areas where fill was required to introduce the 1 m clearance criterion.
- The drainage time-constant was set to ensure that all groundwater reaching the subsurface drainage level would be effectively drained from the model.

The drainage water reported in the model water balance is indicative of the total volume of water which must be managed for each of the development areas. It includes the sum of the subsurface drainage water and the surface drainage water from channels which are not included in the Mike 11 network. It does not necessarily represent the off-site impact on waterways and water bodies. If the drainage water is directed internally to lakes, wetlands or rain gardens, then it may be available for re-use and, depending on residence time, a significant volume of water may be evaporated.

The development and drainage scenarios presented here are intended as regional-scale and indicative. Given the scale of the model, and absence of development specific information, it is not possible to simulate detailed drainage design. The purpose of the scenarios is to provide base-level information on the potential impacts of development. Note that the regional-scale model can be used as a basis for developing local-scale models which can simulate more detailed drainage design.

2.2 Climate scenarios

Background

The Intergovernmental Panel on Climate Change reported in 2007 (IPCC 2007) that:

> Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea-level.

Global atmospheric concentrations of greenhouse gases including CO_2, methane (CH_4) and nitrous oxide (N_2O) have increased due to human activities since 1750, and in 2005 exceeded by far the natural range from the previous 650 000 years (IPCC 2007). The IPCC concludes that:

> There is very high confidence that the net effect of human activities since 1750 has been one of warming.

In south-west Western Australia (SWWA), there has been a significant decline in winter rainfall since 1970 associated with Southern Hemisphere circulation (Frederiksen et al 2011). The decline has been linked to changes in storm tracks in the mid-latitudes, and is consistent with a poleward movement of winter frontal systems (Frederiksen & Frederiksen 2007). Hope et al. (2006) analysed results from several general circulation models and two emissions scenarios and found that all models predicted the rainfall decline in the 1970s. The rainfall decline could be attributed to a reduction in the number of troughs and an increase in high pressure synoptic systems in SWWA. The models also showed that, as atmospheric concentrations of greenhouse gases increased, the synoptic response was more pronounced (Hope et al. 2006).

This evidence indicates that the combination of SWWA's location in relation to the regional synoptic systems makes the region particularly susceptible to changes in climate. As a result, it is necessary to estimate the likely impacts of climate change and account for the uncertainty associated with the various climate projections.

The IPCC developed a suite of scenarios which attempt to project likely greenhouse gas emissions based on such factors as demographic development, socio-economic development and technological change (IPCC 2000). Four storylines which account for possible changes in these factors were developed. For each storyline several scenarios were developed, giving a total of 40 emissions scenarios. The four broad groupings of emissions scenarios are as follows (IPCC 2000):

- The A1 storyline and scenario family describe a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T) or a balance across all sources (A1B).

- The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns which across regions converge very slowly result in a continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

- The B1 storyline and scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity but without additional climate initiatives.

- The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

The storylines produce a large range of potential future emissions (Figure 2-2).

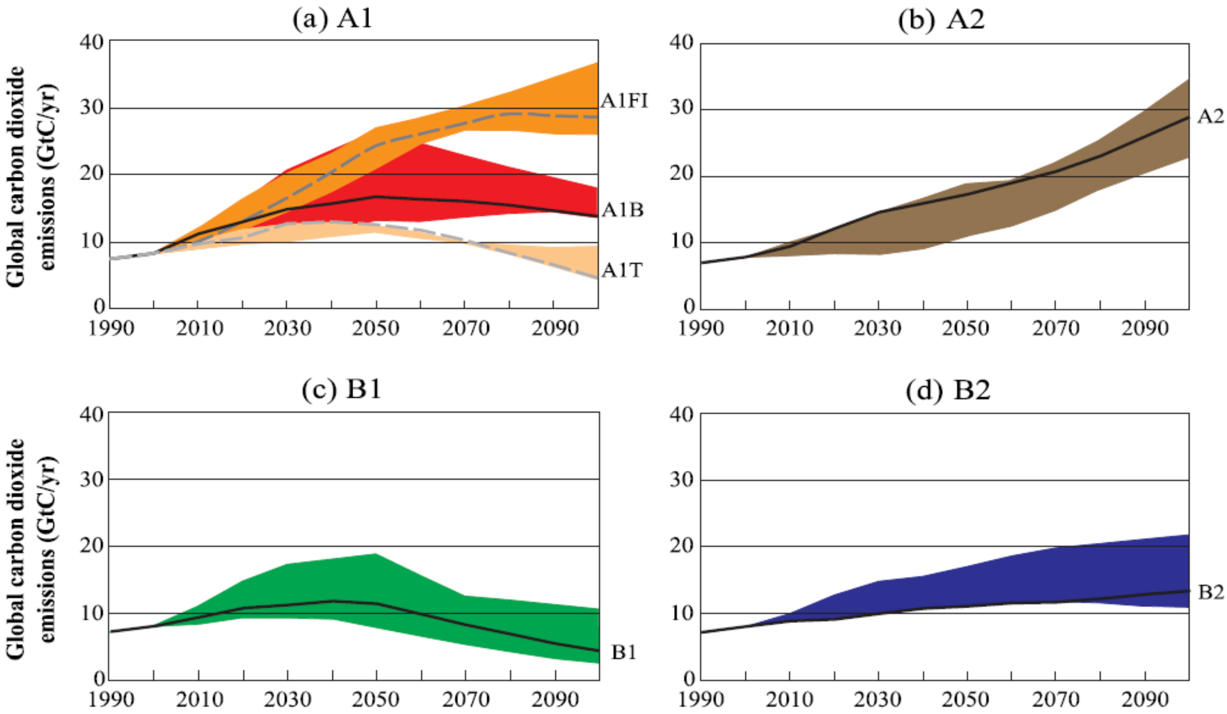


Figure 2-2 Global carbon dioxide emissions for the (a) A1, (b) A2, (c) B1 and (d) B2 emissions scenarios (sourced from IPCC 2000) – the dashed and solid lines show illustrative scenarios, and the colour band show the range of variability

The emissions storylines are used to drive a number of general circulation models (GCMs), which produce estimates of changes in temperature and climate at a global scale when coupled with land surface and ice sheet models. Given the inherent differences in the dynamics of various GCMs, the models produce different results, introducing another layer of uncertainty.

Climate scenario selection

In selecting/choosing appropriate climate scenarios for use with the Lower Serpentine model, and to capture the uncertainty associated with climate projections, results from a combination of various emissions storylines and GCMs were analysed. For each combination of scenario and GCM, the estimated changes in temperature, rainfall and potential evaporation were calculated. The change was simulated for the year 2030, relative to the World Meteorological Organisation (WMO) 'normal' period 1961–90.

The Mike ZERO climate change tool was used to report rainfall, evaporation and temperature for 22 different GCMs using the A2, B1 and A1B emissions scenarios at the longitude and latitude of the Lower Serpentine model. For some GCMs, data for only one or two of the emissions scenarios were available; therefore a total of 52 unique combinations were analysed. Figure 2-3 shows the relative change in average annual rainfall for each GCM and emissions scenario. Based on this distribution, the 10th, 50th and 90th percentile GCM and emissions scenario were selected for simulation of potential future climates in the Lower Serpentine region. This accounts for the uncertainty associated with climate projections and captures the range of likely variation.

Table 2-4 shows the three GCMs and emissions scenarios selected for modelling. These include the 10th percentile rainfall scenario (wet), based on the INMCM model with the B1 emissions scenario; the 50th percentile rainfall scenario (medium), based on the AOM 4x3 model, and the 90th percentile rainfall scenario (dry) based on the CM2-0–AOGCM model.

GCM Acronym	GCM	Research institute	Scenario	Projection year	Baseline climate sequence	Change in annual rainfall
INCM3	INMCM	Institute of Numerical Mathematics, Russian Academy of Science, Russia	B1	2030	1961 to 1990	-5.0%
GIAOM	AOM 4x3	NASA Goddard Institute for Space Studies (NASA/GISS), USA	B1	2030	1961 to 1990	-9.8%
GFCM20	CM2.0 - AOGCM	Geophysical Fluid Dynamics Laboratory, National Oceanic and Atmospheric Administration, USA	A2	2030	1961 to 1990	-19.1%

Table 2-4 GCMs and emissions scenarios selected for Lower Serpentine climate change simulations

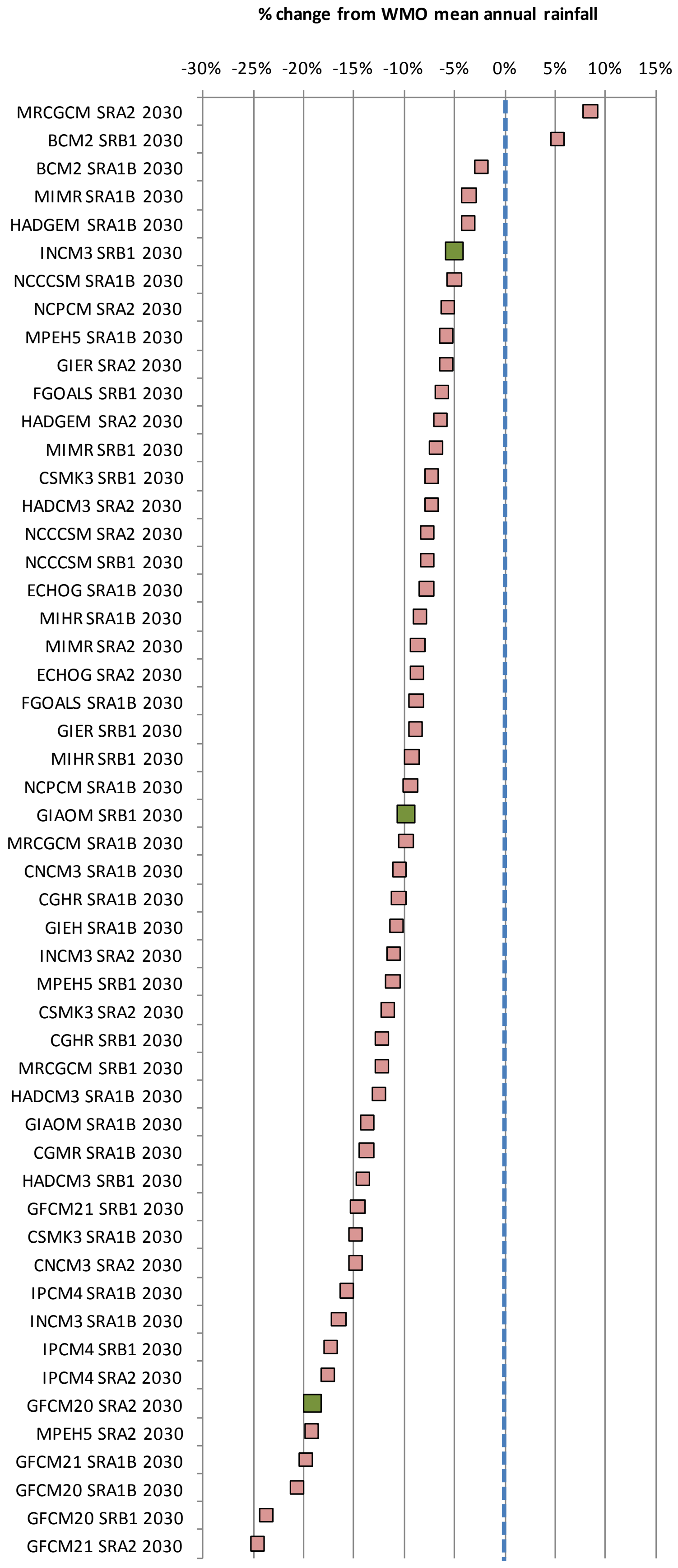


Figure 2-3 Projected reductions in average annual rainfall based on 52 GCMs and three emissions scenarios, showing 10th, 50th and 90th percentile scenarios in green

Model implementation of future climate data

Future climate data

To implement the selected climate scenarios in the Lower Serpentine model it was necessary to generate rainfall and evapotranspiration timeseries datasets representative of the future climate. This was done by scaling historical SILO (QDERM 2011) gridded rainfall and potential evapotranspiration (PET) data from the WMO baseline period 1961–90. The timeseries were scaled according to monthly anomaly indices which capture the differences between the WMO baseline period and the projected climate in 2030. The Mike ZERO climate change tool generates the timeseries by directly scaling rainfall data by the specified anomaly value and infers changes in PET using a temperature based method (DHI 2011). This tool was used to generate climate timeseries for the wet, medium and dry climate scenarios. Figure 2-4 shows the annual rainfall for a 30 year period, with the scaled rainfall based on the projected monthly anomalies for the wet, medium and dry scenarios. Figure 2-5 shows the average monthly rainfall for a 30 year period and scaled average monthly rainfall. Note that the various GCMs project different monthly anomalies in rainfall; however, there is general agreement that winter rainfall is reduced as emissions increase, with a slight increase in summer rainfall.

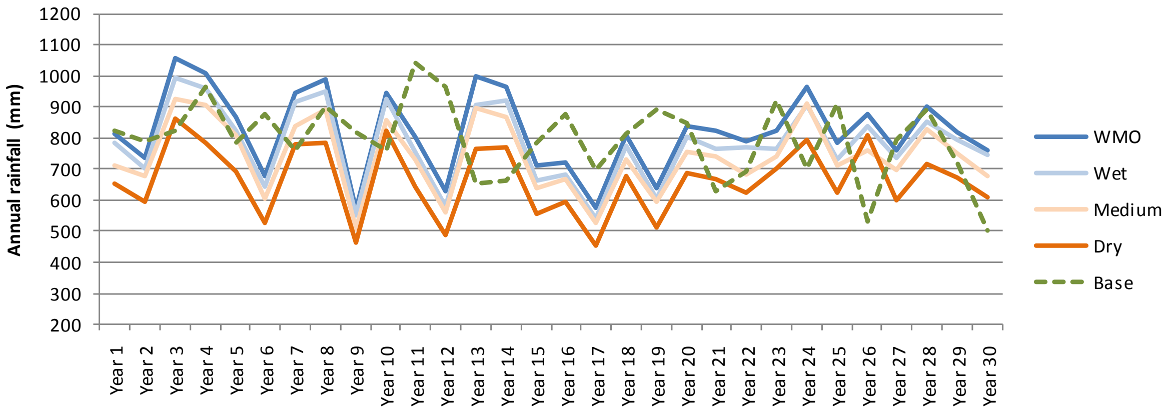


Figure 2-4 Scaled annual rainfall based on GCM projected rainfall anomalies for 2030 compared to the 1961-90 WMO period, and the 1981-2010 base-case period

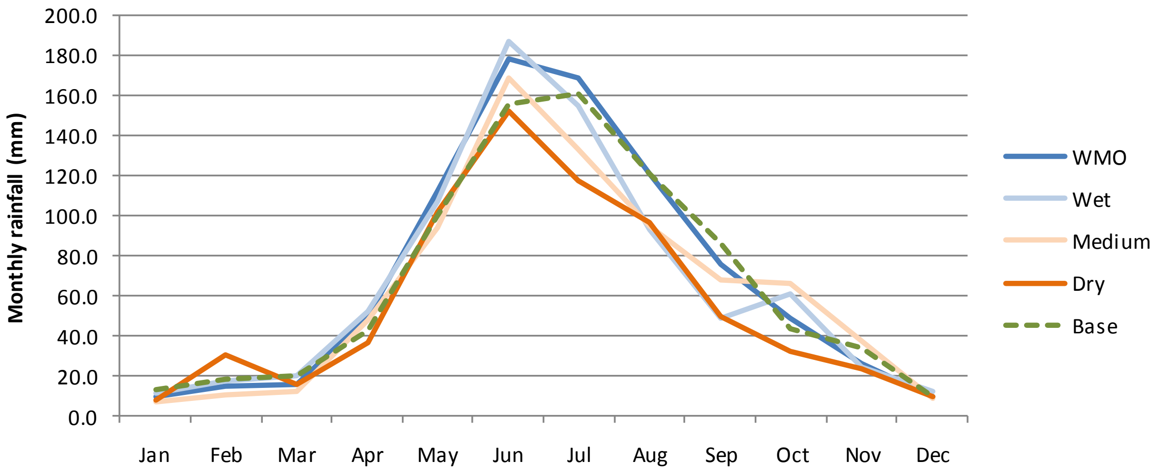


Figure 2-5 Scaled average monthly rainfall based on GCM projected rainfall anomalies for 2030 compared to the 1961-90 baseline, and the 1981-2010 base-case period

The scaled rainfall and PET timeseries are based on the 1961–90 period but are representative of a potential 30 year climate sequence centred on the year 2030. So, the model simulation was configured for the period 2016–45, and discussion of climate scenarios refers to this period. All simulations include a five year 'warm up' period 2011–15 for the model to stabilise to the new climate conditions.

The Department of Water is currently developing standardised procedures for modelling the impacts of climate change. Where possible the procedures used here have been kept in line with the anticipated departmental procedures, and have been developed to account for uncertainty in climate projections.

Historical climate data

Two additional climate scenarios were developed to assess the impact of wet periods on groundwater levels. These scenarios can be considered 'high risk' in terms of surface inundation due to elevated superficial groundwater levels. The two scenarios selected were:

- **Future medium scenario with two wet years** which includes the future medium climate sequence, with the years 2044 and 2045 replaced with the base-case climate sequence for 1963 and 1964 (average rainfall exceeded 1000 mm in both years).
- **Historical wet scenario** which uses the climate sequence 1945–74. The average annual rainfall for this period is 887 mm in the model domain compared to 842 mm for 1961–90.

Summary of climate scenarios

Table 2-5 shows the variables associated with each climate scenario when compared to the WMO climate normal period. The *original climate sequence* refers to the historical data baseline period which was scaled to generate the *scaled climate sequence* that is representative of a possible future climate.

Table 2-5 Climate scenario variables

Scenario name	GCM & emissions scenario	Scenario number	Original climate sequence	Scaled climate sequence	Average annual rainfall (mm)	Average annual PET (mm)
WMO baseline period	na	na	1961 to 1990	na	842	1362
Base case (current)	na	S00	1981 to 2010	na	800	1392
Future dry	INCM3 A2	S01	1961 to 1990	2016 to 2045	682	1423
Future medium	GIAOM B1	S04	1961 to 1990	2016 to 2045	759	1393
Future wet	GFCM20 B1	S09	1961 to 1990	2016 to 2045	800	1423
Future medium 2 wet years	GIAOM B1	S12	1961 to 1990	2016 to 2045*	782	1390
Historical wet	na	S13	1945 to 1974	2016 to 2045	887	1326

**Note years 2044 and 2045 were replaced with unscaled years from 1963 and 1964*

Model implementation of sea-level-rise

Global sea-level-rise has been accurately measured at +2.4 ± 0.4 mm/yr using satellite altimetry over the period 1993–2003 (Cazenave & Nerem 2004). This is in contrast to the 1–2 mm/yr rates from previous decades. Figure 2-6 shows the increase in the rate of sea-level-rise in recent decades. The IPCC (2007) reports that 57% of sea-level-rise is attributable to ocean thermal expansion, with a further 28% due to decreases in glaciers and ice caps, and the remainder due to losses from polar ice sheets.

Estimates of global sea-level-rise for 2090–99 relative to 1980–99 vary between 18 and 59 cm, excluding the influence of rapid dynamic changes in ice flow (IPCC 2007). To account for the uncertainty in sea-level-rise associated with non-linear break-up of the Greenland and West Antarctic ice sheets, a worst-case scenario of 90 cm of sea-level-rise was assumed for the purposes of scenario modelling. This value is consistent with the state planning policy document Position Statement – State Planning Policy No. 2.6 State Coastal Planning Policy Schedule 1 Sea-level-rise which states:

> In recognition of nationally accepted and adopted increases in sea-level-rise projections, the WAPC considers it necessary to amend the sea-level-rise value in SPP2.6. The methodology is changed to SLR increase to 0.9m to 2110, based upon IPCC AR4 (Scenario A1FI) and CSIRO 2008

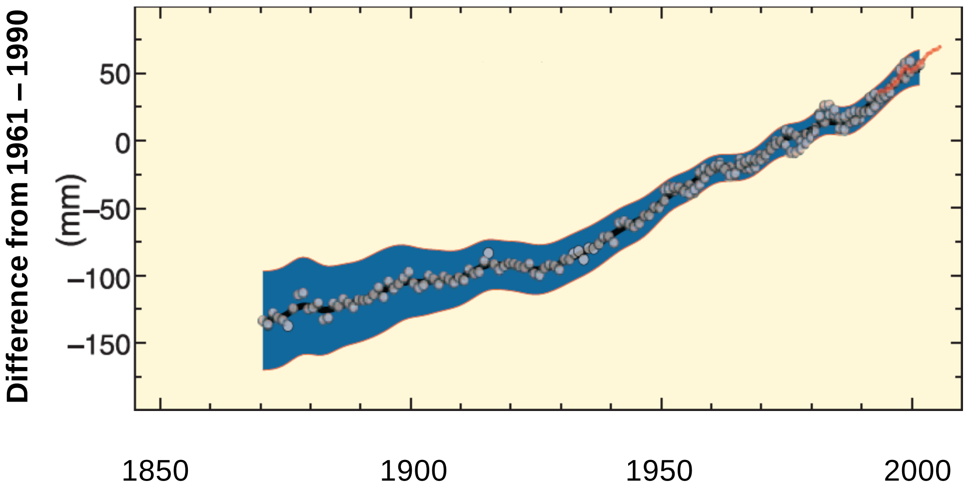


Figure 2-6 Global sea-level-rise from tide gauge (blue) and satellite (red) data. Image sourced from the IPCC (2007). Values are reported relative to average 1961-90.

The sea-level-rise scenario was simulated using the future medium climate sequence with a supplementary scenario simulated using the future wet climate sequence. The ocean boundary condition was increased to 0.9 m for both the Superficial and Rockingham aquifers. The lower boundary condition for the Serpentine River within the Mike 11 model was calculated using Mike 11 stage results from the Murray regional model (Hall et al. 2010) sea-level-rise scenario. The modelling showed a 0.69 m rise in water levels in the Serpentine River just south of Punrack Drain, a result of 0.9 m sea-level-rise. The lower boundary condition for the Serpentine River was therefore set to a constant head of 0.69 m in the Lower Serpentine regional model for the sea-level-rise scenario.

2.3 Assumptions used in scenarios

The scenarios represent *a range* of possible future conditions for the Lower Serpentine region. For the period modelled in the base-case scenario, many of the variables which drive the numerical model are known or can be approximated. Some variables such as geology and soil type are unlikely to change over the timescales considered here. However, other variables are very likely to change, including climate, land use, abstraction and boundary conditions. So, to use the model for projections, it is necessary to make assumptions about the likely changes in these variables over time. For modelling purposes, the future conditions considered are for the 30 year period centred on 2030.

Future land use and climate were described in previous sections. It was also necessary to estimate several other timeseries inputs to the model including boundary conditions for the Leederville and Superficial aquifers, abstraction, and discharge from the Kwinana waste water treatment plant to the infiltration ponds near the Spectacles Wetlands.

Boundary conditions for the Leederville Aquifer

Along the northern boundary of the model, a time-varying head boundary condition is in place. These boundary conditions represent a developing cone of depression in the Leederville Aquifer to the north-west of the model, as the rate of head decline is slower at the coastline than further inland where there is more abstraction. The northern boundary is divided into eleven sections, each with an independently varying head, based on interpolated observations from monitoring bores. For each of these sections, an average annual rate of head decline was calculated by subtracting the 2001–10 average level from the 1971–80 average level. This assumes an ongoing linear decline in head based on the historical head decline for each location. The rate of decline varies between 0.07 and 0.17 cm/yr across the northern boundary. This rate of decline was applied for each year from 2011 to 2045 and used in all scenarios. The resulting boundary for each of the eleven sections is shown in Figure 2-7 for 2011–45. The location of each boundary is shown in Figure 2-8.

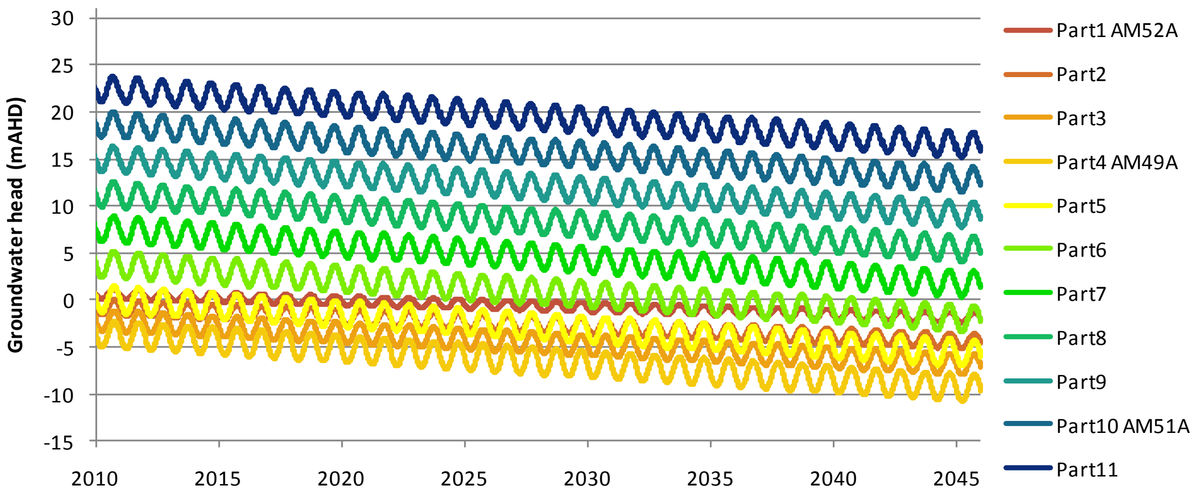


Figure 2-7 Boundary conditions for the Leederville Aquifer 2011-45

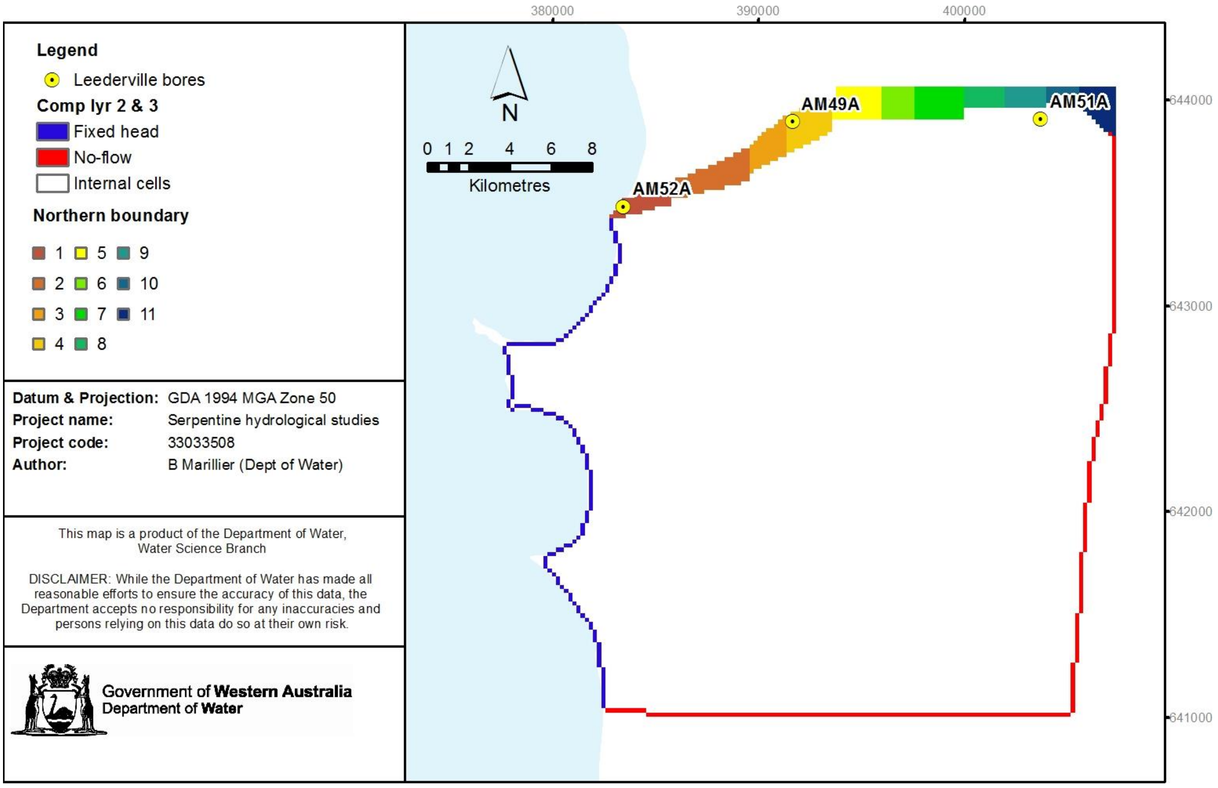


Figure 2-8 Location of Leederville Aquifer boundary conditions

Boundary conditions for the Superficial Aquifer

The north-western boundary of the Superficial Aquifer was set to an average groundwater level based on 2005–10 observed levels and amplitudes. Given that the Superficial Aquifer is unconfined and that the boundary condition is close to the coast, it was assumed future groundwater levels would be relatively stable. However, there is likely to be some fluctuation based on climate which will not be captured by the boundary condition, and this influence should be considered when viewing scenario results. The sensitivity of superficial groundwater levels to this boundary condition is discussed in the companion report *Lower Serpentine hydrological studies: model construction and calibration* (Marillier et al. 2012b).

Kwinana waste water treatment plant discharge

The Kwinana waste water treatment plant discharges treated wastewater to infiltration ponds to the west of the Spectacles Wetlands, resulting in a small groundwater mound. The Water Corporation provided discharge rates for 2001–10. For scenario modelling it was assumed that the discharge remained constant into the future, using the average rate from 2005 to 2010.

Abstraction

Groundwater abstraction from the area is likely to vary significantly in the future. It is difficult to forecast as allocation and use are influenced by demand, government policy and climate. Within the Rockingham, Stakehill and Cockburn groundwater management areas the Superficial, Leederville and Rockingham (where applicable) aquifers are all close to fully allocated, and in some subareas are over-allocated. An allocation plan for the Serpentine groundwater management area is currently under development but likely future allocation limits were not available at the time of writing. Hence, the average 2005–10 estimated abstraction was assumed to continue into the future for scenario analysis for the 2011–45 period. This equates to around 31 GL/yr from the Superficial Aquifer, and 8 GL/yr from the Leederville and Rockingham aquifers.

3 Lower Serpentine regional model scenarios: results and analysis

The Urban Water Management Branch of the Department of Water selected 15 scenarios for comparison to the current 'base-case' scenario. These scenarios include various combinations of climate, drainage and development scenarios (Table 3-1). They were selected to address three requirements:

- Include a reasonable range of future climate scenarios to incorporate the uncertainty associated with climate projections.
- Include a range of drainage scenarios to capture the likely variation in volume from drainage set at different levels.
- Include extreme rainfall scenarios which could influence drainage design.

The first two requirements are addressed by the combinations of future climate, drainage and development scenarios (S1 to S11). The third requirement is addressed by inclusion of scenarios S12 and S13 which incorporate historical wet periods and therefore give an upper-limit on potential inundation. S14 and S14b are sea-level-rise scenarios designed to simulate groundwater responses to increased sea-level. Note that Mike SHE cannot model variable density fluids, and therefore is unsuitable for simulating salt-water intrusion.

Table 3-1 List of scenarios modelled

Scenario #*	Climate scenarios	Subsoil drainage scenarios	Development scenario
S0	Current climate	None	Current land use scenario
S1	Dry	None	Current land use scenario
S2		At AAMaxGL	Full development
S3		At AAMinGL	Full development
S4	Medium	None	Current land use scenario
S5		At AAMaxGL	Full development
S6		0.5m above AAMinGL	Full development
S7		At AAMinGL	Full development
S8		AAMaxGL	Full development Garden bores
S9	Wet	None	Current land use scenario
S10		At AAMaxGL	Full development
S11		At AAMinGL	Full development
S12	Medium with two wet years	None	Current land use scenario
S13	Historical wet	None	Current land use scenario
S14	Sea level rise Future medium	None	Current land use scenario
S14b	Sea level rise Future wet	None	Current land use scenario

**Scenario number is a unique ID which is used in file naming conventions within the Mike SHE model*

Results for each scenario are reported in the form of a water balance and spatial data. Spatial datasets are available from the Department of Water on request in ESRI grid format, and as contours in ESRI shapefile format. Groundwater levels for each scenario are summarised as MaxGL, AAMaxGL, AveGL, MaxGL and MinGL.

The following section describes the results of all 15 scenarios including the base-case scenario. Water balances, calculated for each scenario using the Mike ZERO water balance calculation tool, are summarised in Appendix C. Groundwater levels were calculated by post-processing results within Mike ZERO to provide statistical estimates of groundwater levels such as the AAMaxGL. For each scenario a 30 year period was selected for calculation of groundwater levels and water balances. For the base-case scenario, the sequence 1981–2010 was used for calculations while, for all other scenarios, calculations were based on the sequence 2016–45, which is representative of a hypothetical future period of time centred on 2030.

3.1 Base-case scenario (S0)

The base-case scenario (S0) represents current conditions for the Lower Serpentine area. Base-case results are reported for 1981–2010. The full simulation period is from 1970 to 2010. The *model construction and calibration report* (Marillier et al. 2012b) details the model parameters and water balance for the base-case scenario. Figure 3-1 shows the AAMaxGL calculated from the base-case model results. Figure 3-2 shows the extent of surface inundation due to groundwater based on the MaxGL. Additional model results and groundwater levels are available from the Urban Water Management Branch of the Department of Water on request.

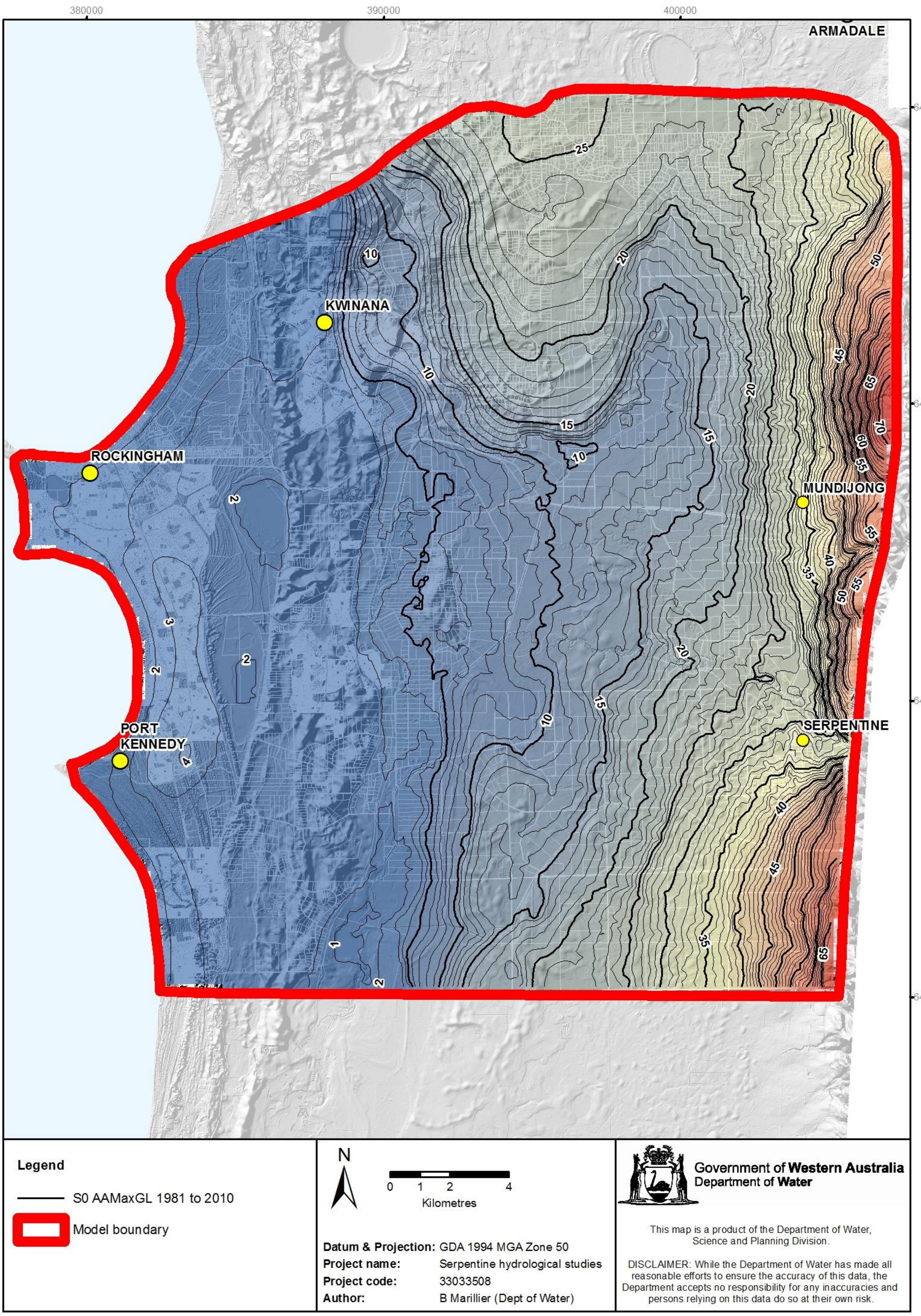


Figure 3-1 AAMaxGL (mAHD) for the base-case (S0) scenario for 1981–2010

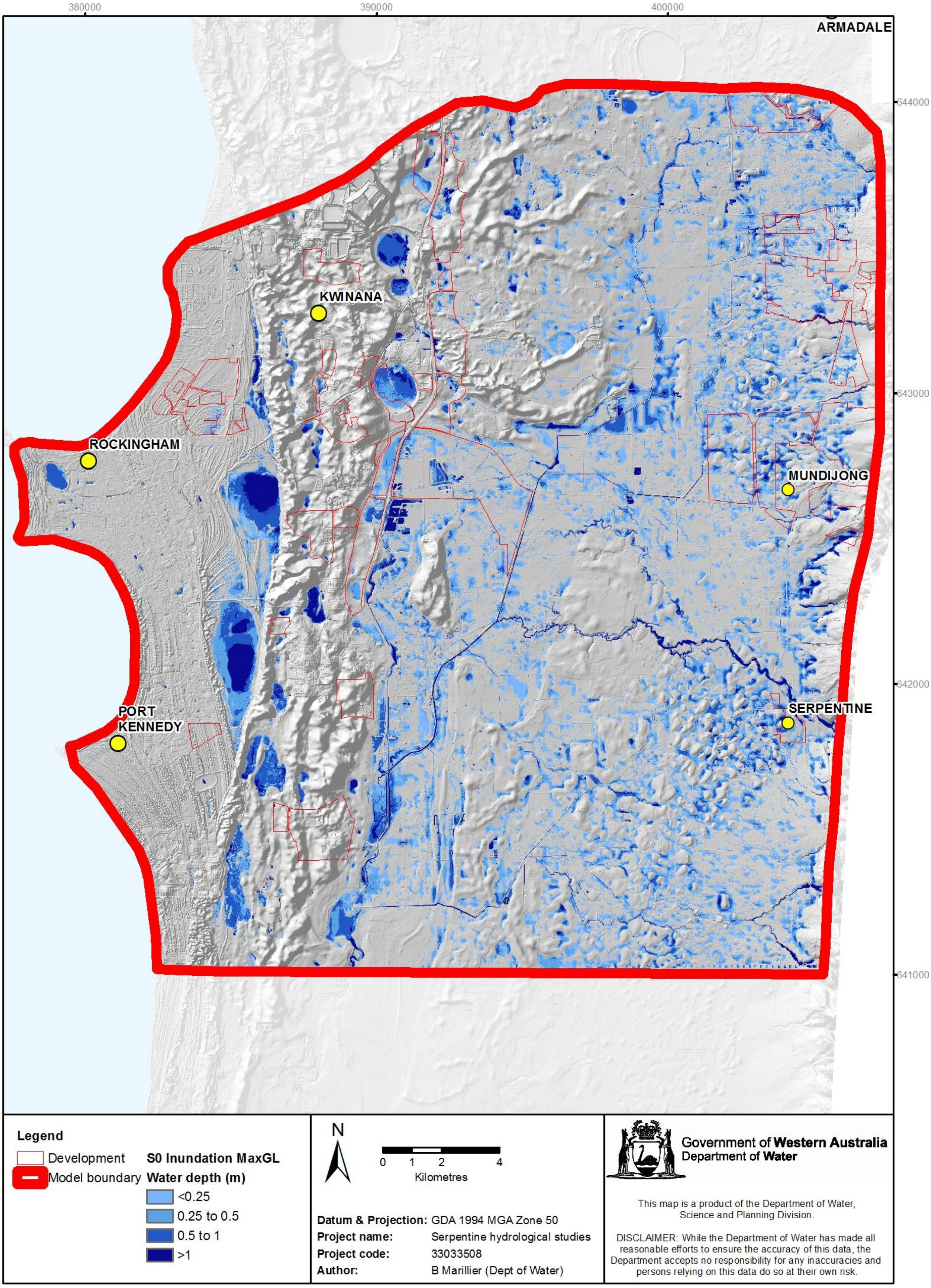


Figure 3-2 Groundwater inundation (m above surface) for the base-case (S0) scenario for 1981–2010, calculated from surface topography and MaxGL surface

3.2 Climate scenarios (S1, S4, S9, S12, S13)

Three future climate scenarios were simulated for the period 2011–45, and results reported for the period 2016–45; the future dry (S1), medium (S4) and wet (S9) climates. A fourth scenario incorporated the future medium climate with two wet years (1963 and 1964) at the end of the sequence (S12), and a fifth was based on an historical wet climate (S13) using 1945–74 data.

These scenarios did not incorporate any drainage or land use changes as a result of development, and aim to quantify the potential impacts of climate change on superficial groundwater levels and river flows. Table 3-2 shows the average change in superficial groundwater levels across the model area for the MaxGL, AAMaxGL, AveGL, AAMinGL and MinGL for each climate scenario relative to the base-case scenario, and changes in outflow from the Serpentine River at the model boundary. Appendix A shows the changes in AAMaxGL and AAMinGL spatially for each scenario relative to the base-case, and can be used to identify areas where groundwater shows greater responses to changes in rainfall.

Note that the changes in modelled groundwater levels result from both reduced rainfall and abstraction rates used in scenarios. As historically abstraction in the 1980s and 1990s was less than at present, and all future scenarios assumed abstraction remained at present levels, the relative differences in abstraction result in slightly lower groundwater levels in some areas independent of the lower rainfall.

Table 3-2 Summary of changes in groundwater levels for climate change scenarios

Scenario #	Scenario name	Rainfall	MaxGL	AAMaxGL	AveGL	AAMinGL	MinGL	Flow (Serpentine)*
		mm/yr	mAHD	mAHD	mAHD	mAHD	mAHD	GL/yr
S0	Base case	800	16.21	15.69	14.91	14.33	13.82	96.7
S1	Future dry climate	682	15.63	14.87	14.19	13.68	13.28	49.3
S4	Future medium climate	759	15.89	15.20	14.48	13.92	13.51	70.7
S9	Future wet climate	800	16.12	15.43	14.65	14.05	13.62	88.0
S12	Future medium climate with two wet years	782	16.24	15.29	14.53	13.93	13.51	84.1
S13	Historical wet climate	887	16.53	15.97	15.08	14.37	13.98	147.9
S14	Sea level rise with future medium climate	759	15.98	15.30	14.58	14.01	13.61	70.6
S14b	Sea level rise with future wet climate	800	16.20	15.53	14.74	14.14	13.72	88.2
Change from base case			**Δm**	**Δm**	**Δm**	**Δm**	**Δm**	**ΔGL/yr**
S1	Future dry climate	-15%	-0.58	-0.82	-0.72	-0.64	-0.54	-47.4
S4	Future medium climate	-5%	-0.32	-0.49	-0.43	-0.41	-0.32	-26.0
S9	Future wet climate	0%	-0.09	-0.26	-0.26	-0.28	-0.20	-8.7
S12	Future medium climate with two wet years	-2%	0.03	-0.40	-0.38	-0.40	-0.32	-12.6
S13	Historical wet climate	11%	0.32	0.28	0.17	0.04	0.15	51.2
S14	Sea level rise with future medium climate	-5%	-0.23	-0.39	-0.33	-0.31	-0.21	-26.1
S14b	Sea level rise with future wet climate	0%	-0.01	-0.16	-0.16	-0.19	-0.11	-8.5

**Outflow at model boundary from the Serpentine River*

The future wet climate scenario (S9) corresponds to reduced winter rainfall but increased summer rainfall, which results in no change in average annual rainfall compared to the base-case scenario. However, the changed rainfall distribution results in less recharge, and, in combination with higher relative abstraction, maximum groundwater levels declined 9 cm, and average groundwater levels declined 26 cm. Figure A-9 shows that both maximum and minimum groundwater levels are mainly reduced near groundwater abstraction points, and in areas with the greatest depth to watertable, through the Spearwood Dunes, on the Jandakot Mound, and along the eastern model boundary near Byford. The low-lying areas of the coastal plain show the least change in groundwater level, and flows from the Serpentine River are reduced by around 9% as a result of lower baseflow, and reduced inflows to tributaries on the Darling Scarp. In all future scenarios groundwater levels near the Kwinana wastewater treatment plant rise as a result of infiltrating waste water.

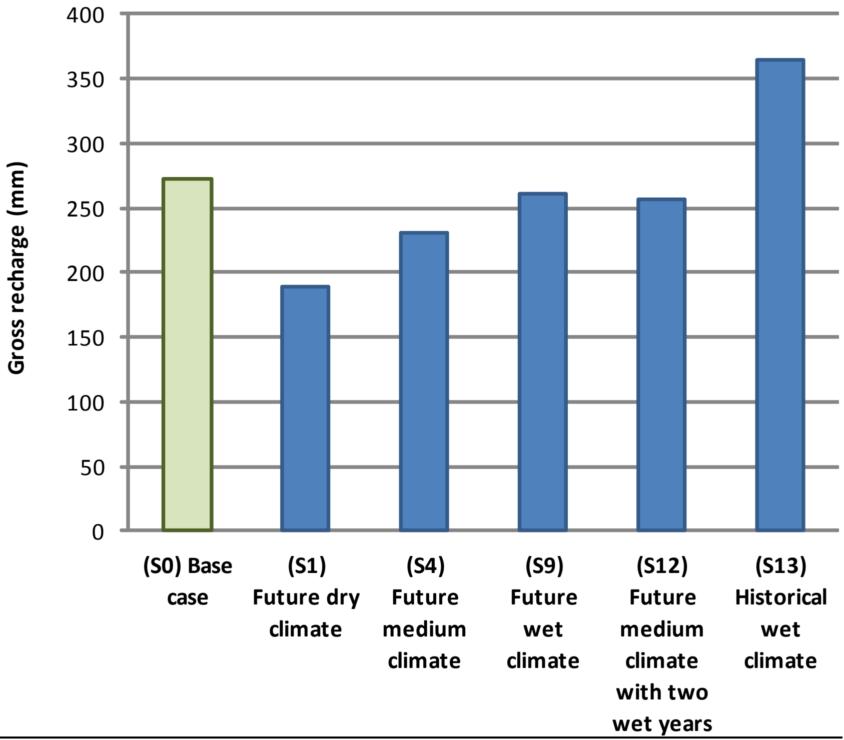
The future medium climate scenario (S4) results in a 5% reduction in average annual rainfall across the model area. As with the wet scenario, the model shows the greatest reductions in groundwater level near abstraction points, and in areas with the deepest groundwater (Figure A-4). The average groundwater level is 43 cm lower when compared to the base-case scenario, and both maximum and minimum groundwater levels are 32 cm lower. Flows from the Serpentine River average 70.7 GL/yr: a 27% reduction.

The average annual rainfall for the future dry climate scenario (S1) was 682 mm (15% less than the base-case scenario), and is 6% lower than the 2001–10 average of 725 mm. The scenario shows a 72 cm drop in average groundwater level and 58 and 54 cm drops respectively in maximum and minimum groundwater levels. The groundwater level is generally 0.5–2 m lower through the Spearwood Dunes and the Jandakot Mound (Figure A-1). There is a dramatic reduction in groundwater of up to 8 m on the eastern margin of the model near the Darling Scarp. In S1 a large portion of the model has groundwater levels lowered relative to S0. Inundation based on the MaxGL surface (Figure B-1) shows that with the drier climate a significant portion of the wetlands within the model area is no longer inundated. Reduced overland and base flow result in 49% less discharge from the Serpentine River at the model boundary.

In the future medium with two wet years scenario (S12) the maximum groundwater level is responsive to the wet years, even after an extended period of lower rainfall. The MaxGL level is 3 cm higher than in the base-case scenario, and 35 cm higher than in the medium climate scenario (S4). This indicates that areas historically at risk of inundation from groundwater will remain so, even after an extended period of a relatively dry climate. Figure B-4 shows the extent of inundation based on the S12 MaxGL.

The historical wet climate scenario (S13) has an average annual rainfall 11% higher than the base-case. The maximum groundwater level is 32 cm higher in this scenario while the MinGL and AAMinGL are only 15 cm and 4 cm higher respectively, as a result of the abstraction dataset used in all future simulations. Figure A-13 shows the change in groundwater level relative to the base-case scenario for S13. The AAMaxGL difference map shows that most of the model area experiences groundwater levels generally 0–1 m higher, with larger increases near the Darling Scarp. The AAMinGL surface is more sensitive to abstraction, and therefore only shows increases in groundwater levels in areas with fewer production bores. The Serpentine River shows a 52% increase in flow with the higher rainfall.

Figure 3-3 shows the average recharge calculated from the model water balance for each climate scenario. The future dry climate indicates that recharge would fall by 30% compared to the base-case scenario, with the medium and wet climates resulting in 15% and 4% less recharge respectively. In the historical wet climate scenario during wetter periods recharge in the area is 34% higher, although surface inundation over much of the area would eventually present an upper limit on recharge.



Precipitation (mm)	800	682	759	800	782	887
Gross recharge (mm)	272	189	231	262	256	364
Gross recharge %*	34%	28%	30%	33%	33%	41%
Gross recharge GL**	198	138	168	190	186	265

**Percentage of rainfall* ***Across the model area of 727.6 km* ^{2}

Figure 3-3 Comparison of recharge for climate scenarios

3.3 Sea-level-rise scenario (S14 & S14b)

The sea-level-rise scenario involved increasing the coastal boundary condition by 0.9 m, and the Serpentine River lower boundary condition by 0.69 m (see Section 2.2). The model was simulated for the period 2011–45 using the future medium climate (S14). An alternate scenario using the future wet climate was also simulated (S14b) and changes in groundwater levels and inundation for both scenarios are reported in Appendix A.

The influence of sea-level-rise is best shown spatially in Appendix A, Figure A-14 and Figure A-15. The reduced rainfall of the future medium scenario (S14) results in lower groundwater across most of the coastal plain, which is consistent with scenario S4. However, on the coastal strip maximum and minimum groundwater levels increased by up to 0.9 m relative to the base-case scenario. The difference is greatest at the coast and reduces inland. Raised groundwater levels are most extensive on the Rockingham Peninsula and Becher Point where the land is surrounded by the ocean on three sides. The higher water levels downstream on the Serpentine River resulted in elevated groundwater levels around the river for up to 3 km upstream although the area covered is not extensive due to the grade of the river bed. Results for the sea-level-rise scenario with the future wet climate are similar (S14b); however, groundwater levels are generally higher relative to S14, and the zone of influence of the raised sea-level extends further inland. Scenario S14b is a higher risk scenario relative to S14, as the increase in coastal groundwater levels due to sea-level-rise is not offset by significantly lower recharge.

The only development in the area affected by elevated water levels is the Kwinana Industrial area. However, depth to maximum groundwater level in the affected parts of the development for S14 and S14b is generally greater than 2 m. Inundation is slightly increased around Lake Richmond and the lower end of the Serpentine River for S14b (Figure B-6).

Note that the extent of elevated groundwater levels **does not** show the extent of salt-water intrusion resulting from sea-level-rise. Mike SHE is not capable of modelling variable density fluids and therefore cannot be used for modelling salt-water intrusion. The sea-level-rise scenario is appropriate for interpreting groundwater levels but not salinity or the location of the salt-water interface.

3.4 Land development and drainage scenarios (S2, S3, S5, S6, S7, S8, S10, S11)

Land development and drainage scenarios were simulated for a combination of drainage levels and climates as follows:

- **S2:** development, drainage at AAMaxGL, future dry climate
- **S3:** development, drainage at AAMinGL, future dry climate
- **S5:** development, drainage at AAMaxGL, future medium climate
- **S6:** development, drainage at 0.5m above AAMinGL, future medium climate
- **S7:** development, drainage at AAMinGL, future medium climate
- **S8:** development, drainage at AAMaxGL, future medium climate, garden bore abstraction in new urban developments
- **S10:** development, drainage at AAMaxGL, future wet climate
- **S11:** development, drainage at AAMinGL, future wet climate.

The total drainage volume for all development areas for various scenarios is shown in Figure 3-4. The drainage volume is the sum of both the subsurface drainage water, and water from the existing agricultural drainage network within the development area. It indicates the total volume of water which must be drained from the area to maintain the groundwater at the specified drainage level post-development. For the non-development scenarios (S0, S1, S4 and S9) the drainage volume indicates only the volume of water which would drain from the existing agricultural drainage network for each climate scenario.

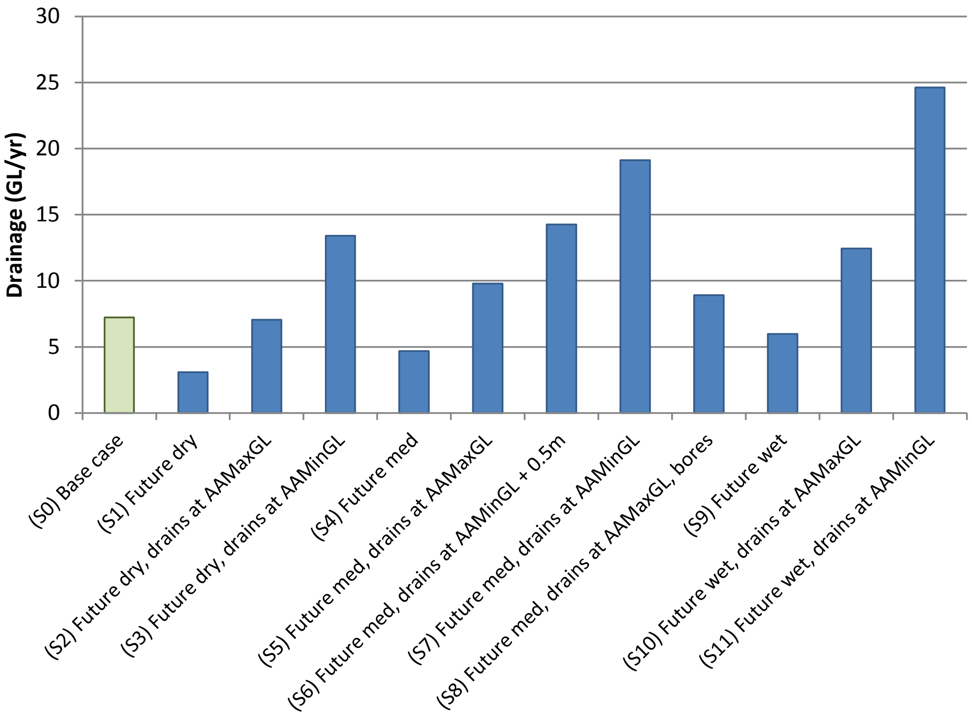


Figure 3-4 Total drainage quantity from developments for various development, drainage and climate scenarios

Figure 3-4 shows that the volume of drainage water increases dramatically as the modelled subsurface drainage level deepens. For the future medium climate scenario, three different drainage levels were simulated, AAMaxGL (S5), AAMinGL + 0.5 m (S6), and AAMinGL (S7). In scenario S5 drainage from all development areas would total 10 GL/yr versus 5 GL/yr for the no-development, future medium climate. Most of this additional water is generated from reduced evapotranspiration and increased recharge under development areas as demonstrated by water balance calculations in Appendix C. Figure A-5 shows that drainage at AAMaxGL acts to control groundwater at the base-case AAMaxGL level while increasing the AAMinGL level (as a result of increased recharge).

For scenario S6, with drainage set at a greater depth relative to AAMaxGL (AAMinGL + 0.5 m), there is an associated increase in the volume of water predicted from the development areas, totalling 14 GL/yr. The increase is greater for scenario S7 which shows a total drainage volume of 19 GL/yr when drains are set at AAMinGL within development areas. For scenarios S6 and S7 the additional water is sourced from increased horizontal groundwater flow into the development areas, decreased horizontal flow out, and increased recharge. These scenarios show that the deeper the subsurface drainage level is set, the greater the off-site impacts on groundwater levels. Figure A-6 and Figure A-7 show that the AAMaxGL is reduced by 0.5 to 2 m in and around the development areas for scenarios S6 and S7.

As expected, drainage volumes are greater with higher rainfall. Comparing the drainage scenarios with drains set at AAMaxGL, drainage is highest (12 GL/yr) in the future wet climate and lowest in the future dry climate at 7 GL/yr (which is comparable to drainage from the agricultural drains alone in the base-case scenario). The future medium climate shows an average drainage volume of 10 GL/yr.

Drainage for individual development areas

The drainage volume in ML from each of the development areas is shown in Table 3-3 and the relative drainage in mm is shown in Table 3-4. Results are displayed spatially for scenario S5 – future medium climate with drains set at AAMaxGL in Figure 3-5 (ML/yr) and Figure 3-6 (mm/yr). The drainage volume in ML indicates the total volume of drainage water generated from the development areas whereas the relative drainage volume in mm shows drainage generated per unit area.

The total drainage volume for each development is related to both the depth to groundwater, and the size of the development. Hence, where drainage is required, the largest development areas generally have the greatest volume of drainage water. The Mundijong Industrial and Baldivis Industrial (North-East) areas generate 1.9 and 3.5 GL/yr drainage water under the S5 scenario, with the Byford, Mandogalup, Casuarina and Mundijong areas producing 0.5–1.6 GL/yr of drainage water.

The developments which generate least drainage water are those with a significant depth to the water table – generally located to the west of the Serpentine River on the Spearwood Dunes or on the Jandakot Mound.

Table 3-3 Predicted drainage volumes (ML) for drainage and land development scenarios

Development name	(S0) Base case	(S1) Future dry	(S2) Future dry, drains at AAMaxGL	(S3) Future dry, drains at AAMinGL	(S4) Future med	(S5) Future med, drains at AAMaxGL	(S6) Future med, drains at AAMinGL + 0.5m	(S7) Future med, drains at AAMinGL + 0.5m	(S9) Future wet	(S10) Future wet, drains at AAMaxGL	(S11) Future wet, drains at AAMinGL
Armadale	124	23	74	700	43	166	795	1068	66	270	1352
Baldivis BA1	0	0	0	0	0	13	6	47	0	101	158
Baldivis BA4	30	1	1	230	5	21	268	458	19	90	706
Baldivis BA6	0	0	0	38	0	1	43	86	0	18	151
Baldivis Industrial (North-East)	1925	920	2836	3551	1322	3488	3917	4177	1721	3918	4641
Baldivis	13	3	10	158	7	30	185	264	13	74	383
Byford	1067	312	335	1239	550	570	1355	1828	768	815	2318
Cardup Industrial	0	0	11	115	0	68	215	237	0	128	345
Casuarina	1061	467	580	1007	680	826	978	1573	849	1058	2149
Eighty Road	0	0	0	11	0	3	21	102	0	53	246
Karnup KA1	0	0	0	47	0	2	64	306	0	115	725
Kwinana Industrial	0	0	12	691	0	123	428	1373	0	342	2063
Kwinana	0	0	2	116	0	23	89	260	0	169	505
Mandogalup	695	199	358	580	344	577	522	991	449	763	1390
Mundijong Industrial	527	306	1573	1958	418	1914	2221	2312	490	2072	2480
Mundijong	1447	670	1052	2460	1042	1596	2577	3320	1286	1953	4089
Port Kennedy Industrial	0	0	0	17	0	8	24	70	0	31	146
Postans	0	0	27	52	0	67	59	96	0	109	137
Serpentine	326	186	189	423	263	288	486	561	312	358	641
Total	7216	3086	7061	13394	4675	9785	14254	19129	5972	12436	24624

ML/yr
0
2000
4000
6000
8000

Table 3-4 Relative drainage (mm) for drainage and land development scenarios

Development name	(S0) Base case	(S1) Future dry	(S2) Future dry, drains at AAMaxGL	(S3) Future dry, drains at AAMinGL	(S4) Future med	(S5) Future med, drains at AAMaxGL	(S6) Future med, drains at AAMinGL + 0.5m	(S7) Future med, drains at AAMinGL + 0.5m	(S9) Future wet	(S10) Future wet, drains at AAMaxGL	(S11) Future wet, drains at AAMinGL
Armadale	28	5	17	156	10	37	177	238	15	60	301
Baldivis BA1	0	0	0	0	0	5	3	19	0	41	65
Baldivis BA4	11	0	0	87	2	8	102	173	7	34	267
Baldivis BA6	0	0	0	24	0	1	27	54	0	12	95
Baldivis Industrial (North-East)	189	90	279	349	130	343	385	411	169	385	457
Baldivis	11	2	8	129	6	25	151	215	11	60	313
Byford	113	33	35	131	58	60	144	194	81	86	246
Cardup Industrial	0	0	7	71	0	42	133	146	0	79	213
Casuarina	221	97	121	210	142	172	204	328	177	221	448
Eighty Road	0	0	0	36	0	9	67	325	0	168	779
Karnup KA1	0	0	0	11	0	0	15	73	0	27	174
Kwinana Industrial	0	0	3	165	0	29	102	327	0	82	491
Kwinana	0	0	1	33	0	7	26	74	0	48	145
Mandogalup	140	40	72	117	69	116	105	200	90	154	280
Mundijong Industrial	113	66	338	420	90	411	477	496	105	445	532
Mundijong	142	66	103	241	102	157	253	326	126	191	401
Port Kennedy Industrial	0	0	0	26	0	11	36	104	0	46	218
Postans	0	0	18	34	0	44	38	62	0	71	89
Serpentine	371	211	215	481	299	328	552	638	355	407	729
Total	1339	611	1217	2723	907	1805	2996	4405	1137	2619	6244

mm/yr	
	0
	200
	400
	600
	800

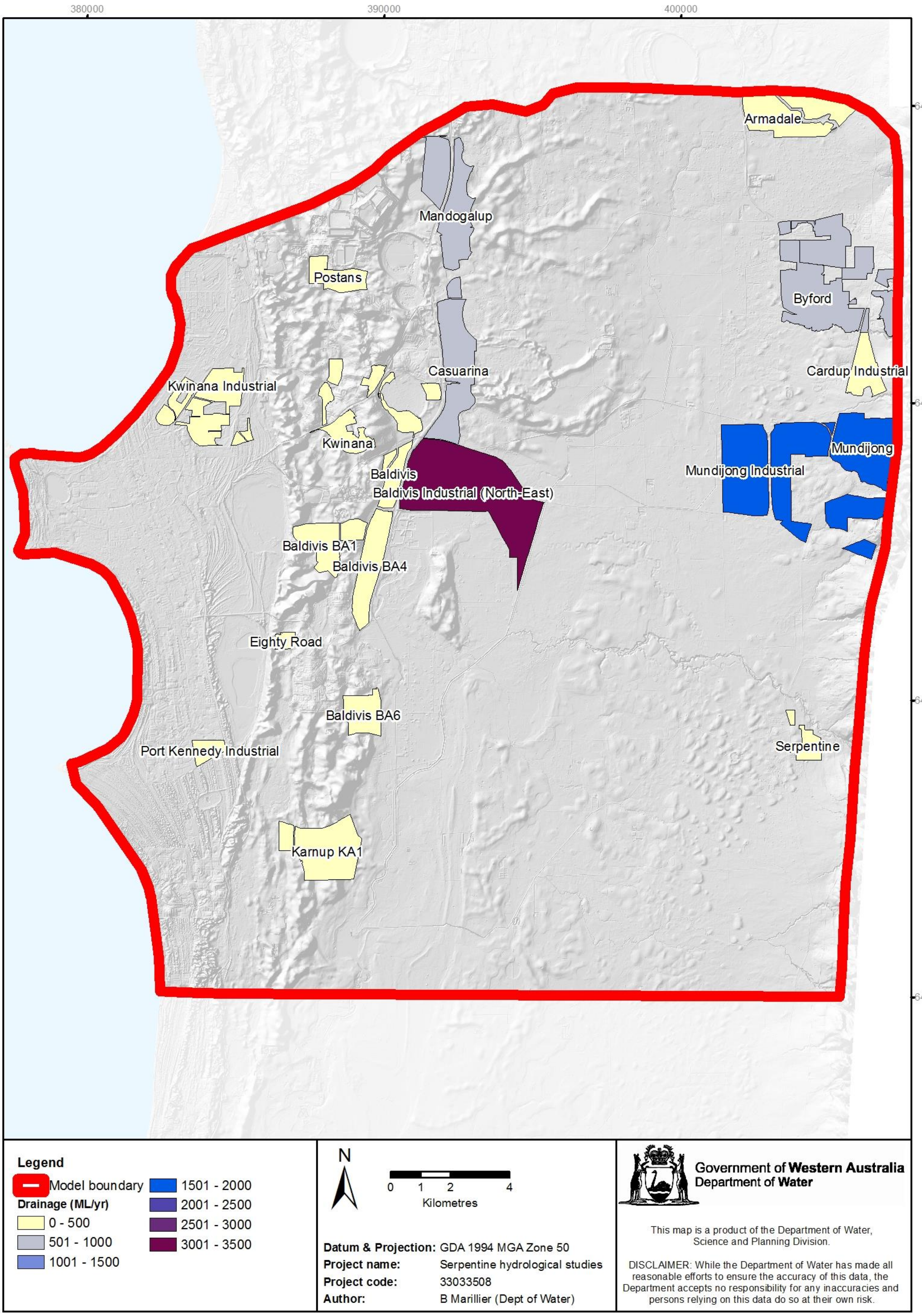


Figure 3-5 Total drainage in ML/yr for the 19 development areas (S5)

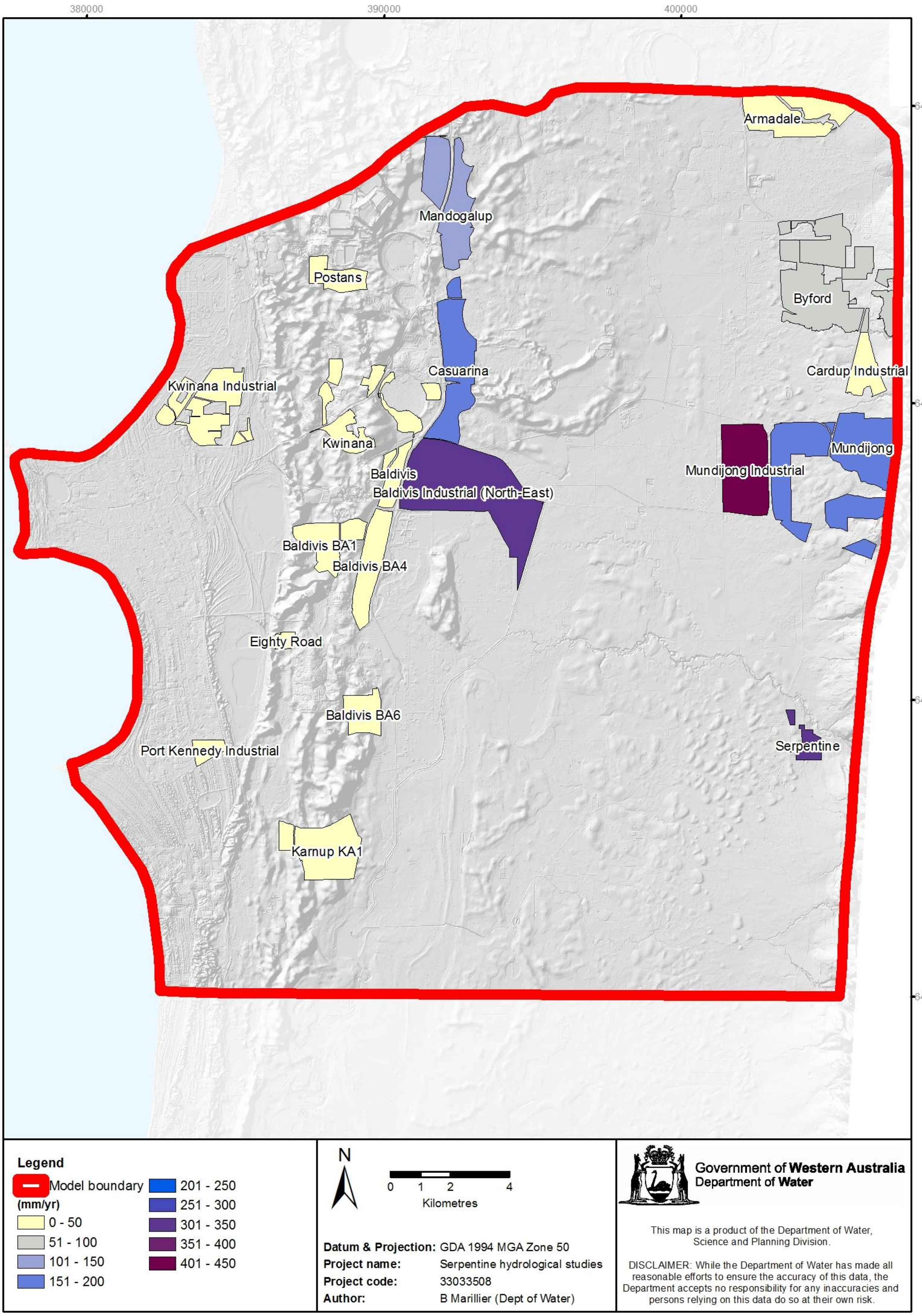


Figure 3-6 Relative drainage in mm/yr for all 19 development areas (S5)

Changes in water balance for development areas

By assessing pre- and post-development water balances it is possible to account for changes in the hydrological cycle associated with development. In many of the development areas with a shallow water table, large volumes of subsurface drainage water are predicted, and it is important to identify the water sources, and how they could affect existing land uses and the environment.

A water balance of the Superficial Aquifer for each development area is provided in Appendix C of this report. The water balance includes all of the major fluxes into and out of the development area. Examples from two development areas are included below. These explain the water balance and how it may be applied in understanding the influence of the development on groundwater and surface water. Firstly, the Karnup KA1 development which, based on the criteria used in scenario analysis, requires very little subsurface drainage, and secondly, the Mundijong Industrial development which is in a part of the study area prone to inundation from groundwater.

Water balances were calculated using the Mike SHE water balance tool, using the period 1981–2010 for the base-case scenario, and 2016–45 for the future scenarios.

Text descriptions of all water balance fluxes are as follows:

Precipitation	Rainfall
Evapotranspiration	Total water losses to the atmosphere through plant transpiration or evaporation
Gross recharge	Water reaching an aquifer via infiltration through the unsaturated zone – gross recharge does not include later losses from the aquifer. *Net recharge* refers to gross recharge minus evapotranspiration directly from the water table (for example, from wetlands and areas of shallow groundwater)
EVT from SZ	Evapotranspiration from the saturated zone. This includes water evaporated directly from wetlands which are surface expressions of groundwater, evaporation from groundwater near the surface and above the extinction depth, and transpiration from plants which have roots reaching the phreatic surface. It does not include evapotranspiration from the unsaturated zone.
Hor. SZ flow out	Horizontal saturated zone (groundwater) flow leaving a defined section of an aquifer laterally.
Hor. SZ flow in	Horizontal saturated zone (groundwater) flow entering a defined section of an aquifer laterally.
Ver. SZ flow out	Vertical saturated zone (groundwater) flow leaving a defined section of an aquifer.
Ver. SZ flow in	Vertical saturated zone (groundwater) flow entering a defined section of an aquifer.

OL flow in	Overland flow into a defined area, not including rivers and drains.
OL flow out	Overland flow out of a defined area, not including rivers and drains.
Drainage (total)	Total drainage water from a defined area, including subsurface drainage and surface drainage systems. In the context of the water balance this does not include flow from the Mike 11 network, which is included as 'base flow to river'.
Base flow to river	Net groundwater contribution to river flows for channels defined in the Mike 11 network.
Irrigation	Water applied to the land surface to support plant growth. For the Serpentine model this includes infiltrated water from the Kwinana waste water treatment plant
Total Error	The error calculated from the water balance due to numerical errors in the model. Unaccounted for losses or gains in the water balance calculations.
ΔStorage	Change in storage is the difference in the total volume of water contained in an aquifer for two distinct times. ΔStorage is calculated by subtracting total outflows from total inflows.

Karnup KA1 development

The Karnup KA1 development is located along the elevated ridge of the Spearwood Dunes in the south of the study area and to the west of the Serpentine River. It is unlikely to require significant drainage infrastructure to maintain clearance from groundwater (Figure 3-7).

Three scenario water balances are shown in Table 3-5: the base-case scenario (S0), the future medium climate scenario with drains at AAMaxGL (S5), and the future medium climate scenario with drains at AAMinGL (S7).

The influence of the development on recharge can be seen in the reduced evapo-transpiration and increased recharge for scenarios S5 and S7 compared to S0. For S5 the increase in recharge is balanced by increased horizontal flow from the site. For S7, the deeper subsurface drainage is intercepted by the phreatic surface more often and, as a result, the volume of drainage increases substantially. Note that the net horizontal and vertical groundwater fluxes are negative for all three scenarios, indicating that groundwater flows away from the development area, however, net outflow is much lower for S7 relative to S0 as horizontal flow within the aquifer is replaced by drainage.

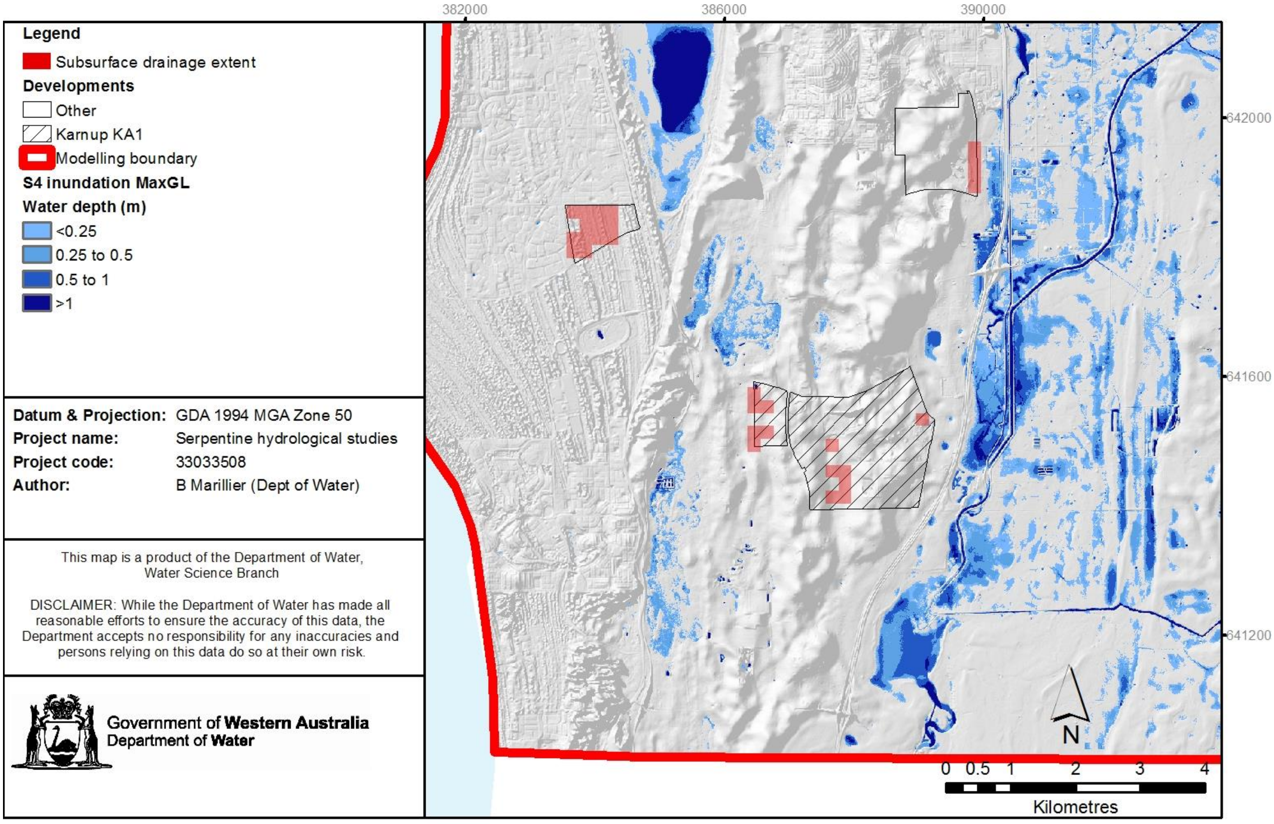


Figure 3-7 Karnup development with surface inundation derived from the MaxGL surface of the future medium scenario (S4)

Table 3-5 Water balance for the Karnup development S0, S5 and S7

Flux	Average annual (mm)			Percentage of rainfall		
	S0	S5	S7	S0	S5	S7
Precipitation	800	766	766	100%	100%	100%
Evapotranspiration	594	552	552	74%	72%	72%
Gross recharge	209	214	214	26%	28%	28%
EVT from SZ	0	0	0	0%	0%	0%
Hor. SZ flow out	109	87	75	14%	11%	10%
Hor. SZ flow in	32	22	61	4%	3%	8%
Ver. SZ flow out	151	157	143	19%	21%	19%
Ver. SZ flow in	7	6	14	1%	1%	2%
Abstraction	0.1	0.1	0.1	0%	0%	0%
OL flow in	0	0	0	0%	0%	0%
OL flow out	0	0	0	0%	0%	0%
Drainage (total)	0	0.4	73	0%	0%	10%
Base flow to River	0	0	0	0%	0%	0%
Irrigation	0	0	0	0%	0%	0%
Total Error	0	0	0	0%	0%	0%

S0 = base case, S5 = Future medium with drains at AAMaxGL, S7 = Future medium with drains at AAMinGL

Mundijong industrial development

The Mundijong industrial development, located to the west of the Mundijong town site, is in an area subject to extensive seasonal inundation from groundwater (Figure 3-8). The water balance results for scenarios S0, S5 and S7 are shown in Table 3-6.

The water balance from the Mundijong industrial development shows distinct differences in comparison to Karnup. Recharge is substantially higher post-development. Pre-development, groundwater was at, or close to, the surface over much of the area, and the evapo-transpiration from the saturated zone (EVT from SZ) totalled 20% of rainfall, and was a substantial outward flux. In addition, overland flow resulting from saturation excess runoff totalled 14% of rainfall. With the post-development scenarios, both fluxes are reduced almost to zero as a result of the free-draining conditions created by the development fill and subsurface drainage. These changes result in a significant increase in recharge and a large volume of drainage water.

In the case of S7, drainage water volume exceeds gross recharge, with the deficit balanced by reduced net horizontal flows. This shows that, by setting subsurface drainage deeper (AAMinGL), the development drainage is beginning to draw on the regional Superficial Aquifer. However, with drainage set at AAMaxGL (S5) the development increases net horizontal flows, effectively discharging groundwater to the surrounding Superficial Aquifer.

The comparison between the Karnup and Mundijong industrial developments demonstrates the difficulties associated with water management in inundated areas. Karnup requires very little drainage infrastructure and can probably be developed with little impact to groundwater levels off-site whereas Mundijong industrial requires drainage and fill across the whole development. Selection of drainage level (controlled groundwater level) is a very important consideration which will influence both the total drainage volume from the site as well as off-site impacts on surface water and groundwater.

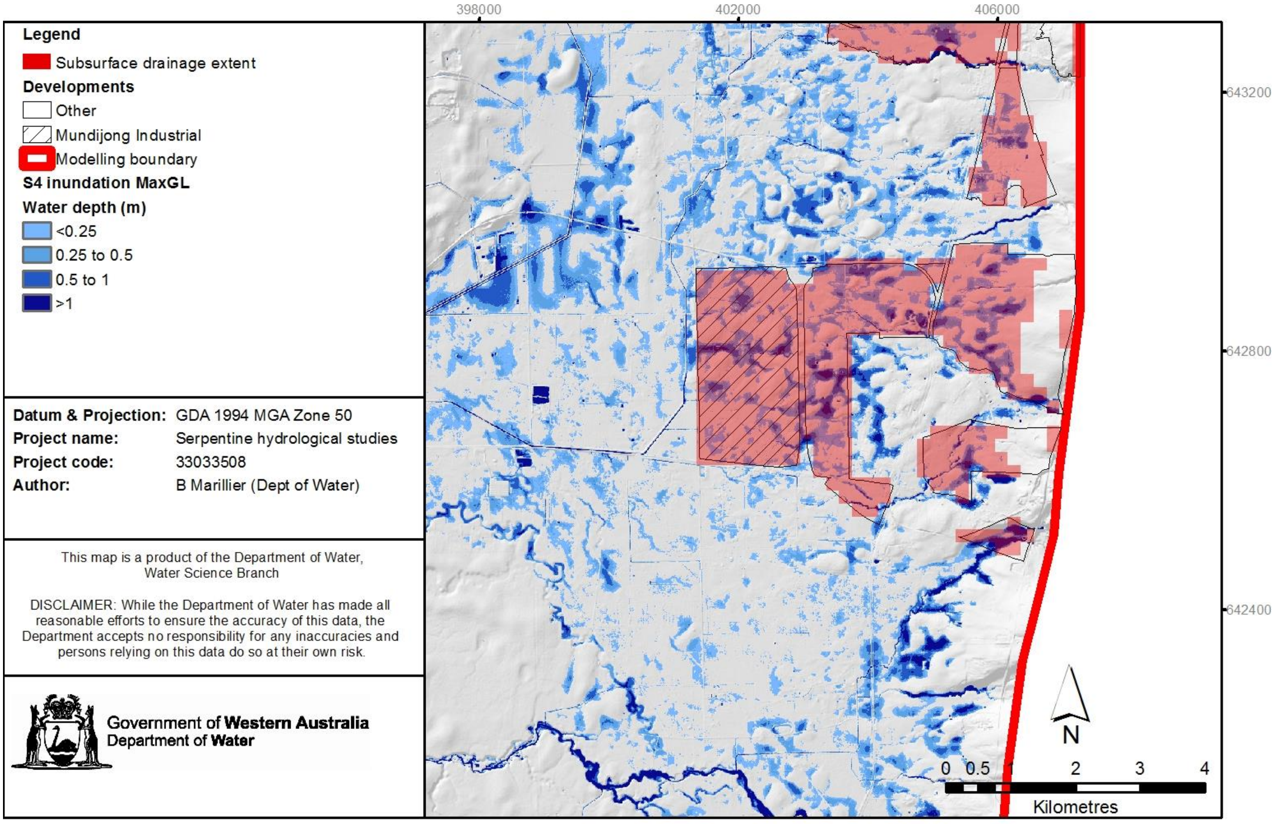


Figure 3-8 Mundijong industrial development with surface inundation derived from the MaxGL surface of the future medium scenario (S4)

Table 3-6 Water balance for the Mundijong industrial development, S0, S5 and S7

Flux	Average annual (mm)			Percentage of rainfall		
	S0	S5	S7	S0	S5	S7
Precipitation	863	831	831	100%	100%	100%
Evapotranspiration	692	362	379	80%	44%	46%
Gross recharge	262	481	452	30%	58%	54%
EVT from SZ	175	17	2	20%	2%	0%
Hor. SZ flow out	27	70	17	3%	8%	2%
Hor. SZ flow in	70	59	86	8%	7%	10%
Ver. SZ flow out	13	23	18	2%	3%	2%
Ver. SZ flow in	4	2	5	1%	0%	1%
Abstraction	2	3	3	0%	0%	0%
OL flow in	35	4	6	4%	0%	1%
OL flow out	119	4	7	14%	1%	1%
Drainage (total)	113	411	496	13%	49%	60%
Base flow to River	8	18	7	1%	2%	1%
Irrigation	0	0	0	0%	0%	0%
Total Error	0	0	0	0%	0%	0%

S0 = base case, S5 = Future medium with drains at AAMaxGL, S7 = Future medium with drains at AAMinGL

3.5 Garden bore scenario (S8)

The garden bore scenario was configured with the future medium climate, drains at AAMaxGL, and abstraction from garden bores in the urban residential developments, as described in Section 2.1. It can be compared with scenario S5, which is identical but without the additional abstraction. The scenario was designed to assess the combined impacts of unlicensed abstraction and urban development.

Scenario S8 demonstrates that garden bore abstraction reduces the volume of drainage water expected from the development areas by 10% from 10 GL/yr (S5) to 9 GL/yr (S8). Figure 3-9 illustrates how scenario S8 compares to the other scenarios with the future medium climate. Drainage volume for S8 is between the base-case scenario and the future medium drains at AAMaxGL scenario, indicating that abstraction acts to offset the increase in recharge from development.

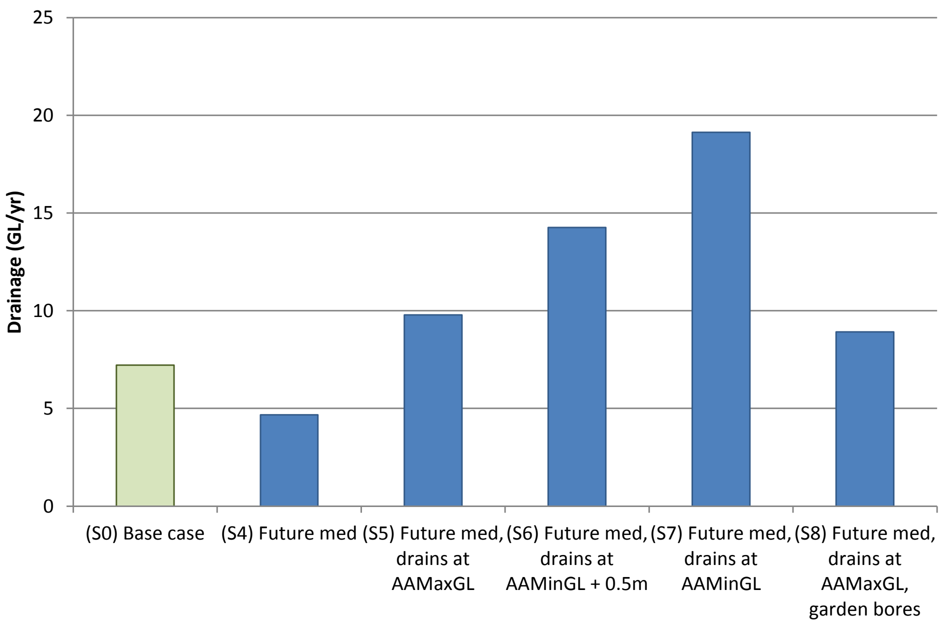
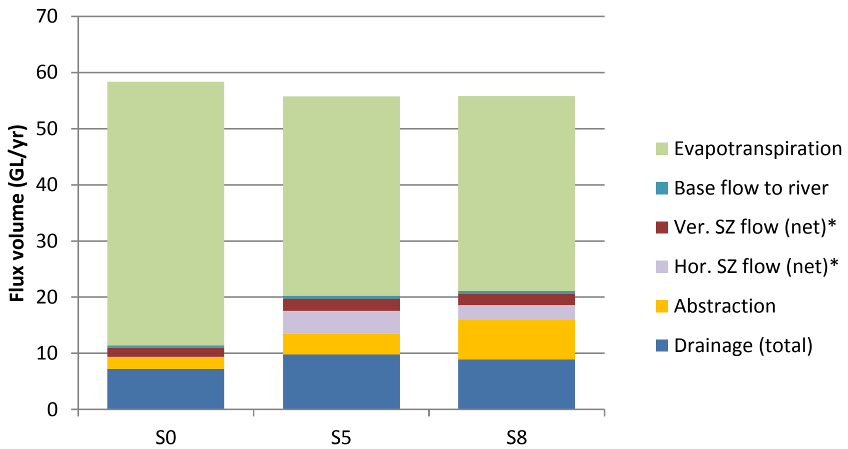


Figure 3-9 Comparison of drainage for future medium climate scenarios

Table 3-7 shows the water balances for the base-case (S0), future medium with drains at AAMaxGL (S5) and garden bore (S8) scenarios for all development areas in mm/yr and GL/yr. Figure 3-10 graphically shows fluxes for evapotranspiration, horizontal flow, abstraction and drainage.

Table 3-7 Water balances for S0, S5 and S8 from all development areas

Flux	S0 GL/yr	S5 GL/yr	S8 GL/yr
Precipitation	59	56	56
Evapotranspiration	47	36	35
Gross recharge	19	23	23
EVT from SZ	9	2	2
Hor. SZ flow out	15	18	16
Hor. SZ flow in	16	14	14
Ver. SZ flow out	2	2	2
Ver. SZ flow in	0	0	0
Abstraction	2	4	7
OL flow in	2	1	1
OL flow out	3	0	0
Drainage (total)	7	10	9
Base flow to River	0	1	0
Irrigation	0	0	0
Total Error	0	0	0



**Net denotes outflows minus inflows*

Figure 3-10 Groundwater fluxes in water balances for S0, S5 and S8

For the garden bores scenario (S8), abstraction is one of the major losses from the aquifer, reducing drainage, and horizontal flow of groundwater from the development areas. The total drainage volume is more than in the pre-development conditions (S0) but less than in the post-development scenario without garden bore abstraction (S5). The key finding of the scenario is that, under development conditions without abstraction, the reduced evapotranspiration is largely offset by increased drainage and horizontal flow whereas with the inclusion of garden bores reduced evapotranspiration is offset by increased abstraction combined with increased drainage.

The increased abstraction from scenario S8 also acts to lower the minimum groundwater level within the development area relative to the base-case scenario in some developments

(Figure A-8). There is a risk of exposing potentially acid sulfate soils (PASS) if groundwater levels are lowered, and abstraction of groundwater is one potential mechanism for this. Therefore the risk of causing acid sulfate soils should be considered when bores are being installed; in particular, community bores which would concentrate the draw in a single location.

There is a high degree of uncertainty associated with the garden bore abstraction scenario, due to uncertainties in model inputs and site characteristics which could inhibit the use of garden bores.

3.6 Waterlogging analysis

Waterlogging refers to areas where the superficial groundwater is above the land surface. Waterlogging was mapped by extracting the maximum superficial groundwater level from the scenario concerned. The MaxGL surface was resampled from 200 m to 10 m resolution using bilinear interpolation. The resampled MaxGL was subtracted from a 10 m resolution digital elevation model (resampled from 1 m LiDAR). This results in a surface representing depth to groundwater, such that negative values indicate water above the ground surface. Note that due to the resampling procedure, areas with steep slopes may misrepresent the true extent of inundation. Results for all non-development scenarios (S1, S4, S9, S12, S13, S14, S14b) are shown in Appendix B.

The waterlogging maps show the maximum inundation extent based on the highest modelled groundwater level for each scenario. The maps can be compared with the base-case (S0) scenario shown previously in Figure 3-2. Table 3-8 lists the total areas of inundation associated with the maximum groundwater level for the climate scenarios, and the average annual flows from the Serpentine River at the model boundary.

Table 3-8 Summary of inundation area and depth at MaxGL, and average annual surface flows for climate scenarios

Scenario	Rainfall (mm)	Area of inundation (km^{2})	Average inundation depth (m)	Discharge Serpentine River (GL/yr)
S0	800	134.3	0.43	96.7
S1	682	104.4	0.39	49.3
S4	759	118.8	0.40	70.7
S9	800	136.4	0.42	88.0
S12	782	144.8	0.44	84.1
S13	887	166.0	0.50	147.9
S14	759	122.6	0.41	70.6
S14b	800	138.9	0.43	88.2

The future dry climate scenario (S1) shows a 30 km^2 reduction in the extent of inundation, and a shallower average depth relative to S0. The areas with the greatest reductions in inundation area are those with free draining soils and deeper groundwater. These include the Spearwood Dunes and Safety Bay Sands in the west of the study area, and the Jandakot Mound. As these areas have little surface runoff as a result of saturation excess, there is no capacity for increased recharge as groundwater drops – which means that the phreatic surface is more responsive to changes in rainfall. Added to this is the effect in residential areas of unlicensed abstraction which tends to be concentrated in areas with significant depth to groundwater within the study area.

With the drier climate and increased abstraction (relative to pre-2000 levels) the S1 scenario shows that many wetlands in these susceptible areas may disappear even in the wettest years. Examples include Churcher Swamp, Pike Swamp and Anstey Swamp, as well as other wetlands located in the Spearwood Dunes and on the Jandakot Mound. Lakes Cooloongup and Walyungup show substantial reductions in surface area and depth. With the continued nearby infiltration of water from the Kwinana waste water treatment plant the water levels in the Spectacles Wetlands did not fall.

To the east of the Peel Main Drain on low-lying sections of the coastal plain, the extent of inundation for S1 relative to S0 is not significantly reduced. As rainfall is reduced, saturation excess runoff (overland flow) is also reduced, allowing increased recharge to groundwater – the groundwater is essentially buffered by the surface water. As such, many of the waterlogging prone areas are likely to remain waterlogged even with large reductions in rainfall. The reduced rainfall is much more apparent in the Serpentine River outflows which are reduced by almost half for S1 relative to S0.

The future medium climate scenario S4 shows similar results to scenario S1. Many wetlands in the base-case scenario are greatly reduced in extent and depth or disappear completely. The future wet climate scenario S9 shows a slight reduction in the extent and depth of wetland water levels on the Jandakot Mound and in the Spearwood Dunes. However, the extent and depth of inundation is actually slightly increased in some areas as a result of the altered rainfall patterns (i.e. the scaled rainfall 1961–90 used for the future wet climate includes higher rainfall years than the base-case period 1981–2010, despite having a similar average rainfall).

Scenario S12, with future medium climate with two wet years at the end of the sequence, shows a similar extent of inundation to the base-case (S0) scenario. Both wet years have in excess of 1000 mm rainfall and the groundwater levels rise dramatically from recharge over the two years. So, even after a sustained period of reduced rainfall, the wet years are sufficient to raise groundwater levels to maximum levels comparable to those modelled in the base-case period. In some sections of the model, the extent and depth of inundation for S12 is increased relative to S0. This indicates that planning for drainage and inundation must consider not only the dry climate scenario or low rainfall years, as isolated wetter than average years could result in significant rises in groundwater levels resulting in inundation and posing a threat to infrastructure.

Scenario S13 shows the response of groundwater to a higher average annual rainfall of 887 mm relative to 800 mm for the base-case (S0) scenario, with several high rainfall years. Figure B-5 shows the extent of inundation at MaxGL for this scenario. In all areas of inundation within the model for S0, S13 has increased waterlogging depth and extent. The affect is most pronounced in local depressions between dunes. The total inundated area is 32 km^2 greater than for S0: a 24% increase.

The sea-level-rise scenario with the future medium climate (S14) shows that, over most of the area, waterlogging does not increase relative to scenario S4 – future medium climate. Similarly, S14b does not show a dramatic increase in inundation extent relative to S9. For both scenarios, S14 and S14b, there is an increase in water levels and the extent of inundation at Lake Richmond, Lake Walyungup, Anstey Swamp and the southernmost pool in the Serpentine River (Figure B-6 and Figure B-7).

3.7 Surface flow data

The Lower Serpentine integrated surface water and groundwater model was used to simulate open channel flows for 12 rivers and drains. Six flow gauges were used for calibrating the river flows, and the results are reported in Marillier et al. (2012b). Stage and discharge data can be extracted from the Mike 11 results files at any computational point within the river network, and this information may be useful in studies concerning environmental water requirements or allocation planning. Detailed flow analysis is beyond the scope of this project, however, the Lower Serpentine model and associated results files are available on request from the Department of Water. The waterways for which data is available include: Beenyup Brook, Berriga Drain, Cardup Brook, Dirk Brook, Karnet Brook, Manjedal Brook, Medulla Brook, Myara Brook, Oaklands Drain, Peel Main Drain, Punrack Drain, and the Serpentine Drain/River. Results are available only for the sections of these waterways located on the Swan Coastal Plain.

Figure 3-11 shows, for each of the climate scenarios, flow duration curves derived from modelled average daily discharge for the Serpentine River at the model boundary. Note that peak flows at subdaily time-step may exceed the maximum flows shown on the curve. Curves were calculated using 1981–2010 data for the base-case scenario and 2016–45 data for all other scenarios. Figure 3-11 shows average annual flows for the same periods.

The graph illustrates the reduction in flows which can be expected with reduced rainfall. The flow duration curve for the future wet (S9) scenario is comparable to that of the base-case scenario, with flows in all sections of the curve slightly less frequent. The future medium and dry climates both show more significant reductions in flow through all parts of the curve, attributed to both reduced baseflow and overland flow. The reduction is greatest for the dry climate, with fewer medium and high flow events in winter. This is a result of the reduced overland flow which occurs as groundwater levels, and therefore rejected recharge, decrease. The historical wet scenario (S13) shows little change in the low-flow end of the curve, however, mid-range and peak flows are larger and more frequent relative to the base-case scenario. This reflects an increase in rejected recharge, and is consistent with the waterlogging results described in Section 3.6.

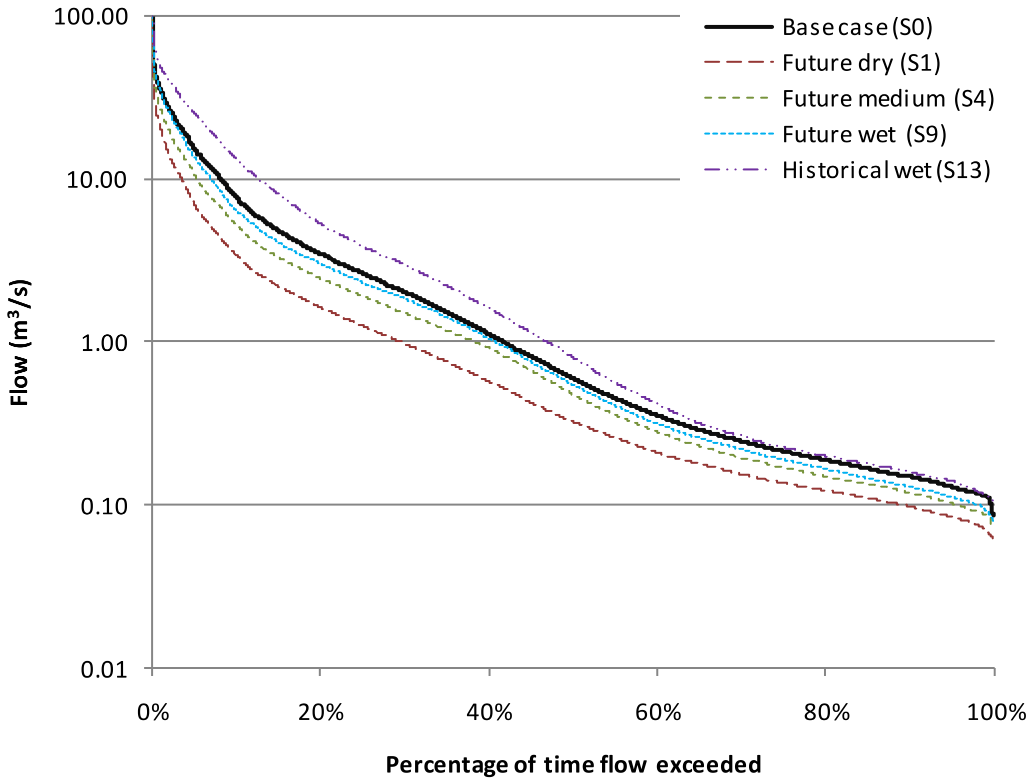


Figure 3-11 Flow duration curves for climate scenarios, based on modelled discharge from the Serpentine River at the model boundary

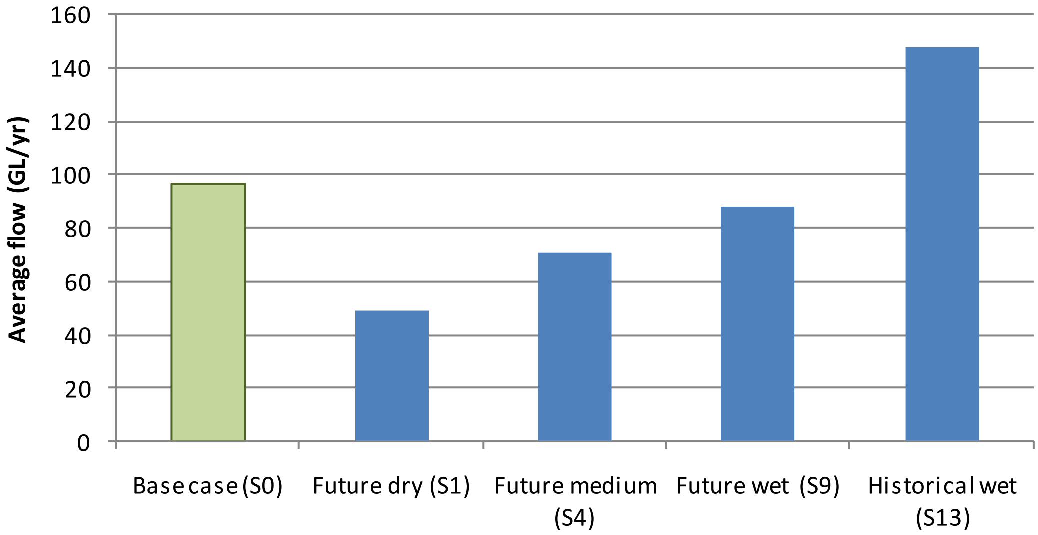


Figure 3-12 Average annual flows for the climate scenarios, based on modelled discharge from the Serpentine River at the model boundary

3.8 Uncertainty and error in model results

Groundwater models are approximations of reality; how faithfully they make those approximations depends on many facets of the modelling process: the quantity and quality of the data available to conceptualise, construct and calibrate the model; the ability of the model's equations to match physical processes; and the accuracy of the projections which are implemented in scenario modelling.

The dynamic nature of groundwater modelling has ramifications for the interpretation and use of models and their output. Dynamic changes of the groundwater system and its forcing agents (for example, abstraction, climate and land use) complicate the task of accurately hind-casting and forecasting hydrogeological behaviour. The fact that groundwater flow modelling is typically based on limited data influences our ability to represent the groundwater system. Lack of data can manifest in several forms within a groundwater model:

- inadequate model conceptualisation
- uncertainty in locations lacking calibration data
- errors associated with insufficient or incorrect forcing data (rainfall, boundary conditions, abstraction)
- insufficient resolution or precision in the model.

All of these points are applicable to the use of the Lower Serpentine regional model for scenario modelling and prediction. Every effort was made to reliably and accurately represent the groundwater and surface water within the study area, however, model results should always be interpreted in the context of the uncertainty and error associated with the model and, where possible, validated by appropriate field observations.

The following sections describe some of the sources of error and uncertainty which should be considered for the Lower Serpentine model.

Calibration error

The *Lower Serpentine hydrological studies: model construction and calibration report* (Marillier et al. 2012b) contains a detailed discussion of areas within the model which did not calibrate well, with some diagnosis of the problems. Error statistics for each of the calibration bores were described in Appendix C of the report and provide the best indication of model reliability for particular areas. Calibration was targeted at accurately reproducing the annual maximum observed groundwater levels. The following areas were problematic for calibration:

- The north-eastern corner of the model area, near T120(O) and T170. In this area, the model calibrated sufficiently for the period 1970–90 but from 1990 onwards the model fails to simulate ongoing declining head in this area. The error is probably a result of the exclusion from the model of the Cattamarra Aquifer which underlies this area and has shown a significant decline in head over the same period. Developments in this area include **Armadale** and **Byford**. This error results in an over-prediction of groundwater levels, surface inundation from groundwater and subsurface drainage within this area for recent decades.

- The area to the west of the Jandakot Mound near T180 (O), T190 (O), T240 (O) and T130 (O). The effects of abstraction seem to be over-estimated in this section of the model, and the declining groundwater trend in the area is over-predicted. In addition, the conceptualisation of the Superficial Aquifer geology is not detailed enough to capture the east to west transition from Bassendean Sand to Tamala Limestone and the associated steep hydraulic gradient. Sections of the **Postans** and **Kwinana** developments are located in this area. Groundwater levels are generally under-predicted in these developments by around 1 m but this is unlikely to affect inundation mapping or drainage estimates given that the depth to the water table is several metres or more in this area.

Boundary conditions

The northern, southern and eastern boundaries of the Superficial Aquifer were set as no-flow, with a small section in the north-east assigned a time-varying head boundary, and the western boundary set to 0 mAHD to approximate mean sea level. A detailed discussion of boundary conditions and model sensitivity is available in the *Lower Serpentine hydrological studies: model construction and calibration report* (Marillier et al. 2012b). Generally, model results will be less reliable along the model boundary, particularly for predictive scenarios where changing conditions outside the model boundary may affect groundwater levels and flows within the model. The **Armadale** and **Mandogalup** development areas may be affected.

Abstraction

Some sections of the model are sensitive to changes in abstraction, as described in the *Lower Serpentine hydrological studies: model construction and calibration report* (Marillier et al. 2012b). There is considerable uncertainty in the abstraction data used in the model base-case period due to the lack of reliable data prior to the mid-2000s and the absence of metering data for the majority of groundwater licenses in the area. Further more, for predictive scenarios it is necessary to make assumptions about future abstraction rates, as described in Section 2.3. This introduces uncertainty into sections of the model which are sensitive to abstraction, including the Spearwood Dunes, sections of the Jandakot Mound, and the eastern extent of Byford. Generally, maximum groundwater levels are less sensitive to abstraction and developments in affected areas have significant depths to groundwater so drainage results from development areas should be relatively unaffected.

Uncertainty in climate and sea-level-rise scenarios

As described in Section 2.2, there is a large degree of uncertainty associated with the projected climate and sea-level-rise scenarios. The selection of the 10th, 50th and 90th percentile climate scenarios for the year 2030 aims to capture uncertainty so the risks associated with climate change can be accounted for. For example, the highest risk scenario for groundwater inundation would be the future wet climate scenario while the future dry scenario would be the highest risk when considering wetland loss. Note that the 50th percentile scenario does *not* represent the most likely scenario. Uncertainty was not considered in the sea-level-rise scenario, the estimated sea-level-rise applied in the model scenario was based on state planning policy. The IPCC (2007) suggest a range of potential sea-level-rise scenarios based on the various emissions scenarios and model projections.

Uncertainty in drainage design and recharge for development scenarios

The Lower Serpentine regional model area is 728 km^2 and not designed for simulating detailed development-scale drainage design. As a result, certain assumptions are made about the urban and industrial developments which influence the outcome of model results. These include the post-development recharge rate, the subsurface drainage level, and the fill level. Depending on the local-scale design of a development, all of these factors may vary, thus influencing post-development groundwater levels and estimates of drainage.

The development scenarios investigated in this report assume infiltration of stormwater on site and, therefore, recharge rates substantially increased post-development. Depending on local hydraulic constraints, this level of infiltration may not be possible in all sites. Recharge rates may be lower, with higher rates of overland flow, and associated requirements for treatment and storage of water at the surface.

The scenarios also assume free-draining outlets for subsurface drainage. In many cases, development areas are situated low in the landscape, and the availability of free-draining outlets for subsurface drainage will determine the controlled groundwater level (CGL). For example, in many developments, a CGL at AAMinGL would not be feasible.

Fill levels were defined based on the selected subsurface drainage level for the development scenarios. To obtain appropriate clearance from groundwater, fill will probably be required in many of the development areas. However, its exact level and location will vary significantly depending on the assumptions used in the modelling. The level of fill and subsurface drainage influence the post-development groundwater levels so the final drainage design within an individual development is likely to result in groundwater levels and drainage volumes that differ from any of the scenarios modelled here.

Lower Serpentine model applicability

The Lower Serpentine regional model is appropriate for assessing the following at the regional scale:

- relative water balance changes for urban development areas
- relative changes in superficial groundwater level and river flows as a result of climate change
- relative changes in superficial groundwater level as a result of urban development, drainage and abstraction
- relative changes in coastal groundwater levels as a result of sea-level rise
- potential volumes of drainage water resulting from urban development based on assumptions of recharge, drainage level and fill.

In addition, the regional model is suitable for provision of district-scale groundwater level evaluation in areas where the inherent model error is deemed acceptable. If the error is unacceptably large then it may be necessary to develop a localised model with a finer grid and revised conceptualisation using local data. Alternatively, local hydrogeological data may be sufficient to provide district-scale information without the requirement for groundwater modelling.

4 Conclusions and recommendations

This scenario report represents the final phase of the Lower Serpentine hydrological studies. It describes the selection process for drainage, climate and development scenarios implemented with the Lower Serpentine regional model, the numerical implementation of the scenarios, and the results of the scenario modelling. The results reported include groundwater levels, groundwater inundation maps, river flows and water balances for each of the 15 scenarios modelled, including the base-case scenario.

The scenarios modelled included:

- **Future climate scenarios** based on IPCC emissions scenarios, including changes in precipitation, evaporation and sea-level-rise. The scenarios were selected to provide results for a *reasonable* range of future climates, and to include historical wet periods. The following scenarios were implemented:
    - Future wet climate: –5.0% change in mean annual rainfall relative to the WMO climate baseline period 1961–90.
    - Future medium climate: –9.8% change in mean annual rainfall relative to the WMO climate baseline period 1961–90.
    - Future dry climate: –19.1% change in mean annual rainfall relative to the WMO climate baseline period 1961–90.
    - Future medium with two wet years: the future medium climate with the years 2044 and 2045 replaced with observed rainfall from 1963 and 1964 – both high rainfall years in excess of 1000 mm.
    - Historical wet: 5.2% increase in mean annual rainfall using the historical climate sequence 1945–74.
    - Sea-level-rise: Increase in sea-level of 0.9 m by the year 2110.
- **Development scenarios** based on information from the Metropolitan Region Scheme (MRS), the Peel Region Scheme (PRS) and Economic and Employment Lands Strategy (EELS) published by the Department of Planning. The development areas modelled included ‘Industrial Investigation’ areas from the EELS and existing undeveloped urban, urban deferred and industrial areas from the region schemes.
- **Subsurface drainage scenarios** in areas of shallow groundwater at different levels including AAMaxGL, AAMinGL and AAMinGL plus 0.5 m, with fill where required. The subsurface drainage scenarios aim to capture a *representative* range of drainage levels.

Table 4-1 lists the scenarios implemented in the model.

Table 4-1 Scenarios implemented in the Lower Serpentine regional model

Scenario #*	Climate scenarios	Subsoil drainage scenarios	Development scenario
S0	Current climate	None	Current land use scenario
S1	Dry	None	Current land use scenario
S2		At AAMaxGL	Full development
S3		At AAMinGL	Full development
S4	Medium	None	Current land use scenario
S5		At AAMaxGL	Full development
S6		0.5m above AAMinGL	Full development
S7		At AAMinGL	Full development
S8		AAMaxGL	Full development Garden bores
S9	Wet	None	Current land use scenario
S10		At AAMaxGL	Full development
S11		At AAMinGL	Full development
S12	Medium with two wet years	None	Current land use scenario
S13	Historical wet	None	Current land use scenario
S14	Sea level rise Future medium	None	Current land use scenario
S14b	Sea level rise Future wet	None	Current land use scenario

**Scenario number is a unique ID which is used in file naming conventions within the Mike SHE model*

For the climate change scenarios without development (S1, S4, S9 and S13), the changes in groundwater levels and flows from the Serpentine River relative to the base-case (S0) scenario were:

- **Future dry climate S1:** –0.82 m AAMaxGL, –0.64 m AAMinGL, –47.5 GL/yr flow.
- **Future medium climate S4:** –0.49 m AAMaxGL, –0.41 m AAMinGL, –26.0 GL/yr flow.
- **Future wet climate S9:** –0.26 m AAMaxGL, –0.28 m AAMinGL, –8.7 GL/yr flow.
- **Historical wet climate S13:** +0.28 m AAMaxGL, +0.04 m AAMinGL, +51.2 GL/yr flow.

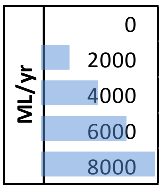
The driest climate scenario resulted in significant reductions in the extent, depth and occurrence of wetlands within the model area. Flows from the Serpentine River were shown to be sensitive to changes in rainfall, with a 19% reduction in rainfall resulting in a 49% reduction in flow. Groundwater levels were most sensitive to changes in rainfall in areas with a significant depth to groundwater, and were least sensitive in areas with groundwater at the surface.

Subsurface drainage was modelled for the 19 development areas within the Serpentine model. Table 4-2 shows the volume of drainage for several of the drainage scenarios. Modelling showed that drainage volumes increase as rainfall increases and as deeper drainage levels are set.

The drainage volumes presented in Table 4-2 are indicative only, and are based on assumptions regarding recharge, drainage level and fill surface. Drainage volume will be highly variable depending on the local-scale design implemented for individual developments. The drainage volume does not necessarily represent water which will be discharged from the development areas. Rather, it is indicative of the volume of water which will require management at the development scale. The development scenarios assumed an increased recharge as a result of increased impervious surface areas, and therefore, increased overland flow infiltrating at the development scale. Depending on drainage design, more or less water may be recharged; however, the total volume requiring management will be similar regardless of impervious area runoff being infiltrated or treated at the surface.

Table 4-2 Drainage volumes from development areas for the future dry, medium and wet scenarios with drains at AAMaxGL

Development name	(S0) Base case	(S2) Future dry, drains at AAMaxGL	(S5) Future med, drains at AAMaxGL	(S10) Future wet, drains at AAMaxGL
Armadale	124	74	166	270
Baldivis BA1	0	0	13	101
Baldivis BA4	30	1	21	90
Baldivis BA6	0	0	1	18
Baldivis Industrial (North-East)	1925	2836	3488	3918
Baldivis	13	10	30	74
Byford	1067	335	570	815
Cardup Industrial	0	11	68	128
Casuarina	1061	580	826	1058
Eighty Road	0	0	3	53
Karnup KA1	0	0	2	115
Kwinana Industrial	0	12	123	342
Kwinana	0	2	23	169
Mandogalup	695	358	577	763
Mundijong Industrial	527	1573	1914	2072
Mundijong	1447	1052	1596	1953
Port Kennedy Industrial	0	0	8	31
Postans	0	27	67	109
Serpentine	326	189	288	358



Many of the development areas are in locations with shallow groundwater, or groundwater above the surface, and these areas are the most constrained from a hydrological perspective. Generally, the developments located along the eastern fringe of the coastal plain and the proposed Baldivis Industrial area generate the greatest volumes of subsurface drainage water, and will require more investment to manage groundwater than other areas with deeper groundwater.

The 0.9 m sea-level-rise scenario showed an increase in groundwater levels up to 2 km inland from the coast, and up to 3 km upstream on the Serpentine River. The changes in groundwater levels are most extensive on the Rockingham Peninsula and Becher Point where the land is surrounded on three sides by the ocean. Of the developments, only the Kwinana Industrial area is within the region affected by sea-level-rise though groundwater is deep enough to avoid any inundation. Note that Mike SHE is not capable of modelling variable density fluids and so the sea-level-rise scenario does not give an indication of salt-water intrusion.

Analysis of inundation due to groundwater (waterlogging) was undertaken for each climate scenario. The analysis indicated that groundwater occurred at, or above, the land surface in many low-lying parts of the study area, particularly in the central and eastern parts of the coastal plain. The base-case scenario indicated that the maximum groundwater level was above the surface across 134 km^2, or 18%, of the total area modelled. The dry climate scenario indicated a smaller area of waterlogging (104 km^2 or 14%) though some low-lying areas were still subject to extensive inundation. The historical wet scenario showed that 166 km^2 (23%) of the study area was inundated by groundwater in the higher rainfall regime.

The future medium climate with two wet years scenario illustrated that a short sequence of high rainfall events could raise groundwater levels quickly, even after long periods of lower rainfall. This resulted in waterlogging at or above levels which occurred under a rainfall regime which is wetter on average but without very high rainfall years.

Abstraction from domestic garden bores within the development areas was modelled for all new urban areas. Abstraction was modelled at a rate of 400 kL/yr, assuming a lot size of 400 m^2 covering 60% of the 50.6 km^2 urban development area, and a bore installation rate of 11% (approximately one in 10 houses). This resulted in an additional 3.4 GL/yr of unlicensed abstraction from the Superficial Aquifer across the study area. Scenario modelling showed that the additional abstraction reduced the volume of subsurface drainage water from the development areas. There is a high degree of uncertainty associated with the garden bore abstraction scenario, due to uncertainties in model inputs and aquifer suitability. Therefore, results from this scenario should be considered as indicative only. Actual abstraction rates will vary according to local aquifer transmissivity and individual usage patterns.

The Lower Serpentine regional model is suitable for downscaling or providing boundary conditions for local area models. These models can be used to refine results for individual developments or wetlands. It is recommended that, before developing local area models, the suitability of the conceptual model is assessed at the local scale, and that local data is used to refine the model and its calibration. The Lower Serpentine regional Mike SHE model and associated results and inputs are available in digital format from the Department of Water on request.

Appendices

Appendix A Changes in groundwater levels for all scenarios

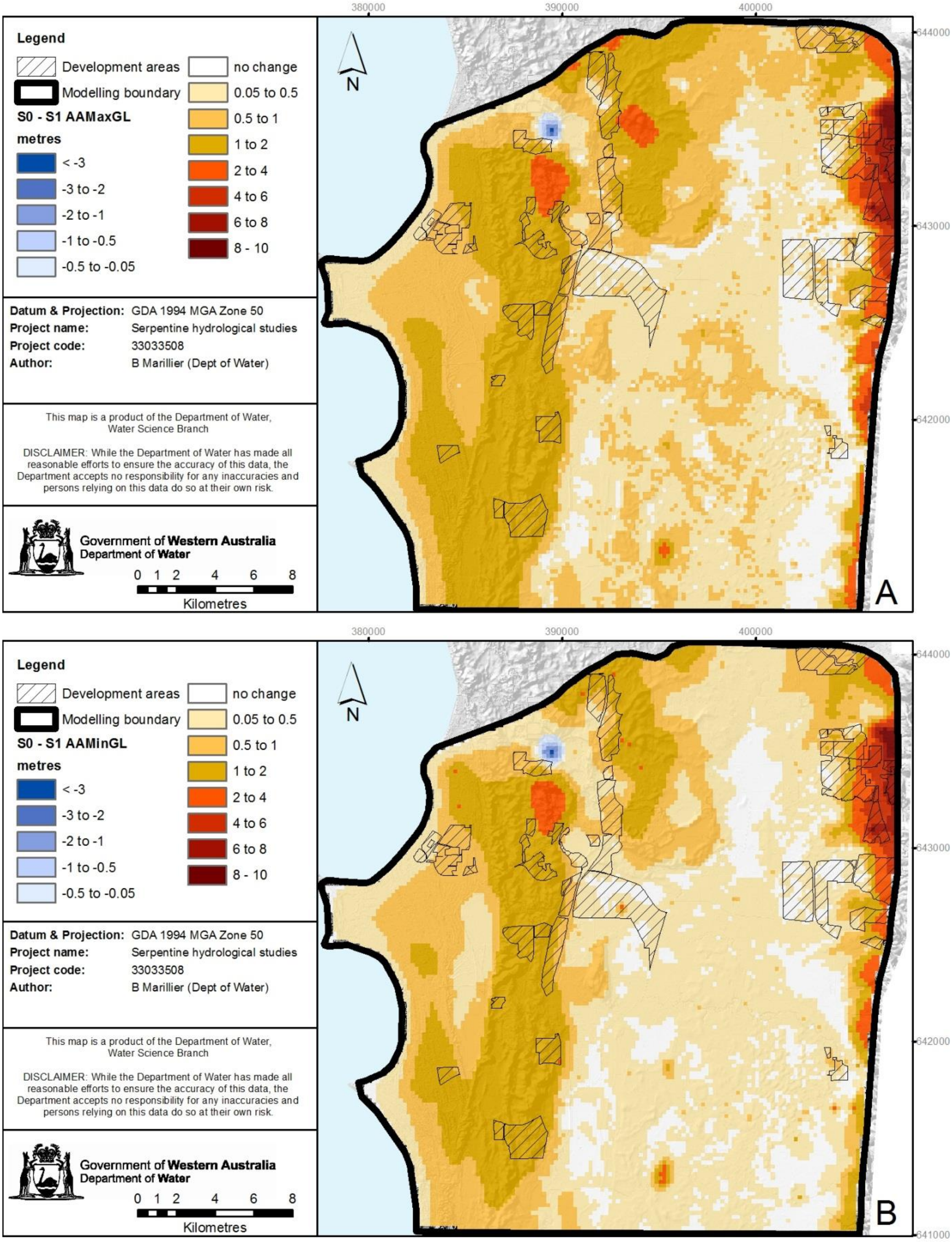


Figure A-1 Difference in AAMaxGL (A) and AAMinGL (B): base-case (S0) subtract future dry climate (S1)

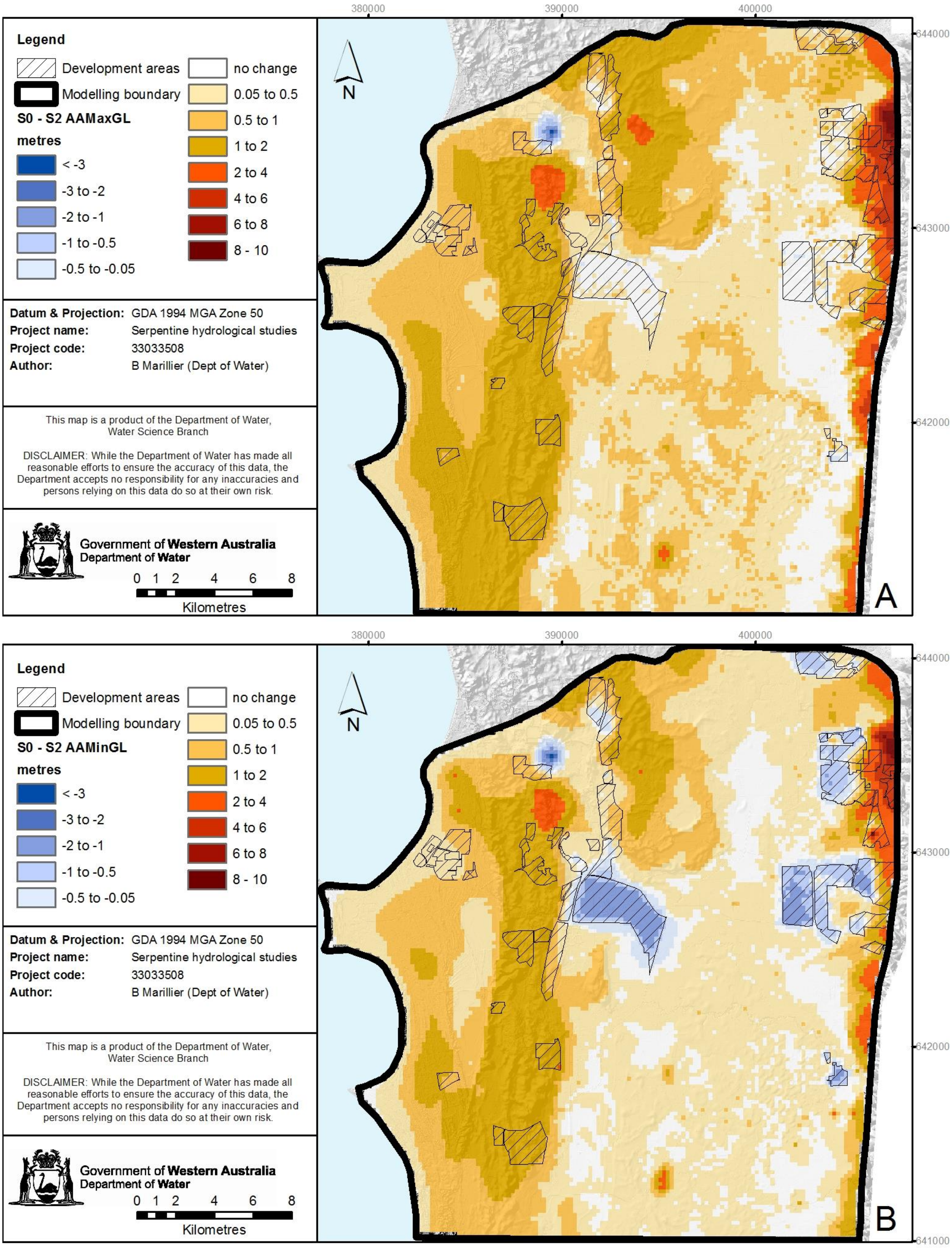


Figure A-2 Difference in AAMaxGL (A) and AAMinGL (B): base-case (S0) subtract future dry climate with development and drainage at AAMaxGL (S2)

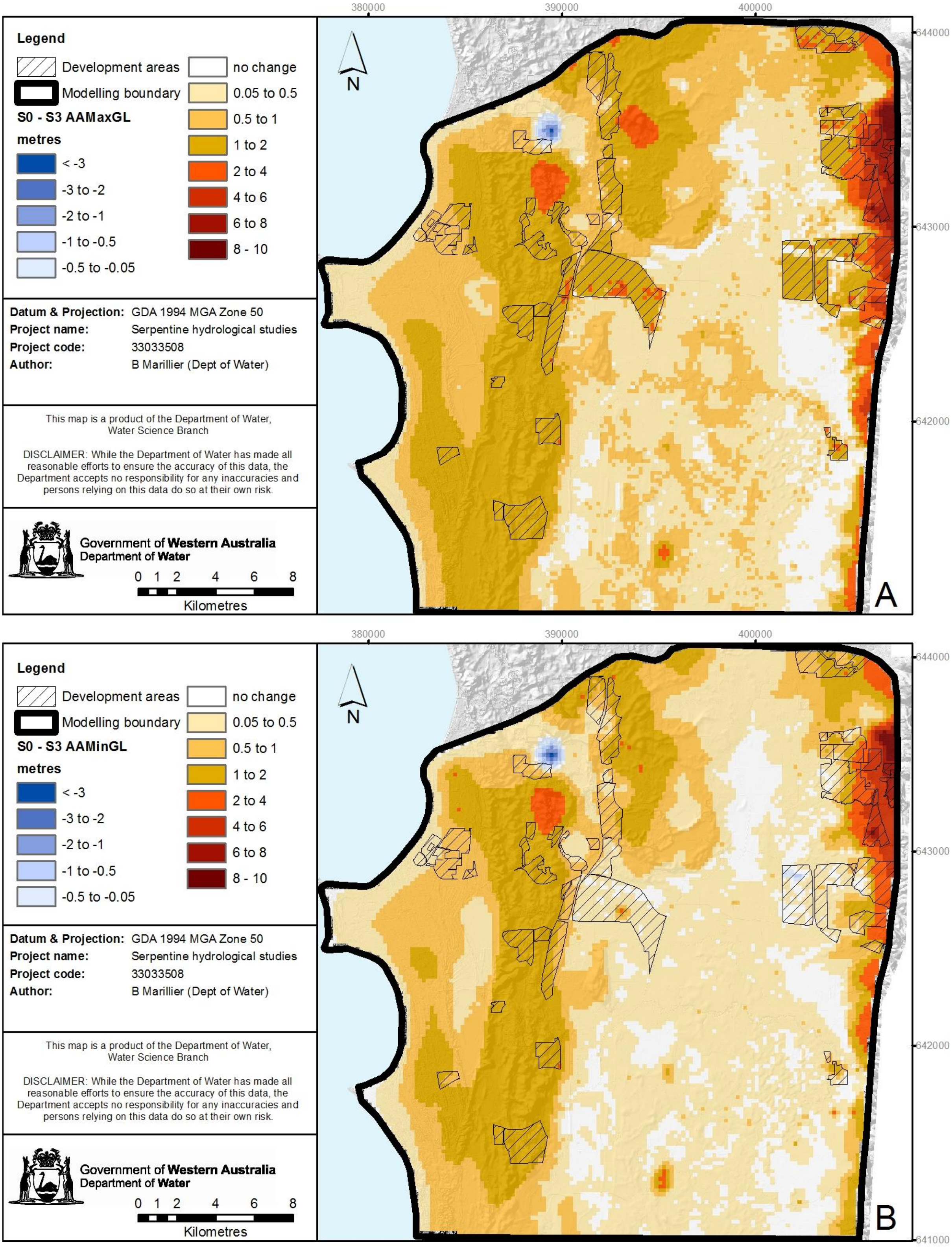


Figure A-3 Difference in AAMaxGL (A) and AAMinGL (B): base-case (S0) subtract future dry climate with development and drainage at AAMinGL (S3)

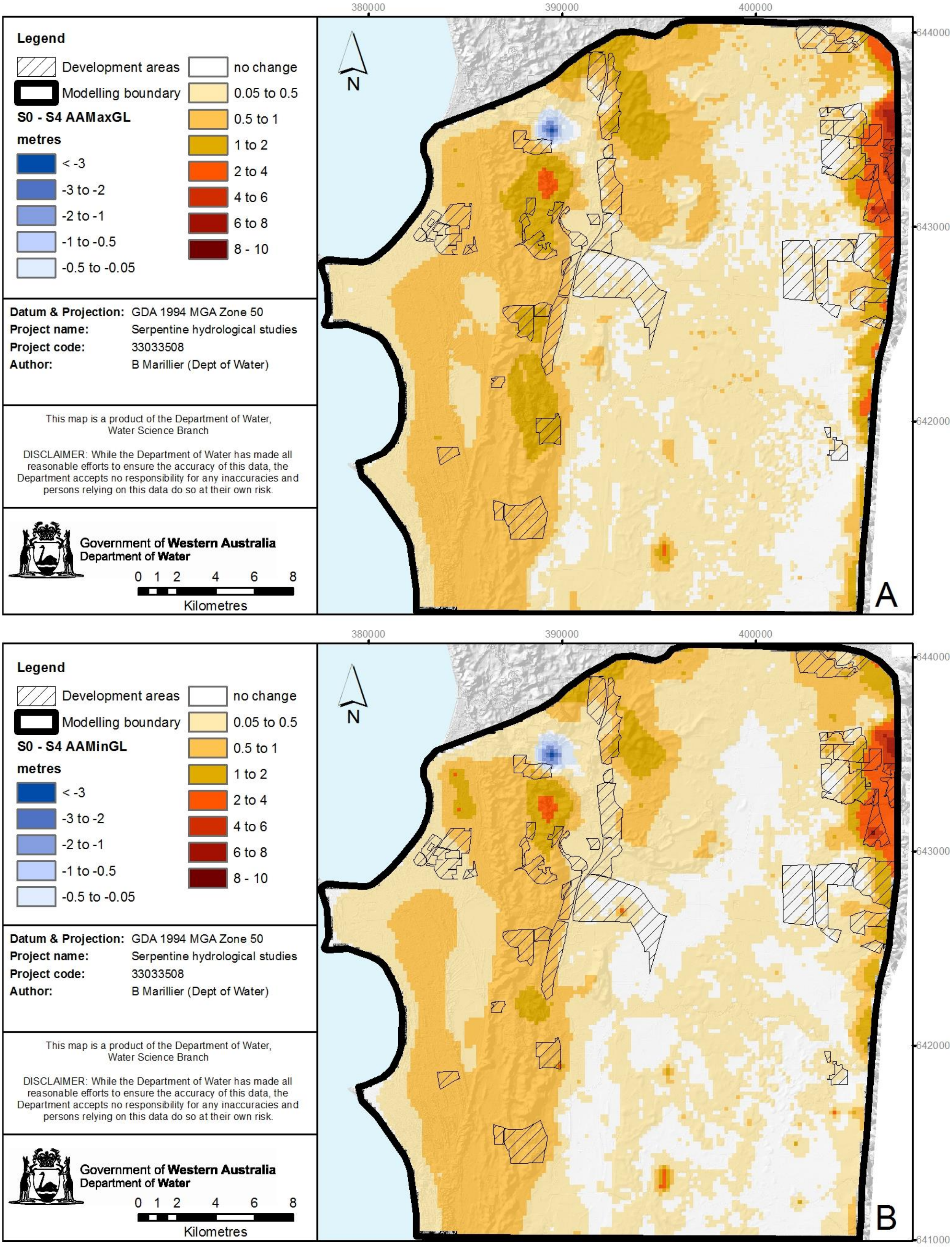


Figure A-4 Difference in AAMaxGL (A) and AAMinGL (B): base-case (S0) subtract future medium climate (S4)

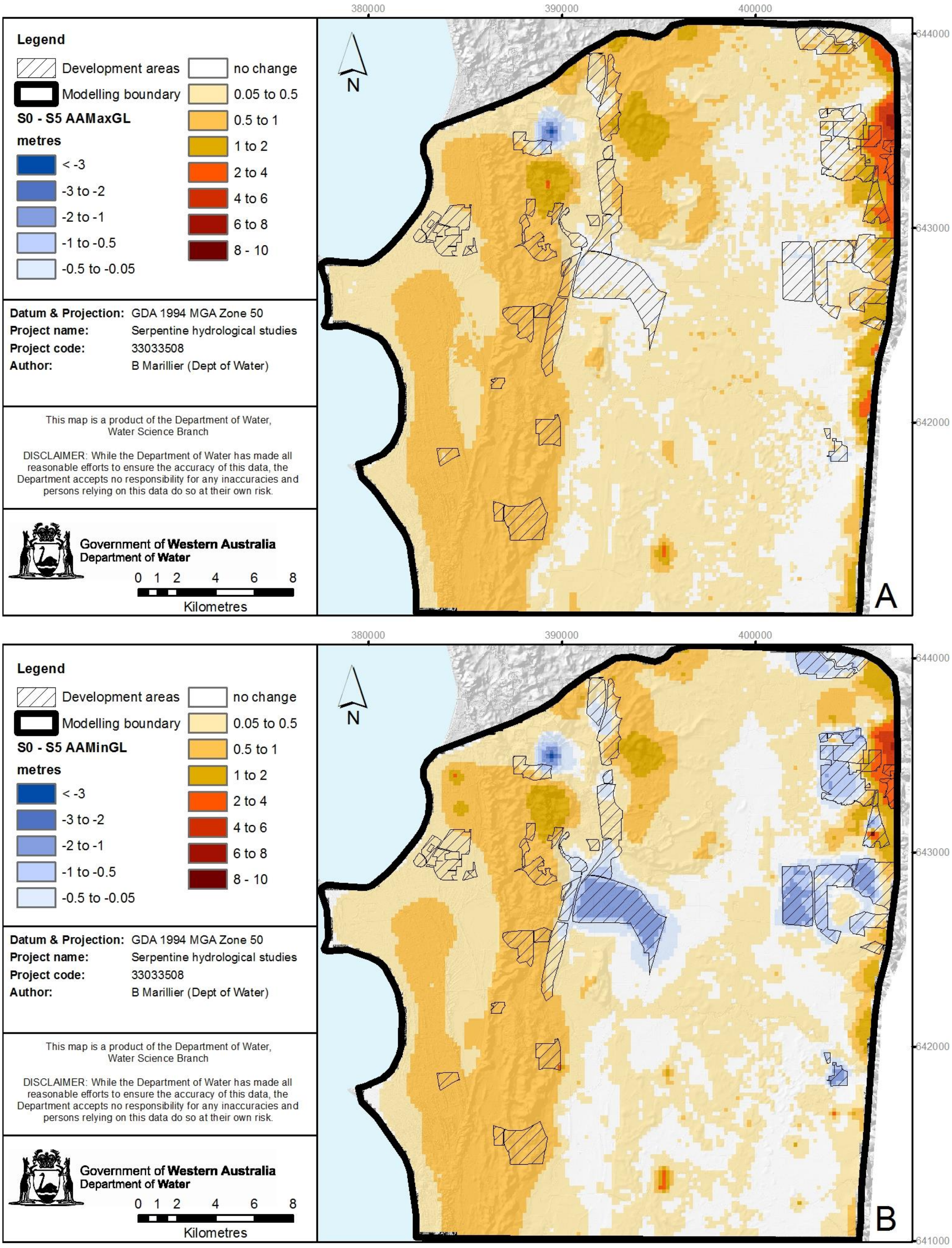


Figure A-5 Difference in AAMaxGL (A) and AAMinGL (B): base-case (S0) subtract future medium climate with development and drains at AAMaxGL (S5)

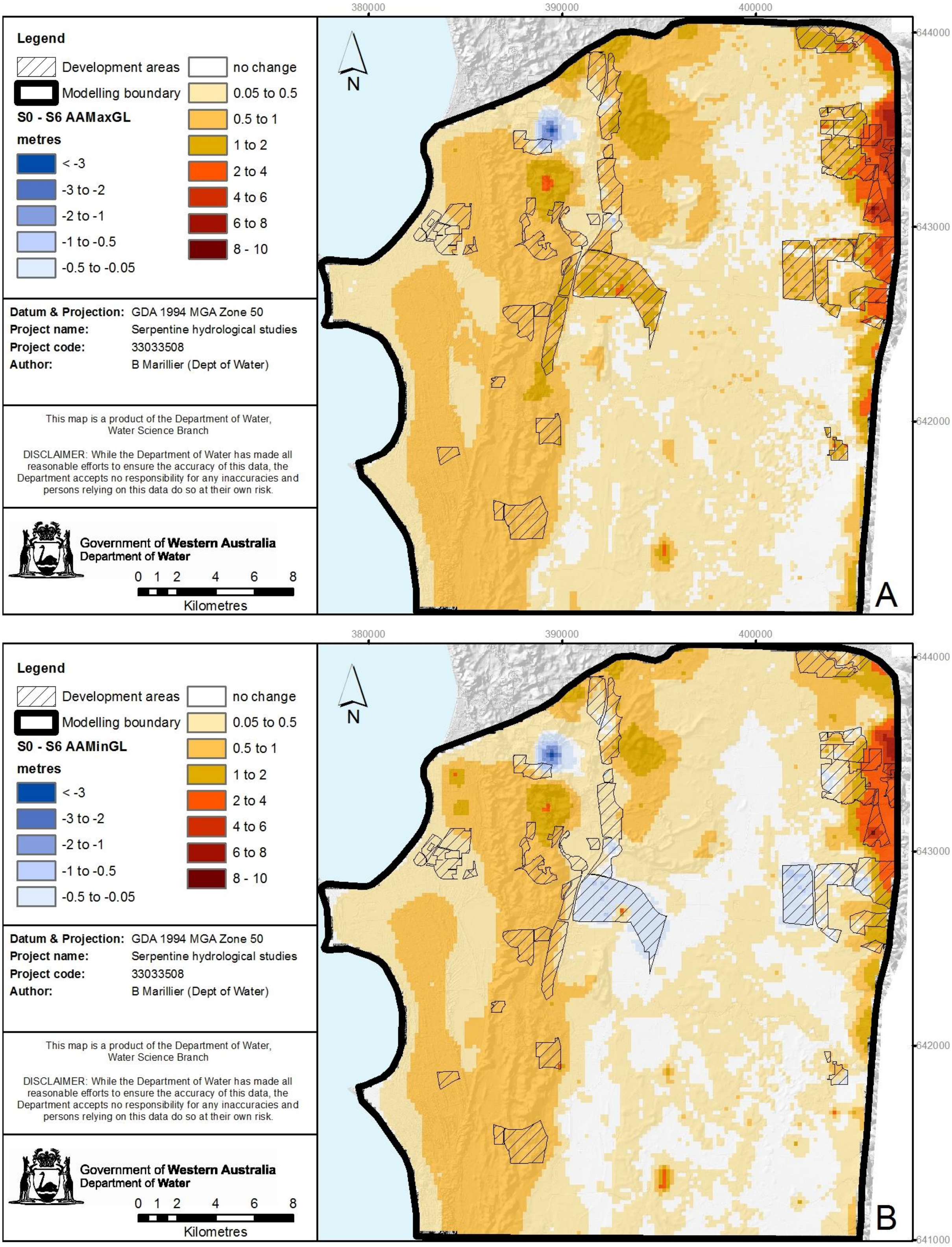


Figure A-6 Difference in AAMaxGL (A) and AAMinGL (B): base-case (S0) subtract future medium climate with development and drains at AAMinGL + 0.5 m (S6)

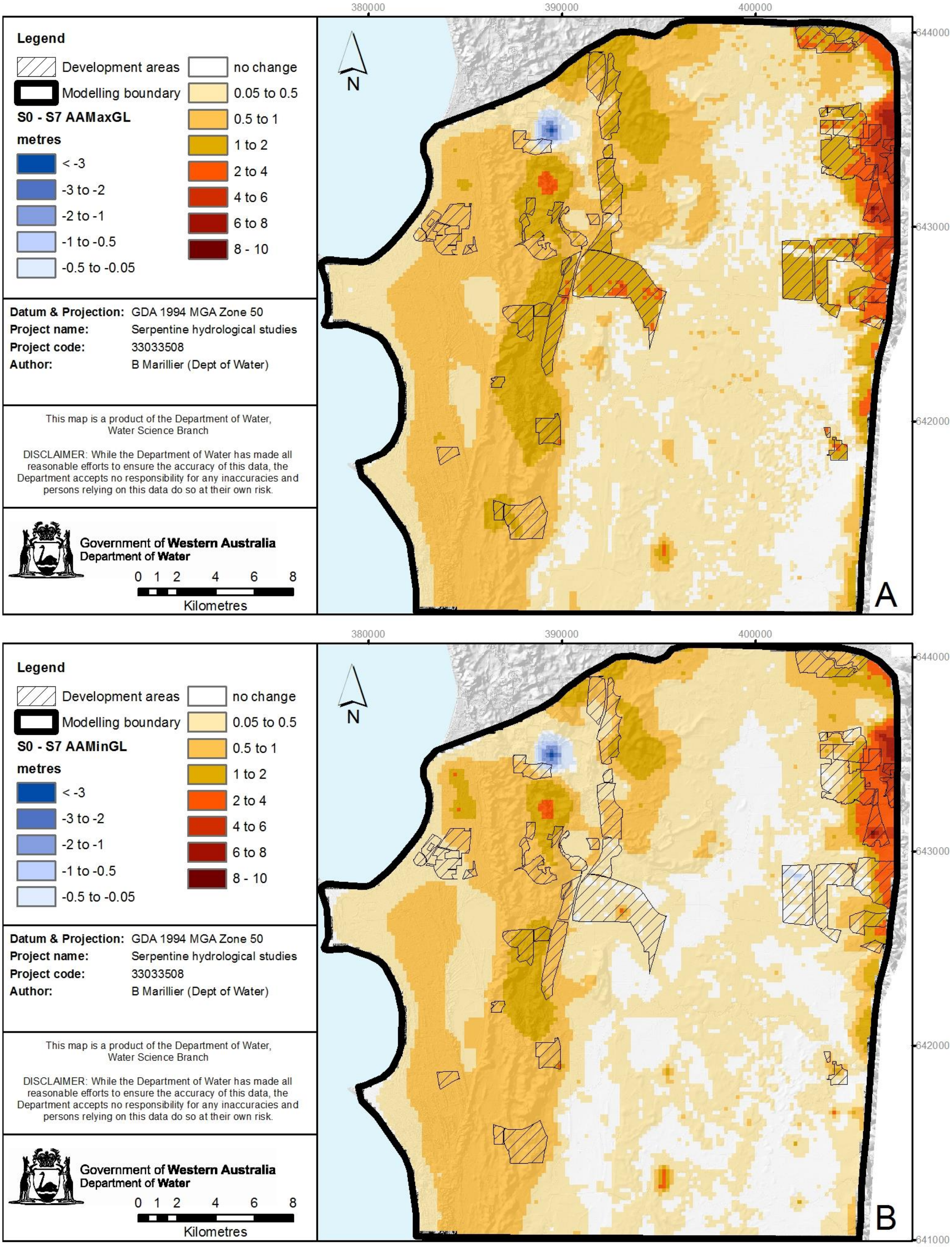
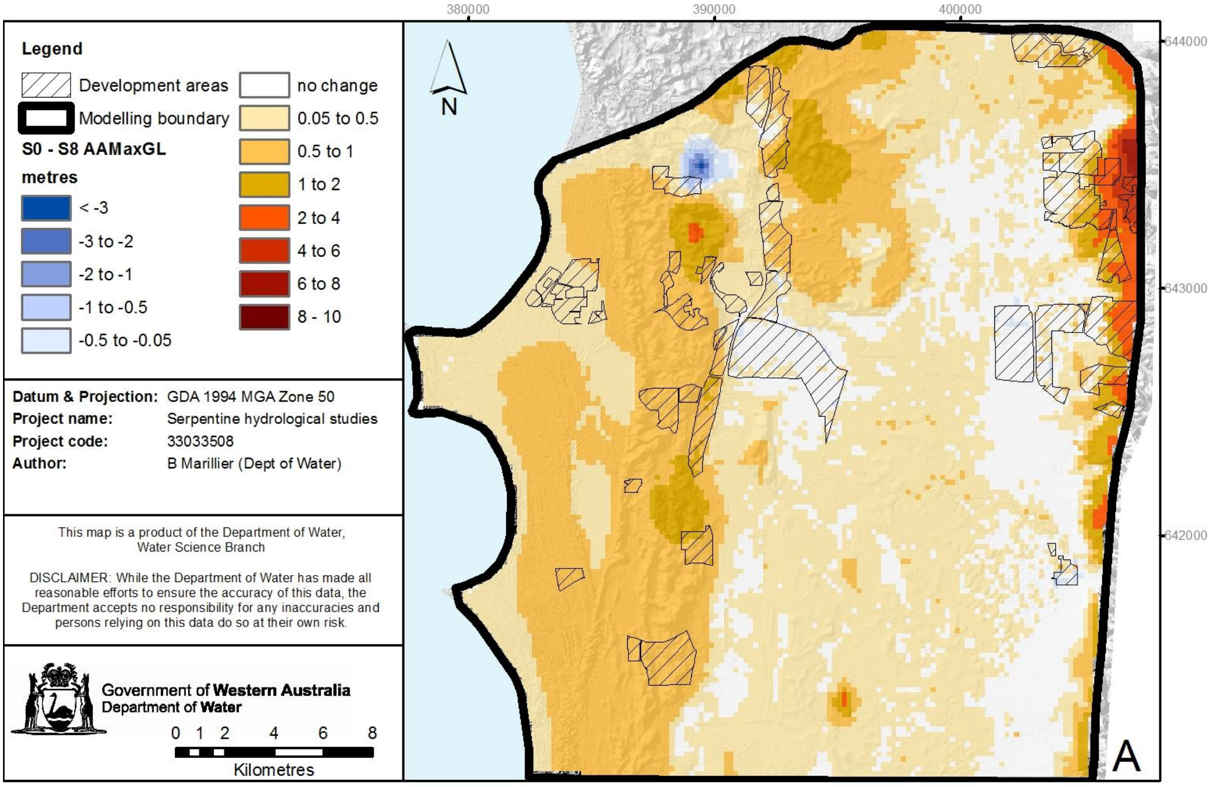


Figure A-7 Difference in AAMaxGL (A) and AAMinGL (B): base-case (S0) subtract future medium climate with development and drains at AAMinGL (S7)



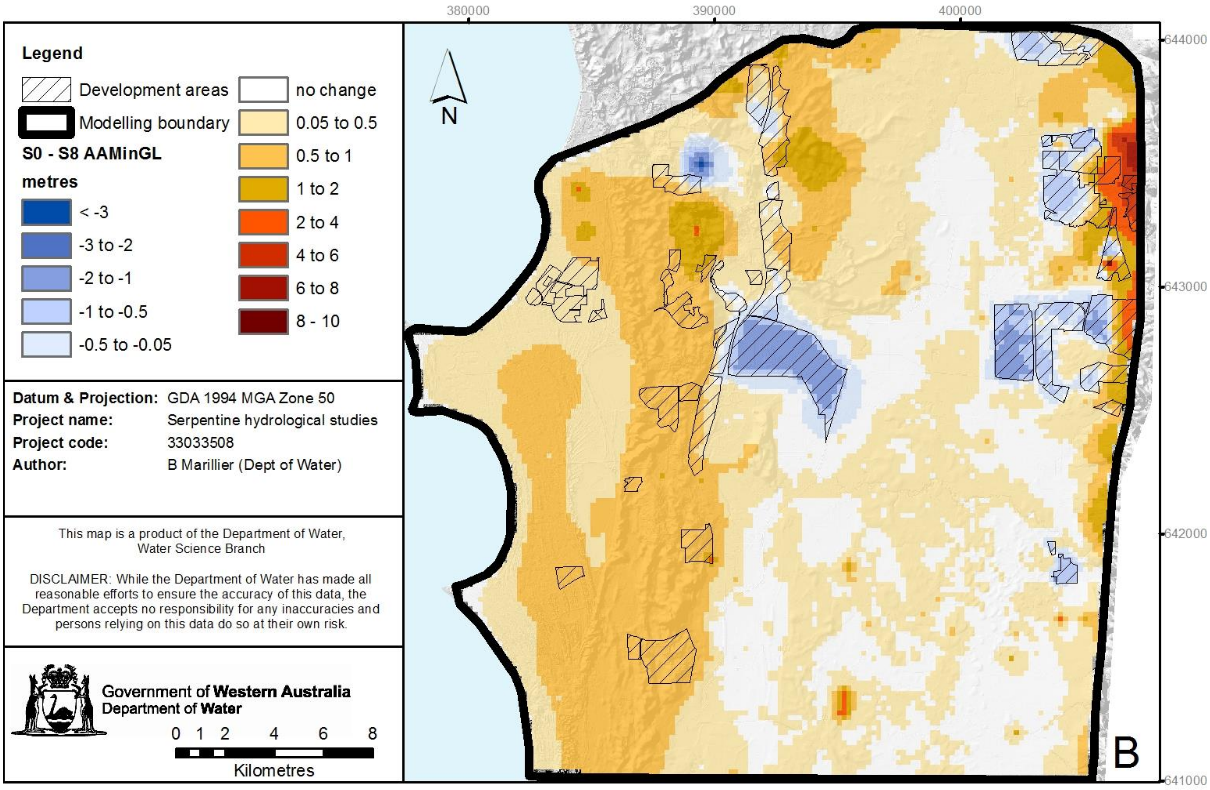


Figure A-8 Difference in AAMaxGL (A) and AAMinGL (B): base-case (S0) subtract future medium climate with development, garden bores and drains at AAMaxGL (S8)

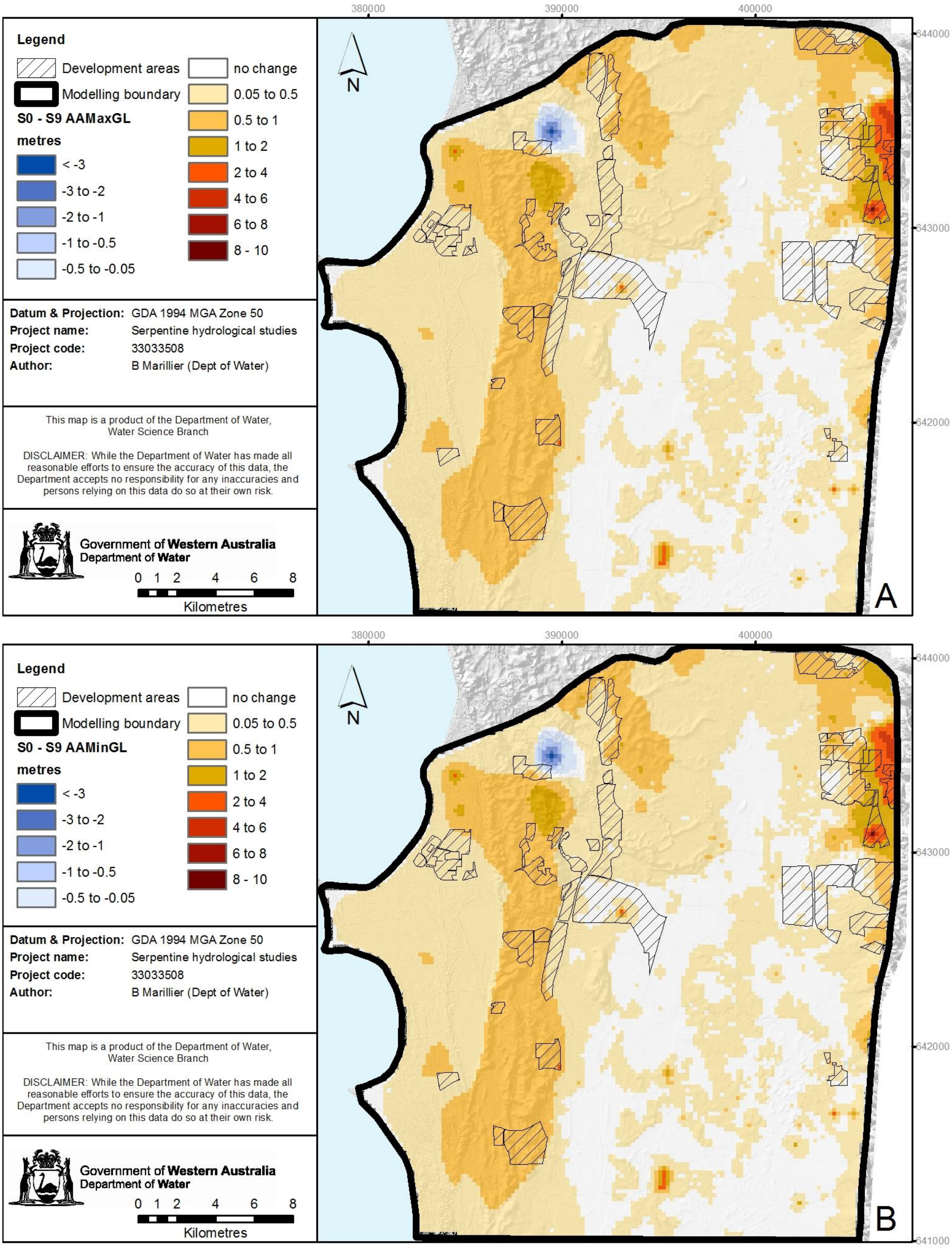


Figure A-9 Difference in AAMaxGL (A) and AAMinGL (B): base-case (S0) subtract future wet climate (S9)

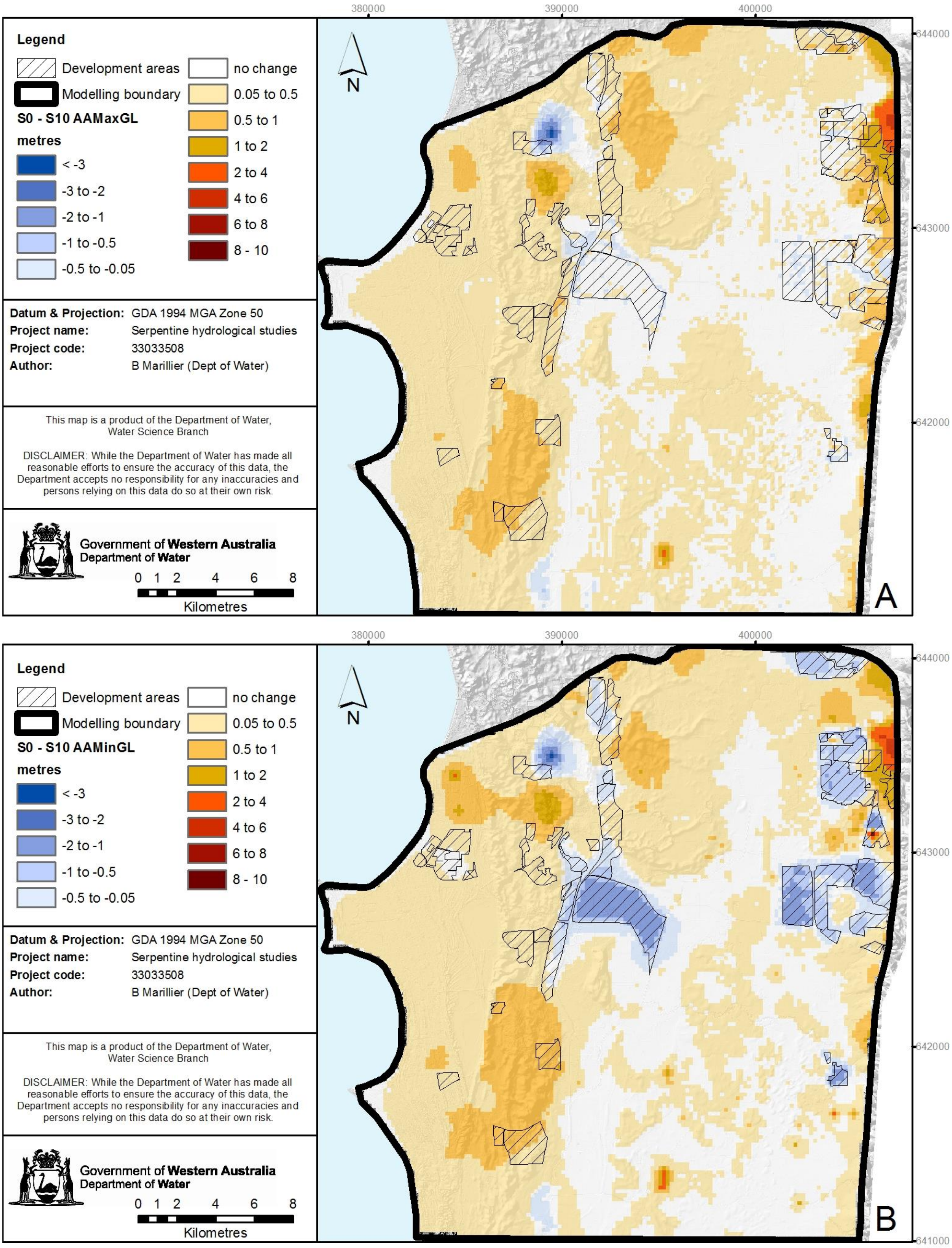


Figure A-10 Difference in AAMaxGL (A) and AAMinGL (B): base-case (S0) subtract future wet climate with development and drains at AAMaxGL (S10)

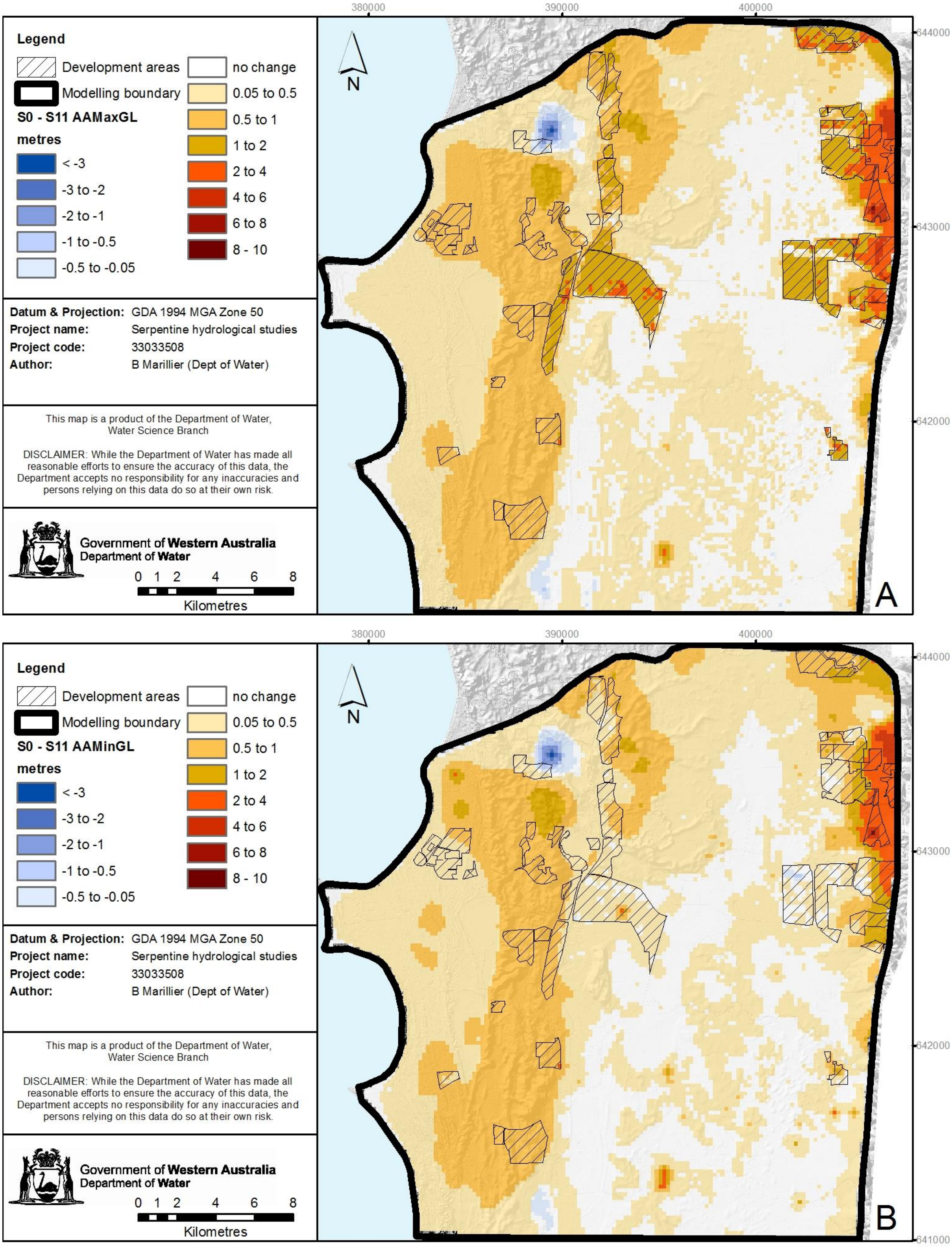


Figure A-11 Difference in AAMaxGL (A) and AAMinGL (B): base-case (S0) subtract future wet climate with development and drains at AAMinGL (S11)

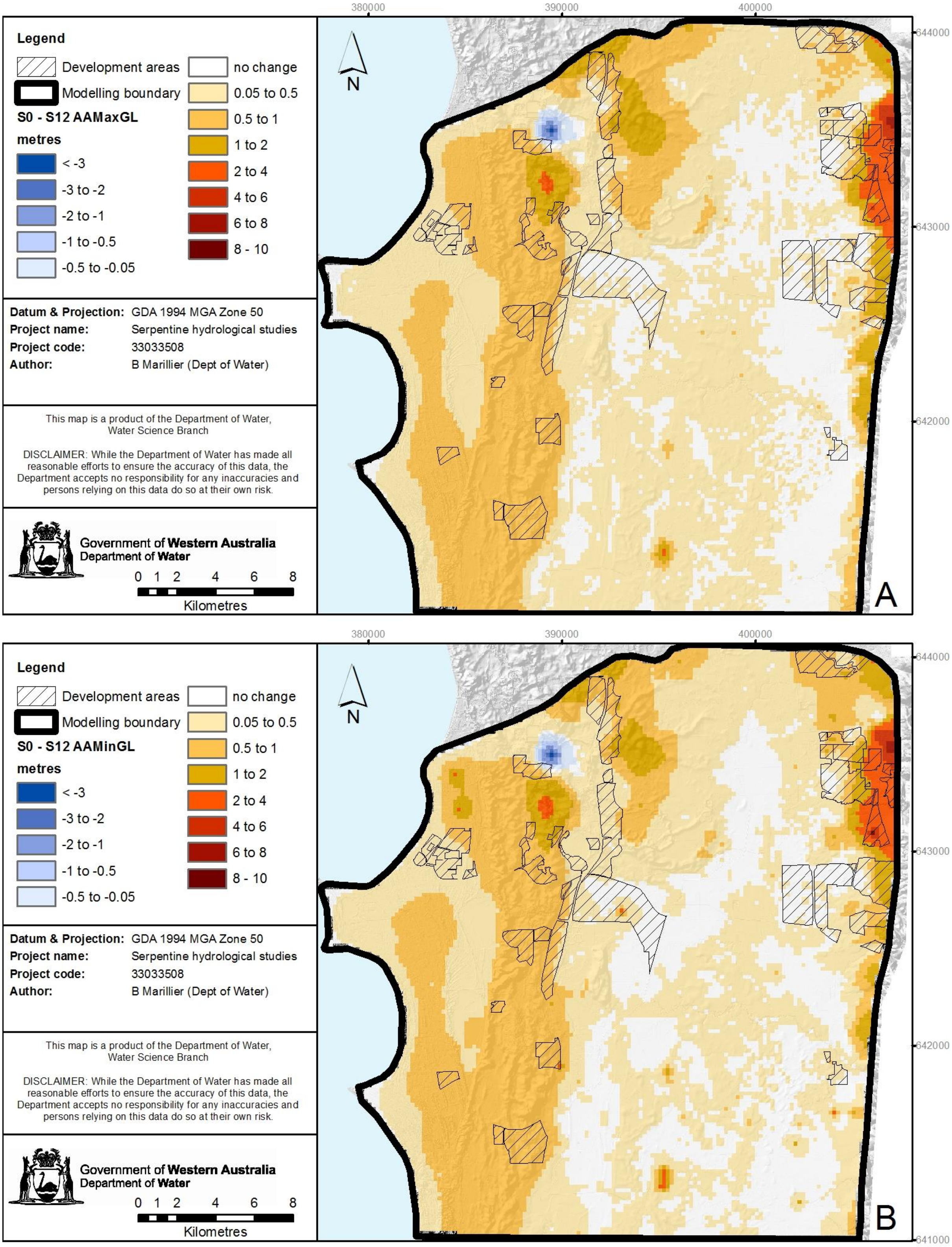


Figure A-12 Difference in AAMaxGL (A) and AAMinGL (B): base-case (S0) subtract medium climate with two wet years (S12)

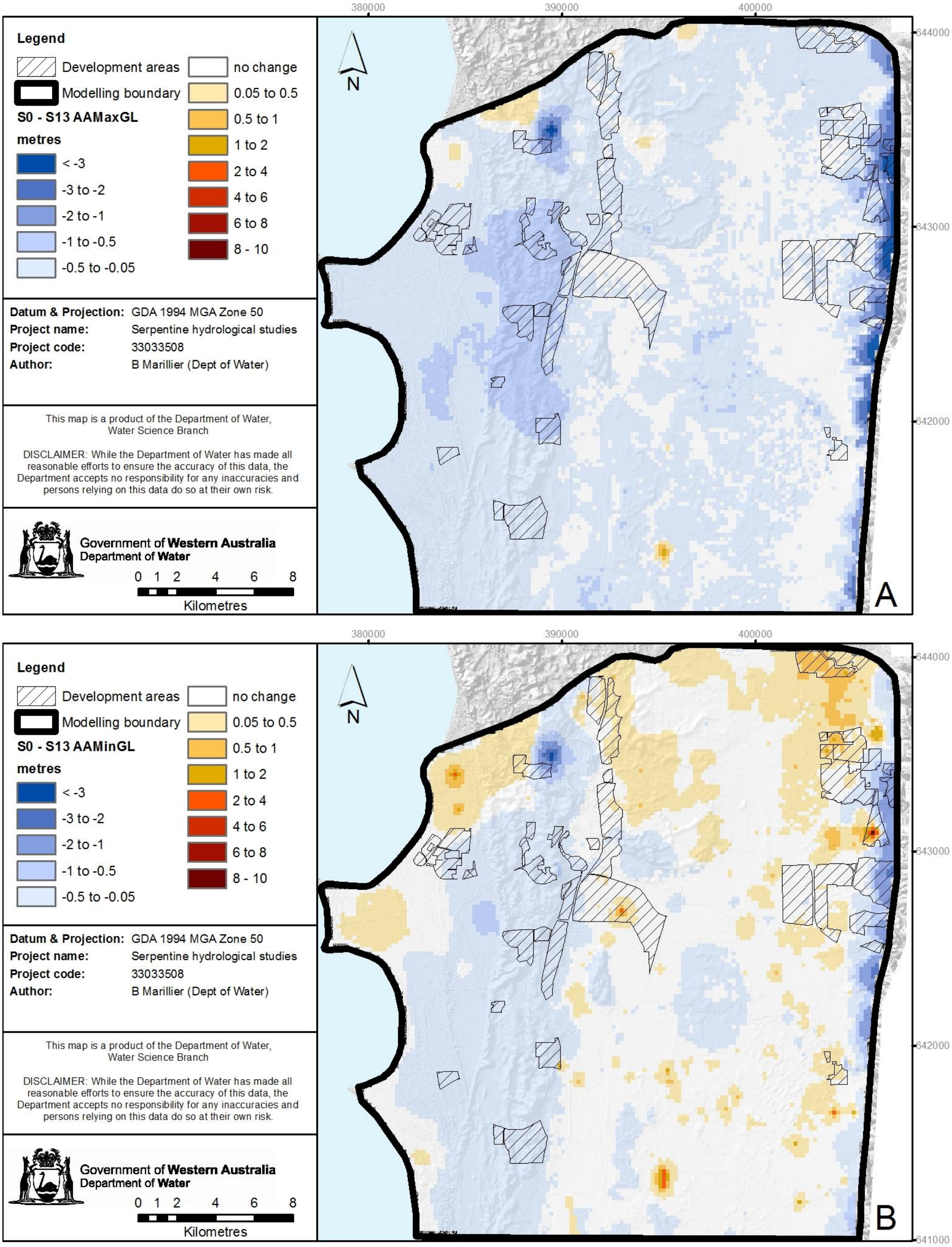
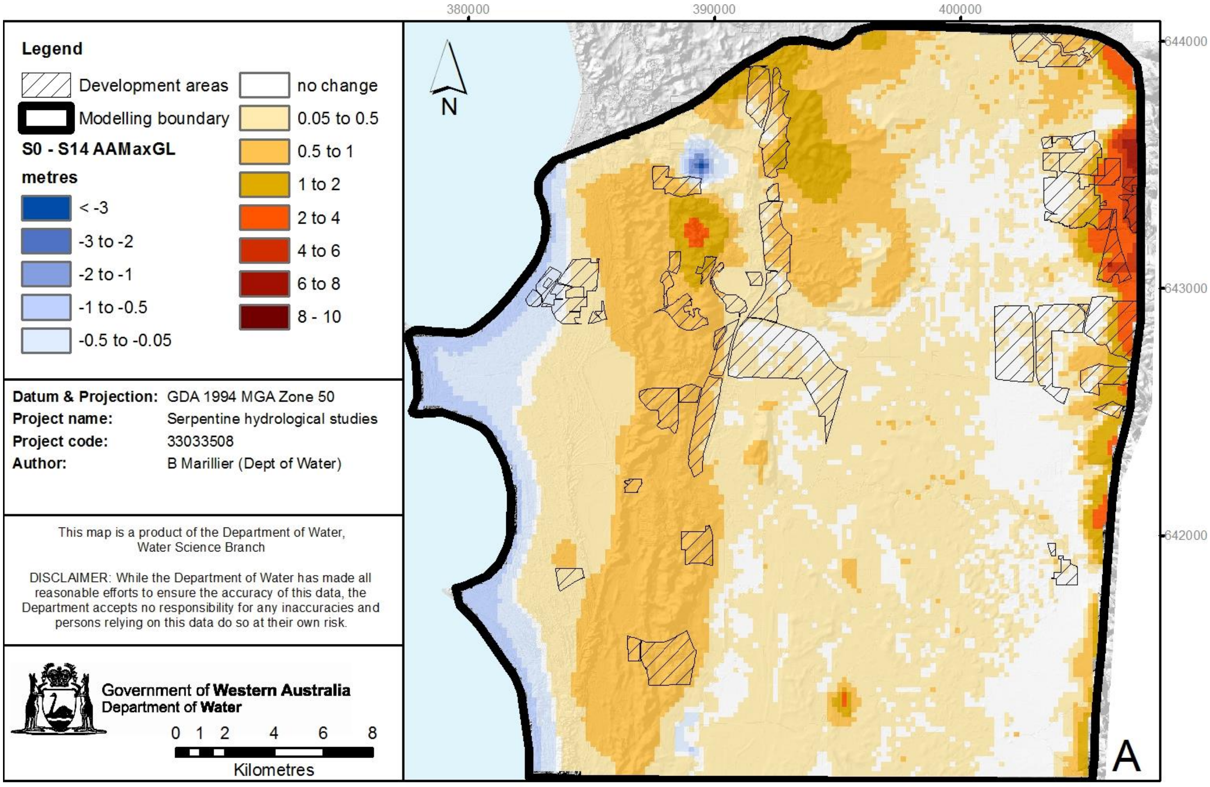


Figure A-13 Difference in AAMaxGL (A) and AAMinGL (B): base-case (S0) subtract historical wet climate (S13)



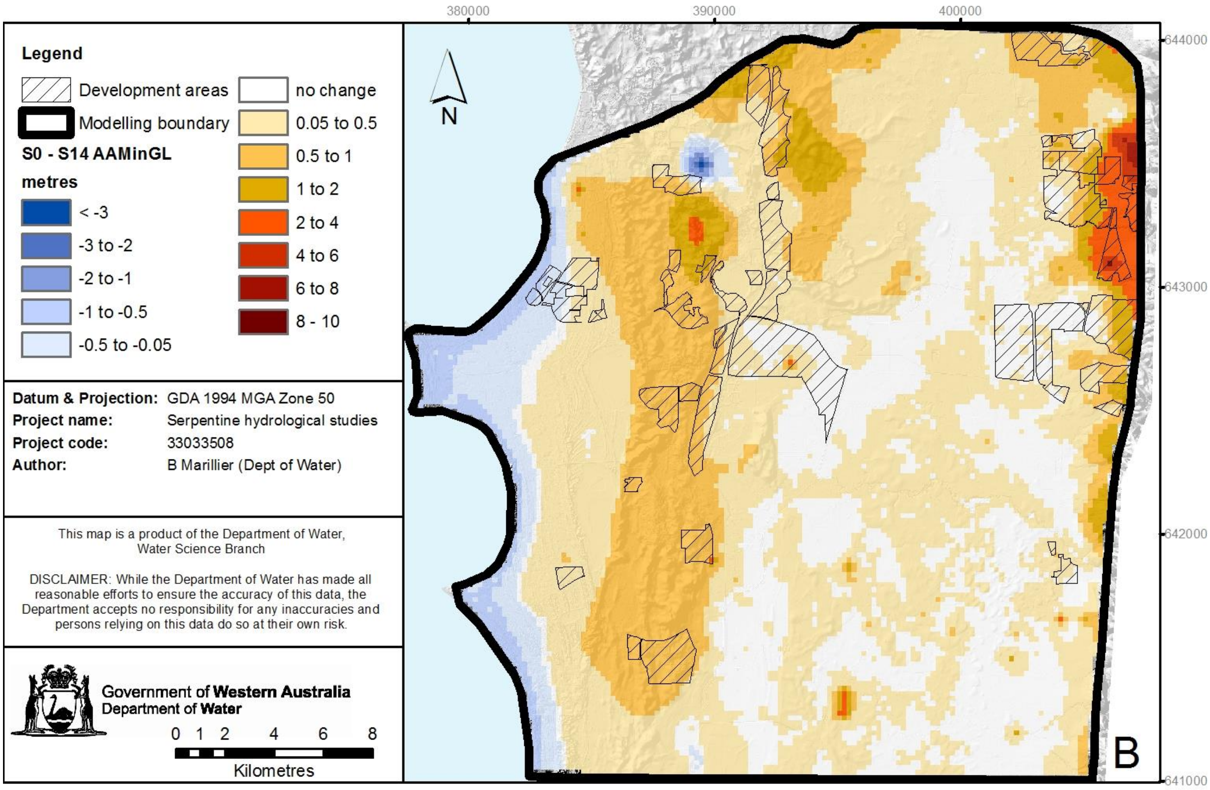


Figure A-14 Difference in AAMaxGL (A) and AAMinGL (B): base-case (S0) subtract medium climate with sea-level-rise (S14)

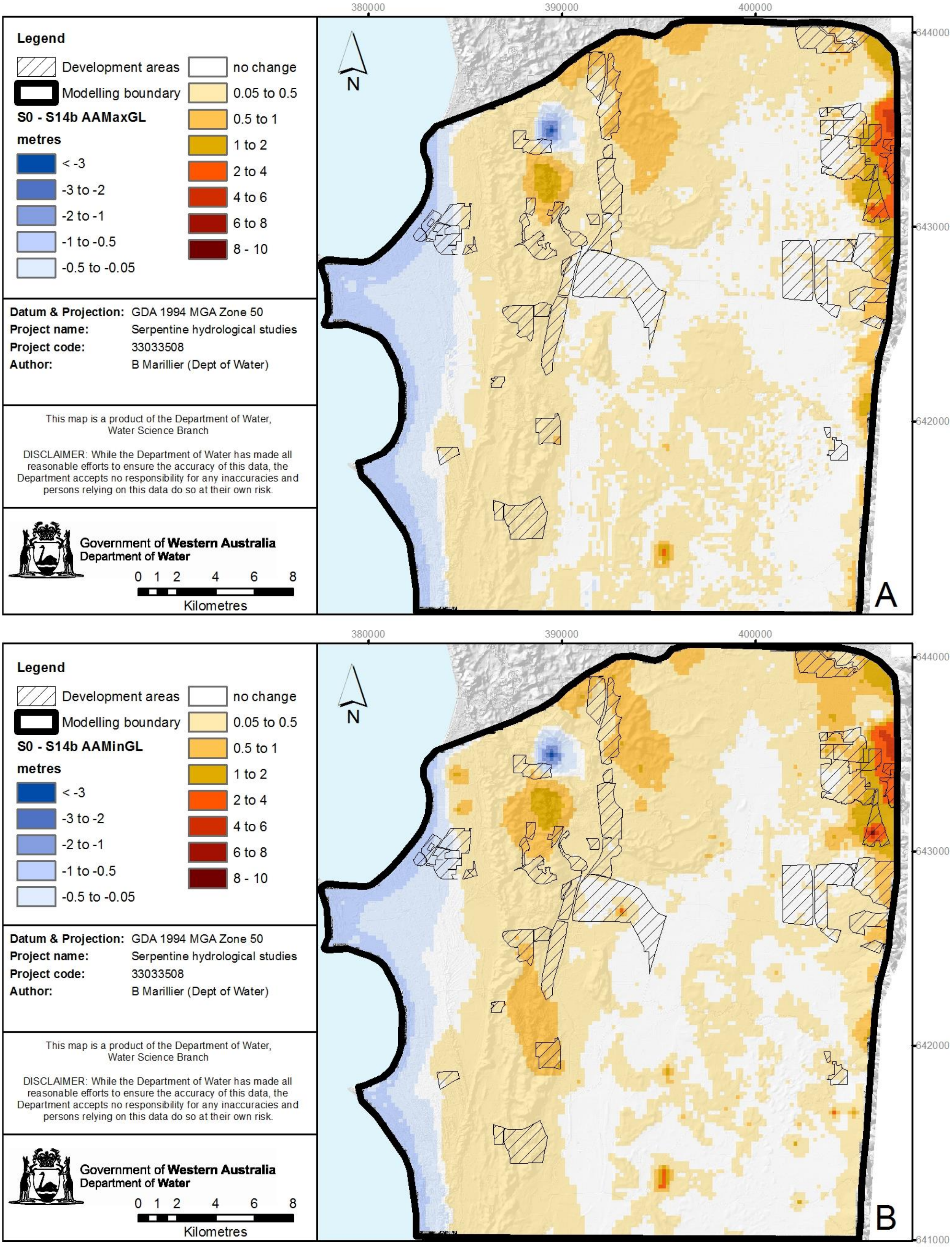


Figure A-15 Difference in AAMaxGL (A) and AAMinGL (B): base-case (S0) subtract wet climate with sea-level-rise (S14b)

Appendix B Waterlogging analysis for climate scenarios

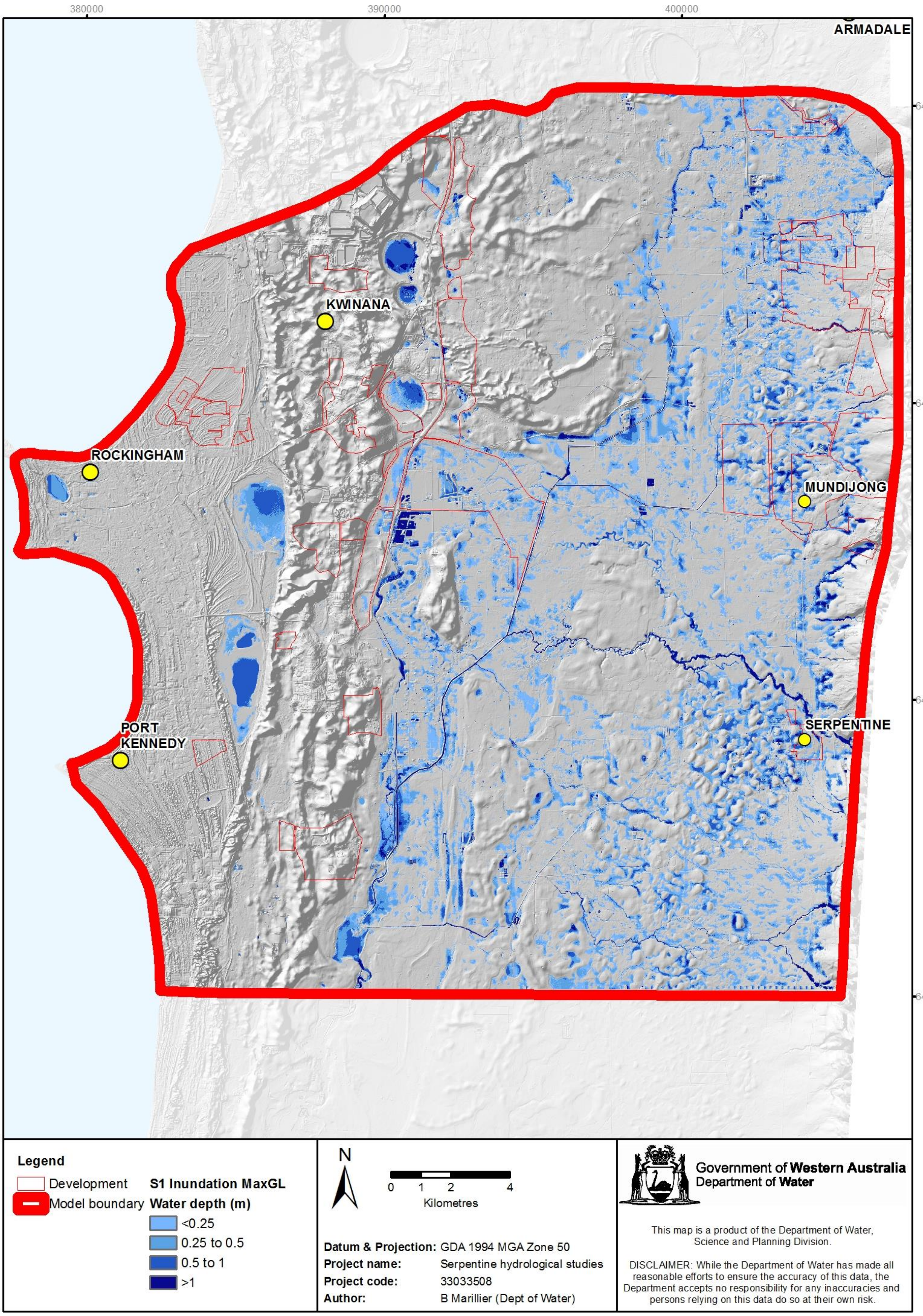


Figure B-1 Extent of inundation at MaxGL with dry climate (S1)

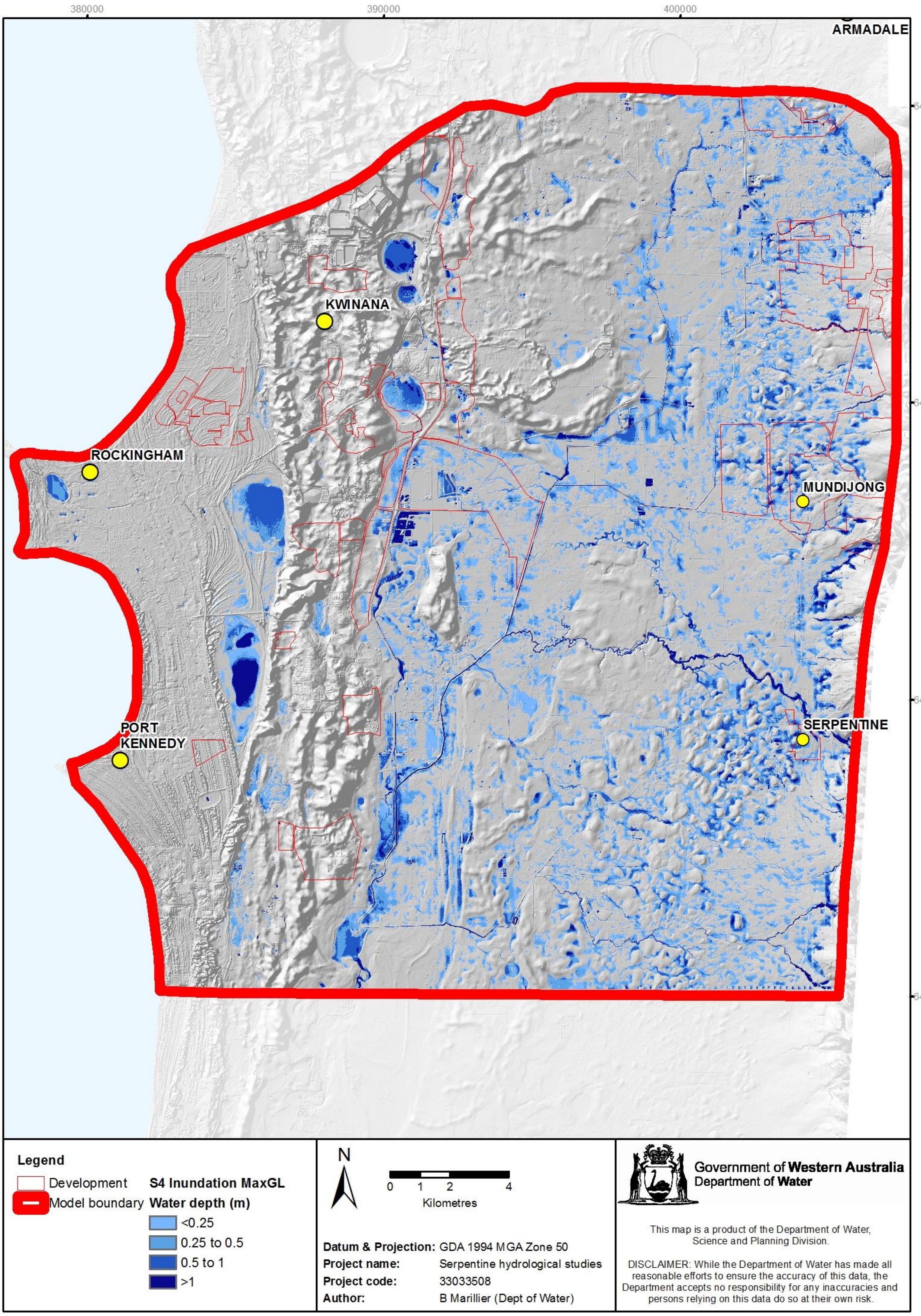


Figure B-2 Extent of inundation at MaxGL with medium climate (S4)

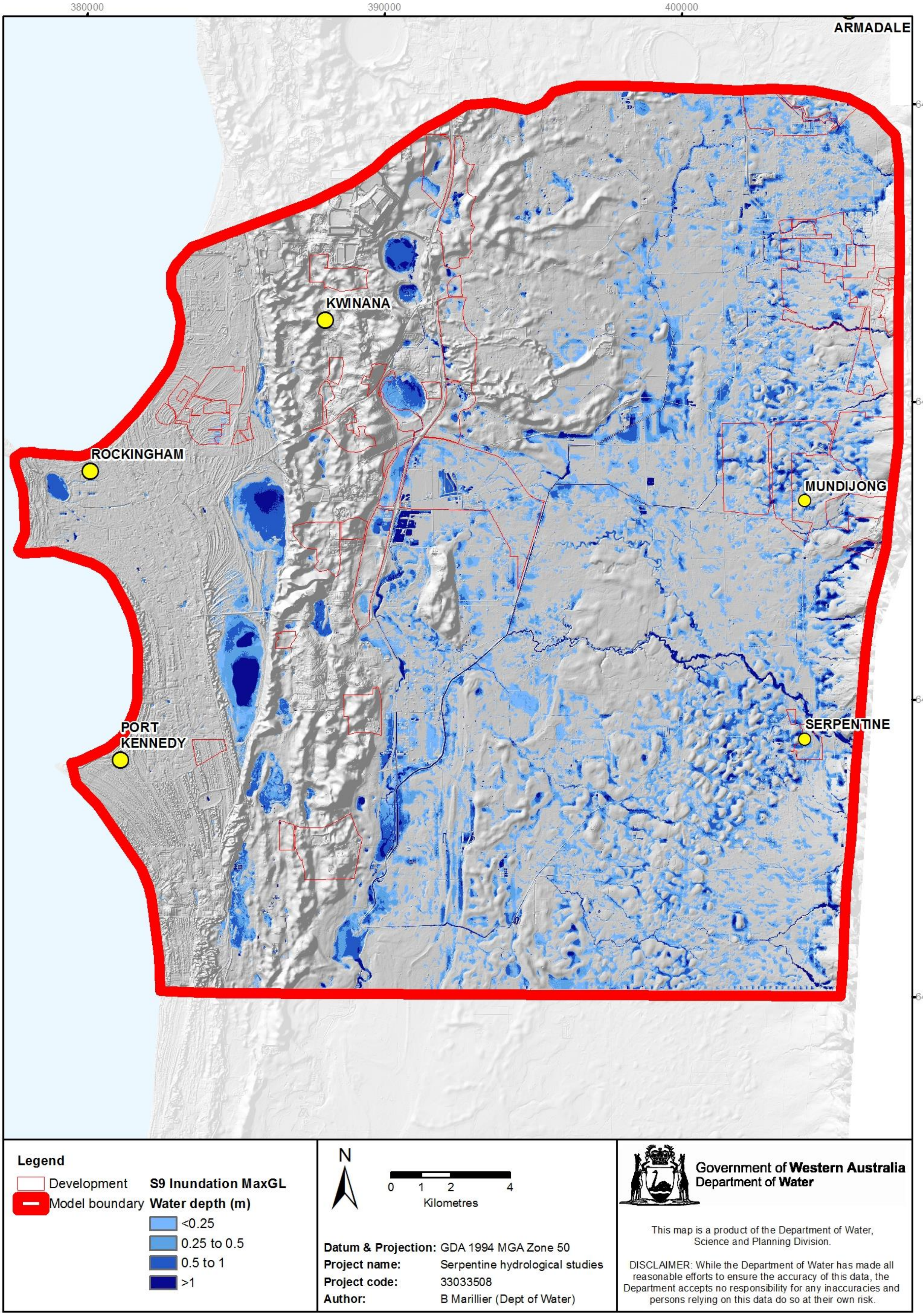


Figure B-3 Extent of inundation at MaxGL with wet climate (S9)

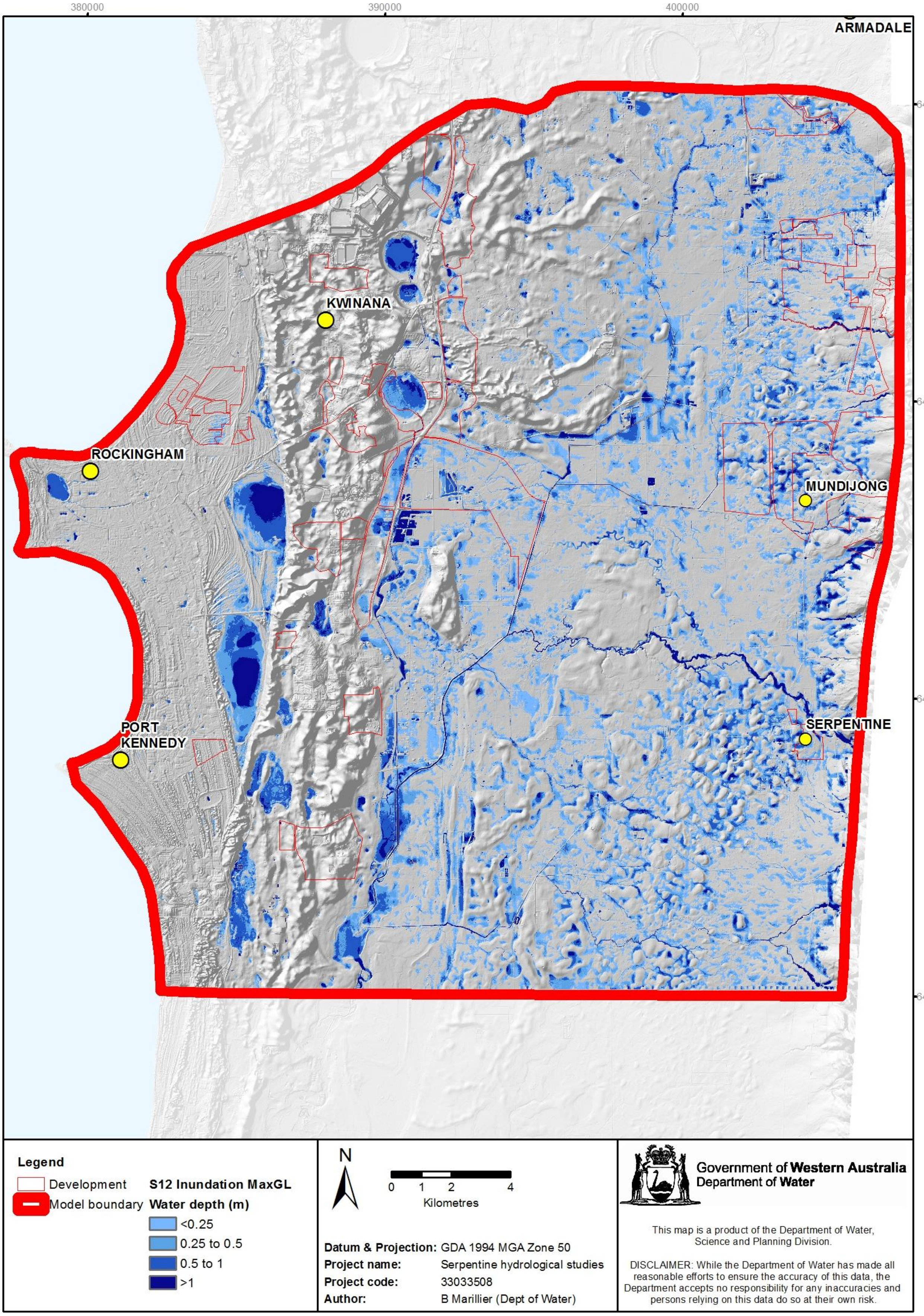


Figure B-4 Extent of inundation at MaxGL with medium climate and two wet year (S12)

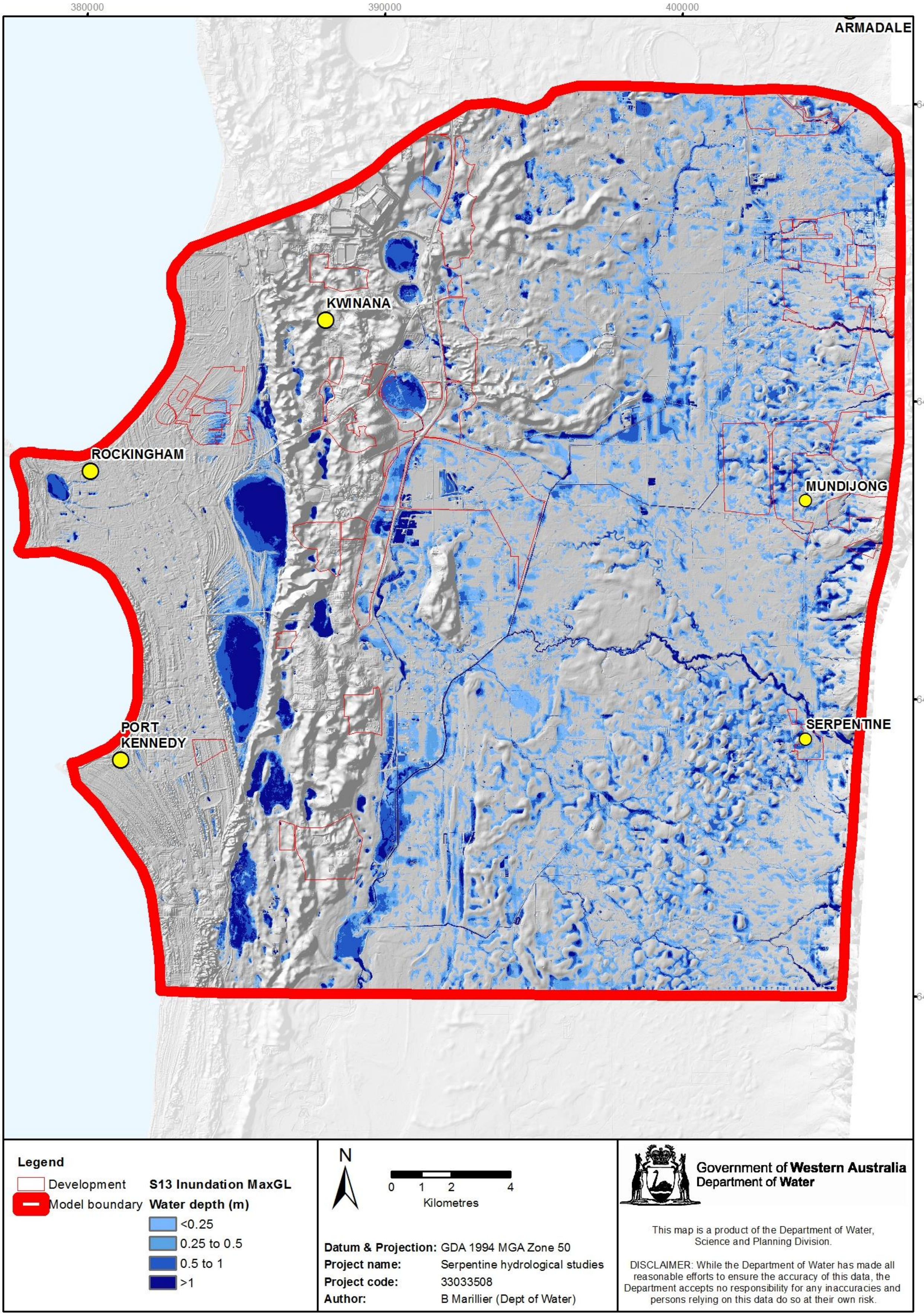


Figure B-5 Extent of inundation at MaxGL with historical wet climate (S13)

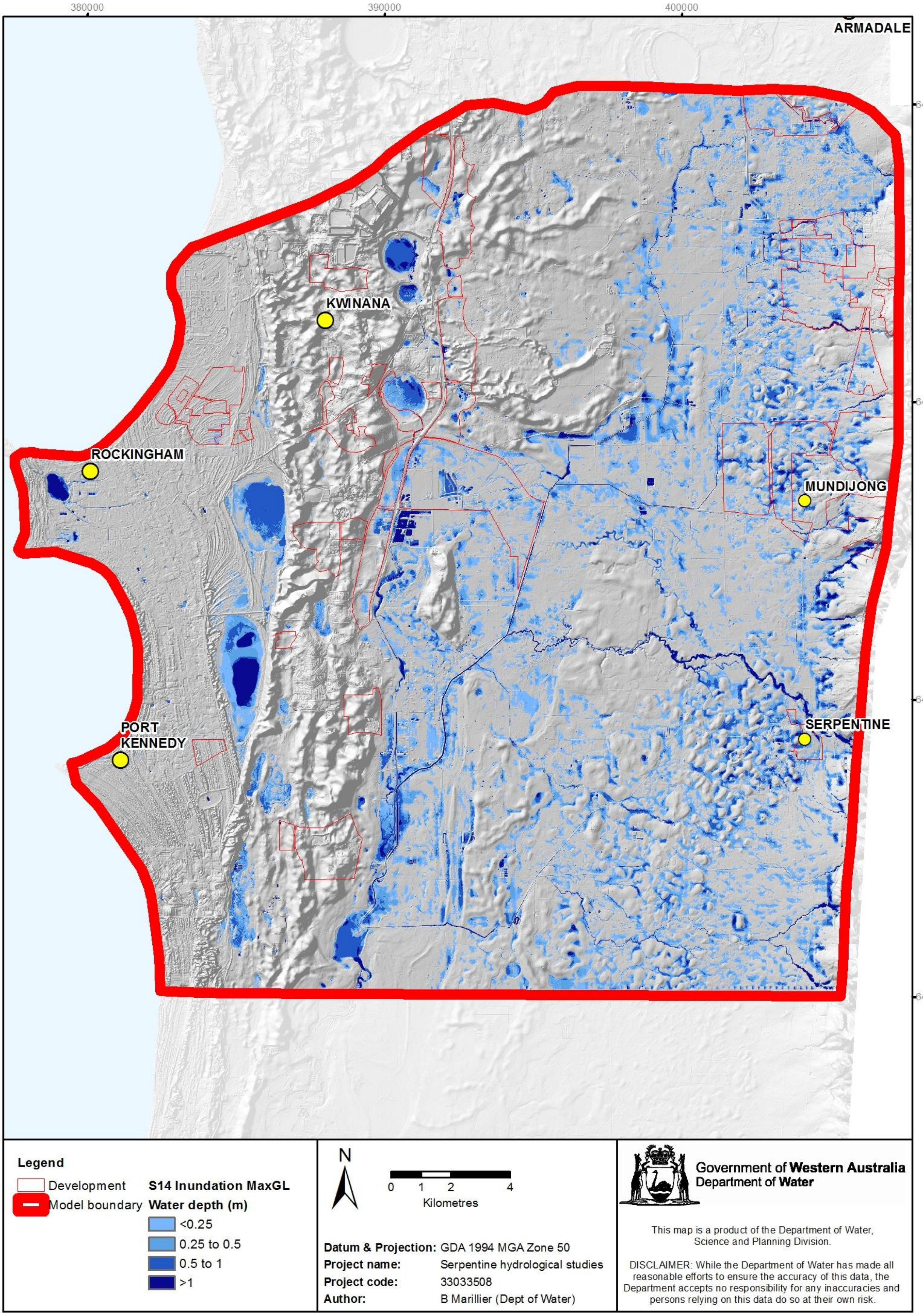


Figure B-6 Extent of inundation at MaxGL with sea-level-rise and medium climate (S14)

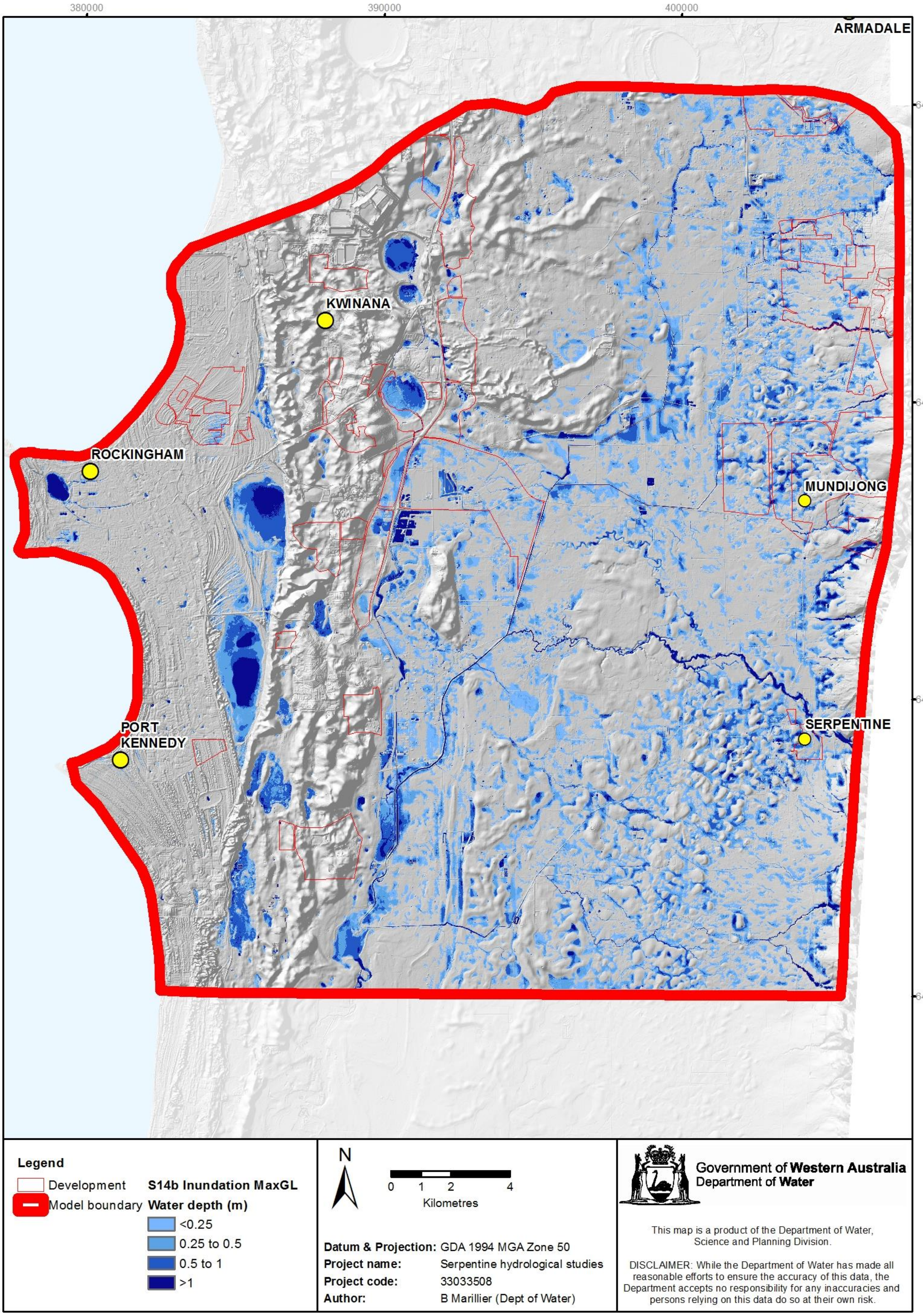


Figure B-7 Extent of inundation at MaxGL with sea-level-rise and wet climate (S14b)

Appendix C Scenario water balances

Average annual water balances calculated for the model area

Development	Area	Flux	Average annual flux quantity (mm/yr)														
			S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Full catchment	727.6	Precipitation	800	682	682	682	759	759	759	759	759	800	800	800	782	887	759
		Evapotranspiration	644	564	556	551	613	604	602	597	602	632	622	612	611	632	619
		Gross recharge	272	189	197	197	231	239	238	239	239	262	270	271	256	364	229
		EVT from SZ	125	75	74	69	92	90	86	83	88	103	100	90	96	131	96
		Hor. SZ flow out	12	5	6	5	7	8	8	7	8	9	9	8	8	13	6
		Hor. SZ flow in	0	1	1	1	1	1	1	1	1	1	0	1	1	0	1
		Ver. SZ flow out	42	36	36	36	40	41	41	40	41	44	45	43	42	54	38
		Ver. SZ flow in	11	7	7	7	7	7	7	7	7	7	8	8	8	10	10
		Abstraction	26	43	43	43	43	43	43	43	48	43	43	43	43	43	43
		OL flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		OL flow out	1	0	0	0	1	1	1	1	1	1	1	1	1	3	1
		Drainage (total)	74	32	39	45	49	56	61	67	55	62	73	87	60	116	49
		Base flow to River	11	7	8	7	9	9	9	9	9	10	10	9	9	13	9
		Irrigation	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Development	Area	Flux	Average annual flux quantity (GL/yr)														
			S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Full catchment	727.6	Precipitation	582	496	496	496	552	552	552	552	552	582	582	582	569	645	552
		Evapotranspiration	468	410	404	401	446	440	438	435	438	460	453	446	445	460	451
		Gross recharge	198	138	143	143	168	174	173	174	174	190	196	197	186	265	167
		EVT from SZ	91	55	54	50	67	65	62	60	64	75	72	66	70	95	70
		Hor. SZ flow out	9	4	4	4	5	6	5	5	6	6	7	6	6	10	5
		Hor. SZ flow in	0	1	1	1	1	0	1	1	0	0	0	0	1	0	1
		Ver. SZ flow out	30	26	26	26	29	30	30	29	30	32	32	32	30	40	27
		Ver. SZ flow in	8	5	5	5	5	5	5	5	5	6	6	6	6	7	7
		Abstraction	19	31	31	31	31	31	31	31	35	31	31	31	31	31	31
		OL flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		OL flow out	1	0	0	0	1	0	0	0	0	1	1	1	1	2	1
		Drainage (total)	54	23	28	33	35	41	44	49	40	45	53	63	44	85	35
		Base flow to River	8	5	6	5	7	7	6	6	7	7	7	6	7	9	7
		Irrigation	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Average annual water balances calculated for each development area (mm/yr)

Development	Area (km^2)	Flux	Average annual flux quantity (mm)														
			S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Armadale	4.5	Precipitation	781	663	663	663	741	741	741	741	741	779	779	779	764	903	741
		Evapotranspiration	618	496	422	432	556	475	486	464	453	573	493	466	556	584	556
		Gross recharge	203	180	256	231	206	291	270	282	305	222	319	322	221	291	206
		EVT from SZ	125	31	12	1	50	19	10	1	11	62	23	1	57	104	50
		Hor. SZ flow out	67	53	101	41	58	111	47	41	92	61	116	39	59	70	58
		Hor. SZ flow in	103	85	58	138	92	64	141	171	73	96	68	193	94	112	92
		Ver. SZ flow out	48	109	118	104	111	119	107	104	117	111	119	104	111	113	111
		Ver. SZ flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Abstraction	42	70	70	70	70	70	70	70	136	70	70	70	70	70	70
		OL flow in	75	11	3	5	20	6	9	7	6	38	11	14	38	153	20
		OL flow out	160	29	0	5	50	0	4	3	0	84	0	7	82	286	50
		Drainage (total)	28	5	17	156	10	37	177	238	25	15	60	301	15	45	10
		Base flow to River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Baldivis BA1	2.4	Precipitation	763	667	667	667	738	738	738	738	738	782	782	782	762	863	738
		Evapotranspiration	623	571	522	525	614	556	560	558	556	625	559	560	611	616	614
		Gross recharge	151	96	145	143	126	182	180	180	183	160	224	222	151	258	126
		EVT from SZ	8	0	0	0	1	1	2	1	1	4	2	2	2	11	2
		Hor. SZ flow out	204	87	142	106	111	172	139	121	138	143	199	142	117	214	111
		Hor. SZ flow in	221	290	296	263	287	296	264	262	323	287	319	287	289	284	288
		Ver. SZ flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Ver. SZ flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Abstraction	177	305	305	305	305	305	305	305	371	305	305	305	305	305	305
		OL flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		OL flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Drainage (total)	0	0	0	0	0	5	3	19	1	0	41	65	0	0	0
		Base flow to River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Baldivis BA4	2.6	Precipitation	763	667	667	667	738	738	738	738	738	782	782	782	762	863	738
		Evapotranspiration	609	495	451	477	544	492	516	509	486	573	503	511	546	657	547
		Gross recharge	218	176	217	190	207	250	226	229	253	240	284	271	234	323	206
		EVT from SZ	60	3	1	0	13	3	4	0	2	29	6	0	18	101	15
		Hor. SZ flow out	182	217	253	178	224	263	182	151	222	225	264	125	231	190	218
		Hor. SZ flow in	42	67	57	97	55	47	85	118	60	45	42	146	54	47	52
		Ver. SZ flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Ver. SZ flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Abstraction	15	26	26	26	26	26	26	26	92	26	26	26	26	26	26
		OL flow in	3	0	0	0	1	0	0	0	0	4	1	1	3	21	1
		OL flow out	1	0	0	0	1	0	0	0	0	1	0	1	1	4	1
		Drainage (total)	11	0	0	87	2	8	102	173	3	7	34	267	5	47	2
		Base flow to River	1	0	0	0	0	0	0	0	0	1	1	0	0	2	0
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Baldivis BA6	1.6	Precipitation	795	688	688	688	762	762	762	762	762	805	805	805	784	891	762
		Evapotranspiration	669	588	524	524	635	555	555	555	555	653	557	557	632	655	637
		Gross recharge	149	100	163	163	129	206	206	206	206	157	248	248	153	251	128
		EVT from SZ	20	1	0	0	3	0	0	0	0	5	0	0	3	16	3
		Hor. SZ flow out	183	107	147	134	133	184	169	156	151	161	215	172	140	210	123
		Hor. SZ flow in	182	251	227	239	251	223	234	248	255	252	222	264	254	235	243
		Ver. SZ flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Ver. SZ flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Abstraction	144	248	248	248	248	248	248	248	314	248	248	248	248	248	248
		OL flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		OL flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Drainage (total)	0	0	0	24	0	1	27	54	0	0	12	95	0	0	0
		Base flow to River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Baldivis Industrial (North-East)	10.2	Precipitation	787	665	665	665	740	740	740	740	740	780	780	780	761	863	740
		Evapotranspiration	647	595	328	380	638	347	396	407	346	645	350	409	632	619	638
		Gross recharge	275	166	347	288	215	405	351	338	405	254	444	377	245	379	215
		EVT from SZ	130	96	8	4	110	8	5	4	8	116	9	4	113	130	111
		Hor. SZ flow out	19	22	72	17	21	70	23	15	72	20	68	14	21	18	21
		Hor. SZ flow in	82	71	44	108	76	50	91	119	47	80	53	125	78	92	76
		Ver. SZ flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Ver. SZ flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Abstraction	15	25	25	25	25	25	25	25	25	25	25	25	25	25	25
		OL flow in	11	4	2	1	7	4	3	2	4	10	6	3	9	19	7
		OL flow out	8	3	0	1	4	0	0	1	0	7	0	1	6	15	4
		Drainage (total)	189	90	279	349	130	343	385	411	339	169	385	457	158	292	130
		Base flow to River	5	3	7	2	4	8	3	2	8	4	9	2	4	6	4
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Average annual water balances calculated for each development area (mm/yr) cont.

Development	Area (km^2)	Flux	Average annual flux quantity (mm)														
			S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Baldivis	1.2	Precipitation	763	667	667	667	738	738	738	738	738	782	782	782	762	863	738
		Evapotranspiration	605	486	457	440	547	508	511	474	494	582	532	478	552	660	551
		Gross recharge	235	201	254	231	227	281	257	272	289	251	307	312	248	293	226
		EVT from SZ	80	20	43	3	37	49	30	6	44	58	56	8	44	132	39
		Hor. SZ flow out	284	366	424	292	351	399	279	245	380	333	371	203	355	278	342
		Hor. SZ flow in	141	187	222	193	168	195	204	195	219	154	185	213	168	155	163
		Ver. SZ flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Ver. SZ flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Abstraction	1	1	1	1	1	1	1	1	67	1	1	1	1	1	1
		OL flow in	3	1	0	1	1	1	1	1	1	3	1	2	2	8	1
		OL flow out	8	0	0	0	2	0	0	0	0	9	0	1	7	49	2
		Drainage (total)	11	2	8	129	6	25	151	215	17	11	60	313	9	29	6
		Base flow to River	4	2	3	0	3	5	1	1	4	3	5	1	3	6	3
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Byford	9.4	Precipitation	781	663	663	663	741	741	741	741	741	779	779	779	764	903	741
		Evapotranspiration	591	520	487	454	571	539	524	488	513	582	551	488	566	572	571
		Gross recharge	266	174	208	211	216	242	241	257	253	247	271	292	244	394	216
		EVT from SZ	99	42	34	5	60	43	25	5	28	71	47	2	65	103	60
		Hor. SZ flow out	190	141	180	131	161	197	148	140	174	174	209	146	165	216	161
		Hor. SZ flow in	185	111	115	123	137	138	146	151	133	155	152	172	141	204	137
		Ver. SZ flow out	23	33	36	31	33	36	32	31	35	32	36	30	33	32	33
		Ver. SZ flow in	2	1	1	1	1	1	1	2	1	1	1	2	1	1	1
		Abstraction	23	39	39	39	39	39	39	39	105	39	39	39	39	39	39
		OL flow in	40	12	3	10	16	4	12	11	4	29	7	20	24	94	16
		OL flow out	56	21	3	12	27	4	10	12	3	44	6	20	37	118	27
		Drainage (total)	113	33	35	131	58	60	144	194	42	81	86	246	76	195	58
		Base flow to River	8	2	4	1	4	6	2	1	4	6	7	2	5	13	4
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cardup Industrial	1.6	Precipitation	831	710	710	710	796	796	796	796	796	835	835	835	822	956	796
		Evapotranspiration	563	486	364	401	528	384	426	426	384	539	388	429	525	550	528
		Gross recharge	257	221	348	305	264	413	365	365	413	286	450	400	284	342	264
		EVT from SZ	67	3	0	0	12	0	0	0	0	21	0	0	18	78	12
		Hor. SZ flow out	310	216	296	226	254	333	246	239	333	275	350	237	259	318	254
		Hor. SZ flow in	272	235	213	233	262	237	271	273	230	278	256	305	267	340	262
		Ver. SZ flow out	11	15	19	18	16	18	18	18	19	16	18	17	16	15	16
		Ver. SZ flow in	9	16	15	18	15	14	18	19	14	15	14	19	15	15	15
		Abstraction	155	245	265	245	261	271	258	256	271	267	271	257	262	271	261
		OL flow in	7	4	4	4	5	4	4	4	4	7	6	6	7	17	5
		OL flow out	86	11	2	9	20	2	9	9	2	39	3	13	37	159	20
		Drainage (total)	0	0	7	71	0	42	133	146	38	0	79	213	0	1	0
		Base flow to River	4	0	0	0	1	2	0	0	1	2	3	0	2	10	1
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Casuarina	4.8	Precipitation	809	665	665	665	742	742	742	742	742	782	782	782	761	856	742
		Evapotranspiration	623	524	445	456	578	492	527	485	480	601	507	459	577	602	578
		Gross recharge	364	245	257	262	290	296	292	315	301	327	327	358	317	441	290
		EVT from SZ	170	103	38	53	124	46	77	58	39	142	52	35	130	172	124
		Hor. SZ flow out	438	431	451	412	436	453	436	395	439	436	449	380	436	435	436
		Hor. SZ flow in	474	409	375	436	436	400	449	490	413	452	419	529	439	479	436
		Ver. SZ flow out	0	0	1	0	1	1	1	0	1	1	1	0	1	1	0
		Ver. SZ flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Abstraction	14	23	23	23	23	23	23	23	89	23	23	23	23	23	23
		OL flow in	8	1	0	0	2	0	1	0	0	5	0	0	4	16	2
		OL flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Drainage (total)	221	97	121	210	142	172	204	328	146	177	221	448	160	284	142
		Base flow to River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eighty Road	0.3	Precipitation	763	667	667	667	738	738	738	738	738	782	782	782	762	863	738
		Evapotranspiration	588	547	524	524	584	557	557	557	557	588	558	558	579	578	584
		Gross recharge	181	120	143	143	154	181	181	181	181	193	223	223	182	291	154
		EVT from SZ	3	0	0	0	0	0	0	0	0	0	0	0	0	6	0
		Hor. SZ flow out	272	67	68	66	79	106	80	56	85	135	151	65	90	329	75
		Hor. SZ flow in	695	516	536	535	607	658	656	833	654	718	885	1267	623	1039	570
		Ver. SZ flow out	204	7	14	6	38	52	35	17	38	86	90	28	45	258	26
		Ver. SZ flow in	9	160	125	152	77	51	68	106	77	32	23	104	72	1	100
		Abstraction	423	726	726	726	726	726	726	726	792	726	726	726	726	726	726
		OL flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		OL flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Drainage (total)	0	0	0	36	0	9	67	325	1	0	168	779	0	0	0
		Base flow to River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Average annual water balances calculated for each development area (mm/yr) cont.

Development	Area (km^2)	Flux	Average annual flux quantity (mm)														
			S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Karnup KA1	4.2	Precipitation	800	691	691	691	766	766	766	766	766	810	810	810	788	896	766
		Evapotranspiration	594	569	522	522	605	552	552	552	552	609	554	554	599	579	605
		Gross recharge	209	121	169	169	161	214	214	214	214	201	255	255	188	317	161
		EVT from SZ	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
		Hor. SZ flow out	109	53	72	68	65	87	84	75	59	78	95	74	69	113	61
		Hor. SZ flow in	32	34	23	28	33	22	29	61	34	31	33	115	33	35	37
		Ver. SZ flow out	151	125	134	131	146	157	154	143	134	169	175	149	151	232	152
		Ver. SZ flow in	7	19	10	11	15	6	8	14	9	12	6	24	15	6	13
		Abstraction	0	0	0	0	0	0	0	0	66	0	0	0	0	0	0
		OL flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		OL flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Drainage (total)	0	0	0	11	0	0	15	73	0	0	27	174	0	0	0
		Base flow to River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kwinana Industrial	4.2	Precipitation	763	667	667	667	738	738	738	738	738	782	782	782	762	863	738
		Evapotranspiration	551	403	294	292	462	309	307	307	309	499	311	309	466	578	518
		Gross recharge	294	278	374	375	304	429	431	431	429	325	471	472	326	379	273
		EVT from SZ	80	14	0	0	27	0	0	0	0	43	0	0	31	94	53
		Hor. SZ flow out	425	377	467	367	406	512	468	337	514	434	532	311	418	506	333
		Hor. SZ flow in	271	170	167	204	196	193	213	277	192	225	228	367	204	321	163
		Ver. SZ flow out	65	51	65	42	61	75	67	38	75	68	79	32	64	84	44
		Ver. SZ flow in	0	0	0	0	0	0	0	1	0	0	0	3	0	0	0
		Abstraction	5	8	8	8	8	8	8	8	8	8	8	8	8	8	8
		OL flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
		OL flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Drainage (total)	0	0	3	165	0	29	102	327	27	0	82	491	0	0	0
		Base flow to River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kwinana	3.5	Precipitation	764	667	667	667	738	738	738	738	738	781	781	781	761	862	738
		Evapotranspiration	684	587	476	485	649	519	543	521	512	677	533	527	650	685	653
		Gross recharge	115	75	156	153	92	184	175	187	187	117	214	223	112	209	91
		EVT from SZ	91	45	14	20	59	21	36	26	18	74	28	29	62	108	62
		Hor. SZ flow out	604	495	600	527	551	662	599	572	594	612	710	616	562	760	533
		Hor. SZ flow in	588	484	482	445	541	532	507	505	518	592	599	587	551	700	526
		Ver. SZ flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Ver. SZ flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Abstraction	10	17	17	17	17	17	17	17	83	17	17	17	17	17	17
		OL flow in	11	9	0	9	11	0	11	11	0	11	0	12	11	14	11
		OL flow out	72	58	49	58	66	56	67	66	56	72	61	72	70	89	66
		Drainage (total)	0	0	1	33	0	7	26	74	3	0	48	145	0	0	0
		Base flow to River	11	6	10	4	8	11	7	5	10	10	12	5	9	14	8
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mandogalup	5.0	Precipitation	812	663	663	663	739	739	739	739	739	779	779	779	756	845	739
		Evapotranspiration	736	597	510	541	654	561	609	577	543	686	583	563	653	696	654
		Gross recharge	291	158	176	170	204	211	187	217	215	238	236	243	225	341	204
		EVT from SZ	311	144	74	93	186	92	117	105	79	223	106	94	195	298	186
		Hor. SZ flow out	473	424	450	414	438	461	445	415	448	444	466	413	439	457	438
		Hor. SZ flow in	688	534	511	533	577	553	568	585	565	609	585	626	584	667	577
		Ver. SZ flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Ver. SZ flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Abstraction	42	73	73	73	73	73	73	73	139	73	73	73	73	73	73
		OL flow in	16	12	12	12	14	14	14	14	14	15	15	15	14	17	14
		OL flow out	20	13	24	15	15	29	30	18	29	17	34	35	16	23	15
		Drainage (total)	140	40	72	117	69	116	105	200	96	90	154	280	77	153	69
		Base flow to River	20	11	18	7	14	20	14	8	19	15	20	9	14	20	14
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mundijong Industrial	4.7	Precipitation	863	741	741	741	831	831	831	831	831	872	872	871	859	990	831
		Evapotranspiration	692	649	346	360	693	362	366	379	362	702	367	385	687	679	693
		Gross recharge	262	184	408	380	233	481	471	452	481	251	516	486	253	341	233
		EVT from SZ	175	135	16	1	158	17	4	2	17	161	18	2	161	178	158
		Hor. SZ flow out	27	27	71	18	28	70	29	17	70	28	70	16	28	28	28
		Hor. SZ flow in	70	68	58	82	69	59	69	86	57	70	59	88	70	72	69
		Ver. SZ flow out	13	18	23	18	18	23	19	18	23	18	23	18	18	19	18
		Ver. SZ flow in	4	2	2	4	2	2	3	5	2	2	2	5	2	3	2
		Abstraction	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3
		OL flow in	35	14	3	4	24	4	5	6	3	34	5	7	34	79	24
		OL flow out	119	55	3	6	86	4	3	7	4	111	5	9	111	220	86
		Drainage (total)	113	66	338	420	90	411	477	496	409	105	445	532	106	177	90
		Base flow to River	8	6	16	6	7	18	11	7	18	8	18	8	8	10	7
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Average annual water balances calculated for each development area (mm/yr) cont.

Development	Area (km^2)	Flux	Average annual flux quantity (mm)														
			S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Mundijong	10.2	Precipitation	863	741	741	741	831	831	831	831	831	872	872	871	859	990	831
		Evapotranspiration	696	632	566	513	686	612	598	546	587	700	623	525	681	689	686
		Gross recharge	328	216	258	272	278	317	312	335	324	310	354	380	312	465	278
		EVT from SZ	171	114	76	42	143	87	70	45	69	154	91	26	149	194	143
		Hor. SZ flow out	143	131	159	115	137	162	119	113	153	141	165	112	139	153	137
		Hor. SZ flow in	145	114	102	142	128	115	150	165	118	136	121	177	131	157	128
		Ver. SZ flow out	7	7	7	6	7	8	6	6	7	7	8	6	7	8	7
		Ver. SZ flow in	5	4	4	4	4	4	5	5	4	5	5	6	5	6	4
		Abstraction	6	10	10	10	10	10	10	10	76	10	10	10	10	10	10
		OL flow in	46	17	12	7	29	20	15	11	19	41	26	17	42	99	29
		OL flow out	40	17	1	3	28	2	3	4	2	40	2	5	40	90	28
		Drainage (total)	142	66	103	241	102	157	253	326	130	126	191	401	126	242	102
		Base flow to River	14	8	10	5	11	13	8	7	11	13	14	8	12	19	11
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Port Kennedy Industrial	0.7	Precipitation	800	691	691	691	766	766	766	766	766	810	810	810	788	896	766
		Evapotranspiration	480	398	301	301	430	314	314	315	314	448	317	317	429	531	444
		Gross recharge	339	294	391	391	337	452	452	452	452	366	493	493	360	399	327
		EVT from SZ	18	0	0	0	1	0	0	0	0	4	0	0	2	35	5
		Hor. SZ flow out	93	91	141	129	101	155	145	119	156	107	153	92	101	97	106
		Hor. SZ flow in	36	11	1	5	13	2	8	28	2	17	12	68	14	45	22
		Ver. SZ flow out	274	217	253	244	251	289	281	258	290	276	308	251	255	301	239
		Ver. SZ flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Abstraction	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
		OL flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		OL flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Drainage (total)	0	0	0	26	0	11	36	104	10	0	46	218	0	0	0
		Base flow to River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Postans	1.5	Precipitation	668	572	572	572	635	635	635	635	635	672	672	672	651	732	635
		Evapotranspiration	617	544	365	365	601	393	393	393	393	624	393	393	601	631	602
		Gross recharge	68	37	207	207	50	242	242	242	242	68	279	279	63	123	50
		EVT from SZ	14	8	0	0	16	0	0	0	0	20	0	0	16	23	16
		Hor. SZ flow out	319	302	399	400	280	395	399	391	398	289	416	405	282	393	264
		Hor. SZ flow in	322	388	325	342	360	312	311	327	314	355	323	330	361	419	346
		Ver. SZ flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Ver. SZ flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Abstraction	67	116	116	116	116	116	116	116	116	116	116	116	116	116	116
		OL flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		OL flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Drainage (total)	0	0	18	34	0	44	38	62	43	0	71	89	0	0	0
		Base flow to River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Serpentine	0.9	Precipitation	916	806	806	806	907	907	907	907	907	949	949	949	941	1037	907
		Evapotranspiration	633	607	567	492	646	616	584	520	592	654	626	521	640	606	646
		Gross recharge	488	335	376	450	436	485	570	586	494	489	564	665	491	662	436
		EVT from SZ	111	78	48	5	96	55	39	6	41	95	55	0	97	99	96
		Hor. SZ flow out	45	44	100	21	44	98	26	18	90	44	99	17	44	43	44
		Hor. SZ flow in	62	52	46	107	57	54	99	125	57	58	56	130	58	63	57
		Ver. SZ flow out	14	35	39	31	35	38	31	30	38	34	38	30	34	34	35
		Ver. SZ flow in	3	1	1	3	2	1	2	3	1	2	1	3	2	2	2
		Abstraction	14	22	22	22	22	22	22	22	88	22	22	22	22	22	22
		OL flow in	328	178	92	155	259	145	236	227	144	325	192	290	318	509	259
		OL flow out	236	120	3	24	179	4	27	33	4	226	6	54	225	377	179
		Drainage (total)	371	211	215	481	299	328	552	638	297	355	407	729	353	529	299
		Base flow to River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Average annual water balances calculated for each development area (ML/yr)

Development	Area (km^2)	Flux	Average annual flux quantity (ML)														
			S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Armadale	4.5	Precipitation	3502	2974	2974	2974	3323	3323	3323	3323	3323	3494	3494	3494	3426	4049	3323
		Evapotranspiration	2773	2225	1893	1939	2493	2131	2180	2079	2030	2572	2211	2090	2495	2617	2493
		Gross recharge	912	808	1147	1037	922	1305	1209	1263	1369	995	1432	1442	989	1304	922
		EVT from SZ	558	139	54	2	224	86	45	4	51	280	102	5	258	469	224
		Hor. SZ flow out	301	238	454	186	259	496	213	182	412	272	519	175	266	313	259
		Hor. SZ flow in	461	383	261	620	411	285	634	766	329	432	304	865	420	503	411
		Ver. SZ flow out	215	488	527	465	496	533	482	466	524	500	536	465	498	508	496
		Ver. SZ flow in	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
		Abstraction	188	313	313	313	313	313	313	313	609	313	313	313	313	313	313
		OL flow in	338	51	12	23	92	28	38	31	26	170	48	64	169	686	92
		OL flow out	716	131	0	23	224	0	16	16	0	376	1	30	366	1283	224
		Drainage (total)	124	23	74	700	43	166	795	1068	111	66	270	1352	67	200	43
		Base flow to River	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Baldivis BA1	2.4	Precipitation	1862	1628	1628	1628	1801	1801	1801	1801	1801	1906	1906	1906	1859	2105	1801
		Evapotranspiration	1521	1393	1273	1280	1497	1357	1366	1362	1355	1524	1364	1367	1490	1501	1498
		Gross recharge	368	235	354	348	307	445	438	440	446	390	547	543	369	629	306
		EVT from SZ	20	0	0	0	3	2	4	2	1	9	5	4	5	28	4
		Hor. SZ flow out	497	212	346	258	270	420	340	296	338	348	485	346	285	521	271
		Hor. SZ flow in	539	707	723	642	699	723	645	639	788	699	777	700	705	692	702
		Ver. SZ flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Ver. SZ flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Abstraction	432	743	743	743	743	743	743	743	904	743	743	743	743	743	743
		OL flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		OL flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Drainage (total)	0	0	0	0	0	13	6	47	2	0	101	158	0	0	0
		Base flow to River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Baldivis BA4	2.6	Precipitation	2015	1762	1762	1762	1949	1949	1949	1949	1949	2063	2063	2063	2011	2278	1949
		Evapotranspiration	1607	1307	1190	1259	1437	1298	1362	1343	1284	1513	1329	1349	1442	1735	1445
		Gross recharge	576	464	574	502	547	659	598	605	669	633	750	715	619	853	544
		EVT from SZ	158	9	2	0	35	8	11	0	4	76	16	0	48	267	40
		Hor. SZ flow out	480	574	668	470	593	695	481	399	586	595	696	331	610	502	574
		Hor. SZ flow in	111	178	151	256	145	124	223	313	160	119	111	385	142	125	137
		Ver. SZ flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Ver. SZ flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Abstraction	39	67	67	67	67	67	67	67	242	67	67	67	67	67	67
		OL flow in	8	1	1	1	2	1	1	1	1	10	1	2	8	56	3
		OL flow out	3	1	0	1	1	0	1	1	0	3	1	1	3	10	1
		Drainage (total)	30	1	1	230	5	21	268	458	8	19	90	706	14	123	6
		Base flow to River	2	0	0	0	1	1	0	0	1	2	2	0	1	4	1
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Baldivis BA6	1.6	Precipitation	1265	1094	1094	1094	1213	1213	1213	1213	1213	1282	1282	1282	1247	1418	1213
		Evapotranspiration	1066	936	835	835	1010	884	884	884	884	1039	887	887	1006	1042	1013
		Gross recharge	237	160	260	259	206	328	328	328	328	250	395	395	243	399	204
		EVT from SZ	32	1	0	0	4	0	0	0	0	8	0	0	5	25	5
		Hor. SZ flow out	291	171	234	213	212	293	270	248	240	256	342	274	222	334	195
		Hor. SZ flow in	290	400	362	380	399	355	373	395	406	402	354	420	404	374	386
		Ver. SZ flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Ver. SZ flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Abstraction	230	395	395	395	395	395	395	395	500	395	395	395	395	395	395
		OL flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		OL flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Drainage (total)	0	0	0	38	0	1	43	86	1	0	18	151	0	0	0
		Base flow to River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Baldivis Industrial (North-East)	10.2	Precipitation	7999	6757	6757	6757	7517	7517	7517	7517	7517	7929	7929	7929	7738	8772	7517
		Evapotranspiration	6575	6053	3331	3864	6482	3525	4028	4134	3520	6555	3562	4155	6425	6287	6485
		Gross recharge	2792	1687	3527	2932	2183	4118	3566	3432	4119	2586	4515	3834	2487	3857	2183
		EVT from SZ	1324	971	78	36	1123	86	51	39	81	1182	92	43	1152	1322	1125
		Hor. SZ flow out	193	229	728	170	213	707	238	151	731	198	696	145	213	187	209
		Hor. SZ flow in	836	717	443	1094	770	504	927	1208	480	815	537	1269	789	935	771
		Ver. SZ flow out	0	1	2	1	1	2	1	1	2	1	2	1	1	1	1
		Ver. SZ flow in	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Abstraction	148	254	254	253	254	254	254	254	254	254	254	253	254	254	254
		OL flow in	110	41	24	9	68	43	31	15	43	98	60	28	87	197	68
		OL flow out	78	28	2	6	42	3	5	6	3	69	4	11	60	148	42
		Drainage (total)	1925	920	2836	3551	1322	3488	3917	4177	3448	1721	3918	4641	1610	2972	1325
		Base flow to River	48	33	74	19	41	84	35	22	82	46	89	24	43	57	41
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	4	1	0	3	2	0	3	3	0	2	0	3	2	2	2

Average annual water balances calculated for each development area (ML/yr) cont.

Development	Area (km^2)	Flux	Average annual flux quantity (ML)														
			S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Baldivis	1.2	Precipitation	935	817	817	817	904	904	904	904	904	957	957	957	933	1056	904
		Evapotranspiration	741	595	559	539	670	621	626	580	604	713	652	586	676	808	674
		Gross recharge	288	246	311	283	278	344	315	332	354	307	375	382	304	359	276
		EVT from SZ	98	24	52	4	45	60	36	7	54	71	69	10	54	162	48
		Hor. SZ flow out	348	448	519	358	429	488	341	300	465	408	454	249	435	341	418
		Hor. SZ flow in	172	230	272	237	206	239	249	239	269	189	226	260	205	190	199
		Ver. SZ flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Ver. SZ flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Abstraction	1	1	1	1	1	1	1	1	82	1	1	1	1	1	1
		OL flow in	3	1	1	1	2	1	1	1	1	4	2	3	3	9	2
		OL flow out	9	0	0	0	3	0	0	0	0	11	0	1	8	60	3
		Drainage (total)	13	3	10	158	7	30	185	264	21	13	74	383	11	35	7
		Base flow to River	5	2	4	1	3	6	2	1	5	4	7	1	4	7	3
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Byford	9.4	Precipitation	7370	6258	6258	6258	6992	6992	6992	6992	6992	7352	7352	7352	7210	8521	6992
		Evapotranspiration	5578	4908	4596	4286	5386	5084	4948	4606	4841	5495	5200	4601	5344	5400	5386
		Gross recharge	2512	1641	1963	1990	2038	2281	2278	2422	2388	2331	2554	2752	2304	3715	2038
		EVT from SZ	932	392	319	45	567	405	232	52	261	666	443	23	611	971	567
		Hor. SZ flow out	1796	1333	1697	1236	1517	1859	1397	1323	1646	1647	1971	1382	1552	2035	1517
		Hor. SZ flow in	1748	1048	1089	1161	1290	1300	1374	1429	1256	1460	1438	1621	1334	1929	1290
		Ver. SZ flow out	220	308	341	296	307	338	298	289	331	306	338	287	307	305	307
		Ver. SZ flow in	15	6	6	12	7	7	11	15	7	8	8	18	8	12	7
		Abstraction	216	372	372	372	372	372	372	372	995	372	372	372	372	372	372
		OL flow in	381	115	30	95	155	40	110	106	33	274	67	185	224	884	155
		OL flow out	527	197	28	114	258	38	94	112	32	413	59	189	346	1115	257
		Drainage (total)	1067	312	335	1239	550	570	1355	1828	400	768	815	2318	721	1839	550
		Base flow to River	77	20	34	9	37	54	19	13	42	52	70	16	46	121	37
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	2	1	0	1	1	0	1	1	0	1	0	1	1	1	1
Cardup Industrial	1.6	Precipitation	1344	1149	1149	1149	1287	1287	1287	1287	1287	1351	1351	1351	1329	1546	1287
		Evapotranspiration	911	786	589	648	854	622	688	688	622	871	628	693	850	889	854
		Gross recharge	415	357	563	493	426	668	590	590	668	462	728	646	459	553	426
		EVT from SZ	109	4	0	0	19	0	0	0	0	34	0	0	30	126	19
		Hor. SZ flow out	502	349	478	366	411	539	398	386	538	445	566	383	420	513	411
		Hor. SZ flow in	440	381	345	377	423	384	438	442	372	450	413	494	431	549	423
		Ver. SZ flow out	18	25	30	29	25	29	29	29	30	25	29	28	25	24	25
		Ver. SZ flow in	15	26	25	29	25	23	30	30	23	24	23	31	25	23	25
		Abstraction	251	397	428	396	423	438	418	413	438	433	439	416	423	439	423
		OL flow in	11	7	6	7	7	7	7	7	7	12	10	10	11	28	7
		OL flow out	140	17	3	15	33	3	15	15	3	63	5	21	60	257	33
		Drainage (total)	0	0	11	115	0	68	215	237	61	0	128	345	0	2	0
		Base flow to River	6	0	1	0	1	3	0	0	2	3	4	0	3	16	1
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Casuarina	4.8	Precipitation	3876	3188	3188	3188	3556	3556	3556	3556	3556	3747	3747	3747	3647	4102	3556
		Evapotranspiration	2986	2510	2135	2186	2771	2360	2527	2326	2301	2882	2430	2201	2765	2885	2771
		Gross recharge	1746	1176	1233	1254	1391	1418	1402	1508	1442	1567	1569	1715	1519	2116	1391
		EVT from SZ	814	494	180	252	595	222	370	278	187	680	251	168	621	825	595
		Hor. SZ flow out	2100	2068	2162	1977	2091	2171	2091	1893	2107	2092	2153	1822	2088	2087	2090
		Hor. SZ flow in	2273	1962	1799	2092	2090	1916	2151	2350	1981	2167	2007	2537	2105	2296	2090
		Ver. SZ flow out	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
		Ver. SZ flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Abstraction	65	112	112	112	112	112	112	112	428	112	112	112	112	112	112
		OL flow in	38	3	0	0	10	0	3	0	0	22	0	1	19	75	10
		OL flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Drainage (total)	1061	467	580	1007	680	826	978	1573	698	849	1058	2149	766	1364	680
		Base flow to River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eighty Road	0.3	Precipitation	241	211	211	211	233	233	233	233	233	247	247	247	241	272	233
		Evapotranspiration	186	173	166	166	184	176	176	176	176	186	176	176	183	182	184
		Gross recharge	57	38	45	45	49	57	57	57	57	61	70	70	57	92	49
		EVT from SZ	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0
		Hor. SZ flow out	86	21	21	21	25	34	25	18	27	43	48	20	28	104	24
		Hor. SZ flow in	219	163	169	169	192	208	207	263	207	227	279	400	197	328	180
		Ver. SZ flow out	64	2	4	2	12	16	11	5	12	27	28	9	14	81	8
		Ver. SZ flow in	3	50	39	48	24	16	21	34	24	10	7	33	23	0	32
		Abstraction	133	229	229	229	229	229	229	229	250	229	229	229	229	229	229
		OL flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		OL flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Drainage (total)	0	0	0	11	0	3	21	102	0	0	53	246	0	0	0
		Base flow to River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Average annual water balances calculated for each development area (ML/yr) cont.

Development	Area (km^2)	Flux	Average annual flux quantity (ML) S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Karnup KA1	4.2	Precipitation	3336	2882	2882	2882	3194	3194	3194	3194	3194	3376	3376	3376	3283	3734	3194
		Evapotranspiration	2477	2374	2174	2175	2522	2301	2301	2301	2301	2537	2310	2310	2497	2414	2522
		Gross recharge	870	507	706	706	669	891	891	891	891	837	1065	1065	782	1323	669
		EVT from SZ	2	0	0	0	0	0	0	0	0	0	0	0	0	4	0
		Hor. SZ flow out	457	220	298	285	272	363	348	312	247	327	394	309	288	471	255
		Hor. SZ flow in	133	141	96	115	136	91	120	253	142	130	136	479	136	145	155
		Ver. SZ flow out	630	520	559	548	607	655	641	596	560	703	731	622	630	968	636
		Ver. SZ flow in	30	78	41	45	62	27	32	60	37	48	26	102	61	24	56
		Abstraction	0	0	0	0	0	0	0	0	275	0	0	0	0	0	0
		OL flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		OL flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Drainage (total)	0	0	0	47	0	2	64	306	0	0	115	725	0	0	0
		Base flow to River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kwinana Industrial	4.2	Precipitation	3204	2801	2801	2801	3099	3099	3099	3099	3099	3280	3280	3280	3198	3621	3099
		Evapotranspiration	2311	1692	1232	1227	1937	1296	1290	1290	1296	2096	1304	1298	1956	2427	2174
		Gross recharge	1234	1166	1569	1574	1274	1802	1809	1809	1802	1365	1976	1982	1369	1589	1146
		EVT from SZ	335	57	0	0	112	0	0	0	0	180	0	0	131	393	221
		Hor. SZ flow out	1784	1584	1960	1540	1705	2147	1964	1414	2157	1819	2233	1304	1752	2124	1397
		Hor. SZ flow in	1136	713	701	857	823	809	893	1162	806	946	958	1540	857	1346	684
		Ver. SZ flow out	272	216	273	177	255	315	283	159	313	287	333	136	267	352	184
		Ver. SZ flow in	0	0	0	2	0	0	0	6	0	0	0	14	0	0	0
		Abstraction	21	35	35	35	35	35	35	35	35	35	35	35	35	35	35
		OL flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
		OL flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
		Drainage (total)	0	0	12	691	0	123	428	1373	112	0	342	2063	0	0	0
		Base flow to River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kwinana	3.5	Precipitation	2669	2328	2328	2328	2576	2576	2576	2577	2576	2727	2727	2727	2658	3010	2577
		Evapotranspiration	2387	2051	1661	1695	2267	1811	1897	1820	1789	2364	1862	1839	2269	2392	2280
		Gross recharge	400	264	544	533	320	641	611	652	652	407	748	778	392	731	318
		EVT from SZ	318	156	49	70	206	73	127	90	61	257	96	102	216	379	217
		Hor. SZ flow out	2109	1728	2096	1838	1926	2310	2090	1997	2075	2135	2479	2152	1963	2655	1860
		Hor. SZ flow in	2053	1690	1685	1555	1890	1856	1771	1763	1809	2068	2090	2050	1923	2445	1838
		Ver. SZ flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
		Ver. SZ flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Abstraction	34	58	58	58	58	58	58	58	288	58	58	58	58	58	58
		OL flow in	40	32	0	32	37	0	38	37	0	40	0	41	39	49	37
		OL flow out	251	203	172	203	232	197	232	232	197	252	213	251	244	309	232
		Drainage (total)	0	0	2	116	0	23	89	260	9	0	169	505	0	0	0
		Base flow to River	38	22	33	15	28	39	25	17	35	33	43	19	30	49	28
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mandogalup	5.0	Precipitation	4029	3289	3289	3289	3670	3670	3670	3670	3670	3869	3869	3869	3753	4196	3670
		Evapotranspiration	3652	2963	2534	2688	3246	2787	3022	2863	2698	3404	2896	2796	3243	3457	3246
		Gross recharge	1447	786	874	846	1014	1047	928	1078	1069	1182	1169	1206	1118	1692	1014
		EVT from SZ	1543	716	367	460	925	459	580	521	390	1107	529	467	968	1481	925
		Hor. SZ flow out	2350	2106	2236	2055	2174	2289	2212	2063	2224	2207	2313	2051	2182	2270	2174
		Hor. SZ flow in	3415	2651	2536	2644	2867	2744	2822	2902	2808	3023	2904	3110	2899	3310	2866
		Ver. SZ flow out	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Ver. SZ flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Abstraction	211	361	361	361	361	361	361	361	689	361	361	361	361	361	361
		OL flow in	78	59	59	59	68	68	69	68	68	72	73	73	70	83	68
		OL flow out	98	64	121	76	76	145	150	89	144	84	169	171	80	113	76
		Drainage (total)	695	199	358	580	344	577	522	991	475	449	763	1390	383	761	344
		Base flow to River	97	56	88	35	69	98	69	39	92	75	101	43	71	97	69
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mundijong Industrial	4.7	Precipitation	4023	3452	3452	3452	3871	3871	3871	3871	3871	4061	4061	4061	4002	4611	3871
		Evapotranspiration	3225	3024	1611	1677	3227	1688	1707	1767	1687	3271	1712	1792	3200	3163	3227
		Gross recharge	1220	859	1901	1772	1085	2243	2194	2105	2243	1168	2402	2266	1179	1589	1085
		EVT from SZ	815	627	75	6	738	81	21	8	81	749	82	8	750	832	738
		Hor. SZ flow out	127	127	332	84	129	324	134	77	324	128	325	76	129	130	129
		Hor. SZ flow in	328	316	270	381	323	275	323	401	265	325	276	409	325	334	323
		Ver. SZ flow out	61	84	109	83	85	108	89	82	109	85	108	82	85	87	85
		Ver. SZ flow in	20	9	8	19	10	9	13	21	9	11	9	22	10	13	10
		Abstraction	8	14	14	14	14	14	14	14	14	14	14	14	14	14	14
		OL flow in	165	65	12	20	111	17	24	28	16	160	21	35	160	369	111
		OL flow out	554	257	15	28	399	20	12	33	20	519	24	44	517	1024	399
		Drainage (total)	527	306	1573	1958	418	1914	2221	2312	1904	490	2072	2480	495	823	418
		Base flow to River	39	27	77	28	34	84	52	34	83	37	85	36	36	48	34
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	2	1	0	1	1	0	1	1	0	1	0	1	1	1	1

Average annual water balances calculated for each development area (ML/yr) cont.

Development	Area (km^2)	Flux	Average annual flux quantity (ML)														
			S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Mundijong	10.2	Precipitation	8806	7555	7555	7555	8472	8472	8472	8472	8472	8889	8888	8888	8760	10094	8472
		Evapotranspiration	7102	6447	5768	5235	6992	6240	6104	5571	5984	7144	6356	5359	6945	7032	6992
		Gross recharge	3348	2203	2635	2774	2831	3234	3178	3414	3302	3161	3606	3874	3182	4742	2831
		EVT from SZ	1744	1164	777	429	1459	887	717	454	700	1574	931	261	1521	1983	1459
		Hor. SZ flow out	1455	1337	1624	1178	1398	1657	1214	1150	1563	1434	1681	1143	1419	1564	1398
		Hor. SZ flow in	1480	1161	1038	1449	1305	1171	1529	1687	1206	1383	1235	1804	1337	1601	1305
		Ver. SZ flow out	68	68	74	64	71	77	64	64	70	74	79	65	73	83	71
		Ver. SZ flow in	53	39	38	46	46	44	48	53	41	50	48	58	48	62	46
		Abstraction	59	100	100	100	100	100	100	100	773	100	100	100	100	100	100
		OL flow in	474	171	122	71	297	201	149	116	189	416	263	169	425	1010	297
		OL flow out	411	174	13	35	285	17	28	38	16	404	23	54	404	920	285
		Drainage (total)	1447	670	1052	2460	1042	1596	2577	3320	1329	1286	1953	4089	1287	2467	1042
		Base flow to River	141	80	98	48	112	132	85	68	116	128	146	80	122	190	112
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	3	1	0	1	1	0	1	1	0	1	0	1	1	1	1
Port Kennedy Industrial	0.7	Precipitation	536	463	463	463	514	514	514	514	514	543	543	543	528	601	514
		Evapotranspiration	322	267	202	202	288	211	211	211	211	300	213	213	288	356	298
		Gross recharge	227	197	262	262	226	303	303	303	303	245	330	330	241	267	219
		EVT from SZ	12	0	0	0	1	0	0	0	0	3	0	0	2	23	3
		Hor. SZ flow out	63	61	95	86	68	104	97	80	105	72	103	62	68	65	71
		Hor. SZ flow in	24	7	1	4	9	2	6	19	2	12	8	45	9	30	15
		Ver. SZ flow out	184	145	170	164	168	194	188	173	194	185	206	168	171	202	160
		Ver. SZ flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Abstraction	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		OL flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		OL flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Drainage (total)	0	0	0	17	0	8	24	70	7	0	31	146	0	0	0
		Base flow to River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Postans	1.5	Precipitation	1027	880	880	880	977	977	977	977	977	1034	1034	1034	1001	1126	977
		Evapotranspiration	949	837	562	562	924	605	605	605	605	959	605	605	925	971	925
		Gross recharge	105	57	318	318	77	372	372	372	372	105	429	429	97	188	77
		EVT from SZ	22	13	0	0	24	0	0	0	0	30	0	0	25	36	25
		Hor. SZ flow out	490	464	614	615	430	608	614	602	612	444	640	623	434	604	407
		Hor. SZ flow in	495	596	499	525	554	480	478	503	483	547	497	508	555	644	532
		Ver. SZ flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Ver. SZ flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Abstraction	104	178	178	178	178	178	178	178	178	178	178	178	178	178	178
		OL flow in	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		OL flow out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Drainage (total)	0	0	27	52	0	67	59	96	66	0	109	137	0	0	0
		Base flow to River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Serpentine	0.9	Precipitation	806	709	709	709	797	797	797	797	797	835	835	835	828	912	797
		Evapotranspiration	557	534	499	433	568	542	514	458	521	575	550	458	562	533	568
		Gross recharge	429	294	330	396	384	427	502	515	435	430	496	584	431	582	384
		EVT from SZ	98	68	42	5	84	48	35	5	36	83	49	0	85	87	84
		Hor. SZ flow out	40	38	88	19	39	86	23	16	79	38	87	15	39	37	39
		Hor. SZ flow in	55	46	41	94	50	47	87	110	50	51	49	114	51	55	50
		Ver. SZ flow out	13	30	34	27	30	34	28	26	33	30	34	26	30	30	30
		Ver. SZ flow in	3	1	1	2	1	1	2	3	1	1	1	3	1	1	1
		Abstraction	12	19	19	19	19	19	19	19	77	19	19	19	19	19	19
		OL flow in	289	156	81	136	228	127	208	200	126	285	169	255	279	448	228
		OL flow out	207	105	3	21	157	4	24	29	4	199	6	47	198	332	157
		Drainage (total)	326	186	189	423	263	288	486	561	261	312	358	641	310	465	263
		Base flow to River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total Error	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Shortened forms

AHD	Australian height datum
AAMaxGL	average annual maximum groundwater level
AAMinGL	average annual minimum groundwater level
AR4	(IPCC) assessment report four
AveGL	average groundwater level
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DHI	Danish Hydraulic Institute
DoP	Department of Planning
DoW	Department of Water
DWMP	drainage and water management plan
ESRI	Earth Systems Research Institute
EVT	evapotranspiration
GCM	general circulation model
IPCC	Intergovernmental Panel on Climate Change
LAI	leaf area index
LiDAR	light detection and ranging
MaxGL	maximum groundwater level
MinGL	minimum groundwater level
MRS	Metropolitan Region Scheme
OL	overland (flow)
PASS	potentially acid sulfate soils
PET	potential evapotranspiration
PRAMS	Perth Regional Aquifer Modelling System
RD	root depth
SLR	sea-level-rise
SWWA	south west Western Australia
SZ	saturated zone
WAPC	Western Australian Planning Commission
WMO	World Meteorological Organisation

Glossary

abstraction	Pumping groundwater from an aquifer
acid sulfate soils	Soils containing iron sulphides which have been exposed to oxygen and produced sulphuric acid
aquifer	A geological formation or group of formations which have the ability to receive, store and transmit significant quantities of water
baseflow	The contribution of groundwater to river flows
emissions scenario	A social, political and economic scenario which is used to estimate future greenhouse gas emissions
flow duration curve	A visual summary of the percentage of time that a given flow is exceeded at a point in a river system
general circulation model (GCM)	A numerical model which describes circulation within the atmosphere and/or ocean. GCMs form the basis of global climate models in combination with land surface, ice sheet and sea ice models. Note that the terms 'global climate model' and 'general circulation model' are used interchangeably, but are in fact distinct.
gross recharge	Water reaching an aquifer via infiltration through the unsaturated zone – gross recharge does not include later losses from the aquifer.
net recharge	Gross recharge minus evapotranspiration directly from the water table (for example, from wetlands and areas of shallow groundwater)
hydrological cycle	Describes the cycle of water on and in the earth and atmosphere
Intergovernmental Panel on Climate Change	A scientific body established to provide ongoing assessment of information concerning the risk of climate change
overland flow	Also 'surface runoff', flow across the surface of the earth that is not in defined channels
peak flow	Flows in rivers and drains which are at the top of the hydrograph. Generally infrequent and for a short duration
phreatic surface	See water table
potentially acid sulfate soils	Soils which have the potential to produce sulphuric acid when exposed to oxygen
salt-water intrusion	The movement of saline water into freshwater aquifers
satellite altimetry	The measurement of altitude from a satellite platform. Can be used to determine the elevation of the earth and ocean surface.
saturated zone	The portion of an aquifer below the water table where all pore spaces are saturated with water.

Southern Hemisphere circulation	A general term used to describe atmospheric circulation within the Southern Hemisphere.
transmissivity	The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient
unsaturated zone	Also the 'vadose zone' is part of the earth between the water table and the earth's surface
water balance	Describes the flow of water into and out of a system (e.g. an aquifer)
water table	The water surface within an unconfined aquifer where the pressure head is equal to atmospheric pressure
waterlogging	Saturation of the soil and land surface from groundwater. In the context of this report, waterlogging refers to inundation which occurs from groundwater at, or above the surface topography
wetland	A permanently or seasonally saturated area of land. Within the Serpentine study area wetlands are generally surface expressions of groundwater

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